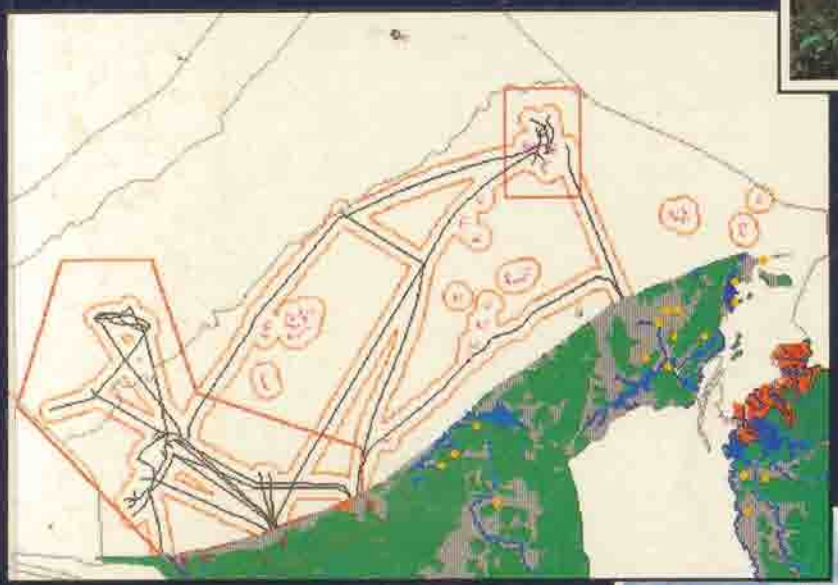
The Coastal Resources of Brunei Darussalam

Status, Utilization and Management



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The Coastal Resources of Brunei Darussalam: Status, Utilization and Management

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Cover: (Clockwise) (1) Gorgonian corals and reef-associated organisms - Abana Rock. (2) Artisanal fishery in Brunei Bay. (3) Map of Brunei Darussalam showing the elements of the zonation scheme for the coastal zone.

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Contents

List of Acronyms

AD	Agriculture Department
ANOVA	analysis of variance
ASEAN/US CRMP	Association of Southeast Asian Nations/United States Coastal Resources Management Project
BOD	biological oxygen demand
BSP	Brunei Shell Petroleum Co.
CAM	coastal area management
COD	chemical oxygen demand
CRM	coastal resources management
Dab	diameter above the highest bud root
Dbh	diameter at breast height
DCA	Development Control Area
DDT	dichloro-diphenyl-trichloro-ethane
Dg	diameter of the mean basal area of the tree
Dho	mean diameter of dominant height
DO	dissolved oxygen; District Office
DOF	Department of Fisheries
DOM	Department of Museums
DOTCP	Department of Town and Country Planning
EDB	Economic Development Board
EEC	European Economic Community
EES	Extension and Enforcement Section
EEZ	Exclusive Economic Zone
EIA	environmental impact assessment
EIRC	Environmental Impact Review Committee
EPU	Economic Planning Unit
FAD	fish aggregating device
FC	fecal coliform
FD	Forestry Department
G	stand basal area
GDP	gross domestic product
GNP	gross national product
GVA	gross value added
H	stand mean height
HC	hydrocarbon
HMIC	His Majesty in Council
Ho	stand dominant height
hp	horsepower
ICRCA	International Coastal Resources Conservation Area
IDS	industrial development site
IU	Industrial Unit
KBFLC	Kuala Belait Fish Landing Complex

Kg.	Kampong or village
LD	Land Department
LaD	Labour Department
LFR	Labu Forest Reserve
LSWS	Labu Selirong Wildlife Sanctuary
MB	Municipal Board
MD	Marine Department
MEY	maximum economic yield
MFLC	Muara Fish Landing Complex
MFS	Muara Fisheries Station
MIDS	Muara Industrial Development Site
MIPR	Ministry of Industry and Primary Resources
MOD	Ministry of Development
MOF	Ministry of Finance
MOH	Ministry of Health
MOL	Ministry of Law
MPN	most probable number
MSY	maximum sustainable yield
N	normality; stand stock per hectare
NBDMP	Negara Brunei Darussalam Master Plan
NDP	National Development Plan
NH_3-N	ammonia nitrogen
nm	nautical mile
$N0_3$-N	nitrate nitrogen
$N0_2$-N	nitrite nitrogen
NPCC	National Pollution Control Commission
OMS	Office of Medical Services
OSA	One Stop Agency
OSY	optimum sustainable yield
P.	Pulau or island
PAC	Pesticide Assessment Committee
PCB	polychlorinated biphenyl
PD	Ports Department
PHS	Post-Harvest Section
PMO	Prime Minister's Office
ppm	parts per million
ppt	parts per thousand
PU	Petroleum Unit
PWD	Public Works Department
SFR	Selirong Forest Reserve
Sg.	Sungai or river
SPOILS	Simulation and Prediction of Oil Spills
SS	suspended solids
STP	sewage treatment plant
STW	sewage treatment works
SV	stand volume
TC	total coliform
TCPA	Town and Country Planning Act
Tg.	Tanjong or cape
TP	total phosphorus
TPA	Totally Protected Area
UBD	Universiti Brunei Darussalam
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency

V	wood volume
VSS	volatile suspended solids
WGIM	Working Group on Island Management
WHO	World Health Organization
WQMS	water quality monitoring station
Y/B	yield-to-biomass ratio

Preface

The coastal waters of Southeast Asia have some of the world's richest ecosystems and habitats characterized by extensive coral reefs and dense mangrove forests. Blessed with warm tropical climate and high rainfall, these waters are further enriched with nutrients from the land, which enable them to support a wide diversity of marine life. Because economic benefits could be derived from them, the coastal zones in these countries teem with human settlements. Over 70% of the population in the region lives in coastal areas where resources have been heavily exploited. This situation became apparent between the 1960s and 1970s when socioeconomic pressures increased. Large-scale destruction of the region's valuable resources has caused serious degradation of the environment, thus affecting the economic life of the coastal inhabitants. This situation is mainly the result of ineffective or poor management of the coastal resources.

Coastal resources are valuable assets that should be utilized on a sustainable basis. Unisectoral overuse of some resources has caused grave problems. Indiscriminate logging and mining in upland areas might have brought large economic benefits to companies undertaking these activities and, to a certain extent, increased government revenues, but could prove detrimental to lowland activities such as fisheries, aquaculture and coastal-tourism dependent industries. Similarly, unregulated fishing effort and the use of destructive fishing methods, such as mechanized push-nets and dynamiting, have seriously destroyed fish habitats and reduced fish stocks. Indiscriminate cutting of mangroves for aquaculture, fuel wood, timber and the like has brought temporary gains in fish production, fuel wood and timber supply but losses in nursery areas of commercially important fish and shrimp, coastal erosion and land accretion.

The coastal zones of most nations in the Association of Southeast Asian Nations (ASEAN) are subjected to increasing population and economic pressures manifested by a variety of coastal activities, notably, fishing, coastal aquaculture, waste disposal, salt-making, tin mining, oil drilling, tanker traffic, construction and industrialization. This situation is aggravated by the expanding economic activities attempting to uplift the standard of living of coastal people, the majority of whom live below the official poverty line.

Some ASEAN members have formulated regulatory measures for their coastal resources management (CRM) such as the issuance of permits for fishing, logging, mangrove harvesting, etc. However, most of these measures have not proven effective due partly to enforcement failure and largely to lack of support for the communities concerned.

Experiences in CRM in developed nations suggest the need for an integrated, interdisciplinary and multisectoral approach in developing management plans that will provide a course of action usable for the daily management of the coastal areas.

The ASEAN/United States (US) Coastal Resources Management Project (CRMP) arose from the existing CRM problems. Its goal is to increase existing capabilities within ASEAN for developing and implementing CRM strategies. The project, which is funded by the US Agency for International Development (USAID) and executed by the International Center for Living Aquatic Resources Management (ICLARM) in cooperation with ASEAN institutions, attempts to attain its goals through these activities:

- analyzing, documenting and disseminating information on trends in coastal resources development;
- increasing awareness of the importance of CRM policies and identifying, and where possible, strengthening existing management capabilities;
- providing technical solutions to coastal resource use conflicts; and
- promoting institutional arrangements that bring multisectoral planning to coastal resources development.

In addition to implementing training and information dissemination programs, CRMP also attempts to develop site-specific CRM plans to formulate integrated strategies that could be implemented in the prevailing conditions in each nation. To date, these management plans have essentially reached the final phase of completion and require approval, endorsement and funding for implementation.

Brunei Darussalam has actively participated in the development of its CRM plan and the research necessary to the planning process. This publication, a product of a series of studies and consultations under the Brunei component of ASEAN/US CRMP, contains the elements that would make an operational CRM plan for the country a reality.

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Introduction

One of the six pilot sites of ASEAN/US CRMP, Brunei Darussalam is a coastal state in northern Borneo Island with a land area of 5,765 km² and a 130-km coastline fronting the South China Sea. About 85% of the population (roughly 256,500 in 1990) lives in the coastal area where almost all social, cultural and economic activities are concentrated. The country's economy has been largely dependent on the exploitation of petroleum hydrocarbons since the late 1920s. In the last 15 years, over 95% of exports and 58-88% of GDP were accounted for by the dominant oil and gas sector. Aware of the uncertainties associated with a heavy reliance on a single, nonrenewable commodity, the Government of Brunei Darussalam has embarked on broad-based strategies to diversify its economy by shifting to non-oil resource-based industries. These efforts have accelerated particularly in the last decade. The country is in a favorable position to promote sustainable development of its non-oil coastal resources. The dominance of the oil and gas sector has resulted in comparatively little pressure on its coastal resources in general. The government, however, has taken active interest in coastal area management (CAM) in the light of regional trends and the potential pressure from development activities accompanying economic diversification.

Full participation of Brunei Darussalam in ASEAN/US CRMP began in early 1987. Project activities were coordinated by a National Steering Committee composed of representatives from various government departments, with technical assistance from ICLARM. The main cooperating institutions were the Department of Fisheries (DOF) (coordinating agency), Department of Forestry, Department of Agriculture, Department of Town and Country Planning, Department of Public Works, Brunei Museum and Universiti Brunei Darussalam. In late 1987, the coastal environmental profile of the country was published. It identified the following priority studies:

- fisheries resource assessment;
- assessment of mangroves;
- evaluation of artificial reefs for resource enhancement;
- water quality baseline information for the coastal area;
- evaluation of legal/institutional framework; and
- socioeconomic significance of coastal resource use.

Between 1988 and 1990, a number of biogeographical/technical, socioeconomic and legal/institutional studies were completed in response to the information needs. These were integrated into the CAM plan for Brunei Darussalam as they became available.

Consistent with the need for widespread consultation and recognizing that planning is a dynamic process, the Brunei Darussalam component of ASEAN/US CRMP conducted a national conference on coastal resources management and planning at the International Convention Centre, Brunei Darussalam, on 30 April-1 May 1991. The purpose of the conference was twofold, namely:

- to present the results of the various studies for evaluation and possible improvement, and
- to present the initial draft of the CAM plan for discussion, comments and suggestions.

These proceedings attempt to document the papers presented at the conference. Moreover, the articles incorporate the various suggestions generated during the course of the conference discussions. Several contributions have been intentionally excluded as they belong more appropriately (and have accordingly been published) to specialized workshops conducted regionally under the auspices of ASEAN/US CRMP (e.g., on red tides, waste management). This publication, therefore, combined with the coastal profile, represents the major basis for the upcoming CAM plan for Brunei Darussalam.

The conference and its subsequent proceedings would not have been possible without the assistance of various agencies and the participants. We particularly wish to acknowledge the Government of Brunei Darussalam for hosting the conference and the officers and staff of DOF who made it a success; and the ICLARM staff who facilitated the completion of the proceedings: Mr. James N. Paw, Ms. Elsie T. Tech and Ms. Dolores D. Diamante for technical assistance; Ms. Marie Sol M. Sadorra, Ms. Rachel D. Africa and Ms. Ma. Angelina A. Agulto for editorial work; Ms. Rachel C. Josue, Ms. Ma. Teresa G. Cruz and Ms. Imelda S. Rañada for typing the manuscript; and Ms. Rachel C. Atanacio and Mr. Reynaldo C. Silvestre for drawing the figures and preparing the layout.

Finally, we wish to thank USAID and the Government of Brunei Darussalam for funding support and making the national project possible.

The editors

Brunei Darussalam Capture Fisheries: A Review of Resources, Exploitation and Management*

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Abstract

This paper presents an overview of the capture fisheries of Brunei Darussalam covering: (1) fishing ground and environment; (2) resources distribution, characteristics and potential; (3) capture technology; (4) marketing and consumption; (5) current resources exploitation level; (6) legal and institutional structure relevant to management; and (7) management objectives for the sector. Sustainable fisheries development is the long-term management goal. Proposed management guidelines center around: (1) appropriate exploitation levels and patterns; (2) minimizing sectoral and gear conflicts; and (3) maintenance of environmental quality consistent with sectoral objectives. Implementation strategies define key approaches to proper administration and review of the guidelines. Management constraints are identified and program recommendations that address these limitations are outlined.

*ICLARM Contribution No. 820

Introduction

This paper provides a sectoral background of the capture fisheries of Brunei Darussalam. Discussion is limited to coastal fisheries resources for the following reasons: (1) the management plan for which this paper is a background document concerns only the coastal zone (delimited to have a seaward limit at the edge of the continental shelf); (2) studies covering offshelf fisheries resources are few; and (3) resource biomass is concentrated on shelf areas, based on available information. Moreover, biological and technological considerations are emphasized (particularly the nature, potential and status of exploitation of the resources), given the nature of available studies. Socioeconomic research essential to resource allocation decisions, for example, is notably lacking. Nevertheless, this synopsis suffices for the plan formulation process. In this context, available studies, while deemed sufficient, are neither exhaustive nor complete. These require continuous extension and/or refinement as an integral part of the management plan.

Brunei Darussalam has a relatively short history of quantitative fisheries research. This is evident from the

paucity of published works up to the late 1970s. Research was subsequently spurred by fisheries development pressure, on the one hand, and the pragmatic development approach adopted by the Department of Fisheries (DOF), on the other. A fair amount of materials has accumulated since the first systematic survey of demersal resources in 1979-1980 (Beales et al. 1982). Albeit largely unpublished, these data and studies exist in the files of DOF. The contributions in Chua et al. (1987) and Silvestre et al. (in press, c) represent attempts to synthesize and draw inferences from the available information on the country's fisheries and coastal environment. Of late, DOF (1989) and Silvestre et al. (in press, b) present results of recently conducted pelagic acoustic and demersal surveys, respectively. This paper relies principally on these studies.

Fishing Ground and Environment

Located in the northwestern portion of Borneo Island, Brunei Darussalam (Fig. 1) has a land area of 5,765 km^2 situated within latitudes 5°05'N and 4°00'N, and longitudes 114°04'E and 115°22'E. The country has a coastline roughly 130 km long fronting the South China Sea and borders the east Malaysian state of Sarawak. It is partitioned administratively into four districts: Temburong, Brunei-Muara (where the national capital, Bandar Seri Begawan, is located), Tutong and Belait. The contributions in Chua et al. (1987) detail the country's biophysical environment. The eastern district of Temburong is mountainous inland near the Sarawak border, becoming hilly towards the coastal area, fringed by floodplains and swamplands of Sungai or Sg. (i.e., River) Temburong. The western districts of Belait, Tutong and Brunei-Muara are predominantly hilly lowlands, becoming alluvial, occasionally swampy plains toward the coast. A considerable tract of urbanized, cleared land exists (particularly in Brunei-Muara) within a 20-km belt along the coast where 85% of the country's 250,000 population resides. Four river systems drain the country and affect the coastal waters, namely, Belait, Tutong, Brunei and Temburong. In addition, Limbang and Trusan Rivers drain into Brunei Estuary from Sarawak.

The sea boundaries of Brunei Darussalam are defined in the 1982 Territorial Waters of Brunei Enactment (DOTCP 1986). This enactment synthesized provisions of government pronouncements and United Kingdom Statutory Instrument Nos. 1517 and 1518 of 1958 defining the boundaries of North Borneo and Sarawak. With the emergence of the international regime of 200-mile Exclusive Economic Zones (EEZs), the country's marine jurisdictional claim expanded considerably. The area of the continental shelf (defined as waters between the shoreline and 200-m isobath) is about 8,600 km^2 while the EEZ totals roughly 38,600 km^2. Fig. 2 illustrates in detail the bathymetry of Brunei shelf waters. The belt of shallow water down to 10 m is from 3 to 10 km from the shoreline. Between the 10-m and 40-m isobaths, the depth gradients are irregular due to sand deposition by longshore drifts (resulting in shallow waters below 30 m as far as 30 km from the shoreline near Champion Shoal) and raised areas covered by coral/hard grounds (e.g., Ampa and Champion areas). Beyond the 40-m isobath, depth increases steadily to the 100-m isobath after which slopes increase rapidly to the continental shelf edge.

Coral reefs, productive yet fragile ecosystems, dot the coastal waters within the 40-m isobath. The country is not well endowed with reefs due to its turbid coastal waters (Chou et al. 1987). Total reef area is only about 45 km^2, the major ones being Chearnley, Ampa, Iron Duke, Brunei Patches and Champion (Fig. 2). The major reefs are situated offshore, away from the effects of low salinity from freshwater/river outflows, sedimentation and physical perturbations. Apart from these coral areas, the remaining bottom substrate is sandy or muddy (i.e., soft-bottom). Fig. 3 shows the distribution of bottom sediments in the country's coastal waters. Fine-grained sand forms a narrow belt at least 1 km thick throughout the coastline. Tongues of sandy substrate are deposited as far as 30 km off Tutong and Berakas. Beyond these sandy areas, the substrate is primarily silt or clay up to the continental shelf edge.

Oil and gas pipelines/structures are installed in the country's coastal waters (Fig. 4). The economy of Brunei Darussalam is dominated by the oil and gas industry (i.e., at least 75% of GDP) and any fisheries development program must ensure safety and unhampered operation of the sector's offshore installations. A 1-nautical mile (nm) no fishing "buffer zone" surrounding these structures is currently prescribed by DOF. The major structures are in Champion, Magpie, Fairley, Ampa and Tali Fields with pipeline interconnections among the fields and onshore facilities concentrated in Belait District. These structures, combined with the presence of hard/coral areas and the 1-nm "buffer zone" around them, effectively reduce the fishable areas in the 0- to 50-m depth range by 55% and in the 50- to 100-m depth range by 16%.

Brunei Darussalam has a tropical/equatorial climate characterized by nearly uniform high temperature and rainfall. The country's coastal waters are relatively warm (29.5°C) and less saline (31 ppt). Climatic variation is dominated by the monsoon winds resulting from the seasonal fluctuation of the intertropical convergence

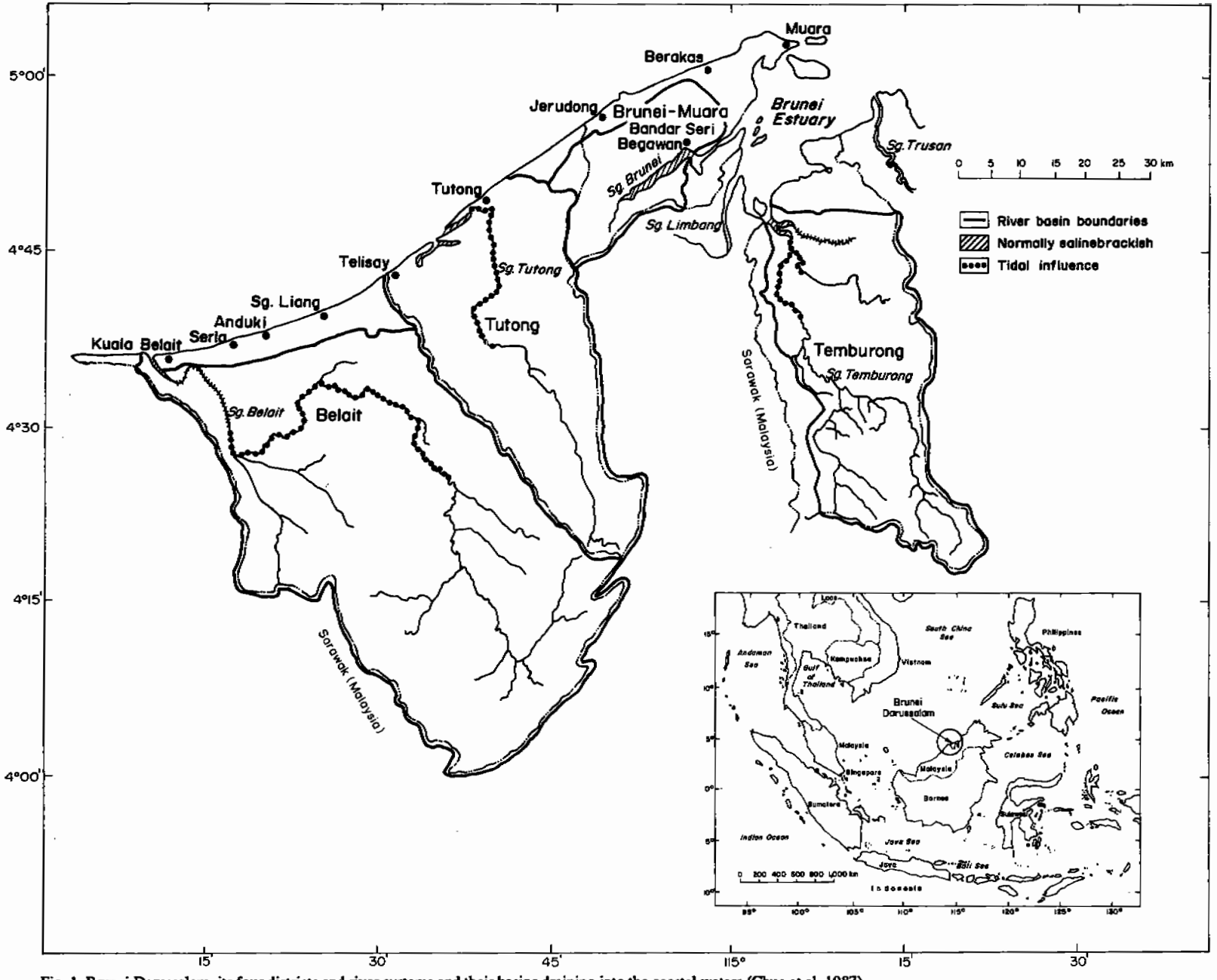

Fig. 1. Brunei Darussalam, its four districts and river systems and their basins draining into the coastal waters (Chua et al. 1987).

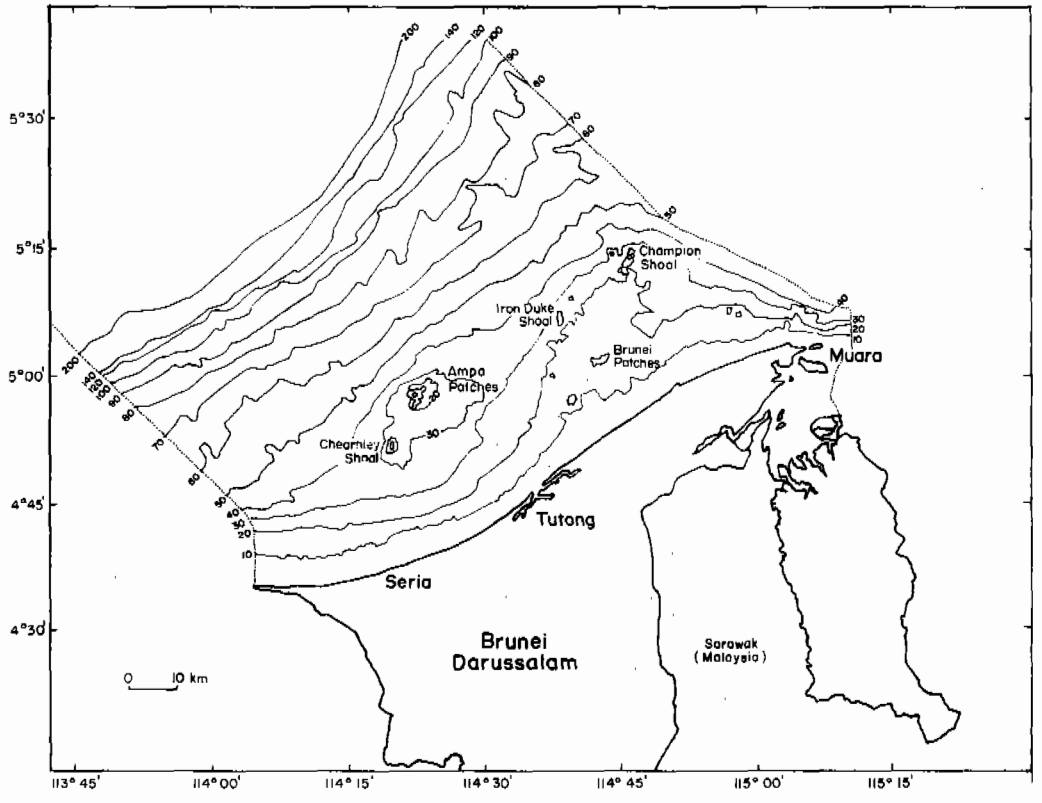

Fig. 2. Depth distribution in the coastal waters of Brunei Darussalam. Isobaths in meters (Silvestre et al., in press, b).

zone in the South China Sea area. Fig. 5 gives a summary of the wind/monsoon regime in Brunei Darussalam and the corresponding within-year variation of selected environmental parameters. The northeast monsoon prevails from December to around March, characterized by minimum annual sea surface and air temperature; high rainfall and low salinity during its early part, turning into minimum annual rainfall and maximum salinity during the latter part; and peak annual wind speeds resulting in maximum wave heights. The southwest monsoon occurs around June to October, characterized by low to average rainfall, temperature, salinity and wave height. Two transition periods occur around April to May and November to December, characterized by light, variable winds. These periods correspond to peaks in rainfall resulting in minimum salinity and maximum turbidity in the coastal areas. Brunei Darussalam is not in the path of major typhoons and experiences very little inclement weather except for occasional, brief squalls that occur during the latter part of the southwest monsoon.

Surface currents generally have a southwesterly direction parallel to the coast during the northeast monsoon and a northeasterly direction during the southwest monsoon. These seasonal trends are complicated by coastal geomorphology, the tidal regime and the presence or absence of typhoons in the northern South China Sea. Coastal geomorphology, for instance, leads to eddy formation near the raised areas of Champion and Magpie as well as the Fairley-Ampa area during certain parts of the year. The tidal regime in the country has a large diurnal component, mixed with a semidiurnal one every few days in a month, which affects local water movements. Mean sea level at Muara Harbor in 1989 was 1.3 m, with mean low water and mean high water at 0.6 m and 2.0 m, respectively.

The coastal waters, typical of tropical areas, are relatively nutrient-poor. This lack of nutrients increases dramatically from the well-mixed and river-fed shallow waters to the deeper areas. In the country's open coastal waters, the thermocline (and depth of biological productivity) is roughly 60 m. Estimates of primary productivity and zooplankton density in northwest Borneo waters are in the range of 150-250 mg C $m^{-2}day^{-1}$ and 51-200 mg m^{-3}, respectively (Valencia 1978). In studies of Brunei Bay, Linden et al. (1989) estimate phytoplankton biomass at 0.31-0.59 mg/l of chlorophyll A and primary productivity at 150-550 mg C $m^{-2}day^{-1}$.

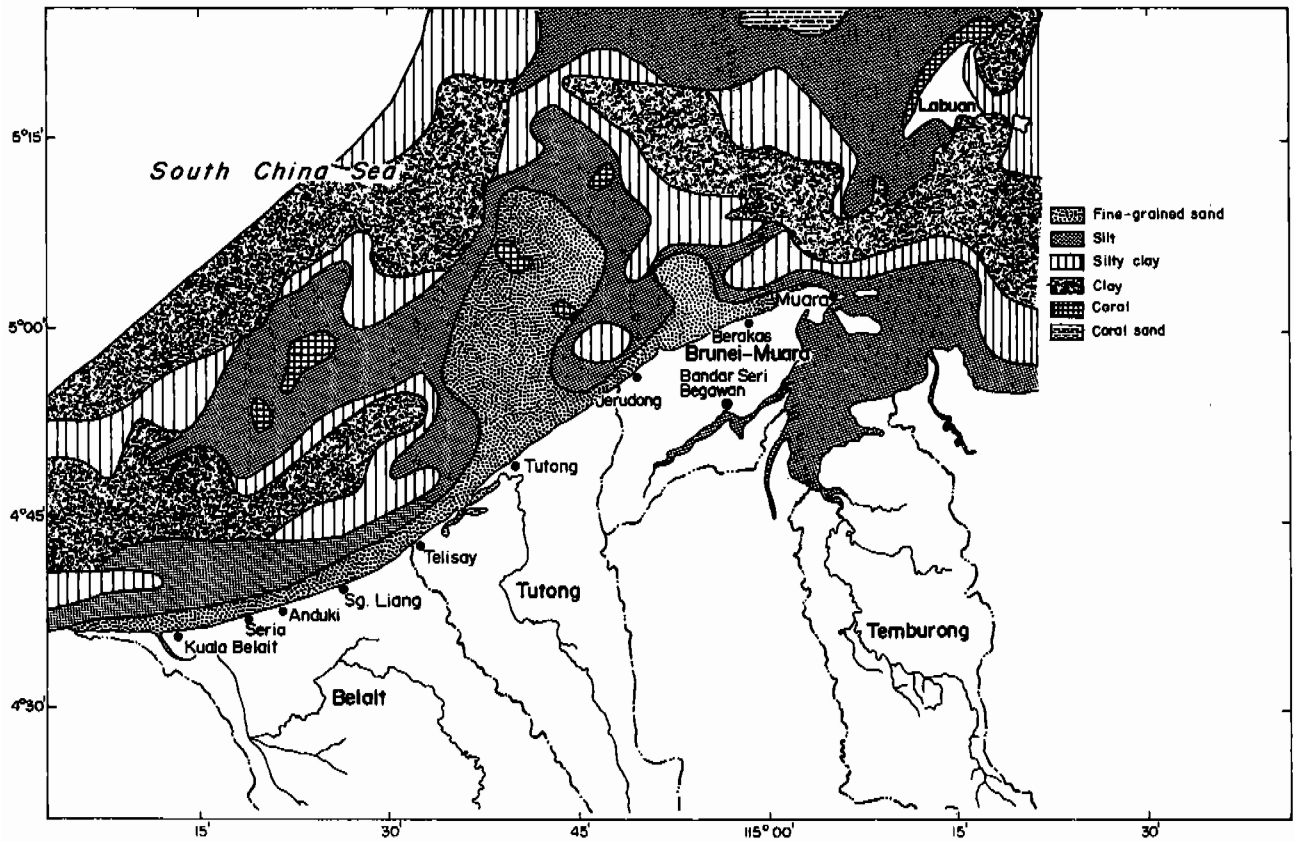

Fig. 3. Distribution of bottom substrates in the coastal waters of Brunei Darussalam (DOTCP 1986).

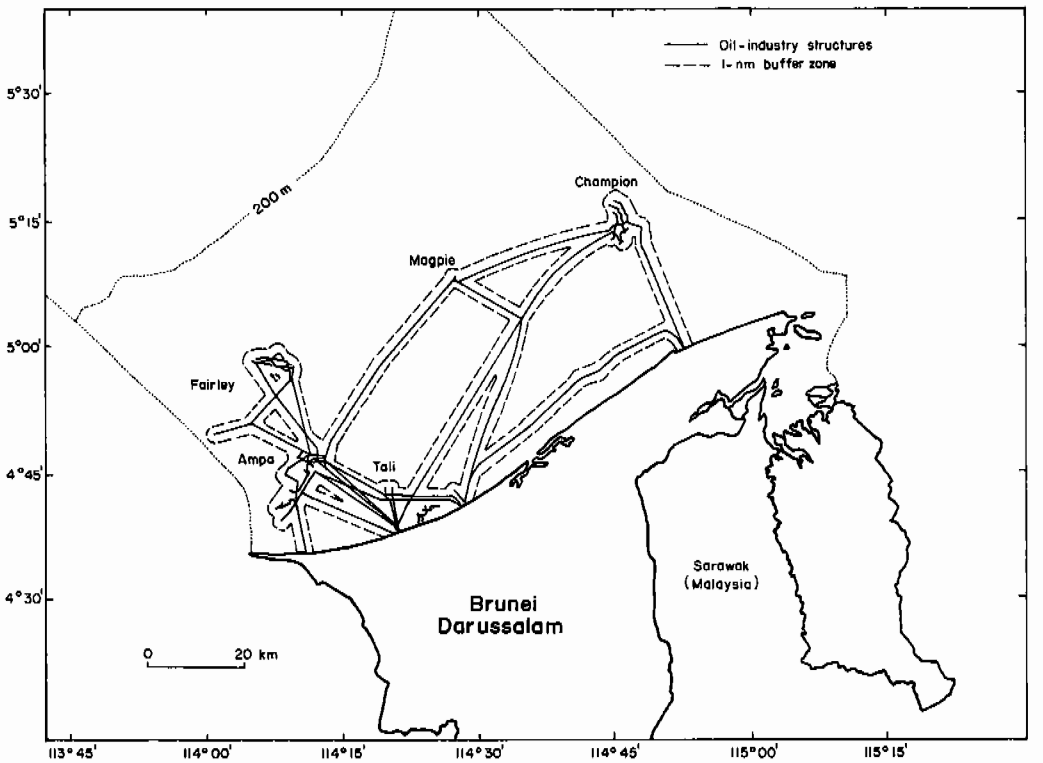

Fig. 4. General distribution of oil-industry structures and the 1-nm buffer zone in the coastal waters of Brunei Darussalam.

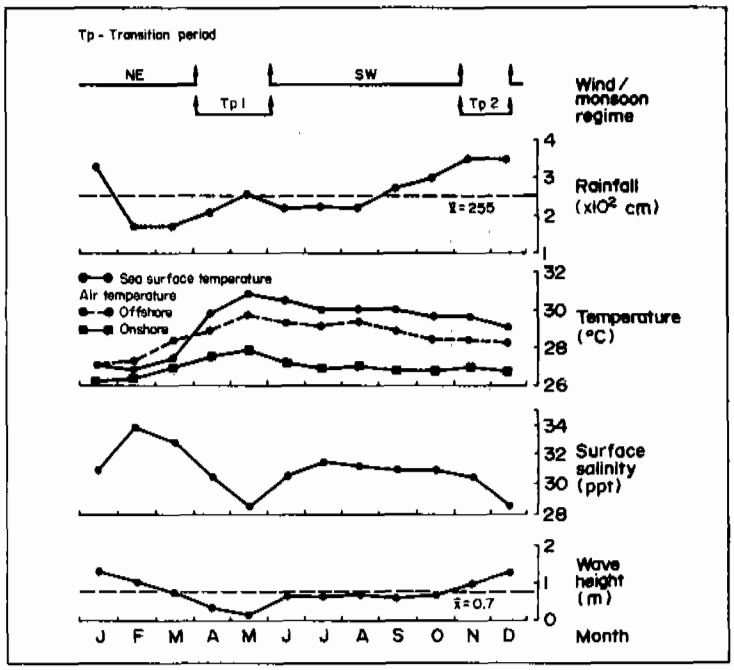

Fig. 5. Summary of within-year variation of selected environmental parameters in the coastal waters of Brunei Darussalam (Silvestre et al., in press, b).

They note that primary production is lowest in April (driest period) and highest around November to December (wettest period), indicating the significance of river runoff to the annual enrichment process of coastal waters. Incorporating the observed seasonality results in annual mean primary production of about 250 mg C $m^{-2}day^{-1}$ or roughly 90 g C $m^{-2}yr^{-1}$.

Among the country's coastal features, the estuaries, mainly Belait, Tutong and Brunei, are of interest for their role as nursery areas. The extensive (325 km^2) and mangrove-fringed (85% of the country's mangroves) Brunei Estuary is of major importance as nursery/feeding grounds and site of the local fishery for penaeid shrimps. Details of the hydrology of Brunei Estuary are given in Currie (1979) and Loo et al. (1987). It has two main deep channels (Brunei and Temburong, leading to Brunei and Temburong Rivers, respectively), both with an average depth of 10 m. Apart from the channels, the estuary is composed of shallow mudbanks with high organic content. Considerable freshwater inflow from Trusan, Temburong, Limbang and Brunei Rivers (see Fig. 1) accounts for reduced salinities and fluctuating conditions in the area. Estuarine waters are partially stratified, both vertically and horizontally. Surface salinity is generally lower than that of bottom water and varies from 3 to 33 ppt from the heads of the rivers to the seaward entrance of the main channels. Periods of minimum salinity and maximum turbidity occur during the peaks in rainfall associated with the intermonsoon periods. Maximum salinity and decreased turbidity occur during the driest months of the year around February to March. Flushing time for the estuary has been estimated at 2-4 days.

Fisheries Resources and Potential

The fish fauna in Brunei coastal waters is typical of fish communities in dominantly soft-bottom areas of the central Indo-West Pacific. This fauna is characterized by high species diversity dominated by species with high growth, mortality and turnover rates. About 500 species belonging to 220 genera and 120 families of fishes and invertebrates have been reported from the catch of various fishing gear used in Brunei waters. The bulk of these species are not preferred fishing targets, having little commercial value and merely caught incidentally during fishing operations. Characteristics and potential yield estimates of the main resource groups are discussed below.

Shrimps

Twelve species of shrimps which belong to three genera (i.e., *Penaeus*, *Metapenaeus* and *Parapenaeopsis*) are of commercial interest in Brunei Darussalam. Of these, the *Metapenaeus brevicornis/ensis/affinis* and

Penaeus merguiensis/indicus species complex are the most abundant and dominate landings. The former complex consists predominantly of the yellow shrimp, *M. brevicornis*, while the latter is chiefly white shrimp, *P. merguiensis*. Shrimps are concentrated in Brunei Estuary and adjacent shallow waters as far down as Berakas and Jerudong. Silvestre et al. (in press, d) give a synopsis of the local shrimp fishery based on available information and studies (e.g., Teng 1971; Currie 1982), while Silvestre et al. (in press, b) give results of recent shrimp assessments in Brunei Estuary.

Both *M. brevicornis* and *P. merguiensis* are widely distributed in the shallow waters of the Indo-West Pacific from marine to estuarine habitats. They prefer muddy, turbid waters and do not have a well-developed burrowing behavior. Their main food items consist of vegetable materials and small crustaceans. Both species are heterosexual and fertilization is external. As with other shrimps with "closed" thelycum, females have to be soft-shelled for spermatophore impregnation. Breeding is a year-round activity with one or two spawning/recruitment peaks annually. Fecundity is characteristically high as with other shrimps, with a range of 50,000 to 1,000,000 ripe ova for observed individuals. Both species exhibit a marked schooling behavior which, together with their nonburrowing habit, renders them quite vulnerable at high fishing effort levels.

Studies indicate that the typical penaeid life cycle (i.e., estuarine postlarval to juvenile phase and marine sub-adult to adult phase) is altered in Brunei Estuary. Distribution of the adult stock in the coastal and offshore waters does not appear to be obligatory for both species. This is due to the different hydrological regime in Brunei Estuary where saline waters persist in the deeper parts, particularly the channels, for most of the year. Mature individuals of *M. brevicornis* and *P. merguiensis* occur in the estuary although a pattern of increasing mean length from the upriver to the offshore areas is apparent.

Spawning of both species occurs year-round with two peaks around February to March and August to September. Subsequent peaks in rainfall (associated with the two intermonsoon periods) after peaks in spawning provide suitable estuarine habitat and, ultimately, drive off older/bigger individuals to deeper, more saline areas. Growth proceeds rapidly after hatching and mortalities are high. Population growth and death rates begin to approximate the von Bertalanffy growth and exponential death process, respectively, at around the juvenile stage. Silvestre et al. (in press, b) give estimates of growth, mortality and recruitment seasonality for *P. merguiensis* and *M. brevicornis* stocks in Brunei Estuary and adjacent waters. Growth rates are high (K=1.25-1.50 yr^{-1}), together with natural mortality (M=2.3-2.7 yr^{-1}), implying fast turnover rates. The pattern of recruitment (similar to independent studies of spawning activity) is bimodal. Individuals spawned in August to September are responsible for the recruits during the major peak in abundance and catches in the inshore areas around February to April, while those spawned around February to March account for recruits during the occasional minor peak in abundance and catches around September.

The abundance of shrimps exhibits a pronounced seasonal cycle in Brunei waters. This seasonality is a combined function of the life cycle chronology and population dynamics of the major species and the hydrology of Brunei Estuary and adjacent waters. Fig. 6 illustrates the average pattern of the monsoons, precipitation and shrimp catch in Brunei Darussalam covering the 1980-1989 period. Peak catches occur from February to April, coinciding with the period of least rainfall and maximum salinity. A minor peak in catches around September, which occurs irregularly, is masked by the averaging process. Catches during the peak rainfall period (November to January) are taken from the more offshore areas of the estuary, if not off Berakas and Jerudong. These indicate an inshore-offshore fluctuation in abundance relative to freshwater inflow to the estuary due to differential salinity tolerance limits with size/age of the major species. Higher salinities around February to April and September allow a more inshore distribution of shrimps, making them vulnerable to the concentration of fishing effort within Brunei Estuary.

Schematic representations of the life cycle hypothesis for *M. brevicornis* and *P. merguiensis* in Brunei waters are given in Fig. 7, together with monsoon regime, rainfall maxima and peak catches. Available growth and size-at-maturity information indicates that both species can spawn within six months from birth. Available size-fecundity relationships combined with the high mortality rate for both species indicate generation time (i.e., the period between massive reproduction of parent and that of progeny generation) to be about six months. For *M. brevicornis*, the minor cohort spawned around February to March gives birth to the major cohort around August to September and vice versa. In the case of *P. merguiensis*, the minor cohort spawned around August to September gives birth to the major cohort around February to March and vice versa. For both species, the six-month and one-year old cohorts appear to be the major and minor contributors, respectively, to each progeny cohort/generation. Similar to observations made by Garcia (1988) on northern Australian stocks of *P. merguiensis* investigated by Rothlisberg et al. (1985), the stock of *P. merguiensis*

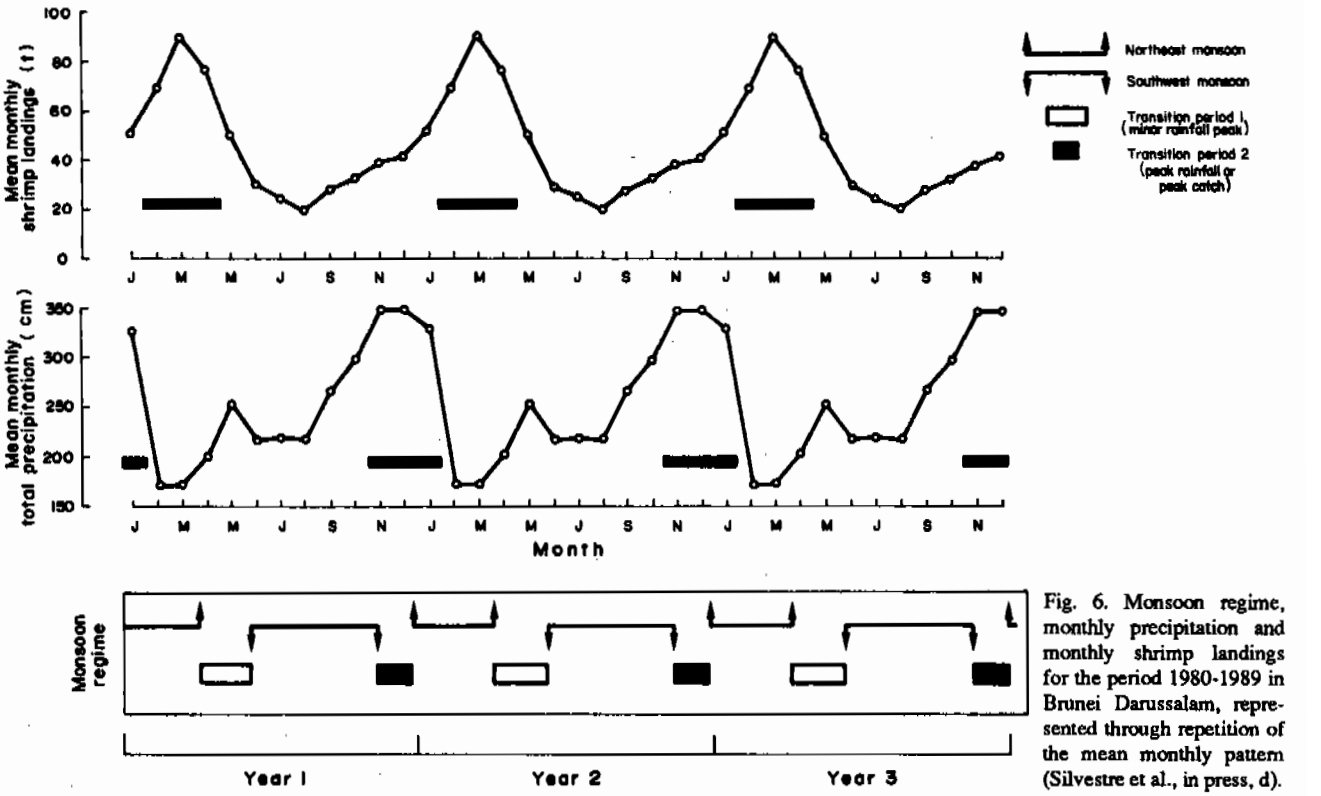

Fig. 6. Monsoon regime, monthly precipitation and monthly shrimp landings for the period 1980-1989 in Brunei Darussalam, represented through repetition of the mean monthly pattern (Silvestre et al., in press, d).

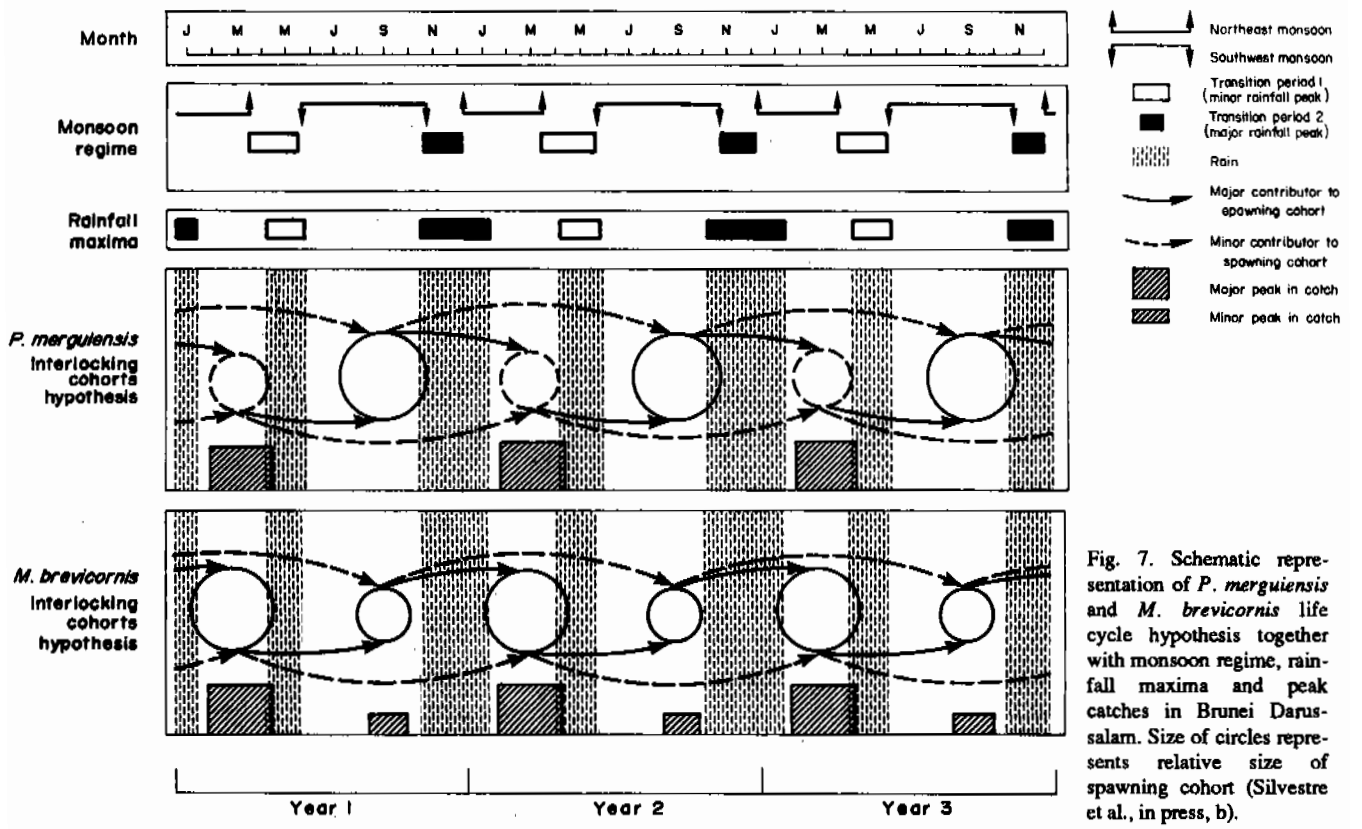

Fig. 7. Schematic representation of *P. merguiensis* and *M. brevicornis* life cycle hypothesis together with monsoon regime, rainfall maxima and peak catches in Brunei Darussalam. Size of circles represents relative size of spawning cohort (Silvestre et al., in press, b).

considered here also appears to be out of phase with the productivity cycle in Brunei waters and the relative cohort sizes may be a consequence of high fishing pressure.

An empirical model relating shrimp yield and fishing effort for the current year to rainfall terms the previous year is presented by Silvestre et al. (in press, d) from which potential yield of the country's shrimp resources may be inferred. Fig. 8 illustrates the model derived which accounts for at least 60% of the observed variation in shrimp catches for the period 1968-1989. Shrimp landings are shown under conditions of minimum, mean and maximum rainfall terms. The model implies maximum shrimp yields of 350-800 t through the range of observed rainfall at effort levels of 500-600 trammel nets.[1] A maximum yield of about 500 t with 550 trammel nets is possible under average rainfall conditions. Apart from its long-term utility for management, the model is a potential predictive tool a month prior to the annual peak fishing season. While the confidence limits are currently fairly wide, refinement of the model should lead to improved predictive ability and management over the long term.

Demersals

The term "demersals" refers to fishes and invertebrates that spend most of their adult life on or near the sea bottom. The demersal assemblage considered here accounts for the bulk of the catch of various gear in Brunei waters, i.e., about 400 species (out of 500) in 170 genera and 100 families. Despite such rich diversity, only about 100 species occur regularly in trawl catches and far less are commercially important and sold in the country's fresh fish markets. Four surveys provide information on the magnitude, composition and distribution of the demersal resources over three time periods--1970 (DOF 1968; Mohammed Shaari et al. 1976); 1980 (Beales 1982); and 1990 (Silvestre et al., in press, b).

Fig. 9 illustrates the distribution of demersal stock density in Brunei coastal waters with the 5-nm grid squares used by DOF. Stock densities vary from 1 to 12 t/km^2, declining from squares close to the shore towards those near the continental shelf edge. Squares within the 50-m depth contour have stock densities from 10 to 12 t/km^2, while those within 50-100 m have 3 to 5 t/km^2. The narrow belt of deep waters within 100-200 m has a stock density of around 1 t/km^2. Such a low abundance in squares near the shelf edge coupled with the distance from bases of operations (e.g., Muara) renders trawling operations commercially unviable, given current fish prices and operational costs (see Silvestre et al., in press, b; Cruz et al., in press).

Apart from the strong effect of depth, a strong seasonality is apparent in demersal abundance. Trawl surveys conducted around 1980 and 1990 indicate that demersal abundance is highest during the first two quarters of the year, particularly between February and April to May. This is similar to observations made by Halidi (1987) based on independent trawl monitoring data for the period 1980-1986. The seasonality in abundance is consistent with the seasonal productivity cycle

[1]Estimates of potential yield and corresponding effort levels cited herein relative to the shrimp stocks in Brunei Darussalam are tentative and require more thorough evaluation. This is in view of questions on integrity of shrimp stocks in the country which may possibly receive recruitment inputs from adjacent shrimp resources in Sarawak, Malaysia.

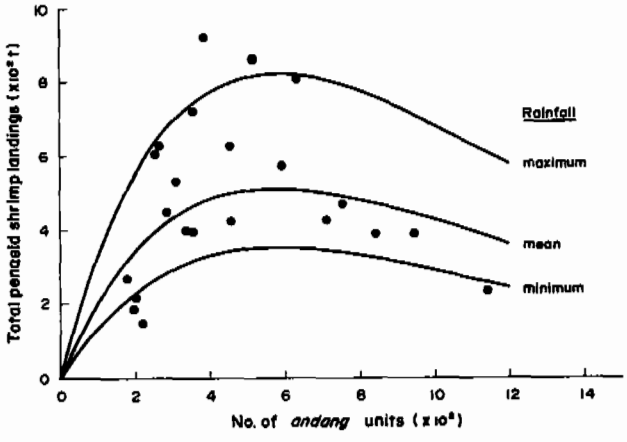

Fig. 8. Model relating total penaeid shrimp landings to *andang* (trammel net) effort and rainfall in Brunei Darussalam (r^2 = 0.63, n = 22, d.f. = 18) (Silvestre et al., in press, d).

in Brunei waters and the life cycle/recruitment phasing of major demersal species. Peak demersal abundance from February to around April and May follows the peak in rainfall and primary productivity around November to January, and corresponds to peaks in recruitment of major demersal species.

A strong diurnal fluctuation in demersal abundance is also apparent. Results of the day-night fishing comparisons in shallow (10-50 m) trawlable grounds off the Muara-Berakas area indicate mean catch rates for nighttime trawling to be only half of those obtained during daytime (i.e., a mean of 439 kg/hour versus 222 kg/hour for day and night hauls, respectively). A closer examination reveals that only nighttime catch rates after 2000 hours differ significantly from daytime catch rates (Silvestre et al., in press, b). Halidi (1987) observes similar trends using trawl monitoring data for the 1980-1986 period. Diurnal variation in catch rates is due to the nightly dispersal through the water column of the major demersal species, as is observed elsewhere in Southeast Asia and other regions. Overall, demersal abundance exhibits spatial and temporal fluctuations strongly related to depth, the seasonal life cycle/recruitment and productivity phasing, and time of day.

The demersal assemblage in Brunei waters is typical of bottom faunal communities in predominantly muddy substrates of the Indo-West Pacific. Table 1 gives the relative abundance of the ten most dominant families/groups comprising trawl catches during surveys around 1970, 1980 and 1990. Demersal resources have been consistently dominated by low-valued families/groups such as slipmouths (Leiognathidae), goatfishes (Mullidae), threadfin breams (Nemipteridae) and sharks/rays. These groups collectively account for around 47-68% of demersal biomass between 1970 and 1990. The bulk of demersal biomass are zoobenthos feeders, indicating the importance of the large detritus biomass as the major driving factor in the coastal fisheries ecosystem of Brunei Darussalam (see Silvestre et al., in press, a). It is apparent from Table 1 that the assemblage is dominated by groups with relatively high growth, mortality and turnover rates. Silvestre et al. (in press, b) give population parameters of major species comprising roughly 70% of demersal biomass during the 1990 survey. Growth rates are high (K=0.60-1.70 yr^{-1}), together with natural mortality estimates (M=1.0-2.0 yr^{-1}). Recruitment is predominantly in dual pulses with one major and one minor peak every year.

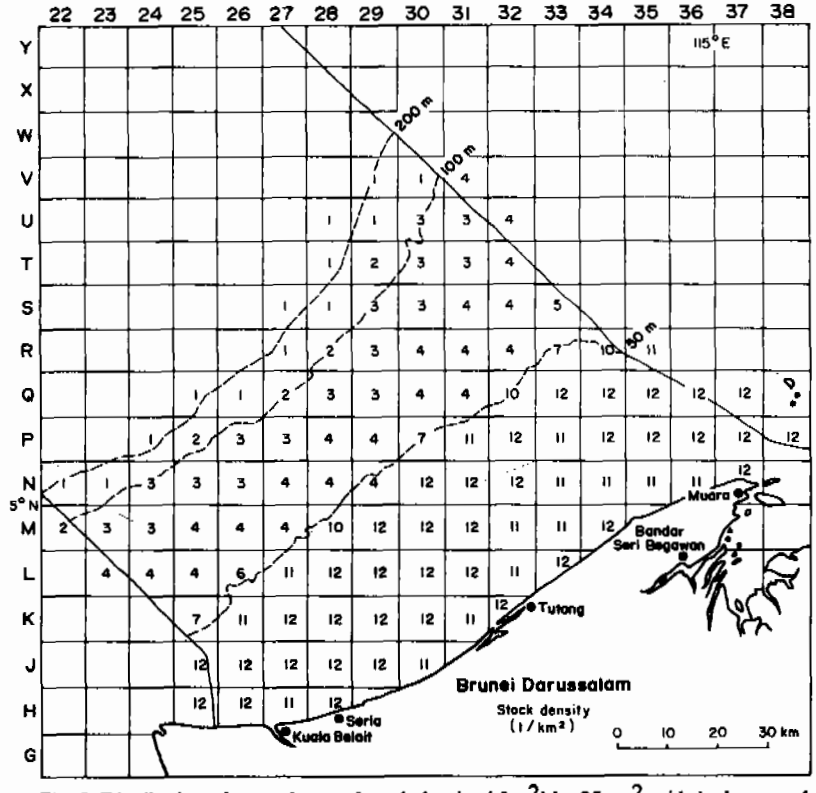

Fig. 9. Distribution of mean demersal stock density (t/km^2) by 25 nm^2 grids in the coastal waters of Brunei Darussalam (Silvestre et al., in press, b).

Table 1. Relative abundance of the 10 most dominant families/groups comprising trawl catches during demersal surveys in the coastal waters of Brunei Darussalam for three time periods.

Rank	1970 Family/group	1970 % abundance	1980 Family/group	1980 % abundance	1990 Family/group	1990 % abundance
1	Leiognathidae	30.9	Leiognathidae	34.1	Leiognathidae	28.1
2	Shark/ray	18.9	Mullidae	6.0	Mullidae	8.0
3	Nemipteridae	10.9	Carangidae	5.5	Shark/ray	7.6
4	Mullidae	6.8	Nemipteridae	3.9	Nemipteridae	7.6
5	Synodontidae	5.5	Shark/ray	3.3	Sciaenidae	7.1
6	Carangidae	3.0	Ariidae	2.9	Haemulidae	6.8
7	Ariidae	1.7	Sciaenidae	2.8	Synodontidae	4.4
8	Haemulidae	1.2	Gerridae	1.5	Carangidae	3.9
9	Squid/cuttlefish	1.0	Lutjanidae	1.2	Ariidae	3.4
10	Sphyraenidae	0.8	Haemulidae	0.9	Gerridae	3.3
	Others	19.3	Others	37.9	Others	19.8

Source: Silvestre et al. (in press, b).

Fig. 10 illustrates the size range of selected species caught in the coastal waters as compared with those caught within Brunei Estuary. The species considered, which dominate demersal biomass, spend a considerable portion of their early life (albeit not exclusively) within the estuarine system. This shows the significance of inshore areas as nursery and feeding grounds for the more abundant species in Brunei waters. It emphasizes the importance of maintaining environmental quality in the shallow inshore areas, particularly Brunei Estuary, to sustain exploitation of the demersal resources (and shrimps) over the long term.

Studies have been conducted to infer the potential yield from the demersal resources. In fact, the surveys cited above primarily assessed harvestable potential and the viability of fishing operations (see Beales et al. 1982; Silvestre et al., in press, b and c).

Two factors restrict the fishing area for industrial trawl development and should be considered in estimating potential yield, namely: (1) the low stock den-

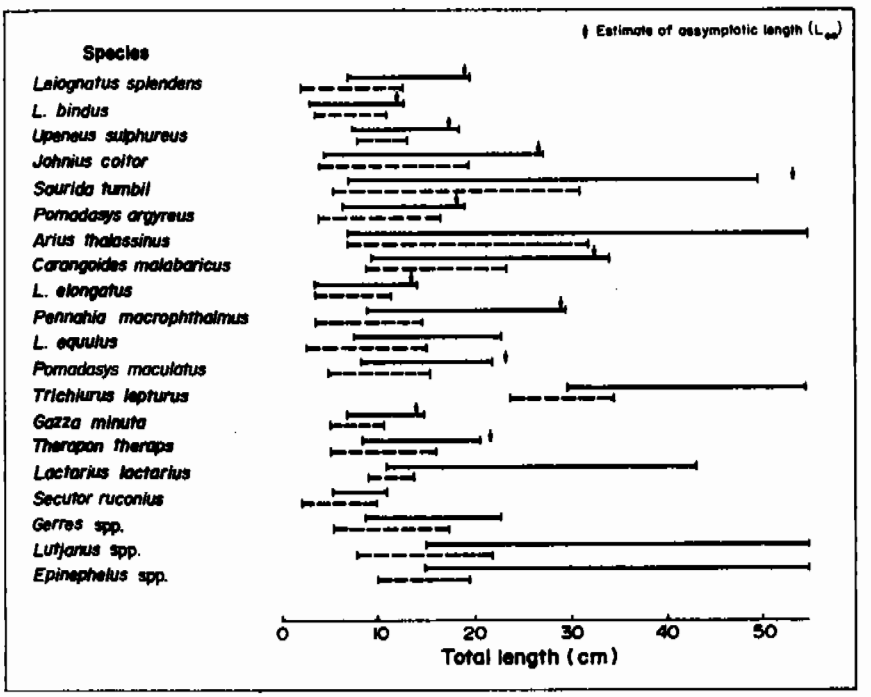

Fig. 10. Size range of selected species in the coastal waters of Brunei Darussalam (solid line) and within Brunei Estuary (dashed line), illustrating the significance of inshore areas as nursery/feeding grounds (Silvestre et al., in press, b).

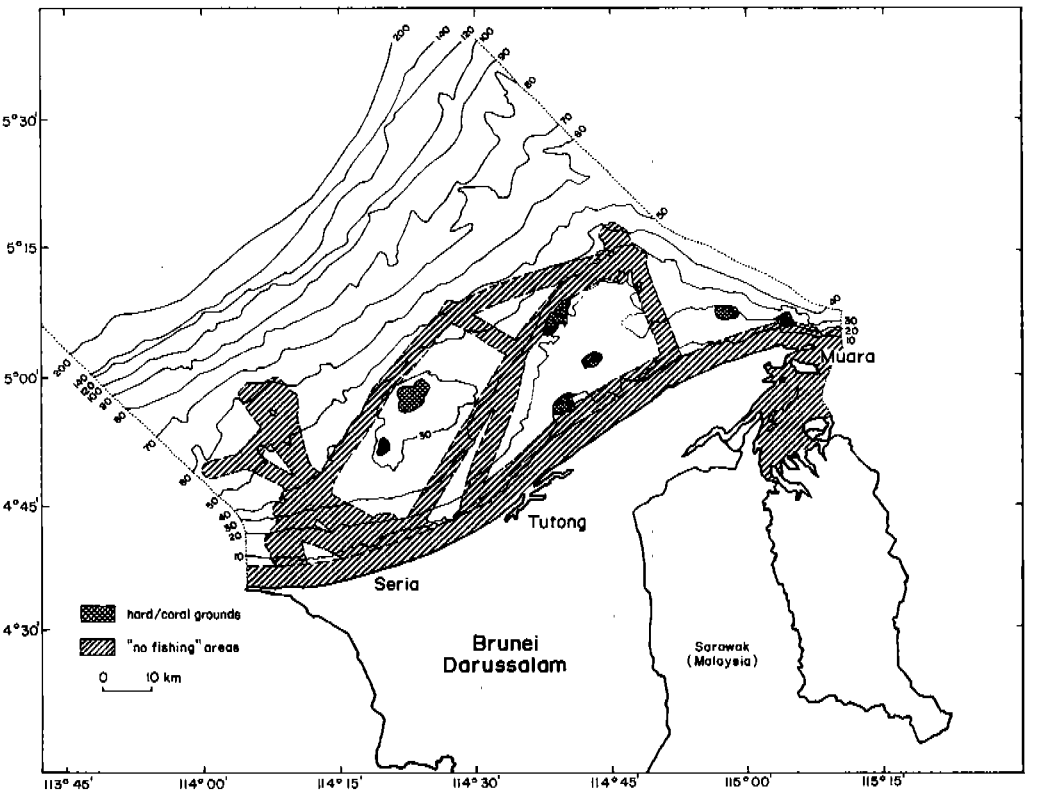

Fig. 11. Distribution of areas in the coastal waters of Brunei Darussalam where industrial fishing is prohibited due to the presence of oil industry structures, hard/coral grounds and the 3-nm zone for artisanal fisheries (Silvestre et al., in press, b).

sity in the 100- to 200-m depth range which renders commercial operations unviable and (2) the presence of "no fishing/inaccessible" areas nearshore. Fig. 11 illustrates the inaccessible areas in the coastal waters of the country due to the presence of oil industry structures, coral/hard grounds and the 3-nm zone for artisanal fisheries imposed by DOF. The prospective fishing areas cover only 4,600 km^2 excluding the no fishing zones, navigation cautionary areas and areas within the 100- to 200-m depth range.

Estimates of potential yield from the accessible areas (Silvestre et al., in press, b) summarized in Table 2 involve the use of two independent methods: the Gulland (1971) equation and the Schaefer model using catch rates from available surveys. The Gulland equation estimates a potential yield of 16,100 t/year. This value is merely a reference point for comparison with similar assessments made previously (both in the country and the region) as the Gulland equation has been noted to give optimistic figures (see Beddington and Cooke 1983; Pauly 1984; Garcia et al. 1989). The Schaefer model gives a more conservative and credible estimate of 11,100 t/year at an effort level of 106,200 standard trawling hours. The effort required to land 3,300 t/year from Stratum II is much higher than that for the potential yield of 7,800 t/year from Stratum I due to the lower stock density at greater depths. Such reality, combined with higher operational costs of fishing in more offshore, deeper areas, has led to coastal encroachment by larger trawlers in most of Southeast Asia (see Longhurst and Pauly 1987). Silvestre et al. (in press, b) note that the figure of 11,100 t/year may be an overestimate given that the catch rate data used for the Schaefer model discount diffusion from currently non-fished areas. Refinement of this estimate is needed as effort on the demersal resources is increased.

Table 2 implies a potential yield for Stratum I (from the results of the Schaefer model) of about 4.1 t/km^2. Assuming a potential yield similar to that of Stratum I gives a demersal potential of roughly 4,300 t/year from the 3-nm exclusive artisanal fishing grounds covering about 1,050 km^2 (which was excluded by Silvestre et al. [in press, b] in their computations). Potential yield from fishable demersal grounds therefore totals 15,400 t/year, including 11,100 t/year from "accessible" areas as defined by Silvestre et al. (in press, b).

Pelagics

The term "pelagics" as used here refers to fishes that spend all or most of their adult life living through the

Table 2. Estimates of demersal potential yield from "accessible" areas in the coastal waters of Brunei Darussalam. The "accessible" trawling areas are illustrated in Fig. 11.

Parameter		Stratum I	Stratum II	Total
Depth range (m)		0-49.9	50-100	0-100
Area (km^2)		4,255	3,141	7,396
Stock density (t/km^2)		11.7	3.6	8.3
Biomass ($x10^3t$)		49.9	11.4	61.3
"Accessible" area (km^2)		1,922	2,666	4,588
Biomass in "accessible" areas ($x10^3t$)		22.5	9.7	32.2
Potential yield from "accessible" areas ($x10^3t/yr$)	1. Gulland (1971) equation	11.3	4.8	16.1
	2. Schaefer model using trawl survey data for various years	7.8	3.3	11.1
Fishing effort to harvest potential yield from "accessible" areas	1. Standard trawl hours[a] ($x10^3/yr$)	44.5	61.7	106.2
	2. Standard boat numbers[b]	33	47	80

[a]Refers to standard survey gear used in Brunei demersal surveys, i.e., Goshawk trawl, 9.1 m effective headrope length at 3 knots.
[b]Refers to standard trawlers currently operating in Brunei waters, i.e., 18-20 m length overall with 150-200 hp engines operating/trawling an average of 1,320 hr/boat.
Source: Silvestre et al. (in press, b).

water column away from the sea bottom. While considerably less diverse than the demersals, the pelagic assemblage is still species-rich consisting of roughly 100 species distributed among 50 genera and 20 families. Table 3 lists the principal pelagic fishes reported from the catch of various gear used in Brunei coastal waters. The dominant pelagics are preferred fish targets that command relatively good prices in the country's fresh fish markets. These pelagics have been categorized into small and large, the former characterized by maximum lengths of 20-30 cm. The small pelagics feed mainly on zooplankton and small crustaceans. They are fast growers (K = 1.0-2.0 yr^{-1}) with high mortality rates (M = 1.0-2.0 yr^{-1}) and relatively short life spans (2-3 years). Spawning is frequently a year-round activity with two spawning and recruitment peaks annually. In contrast, large pelagics are located on top of the aquatic food chain and are piscivorous in their adult life. They are relatively slow-growing (K = 0.4-0.8 yr^{-1}) with low mortality rates (M = 0.4-0.9 yr^{-1}) and relatively long life spans of over five years. Spawning is similarly year-round, although the spawning and recruitment pattern is usually unimodal. Large pelagics are frequently the first resource group to suffer the effects of heavy fishing pressure in the Southeast Asian region and elsewhere in view of their more favorable market prices.

Fig. 12 illustrates the distribution of small pelagic fish density on the Brunei continental shelf. The abundance of small pelagics, similar to demersals, declines with depth as is observed elsewhere in the region. Peak densities at the time of the DOF (1989) survey (June 1989 or mid-southwest monsoon period) occurred in the shallow areas around Magpie (off Seria) and the tongue of shallow waters along the Tutong-Jerudong coast going to Champion Shoals. Similar information for large pelagics is unavailable although it is believed that their peak densities are also shelf-associated due to feeding and nursery considerations.

Table 3. Principal pelagic fishes reported from the catch of various fishing gear used in the coastal waters of Brunei Darussalam.

Small pelagics
Ariommatidae *(Ariomma)*, Carangidae *(Alepes, Carangoides, Decapterus, Megalaspis, Selar, Selaroides)*, Caesionidae, *(Caesio, Pterocaesio)*, Clupeidae *(Dussumieria, Sardinella)*, Engraulidae *(Stolephorus)*, Rachycentridae *(Rachycentron)*, Scombridae *(Auxis, Rastrelliger)*, Stromateidae *(Parastromateus)*

Large pelagics
Carangidae *(Scomberoides)*, Carcharhinidae *(Carcharhinus)*, Chirocentridae *(Chirocentrus)*, Istiophoridae *(Istiophorus)*, Scombridae *(Euthynnus, Katsuwonus, Scomberomorus)*, Sphyraenidae *(Sphyraena)*, Thunnidae *(Thunnus)*

Table 4 gives the estimate of small pelagic fish biomass and composition in the shelf waters of Brunei Darussalam. The genera *Dussumieria, Carangoides, Decapterus* and *Ariomma* were dominant, accounting for over 80% of standing stock. The estimate of 15.4 thousand t translates into 1.79 t/km^2 of shelf area, a figure closely consistent with available estimates in the

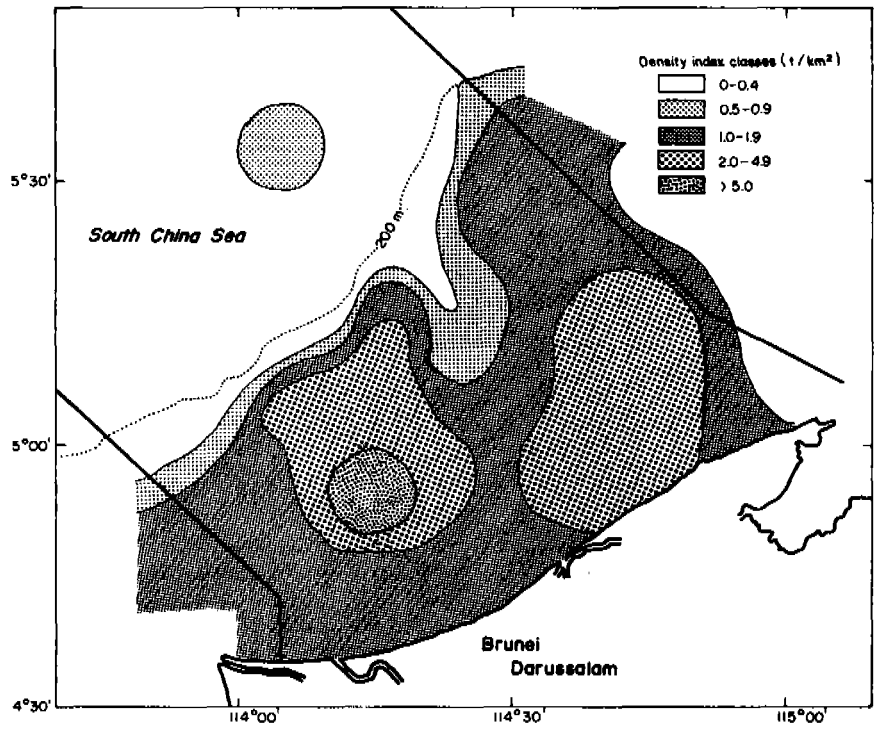

Fig. 12. Small pelagic fish density on the continental shelf of Brunei Darussalam (DOF 1989).

Table 4. Estimate of small pelagic fish biomass in the continental shelf waters (0-200 m) of Brunei Darussalam.

Genera/group	Biomass (t)	Relative abundance (%)
Dussumieria spp.	3,705	24.0
Carangoides spp.	3,580	23.2
Decapterus spp.	3,230	21.0
Ariomma spp.	2,550	16.5
Selar spp.	1,400	9.1
Rastrelliger spp.	270	1.8
Others	680	4.4
Total	15,415	100.0

Source: DOF (1989).

Southeast Asian region (albeit at the lower end of the range of existing estimates, see Dalzell and Ganaden [1987] and references therein). Using biomass, feeding and turnover rates of various trophic groups in Brunei coastal waters, Silvestre et al. (in press, a) essentially give a similar estimate (1.81 t/km^2) of onshelf small pelagic biomass. Moreover, they estimate large pelagic stock density onshelf to be roughly 0.5 t/km^2, or about 4,300 t for the entire shelf area spanning about 8,600 km^2.

These estimates of pelagic biomass are approximate and deserve further research effort. For instance, the DOF (1989) study is admitted to be preliminary based as it is on a single pelagic acoustic survey which may conceivably have missed the considerable seasonal fluctuation in abundance characteristic of small pelagics. Conducted in the mid-southwest monsoon period, the survey presumably provides below average pelagic biomass estimates. Using ecosystem modeling of Brunei coastal fisheries, Silvestre et al. (in press, a) rely largely on literature values of food composition ratios to which the range of biomass estimates are highly sensitive. Nevertheless, these studies are the only ones available from which pelagic fisheries potential may be inferred. The biomass figures imply potential yield (using the Gulland 1971 equation) of 7,700 t/year and 2,100 t/year from the small and large pelagic resources, respectively. Overall, fisheries resources in the country's coastal waters have a potential yield totaling 25,700 t/year consisting of: (1) 500 t/year of shrimps under average rainfall conditions; (2) 15,400 t/year of demersals from "accessible" areas and exclusive artisanal grounds; and (3) an aggregate of 9,800 t/year of small and large pelagics. Utilization of the potential yield estimates should take into account the nature and limitations of the methods used to derive such figures, and the increased variability and limited predictive

ability of existing biological models at harvest levels near these maximum figures.

Capture Fisheries Technology

The capture fisheries of Brunei Darussalam can be subdivided into the industrial and the artisanal sectors based on the level of capital inputs in fishing operations and associated characteristics. The industrial sector reflects the terms "modern", "large-scale", "commercial" and "offshore", while the artisanal sector indicates "traditional", "small-scale", "municipal" and "nearshore" as used in the fisheries literature (see, for example, IPFC 1987). As will become apparent, the industrial sector is comparatively more capital- and technology-intensive, less labor-intensive and energy-efficient per unit of fish landings, and less selective of fish targets, with the bulk of catches composed of relatively less-valued species.

Industrial fisheries sector

The industrial sector currently consists of 12 inboard-powered vessels using bottom trawls (9) and purse seines (3). All are based and land their catches at the Muara Fish Landing Complex (MFLC). The DOF exercises strict control in licensing industrial fishing vessels and gear, covering design, specifications, materials and equipment used. Table 5 gives the number of licensed industrial vessels by type of fishing method/gear for the period 1981-1990. Vessels using traps and longlines ceased operations in 1984 and 1989, respectively. Trawl development started in earnest in 1984 although one to three trawlers were reported to be periodically operational during the late 1960s and early 1970s (Beales et al. 1982). In 1989, only seven of the nine licensed trawlers were operational due to vessel and manning problems. In contrast, purse seiners started operations around the late 1970s, reaching a high of seven boats in 1986 and declining to three vessels in 1990. Overall, the industrial sector is a relatively recent development compared with the artisanal sector which has traditionally supplied the locally-sourced fish needs of the country.

Subramaniam et al. (in press, a) describe the design, operation and catch of industrial fishing vessels/gear used in the country. Trawlers in Brunei are all wooden vessels constructed in Bintulu (Sarawak), Sandakan (Sabah) or Penang--all in Malaysia. The nine trawlers licensed at present are 18-20 m long with 150- to 200-hp inboard diesel engines. Each is equipped with a radar, echo sounder, VHF radio and mechanical winch. Gear used are frequently 2-seam demersal trawls, although two to three vessels use high opening "Goshawk" trawls. The trawls usually have 17-m headline and 23-m footrope length with polyamide netting materials. Cod-end meshes are 70 mm stretched with a 38-mm liner, although liners of 20 mm have been observed.

Purse seine boats are all made of wood and constructed in Penang, Malaysia. All three purse seiners licensed currently are 19 m long each with a 250-hp diesel inboard engine. Each is equipped with a skiff boat about 4.5 m in length and powered by a 30-hp outboard diesel engine. Purse seiners are required to have a radar, echo sounder and VHF radio. Purse seine gear are typically 460 m long by 100 m deep with polyethylene purse, float and sinker line. Netting materials are made of polyamide with 12-mm stretched mesh size.

Table 5. Distribution of inboard-powered fishing vessels in Brunei Darussalam by type of fishing method/gear employed for the period 1981-1990.

Year	Licensed inboard-powered vessels				Total
	Pukat tunda (trawl)	*Pukat lingkong* (purse seine)	*Rawai* (longline)	*Bubu* (trap)	
1981	-	1	2	-	3
1982	-	1	2	1	4
1983	-	2	-	1	3
1984	4	2	2	-	8
1985	4	4	1	-	9
1986	4	7	1	-	12
1987	4	5	1	-	10
1988	5	5	1	-	11
1989	9	3	-	-	12
1990	9	3	-	-	12

Source: DOF, unpublished records.

Trawlers operate with a crew of four to six including the skipper. Each trawl trip lasts from 12 to 20 hours. For each trip, the trawl is hauled an average of three times, each haul lasting from one to three hours. Trawling is conducted mainly during daylight hours between 7 A.M. and 3 P.M. Purse seiners, on the other hand, have a crew of about six to ten per boat. Operations are conducted during daylight hours and each trip usually lasts from 12 to 14 hours (leaving the port at 4 A.M., arriving at the fishing ground at 7 A.M., and back in port between 4 and 6 P.M.). Purse seines are used with fish aggregating devices (FADs) consisting of coconut or nipa fronds set several weeks prior to operations and monitored intermittently for favorable fish concentrations. Excluding scouting time, a single setting to hauling operation lasts two to three hours. A maximum of two to three setting operations is made during the course of a purse seine trip. Occasionally, during moonless nights, nighttime purse seine operations with the use of lights as fish lures are conducted.

Trawl and purse seine vessels are active nine to ten months of the year. Major repairs and drydocking are scheduled during the period of peak winds and wave height around December to February. Activities are concentrated within the 50-m depth contour--trawlers principally off Muara to Jerudong, occasionally off Tutong, and purse seiners off Jerudong to Tutong coast (Fig. 13). Both gear are allowed to operate only in the accessible fishing areas described previously, and fishing charts indicating such areas have been issued by DOF. Potential conflicts over fishing grounds could develop between trawlers and purse seiners due to the obstruction posed by FADs to trawling operations. Conflicts are at present minimal but should be given attention if both trawling and purse seining are to be expanded.

Most inputs to industrial fishing operations are imported. These are not limited to vessel, fishing gear and related equipment but include even fishing crew who are mostly expatriates from Malaysia and Thailand. The industrial sector experiences occasional interruptions in operation due to manpower problems and lack of spare parts for the vessels and related equipment. Moreover, the sector relies on facilities outside the country (particularly those in Labuan and Limbang, Malaysia) for routine ship repair and drydocking.

Subramaniam et al. (in press, a) provide estimates of trawl and purse seine landings as inferred from logbook returns of boat skippers. Mean landings during the 1985-1989 period were about 540 t/year--160 t/year from trawlers and the rest from purse seiners, excluding discards estimated to be roughly 30-40% for trawlers. Tables 6 and 7 give the composition of trawl and purse seine landings, respectively. The trawl chiefly exploits demersal species/groups while the purse seine harvests solely pelagic species/groups. Trawl landings are dominated by less-valued fishes (Grade IV), especially Leiognathidae composed principally of *Leiognathus equulus* and *splendens*. In contrast, purse seine landings are dominated by small pelagics such as *Selaroides, Selar, Decapterus, Alepes* and *Rastrelliger* which collectively account for about 75% of landings.

Table 6. Percentage composition of trawler landings based on monitoring statistics of the Marine Fisheries Section, DOF, during the period 1984-1988. Data exclude discards variously estimated to be between 30% and 40% of total trawl catches.

Grade/family/group	Composition	(%)
Grade I	7.3	
Carangidae		3.3
Lactaridae		0.3
Lutjanidae		1.0
Scombridae		0.2
Serranidae		0.9
Sphyraenidae		0.6
Stromateidae		0.5
Flatfish		0.5
Grade II	6.8	
Drepanidae		0.7
Nemipteridae		2.7
Haemulidae		1.2
Sciaenidae		2.2
Grade III	8.8	
Clupeidae		2.0
Gerridae		5.1
Mullidae		1.7
Grade IV	59.0	
Ariidae		3.0
Balistidae		0.5
Clupeidae		2.0
Leiognathidae		44.3
Scombridae		0.2
Sparidae		0.1
Synodontidae		4.3
Teraponidae		0.9
Trichiuridae		0.7
Sharks		1.6
Rays		1.1
Other marine fish		0.3
Crustacea	0.5	0.5
Squid	0.4	0.4
Cuttlefish	0.2	0.2
Others	17.0	17.0
Total	100.0	100.0

Source: Subramaniam et al. (in press, a).

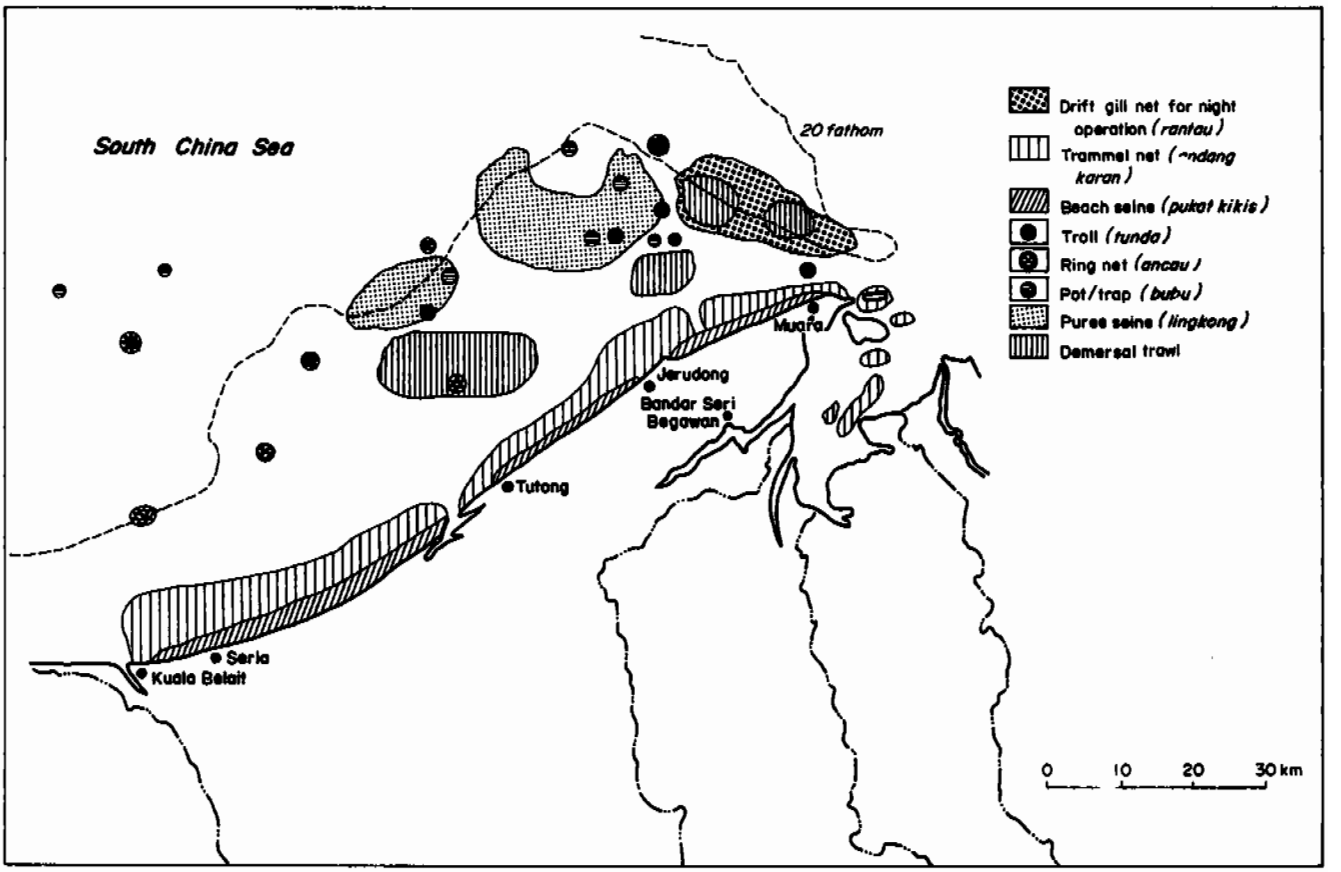

Fig. 13. Distribution of fishing areas by gear type in the coastal waters of Brunei Darussalam (Khoo et al. 1987).

Table 7. Percentage composition of purse seine landings in Brunei Darussalam during the period 1984-1989 based on logbook returns from purse seine operators.

Local name	Genera/species	Composition (%)
Temanong	*Selaroides* sp., *Selar* sp.	21.9
Basong-basong	*Decapterus maruadsi*	19.6
Selidai	*Selar kalla*	14.6
Sanglar	*Alepes djedaba*	9.1
Rumahan laki	*Rastrelliger kanagurta*	9.1
Ikan putih	*Caranx* spp., *Carangoides* spp.	7.4
Geronggong	*Megalaspis cordyla*	2.0
Alu-alu	*Sphyraena* spp.	1.8
Duai hitam	*Parastromateus niger*	0.8
Aur-aur	*Dussumieria* sp., *Sardinella* spp.	0.6
Others		13.1
Total		100.0

Source: Subramaniam et al. (in press, a).

Artisanal fisheries sector

Artisanal fishing operations involve the use of relatively simple, inexpensive fishing gear with or without the use of water craft. A total of 17 types of gear are currently used which include 7 nets, 5 traps and 5 hooks and lines (Table 8). Boats used are made of wood chiefly between 5 m and 9 m length overall powered by two 25- to 40-hp outboard diesel engines. Between 1985 and 1989, an average of 1,242 powered and 25 nonpowered boats were licensed annually.

The artisanal sector exploits a tremendous diversity of fishes and invertebrates. Table 9 gives the principal families/genera that compose the catch of the various gear types. Considerable overlap in resource base occurs among the various artisanal gear, as well as those used by the industrial sector. Comparatively, however, artisanal gear are fairly selective and usually designed for specific fish targets. The *andang karan, tugu* and *rambat* principally target shrimps while the *ancau, rantau* and various hooks and lines target pelagic groups. The rest of the other gear types target specific demersals.

Subramaniam et al. (in press, b) detail the design, operation and catch of the various artisanal gear. Despite the apparent complexity of the artisanal sector, only a few gear types contribute substantially to sectoral landings. For the period 1986-1989, four gear types (i.e., *tugu, andang karan, ancau* and *rambat*) classed under the general category of nets accounted for 85% of about 2,000 t/year of mean landings from full-time fishermen (Table 10). Similar information is unavailable from part-time artisanal fishermen, who chiefly use simple handlines, trammel nets and traps.

Banned in 1967 and reintroduced in the early 1980s, the *tugu* is operated mainly during low tide solely within Brunei Estuary. A *tugu* unit is a funnel-shaped piece of netting with a mouth opening of 2 m^2 and meshes of 2.5-3.2 cm at the cod end. A *tugu* set made up of 6-12 units is mounted on mangrove poles fixed to the bottom of mudbanks along the major channels (primarily Temburong) oriented to the tidal current direction.

The *andang karan* used for catching fish in the open coastal waters off Tutong and Belait Districts has meshes of 4-26.5 cm. The net used for catching shrimps, however, is more common and similar in design except that the meshes are smaller (2.5-4.5 cm). The *andang karan* designed for shrimps is set adrift with the tidal current and traps shrimps around the flexed abdomen. Fishermen operate alone or in pairs during daylight hours using two *andang* units alternately. Each unit is roughly 120-150 m long by 3.5 m deep. Fishermen follow shrimp concentrations within Brunei Estuary and, during seasons of high schooling densities around November to December, off the northern coast as far down as Berakas and Jerudong.

The *ancau* is a rectangular-shaped netting typically about 300 m in length by 15 m in depth. Its construction and operation are similar to those of the purse seine except that the former's dimensions are such that it can be operated manually by four to six fishermen from a 9- to 12-m wooden boat. The netting material is polyamide with 2.5-cm meshes while the float, sinker

Table 8. Classification (by DOF) of artisanal fishing gear used in Brunei Darussalam waters.

Gear class	Gear type: Local name	English name
Net	*Ancau/panau*	Ring net
	Andang jarang	Gill net
	Pukat kikis	Beach seine
	Rantau	Drift gill net
	Rambat	Cast net
	Tugu	Conical tidal trap
Trap	*Bintur*	Crab trap
	Bubu	Fish trap
	Kabat	Intertidal fish trap
	Kilong	Deepwater stake palisade
	Lintau	Shallow water palisade trap
Hook and line	*Pancing*	Handline (without sinker)
	Jaul	Handline (with sinker)
	Papar	Multiple-hook handline
	Rawai	Longline
	Tunda	Troll

Table 9. Principal families/genera of fishes and invertebrates occurring in the catch of commonly used artisanal fishing gear in Brunei Darussalam waters. Data are based on various DOF internal reports. Data for *andang, tugu, kilong, lintau* and *kabat* are from artisanal gear monitoring studies (see Silvestre et al., in press, b).

Gear type	Family/genera
Ring net *(ancau)*	Clupeidae *(Sardinella, Dussumieria)*, Carangidae *(Decapterus)*, Scombridae *(Rastrelliger)*, Engraulidae *(Stolephorus)*
Gill net *(andang jarang)*	Carcharhinidae, Ariidae, Leiognathidae, Carangidae
Trammel net *(andang karan)*	Penaeidae *(Penaeus, Metapenaeus)*, Clupeidae, Sciaenidae, Engraulidae, Leiognathidae
Drift gill net *(rantau)*	Scombridae *(Auxis, Scomberomorus)*, Carangidae *(Carangoides, Selar)*, Stromateidae, Carcharhinidae
Cast net *(rambat)*	Penaeidae, Carangidae *(Selar, Decapterus)*, Clupeidae *(Dussumieria, Sardinella)*
Conical tidal trap *(tugu)*	Penaeidae, Leiognathidae, Engraulidae, Apogonidae
Crab trap *(bintur)*	Portunidae *(Scylla, Portunus)*
Fish trap *(bubu)*	Lutjanidae, Serranidae, Carangidae, Haemulidae
Intertidal fish trap *(kabat)*	Mugilidae, Ariidae, Haemulidae, Leiognathidae, Sciaenidae
Deepwater palisade trap *(kilong)*	Leiognathidae, Clupeidae, Carangidae, Apogonidae, Teraponidae
Shallow water palisade trap *(lintau)*	Siganidae, Scatophagidae, Leiognathidae, Lutjanidae, Gerridae
Hook and line	Carangidae *(Caranx, Scomberoides)*, Carcharhinidae, Scombridae, *(Auxis, Katsuwonus, Scomberomorus)*, Lutjanidae, Serranidae, Sphyraenidae

Table 10. Relative contribution to artisanal fisheries landings by gear type based on monitoring statistics of the Marine Fisheries Section, DOF, for the period 1986-1989.

Gear type	% of mean landings[a]
Tugu	36
Andang karan	21
Ancau/panau	19
Rambat	9
Kabat	3
Kilong	2
Bubu	2
Rantau	1
Others	7

[a]Data from full-time artisanal fishermen whose mean landings for the period were about 2,000 t/yr. Landings data from part-time fishermen are unavailable.
Source: Subramaniam et al. (in press, b).

and purse seine lines are made of polyethylene. *Ancau* operations involve locating fish schools in the coastal waters, sometimes within Brunei Estuary, during daylight hours.

The *rambat* is a fine-meshed net (0.6-1.5 cm) made of polyamide and used within estuarine areas (primarily Brunei Estuary) and shallow coastal waters to catch schooling shrimps and small pelagics. Each unit is typically from 5 to 10 m in diameter and operated by a single fisherman during daylight hours. The use of a boat during operations is not common, the gear being frequently operated near channels (especially Brunei River Channel) and tossed from the shore or riverbank.

Artisanal operations are concentrated in the coastal waters within the 50-m isobath (Fig. 13) and within Brunei Estuary (Fig. 14). Current distribution of fishing areas by gear type does not indicate any incompatible use of fishing ground within the artisanal sector. Between gear used by the industrial and artisanal sectors, a similar assessment can be made, apart from the occasional obstruction posed by unmarked traps *(bubu)* to trawling operations. This situation stems partly from the current low level of fishing effort, which is expected to continue for the artisanal sector, given the competition for manpower from land-based economic activities. Possible expansion of trawling requires trap operators to properly mark the location of their gear (already initiated by DOF) or encouraging them to deploy units in areas inaccessible to trawlers. Current prohibition of industrial gear from estuarine areas and within 3 nm off the coast has precluded potential intersectoral conflicts.

The DOF implements a strict licensing scheme for the country's artisanal fisheries. Only licensed fisher-

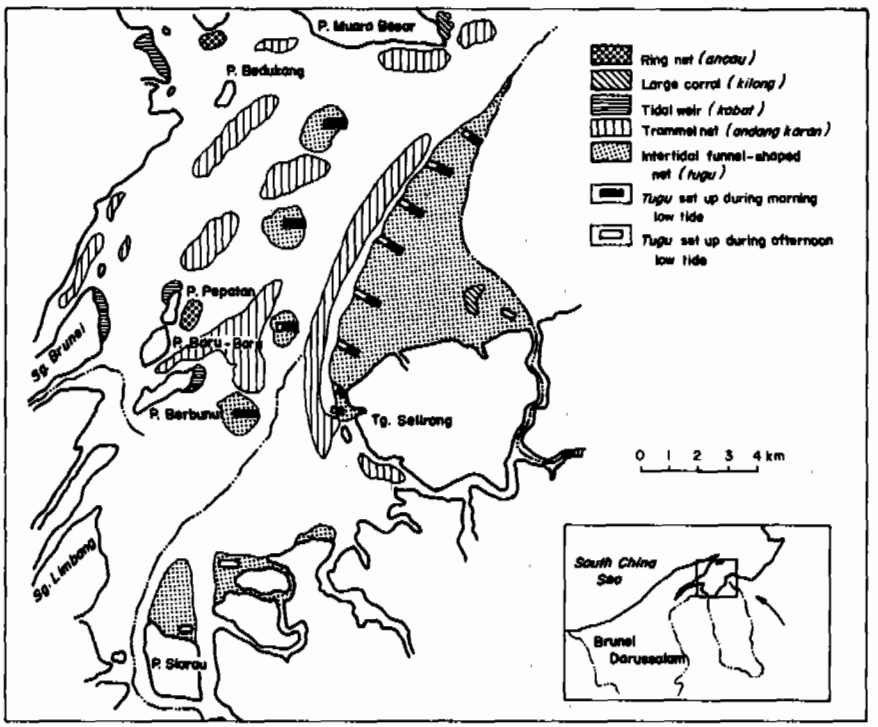

Fig. 14. Distribution of fishing areas by gear type within Brunei Estuary (Khoo et al. 1987).

men are allowed to operate and their individual gear are licensed on an annual basis prior to deployment. During the period 1985-1989, an average of 560 full-time and 1,600 part-time fishermen employing 1,400 units of net gear, 2,300 hooks and 1,700 traps were licensed to operate in the country. As used here, full-time fishermen refer to those solely dependent on fishing for their livelihood while part-time fishermen are those whose chief income sources are from other occupations (mostly land-based) but who fish during weekends, holidays or times of peak fish abundance. The bulk of licensed full-time fishermen are from Brunei-Muara District (65%), followed by Belait (20%) and Tutong (15%). Part-time fishermen are also mostly from the Brunei-Muara area (80%) where over 60% of the country's population resides.

Artisanal fishing operations are highly seasonal activities. Fishing in the open coastal waters is at a minimum during the period of peak winds and wave height around December to February. Deployment of gear types exhibits sequential seasonality and is dependent on peaks in abundance of the main fish targets for which the gear were designed. Thus, it is not uncommon, especially for full-time artisanal fishermen, to obtain licenses for several gear types in a given year. Fishing operations are typically opportunistic of favorable fish densities and switching gear types allows artisanal fishermen to maximize incomes.

Fish Marketing and Consumption

The DOF monitors the magnitude and value of fresh fish marketed by licensed stalls throughout the country. The statistics are published annually in the Brunei Darussalam Statistical Yearbook from which main marketing channels and consumption patterns may be inferred. Fig. 15 illustrates schematically the fish marketing channels in the country. Local fishermen dispose of their catches primarily through wholesalers who distribute the products to retailers in the markets. Some trawl operators and artisanal fishermen have their own retail outlets and sell directly to consumers. A limited number of artisanal fishermen occasionally sell their catch to residents in their village. Similarly, imported fish are coursed primarily through wholesalers, although some retailers import their products directly from the source.

Seven main landing sites are currently used by artisanal fishermen--3 in Brunei-Muara District, 1 each in the districts of Temburong and Tutong, and 2 in Belait District (Fig. 16). Industrial vessels land their catches at MFLC. Imported fresh fish sourced either from Sabah (arriving by sea via Labuan) or Sarawak (arriving by land via Miri) are sold to consumers mainly through seven markets in the country (Table 11). About 230 licensed fish stalls are distributed among these markets

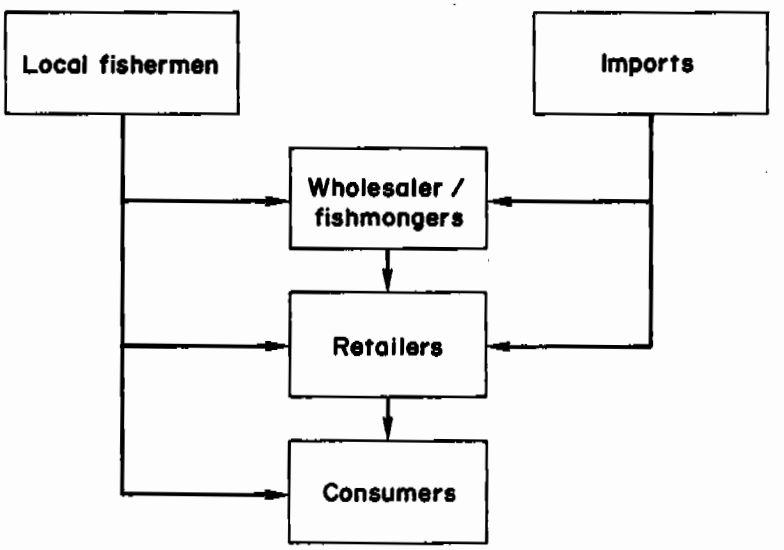

Fig. 15. Schematic representation of fish marketing channels in Brunei Darussalam (DOTCP 1986).

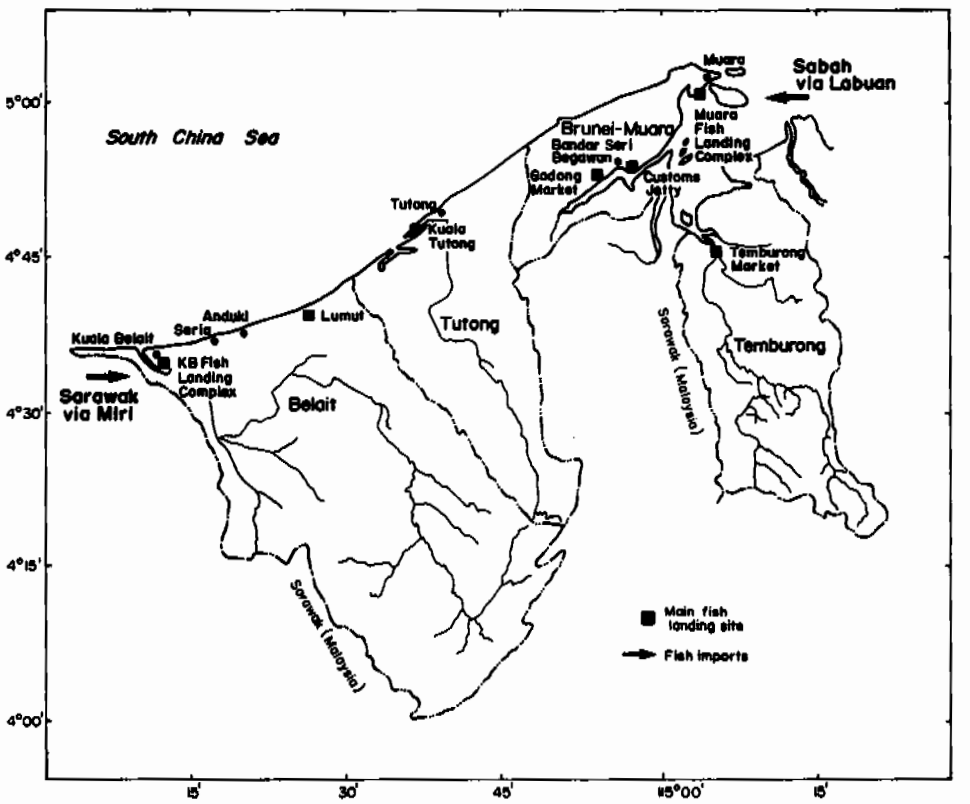

Fig. 16. Location of main landing sites for local fish production and sources of fish imports for Brunei Darussalam (DOTCP 1986).

Table 11. Number of fish stalls and their location in Brunei Darussalam.

District	Market	No. of fish stalls
Brunei-Muara	Gadong	119
	Tambing Kastam	42
	Muara	12
Tutong	Tutong	11
Belait	Kuala Belait	16
	Seria	28
Temburong	Temburong	5
Total		233

Source: Subramaniam et al. (1989).

with the bulk located in the districts of Brunei-Muara (74%) and Belait (19%). Fishes in these markets are displayed on individual stalls without ice for visual inspection by consumers and are frequently sold whole (i.e., with head and ungutted).

The magnitude of fresh fish marketed had increased steadily from about 2,800 t/year during the 1965-1969 period to roughly 4,600 t/year during 1985-1989 (Table 12). The local component of marketed fish had declined from around 80% in 1965-1969 to roughly 44% in 1985-1989, due not only to the rapid increase of fish imports but also to the slight decrease in average local production. This decline was more pronounced around 1988-1989 (Table 13). Locally produced and imported fish were worth an average of B$11.5 million and B$16.9 million, respectively, on an annual basis between 1985 and 1989.[1]

Table 14 provides the mean quantity and unit value of fresh fish marketed in Brunei Darussalam by market category for the 1985-1989 period. About 97% of marketed local fish consisted of marine fish and crustaceans, including 24% shrimps, 14% mackerels, 9% trevallies and 4% roundscads. This reflects the relative insignificance of aquaculture production and capture fisheries in the freshwater/riverine areas. Imports were also dominated by marine fish and crustaceans at 93%, with 19% shrimps, 16% mackerels, 11% Spanish mackerels and 7% tunas. Freshwater prawns, large shrimps and Grade I marine fish commanded the highest prices.

Fresh fish supply for 1985-1989 varied from 5,640 to 7,440 t/year broken down as follows: about 2,540 t/year of local landings from industrial and full-time artisanal sectors; 500-2,300 t/year by part-time fishermen (see Subramaniam et al., in press, b); and about 2,600 t/year of imports. Khoo et al. (1987) estimate the live weight equivalent of imported canned, dried, frozen and comminuted fish products (which came mainly from Singapore, Sarawak and Sabah) at 2,700 t/year. These imply that fish consumption in Brunei Darussalam was from 8,340 to 10,140 t/year or roughly 35-42 kg/person/year during the 1985-1989 period. Assuming constant annual per capita consumption (i.e., 23.5-31.0 kg/person/year of fresh fish and 11.2 kg/person/year of fishery products in live weight equivalent), Table 15 gives consumption estimates up to the year 2000 using projected population estimates from DOF. Projected consumption by the year 2000 is estimated to be 11.8-14.4 thousand t of which 8.0-10.5 thousand t are fresh fish products. Thus, given local landings totaling 3,040-4,840 t/year in 1985-1989, an aggregate of 7.0-11.4 thousand t of fish must be sourced by the year 2000 either through increased local production or importation.

Current Exploitation Status

Various studies on the status of exploitation of Brunei Darussalam fisheries resources include those of Currie (1982) and Silvestre et al. (in press, b and d) on shrimps and those of Beales (1982), Khoo et al. (1987) and Silvestre et al. (in press, b) on demersal resources. As earlier mentioned, less concrete assessments are available on pelagics although the results of DOF (1989) as used by Silvestre et al. (in press, a) provide some indication of exploitation rate. Moreover, the coastal fisheries ecosystem model presented by Silvestre et al. (in press, a) provides independent measures of exploitation level for the various resource groups consistent with the other studies.

Available assessments indicate overall light exploitation of fisheries resources. Such results are consistent with estimates of total yield versus total biomass in coastal areas. Total harvest during the 1985-1989 period was 3,040-4,840 t/year, and mean annual biomass was roughly 81,015 t, consisting of 19,715 t of pelagics and 61,300 t of demersals in the shelf areas. These show a total yield to biomass ratio of 0.04-0.06 which indicates light exploitation. Fishing pressure, however, on the multispecies resources is variable and relatively higher on more valuable species. Details of assessments for the various groups are summarized below.

Shrimps

Shrimp fishery is solely inshore and artisanal, concentrated within Brunei Estuary and adjacent waters.

[1]September 1991: B$1.70 = US$1.00.

Table 12. Mean annual quantity (t) of fresh fish marketed in Brunei Darussalam by source.

Period	Local production (t)	Imports (t)	Total (t)	(% local)
1965-1969	2,244	563	2,807	79.9
1970-1974	2,166	1,068	3,234	67.0
1975-1979	2,225	1,325	3,550	62.7
1980-1984	1,933	2,118	4,051	47.7
1985-1989	2,007	2,602	4,609	43.5

Source: EPU (1966-1990).

Table 13. Quantity and value of fresh fish marketed in Brunei Darussalam for the period 1985-1989.

Year	Local production (t)	(x10^{6}B$)	Imports (%)	(x10^{6}B$)	Total (t)	(x10^{6}B$)
1985	2,401	13.8	3,085	19.5	5,486	33.3
1986	2,187	11.9	2,085	13.6	4,272	25.5
1987	2,071	10.3	1,828	11.9	3,899	22.2
1988	1,548	10.2	2,523	16.5	4,071	26.7
1989	1,826	11.4	3,489	23.2	5,315	34.6
Mean	2,007	11.5	2,602	16.9	4,609	28.5

Source: EPU (1986-1990).

Table 14. Mean quantity (t) and unit value (B$/kg) of fresh fish marketed in Brunei Darussalam by fish grade/market category for the period 1985-1989.

Market category	Local production (t)	(B$/kg)	Imports (t)	(B$/kg)	Total (t)	(B$/kg)
Marine fish						
Grade I	650	4.19	1,003	5.58	1,653	5.01
Grade II	227	3.22	332	3.39	559	3.32
Grade III	136	1.95	45	2.69	181	2.13
Grade IV	508	2.83	460	3.33	968	3.06
Crustacean	434	6.04	587	5.41	1,021	5.69
Mollusk	14	4.12	115	3.97	129	3.99
Freshwater fish	4	6.37	2	6.94	6	6.57
Freshwater shrimp	34	9.46	58	8.92	92	9.13
Total	2,007	-	2,602	-	4,609	-

Source: DOF (1986-1990).

Table 15. Estimates of consumption of fresh fish and other fishery products in Brunei Darussalam up to the year 2000. (See text).

Year	Population[a] (x10^3)	Fresh fish consumption (x10^3 t)	Fresh and processed fish consumption (x10^3 t)
1990	256.3	6.0-7.9	8.9-10.8
1995	298.0	7.0-9.2	10.3-12.6
2000	340.1	8.0-10.5	11.8-14.4

[a]Includes local and expatriate population based on various DOF internal reports.

Annual landings varied between 140 and 920 t/year during the 1968-1989 period, averaging 385 t/year during 1985-1989, composed of 220 t/year of large *(udang besar)* and 165 t/year of small *(udang kecil)* shrimps. Landings consisted primarily of *M. brevicornis* (60%) and *P. merguiensis* (30%). The *andang karan* contributed 70% and the *tugu*, 25% to shrimp landings during the period 1985-1989 (Silvestre et al., in press, d). A marked seasonality in landings is observed from year to year and 40-60% of shrimps are landed during the peak season from February to April.

Shrimps are heavily exploited since the bulk of their biomass coincides with the concentration of artisanal gear in shallow, coastal areas. Fig. 8 illustrates the model relating shrimp production to fishing effort and rainfall, indicating maximum production at 500-600 *andang* units under various rainfall regimes. Average effort during 1985-1989 was 875 licensed *andang* units annually and 710 units in 1989, indicating an excess of 175-275 *andang* units. In addition, an average of 60 *tugu* units were licensed annually during 1985-1989.

Silvestre et al. (in press, b) give estimates of mortality rates from length-converted catch curve analysis for *P. merguiensis* and *M. brevicornis*. For *P. merguiensis*, maximum estimates of fishing mortality (F) vary from 1.15 to 1.45 yr^{-1}, the corresponding exploitation rate (E) varying from 0.31 to 0.39. For *M. brevicornis*, maximum estimate of F is 6.9 yr^{-1}, the corresponding E equivalent to 0.72. While these figures may be overestimates (due to emigration) the rates are still high even if reduced, say, by a third and confirm the excess effort inferred from the empirical model in Fig. 8. The higher E for *M. brevicornis* is attributed to its vulnerability to both *andang karan* and *tugu* compared to *P. merguiensis* which is caught almost solely by *andang karan*.

Fig. 17 gives a synopsis of population growth, survival, size at maturity and exploited length range of *P. merguiensis* in Brunei coastal waters. The length growth (L_t) and survival (N_t) functions are based on growth and natural mortality estimates discussed previously. Maturity information is based on Crocos and Kerr (1983) while data for exploited length range are from a one-year monitoring of artisanal gear (Silvestre et al., in press, b). Growth rate is fast, *P. merguiensis* attaining at least 70% of L_∞ (= 20 cm) during the first year of life. Natural mortality is high, with only about 10% of a cohort surviving after one year. The exploited length range is 11-17 cm, the lower limit just under the size at which the surviving population attains maturity. At least 90% of the catches are in the 12- to 16-cm length range. Growth overfishing does not appear to be a problem in the exploitation of *P. merguiensis*. Results of relative yield- and biomass-per-recruit assessment indicate optimal current exploitation pattern (using *andang karan*) in maximizing yield by harvesting primarily 12- to 16-cm individuals (Silvestre et al., in press, b).

Fig. 18 gives a synopsis of population growth, survival, size at maturity and exploited length range of *M. brevicornis*. The L_t and N_t functions are based on parameter estimates discussed previously, while the source of the maturity data are a compilation in Silvestre et al. (in press d). The exploited size ranges are from artisanal gear monitoring between 1989 and 1990

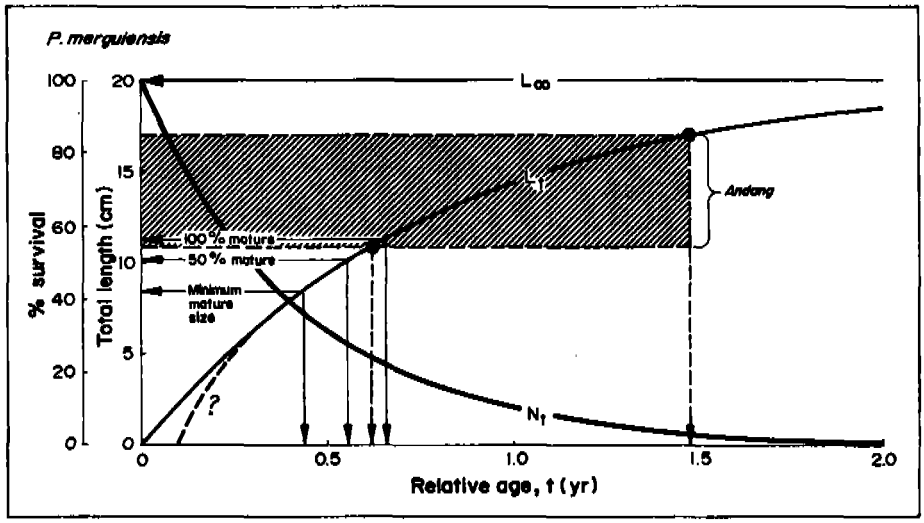

Fig. 17. Population growth, survival, size at maturity and exploited length range of *P. merguiensis* in the coastal waters of Brunei Darussalam (Silvestre et al., in press, b).

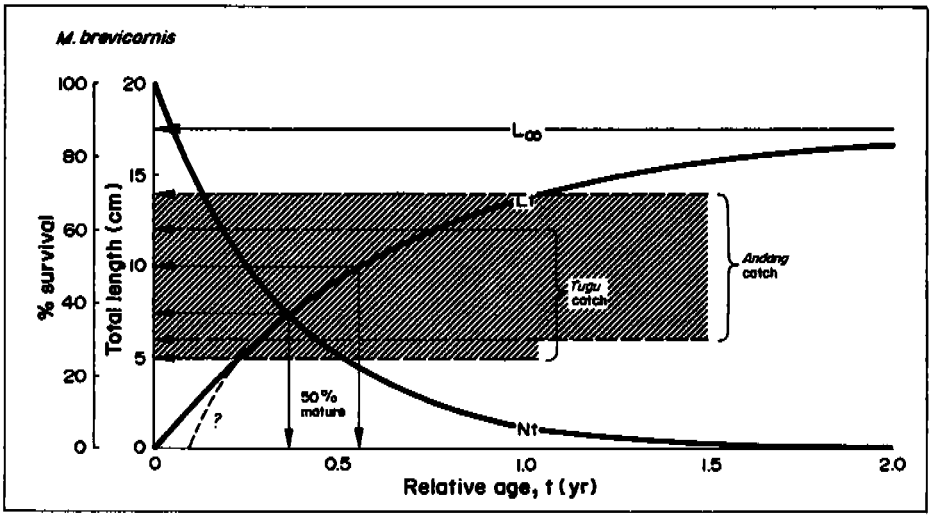

Fig. 18. Population growth, survival, size at maturity and exploited length range of *M. brevicornis* in the coastal waters of Brunei Darussalam (Silvestre et al., in press, b).

(Silvestre et al., in press, b). Growth of *M. brevicornis* is also fast, individuals attaining at least 80% of L_∞ (= 17.5 cm) within the first year of life. Mortality due to natural causes alone is high; only 5% of a cohort survives after one year. The *tugu* is the main gear that exploits 5- to 12-cm *M. brevicornis*, 90% of which are within 6- to 12-cm. *Andang karan* units are used to land individuals of 6-14 cm, about 90% of which are in the 7- to 14-cm range.

Growth overfishing is a problem in the exploitation of *M. brevicornis* primarily due to the small-sized individuals caught using *tugu*. Yield- and biomass-per-recruit assessment for the species indicate the 7- to 14-cm size range as most appropriate (Silvestre et al., in press, b). Achieving such a range may be operationally feasible by increasing the mesh size of *tugu*. However, clogging from long hours of gear deployment easily cancels the effect of such a measure. The best solution, if socially acceptable, is the gradual phase-out of *tugu* licenses since the use of *tugu* affects not only shrimp, but also demersal and pelagic exploitation, through the capture of undersized fish in the estuarine areas (see Fig. 10).

Demersals

Gear that principally exploit demersal species/groups include the trawl, *bintur*, *bubu*, *kilong*, *lintau*, *jaul* and *papar* (see Tables 8 and 9). Demersal biomass in the onshelf areas totals roughly 61,300 t, while total harvests for the 1985-1989 period have been placed at about 3,040-4,840 t/year. Estimates of the demersal component of harvests vary between 30% (market statistics) and 60% (industrial and artisanal gear monitoring statistics) for the same period. Even assuming the extreme case that the total harvest is 100% demersal still leads to a relatively low yield to biomass ratio of 0.05-0.08 and implies that the demersal resources are lightly fished. More recent single- and multispecies assessments support this general observation (e.g., Silvestre et al., in press, a and b).

Silvestre et al. (in press, b) give mortality and exploitation rates (E) for 26 species comprising roughly 70% of demersal biomass. The distribution of the E values for the 26 species is illustrated in Fig. 19. Fishing relative to total mortality is low, the corresponding E varying from 0.02 to 0.27. Mean exploitation rate ($\bar{E}$) is about 0.15, while the same measure weighed by the relative abundance of the various species ($\bar{E}'$) is roughly 0.16. Production models imply that the optimum range of E values is 0.20-0.50 (see Gulland 1971; Beddington and Cooke 1983; Silvestre 1990). Further, yield-per-recruit analysis for the 26 individual species indicates optimum E values (E_{opt}) to be 0.30-0.40. Thus, exploitation rates of demersal species are low and indicate them to be lightly fished.

Growth overfishing is not a major problem in the exploitation of demersal species/groups apart from the use of small-meshed *tugu*, *kabat*, *kilong* and *lintau* in Brunei Estuary and trawl cod-end liners. The use of small-meshed (2-cm) liners by trawlers is rare and could easily be corrected by rigorous enforcement of the 3.8-cm minimum mesh size limit at the trawlers' sole base in Muara. The *kabat*, *kilong* and *lintau* units are very few and contribute a minor portion of total landings (see Table 10). Therefore, only the *tugu* represents a difficulty. Apparently, the scale of the problem owes much to the low fishing effort level. Such is

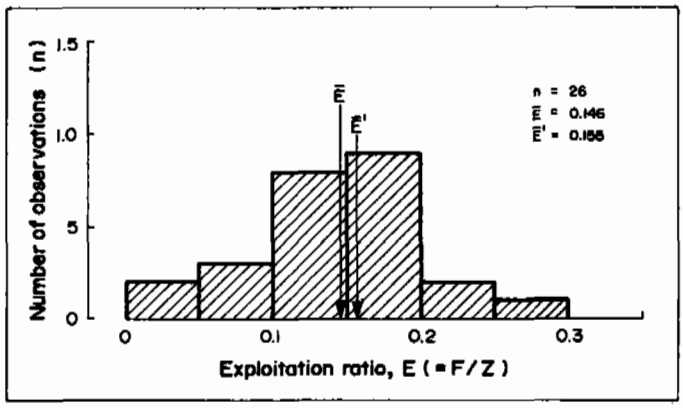

Fig. 19. Distribution of exploitation rates (E) of 26 trawl-caught species comprising about 70% of demersal biomass in Brunei waters (Silvestre et al., in press, b).

expected to be maintained, if not reduced further, for artisanal fisheries due to increased competition for manpower from land-based economic activities.

Trawl operations have been the particular subject of assessments in view of the projected expansion of trawl fishing effort. Currently, licensed trawlers (9 boats) are few compared to the effort required to harvest the potential from accessible areas (e.g., 33 boats in Stratum I), and plans have been put in operation to license more boats. It is acknowledged that growth overfishing cannot be totally eliminated, given the nature of the multispecies resource. The present 3.8-cm mesh size limit reduces growth overfishing. However, results of multispecies yield- and value-per-recruit assessment conducted by Silvestre et al. (in press, b) show that mesh sizes of 4.0 and 4.5 cm for the trawl fishery are more appropriate in maximizing yield and gross value, respectively, from the demersal species mix.

Pelagics

The purse seine, *ancau*, *rantau* and *pancing* are the principal gear used for catching pelagics. Very little information is available, however, concerning the exploitation status of small and large pelagics. The only study from which indications of fishing pressure on these resources may be obtained is provided by Silvestre et al. (in press, a) from a preliminary steady-state trophic model of the coastal fisheries resources of Brunei Darussalam. Table 16 gives the components of the various trophic groups they used and corresponding yield to biomass ratios (Y/B, proportional to E = F/Z) computed. Small pelagics appear to be very lightly exploited (Y/B = 0.07), together with the large pelagics distributed among the large predators (Y/B = 0.19) and intermediate predators (Y/B = 0.03). Exploitation of the other trophic groups (classed under the general category of demersals) is similarly light with Y/B = 0.01-0.17 confirming independent assessments.

Legal and Institutional Structure

Notable among the studies on the legal and institutional structure in Brunei Darussalam relevant to coastal resources management are DOTCP (1986), White et al. (1987) and Tobin (this vol.) which encompass capture fisheries in various degrees. Brunei Darussalam is a Muslim, Malay Sultanate with a legal system

Table 16. Composition and yield-to-biomass ratio (Y/B) of various trophic groups obtained via a steady-state model of the coastal fisheries ecosystem of Brunei Darussalam.

Large predators (Y/B = 0.19)	Carcharhinidae, Scombridae (excluding *Rastrelliger*), Thunidae
Large zoobenthic feeders (Y/B =0.17)	Dasyatididae, Rhynchobatidae, Ephippidae, Rajidae, Gymnuridae
Intermediate predators (Y/B = 0.03)	Carangidae (excluding *Decapterus, Selar, Alepes, Selaroides, Megalaspis*), Sciaenidae, Synodontidae, Ariidae, Lutjanidae, Trichiuridae, Psettodidae, Rachycentridae, Serranidae, Sphyraenidae, Fistularidae, Paralichthyidae, Muraenesocidae, Scorpaenidae, Chirocentridae
Small pelagics (Y/B = 0.07)	Carangidae (e.g., *Decapterus, Selar*, etc.), Clupeidae, Loliginidae, *Rastrelliger*, Engraulidae
Demersal zoobenthos feeders (Y/B = 0.01)	Leiognathidae, Mullidae, Nemipteridae, Haemulidae, Ariommatidae, Priacanthidae, Theraponidae, Balistidae, Tetradontidae, Platycephalidae, Lactaridae, Bothidae, Apogonidae, Triglidae, Dactylopteridae, Lethirinidae, Monocanthidae, Sparidae, Stromateidae, Triacanthidae, Polynemidae, Siganidae, Ostraciidae, Labridae, Cynoglossidae, Sillaginidae, Diodontidae, Gobiidae, etc.
Demersal zooplankton feeders (Y/B = 0.01)	Gerridae, Centriscidae
Large crustaceans (Y/B = 0.10)	Scyllaridae, Portunidae, Penaeidae, Palinuridae, etc.

Source: Silvestre et al. (in press, a).

based primarily on English common law. The English legal system was retained after full independence was granted on 1 January 1984; before, the country was a protectorate of Great Britain with full autonomy apart from defense and foreign affairs. Tobin (this vol.) characterizes the country's legal system as follows:

> Like the laws of England, Brunei Darussalam's laws tend to be brief and general. They provide broad grants of relatively unconstrained power and authority to ministries and departments, reflecting a trust and confidence in the administrator's exercise of discretion.

The governmental structure is headed by His Majesty The Sultan and Yang Di-Pertuan who presides over a cabinet of ministers with responsibility over Communications, Defense, Development, Education, Finance, Foreign Affairs, Health, Home Affairs, Industry and Primary Resources, and Law and Religious Affairs.

Under the Ministry of Industry and Primary Resources (MIPR), DOF is the line agency responsible for vast functions covering fisheries research, extension, enforcement, marketing, conservation, development and management. Its authority and functions are defined in the following instruments: the Fisheries Enactment of 1972, Fisheries Regulations of 1973 and the Fishery Limits Enactment of 1982. The organizational structure of the department (Fig. 20) is headed by a Director who supervises units organized under eight sections. Directly under the Director's Office are two units in charge of fisheries development planning and industrial fisheries development. The Administration and Transport and Maintenance Sections handle administrative and support functions while the Aquarium Section is in charge of the aquarium at the Churchill Memorial in Bandar Seri Begawan. A section deals with the various activities at the Kuala Belait Fish Landing Complex (KBFLC), while the Extension and Enforcement Section licenses industrial and artisanal units, monitors their operations and provides extension services. Conventional areas of fisheries interest (i.e., aquaculture, marine fisheries and postharvest) are handled by separate sections which undertake research, extension, development and management work in various degrees. The department has its headquarters in Bandar Seri Begawan which houses all sections except Post-Harvest (based at MFLC), Aquaculture (based at Muara Fisheries Station [MFS] and demonstration farms in Serasa and Sg. Jambu), Marine Fisheries (based at MFS) and Kuala Belait Fisheries Center (based at KBFLC). Existing and programmed facilities of the department are detailed in DOTCP (1986) and the Fifth (1986-1990) and Sixth (1991-1995) National Development Plans (NDP) (unpublished Economic Planning Unit documents).

In 1989, DOF had 120 full-time salaried and daily-paid personnel. Core staff, however, consisted of only 18 persons; 13 have baccalaureate degrees (4 expatriates), 4 have master's degrees (3 expatriates) and 1 expatriate has a Ph.D. Consolidated budget appropriations of the department have increased in the last five years from about B$2.8 million in 1985 to B$4.9 million in 1989. These exclude appropriations for development work identified in the NDP which represent an independent budget.

As mentioned earlier, DOF implements a strict licensing program to control the level of fishing effort and the kind of gear employed in fishing operations. The use of poisons and explosives in fishing is banned and industrial trawlers are required to have cod-end meshes of 3.8-cm minimum stretched length. Industrial fishing operations are prohibited within 3 nm of the coast and within a 1-nm radius from any oil industry structure and cautionary areas (see Fig. 11). The department has taken a very cautious attitude towards expansion of fishing effort, particularly that of the industrial fisheries sector. Assessments have been commissioned prior to any projected expansion of fishing pressure. Results of recent studies indicate a relatively light exploitation of coastal fish resources. With the projected leveling or decline in artisanal fisheries production, plans to expand the industrial fisheries sector in the next five years project an increase in trawl licenses to 24 and purse seine licenses to 12 by 1995.

Given the scope of its various responsibilities and concerns, DOF coordinates with various government agencies (Table 17). The functions vary from enforcement and extension to research and financing for fisheries ventures. Environmental management, as noted by Tobin (this vol.), requires the most interagency coordination. This has been facilitated by the creation of the Committee on Environmental Management within MIPR and the interagency Tourism and Environment Body which has representatives from the various ministries and departments.

Fisheries Management Goal and Specific Objectives

To avoid ambiguities associated with the use of similar terms in management planning exercises, the goal and specific objectives of fisheries management as used here are thus defined:

- An overall goal expresses the primary, long-term interest and aspiration of the state in resources exploitation and management.

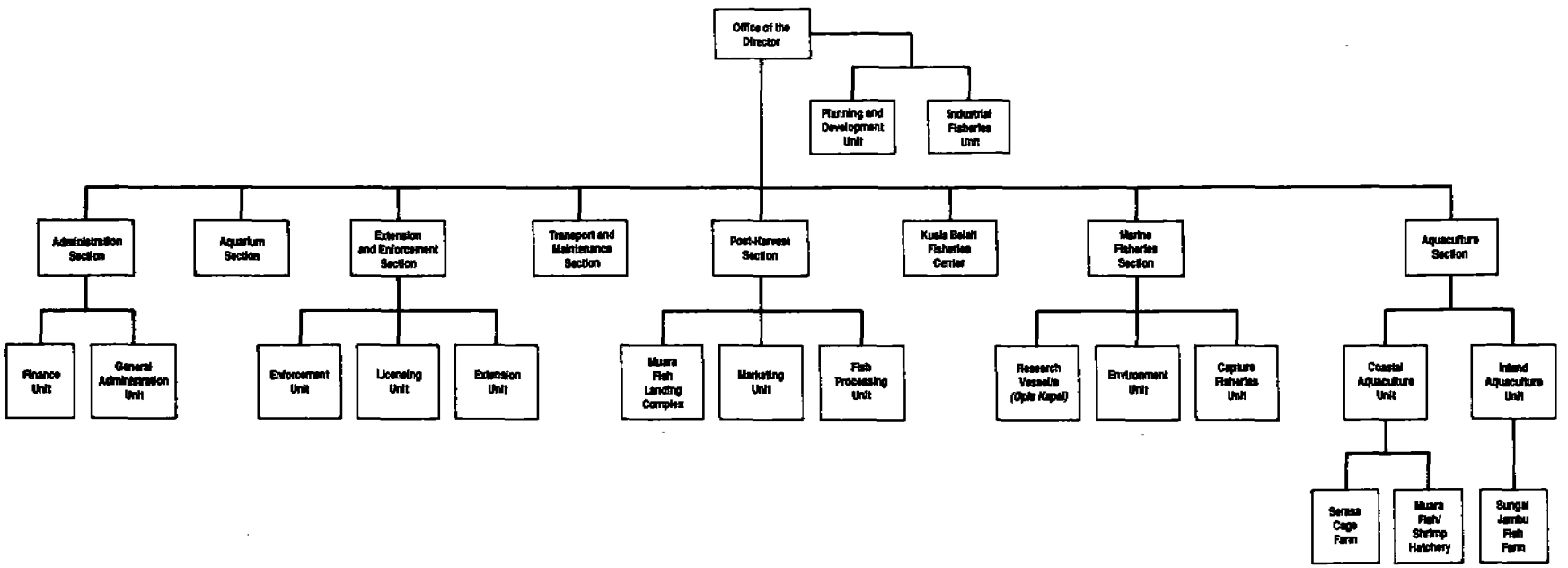

Fig. 20. Organizational structure of Brunei Darussalam's DOF in 1990.

Table 17. Relevant ministries and departments of the Government of Brunei Darussalam with current or potential coordination with DOF as the line agency responsible for fisheries conservation, development and management.

Ministry/department/unit	Fisheries-related concern/function
Prime Minister's Office	
Royal Brunei Police	Enforcement
Petroleum Unit	Accessible fishing area/s
Broadcasting and Information	Information/extension
Ministry of Defence	
Royal Brunei Armed Forces (Flotilla)	Enforcement
Ministry of Finance	
Economic Development Board	Loans/financing
Economic Planning Unit	Development and management
Customs	Importation
Ministry of Home Affairs	
Districts	Development environmental management
Immigration	Expatriate manpower
Labor	Expatriate manpower
Municipal Board	Environmental management, fish marketing
Cooperatives Development	Extension services
Ministry of Education	
Universiti Brunei Darussalam	Research
Ministry of Law	
Legal	Enforcement, legislation
Judicial	Enforcement
Printing	Information
Ministry of Industry and Primary Resources	
Agriculture	Environmental management
Forestry	Environmental management
Industrial Unit	Environmental management
Ministry of Development	
Town and Country Planning	Environmental management
Public Works	Environmental management, fisheries facilities
Lands	Environmental management
Housing Development	Environmental management
Construction Planning and Research	Environmental management
Ministry of Culture, Youth and Sports	
Museums	Wildlife conservation
Ministry of Communications	
Marine	Environmental management, vessel licensing
Ports	Environmental management
Ministry of Health	Environmental management (red tide)

- Specific objectives define the goal in strategic terms in the light of existing national development priorities.

The goal and objectives were condensed from various internal reports, project documents and development plans from DOF files and date back to its establishment in 1966. The materials incorporate or reflect national development objectives for the fisheries sector, often merely implied rather than explicitly stated, but show a remarkable consistency over the years. Presentation of these elements is preceded by an overview of conventional objectives in fisheries management to place them in proper perspective.

Conventional objectives in fisheries management

Objectives in fisheries management are many and varied, although value to society in the broad sense is the overall goal. Variation in specific objectives results from different perceptions of what constitutes the greatest benefit to society as a whole. The conventional criterion used in fisheries management has evolved through the years from maximum sustainable yield (MSY) in the 1950s, to maximum economic yield (MEY) in the 1960s, and to optimum sustainable yield (OSY) in the 1970s. Detailed treatments covering these concepts are given, among others, in the works of Gulland (1974, 1978); Roedel (1975); Cunningham (1981); and Rothschild (1982) and, with special reference to the Southeast Asian context, in Panayotou (1982); the contributions in the Indo-Pacific Fisheries Commission Workshop (IPFC 1987); Pauly (1988); and Pauly et al. (1989). Briefly, these concepts are defined as follows:

- MSY is the largest average quantity of fish that can be harvested from a given fish stock/s on a sustainable basis under existing environmental conditions.
- MEY is the average quantity of fish harvestable on a sustainable basis from a given stock/s that maximizes resource rents under existing environmental and exploitation conditions.
- OSY is the average quantity of fish harvestable on a sustainable basis from a given stock/s that results in the greatest benefit to society given the realities (e.g., biological, economic, sociocultural, ecological, technological, political) of fisheries exploitation.

Fig. 21 illustrates the MSY and MEY concepts in a simple static model of an open-access fishery. As is evident, MSY is purely a biological concept while MEY is a bioeconomic concept. In contrast, OSY incorporates a host of factors relevant to fisheries management. The OSY concept has been criticized mostly for the subjectivity involved in its determination. This is because it is not possible (nor practical) in most situations to objectively quantify all factors of consequence to fisheries exploitation. Formulation of OSY, thus, often relies on expert advice. Nevertheless, the OSY concept affords considerable flexibility to management in dealing with "real world" problems that the MSY or MEY concept does not provide. The OSY concept recognizes that biological and economic efficiency criteria should not solely determine the direction of fisheries management.

Several overfishing concepts associated with the three conventional fisheries management objectives (see Pauly 1988; Pauly et al. 1989) include: (1) biological overfishing, i.e., unfavorable exploitation patterns and excessive effort levels leading to nonattainment of MSY; (2) economic overfishing, i.e., excessive effort that dissipates resource rent leading to nonattainment of MEY; and (3) system overfishing, i.e., excessive effort and exploitation patterns that lead to suboptimal benefits to society and nonattainment of OSY. As is evident, the term "overfished" is used relative to the current exploitation level and patterns (e.g., disposition and selectivity of the extractive capacity) vis-à-vis a more desirable state defined by the objectives of the management entity. Of relevance to previous and subsequent discussions are the three forms of biological overfishing generally recognized (see Pauly 1980, 1988): *growth overfishing* occurs when young fish are caught and not allowed to grow to a suitable size, while *recruitment overfishing* occurs when adult or parental abundance is reduced to low levels that impair the ability of the resource/stock to maintain or reproduce itself. In contrast, *ecosystem overfishing* occurs in multispecies resources when fishing produces undesired and/or uncompensated species composition changes. Overall, these forms of biological overfishing result in reduced abundance and harvests that impair attainment of MSY.

A survey of fisheries sector objectives in Southeast Asia yields a wide range of management criteria (see, for example, Lawson 1978). A considerable number of stated objectives are specific to local situations or concerns. A common trend, however, pertains to the following criteria sought by management:

- stable supply and reasonable prices of fish and fishery products,
- generation of employment,
- generation of foreign exchange and
- improved socioeconomic well-being of participants in capture fisheries.

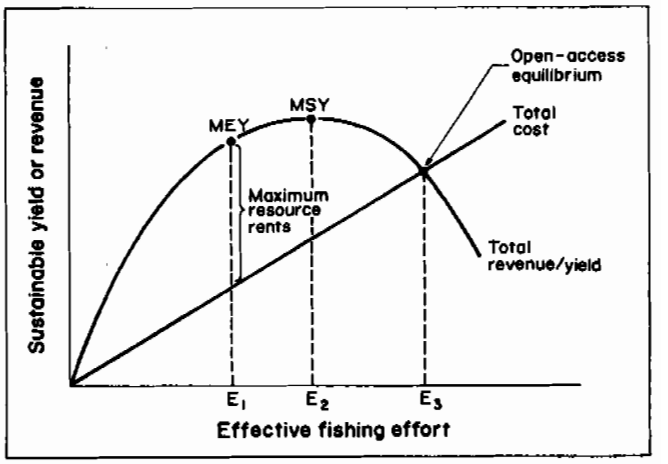

Fig. 21. Simple static model of an open-access fishery showing the location of MSY and MEY.

All these criteria presume sustainable development as a basis and that either the MSY or MEY concept is appropriate in maximizing the benefit stipulated by any one criterion. It is the OSY concept, however, which dictates a balance among these criteria in a manner that maximizes benefits and minimizes conflicts in resources exploitation.

It is acknowledged that realities relevant to fisheries exploitation and management are dynamic in nature. Thus, the relative weight or value of elements in a basket of objectives/criteria may change dramatically over the temporal scale. Successful fisheries management experiences imply not only clearly defined objectives, but also responsive review systems that ensure appropriateness of objectives and their relative significance. In practice, the approach has been to identify a basket of objectives in the broad sense, sufficient to define the overall goal over the medium-term. It is in the short-term, working system of programs/projects that the relative significance and appropriateness of the various criteria are operationalized in current terms.

As will become apparent below, the overall goal and specific objectives address medium- to long-term concerns relevant to sustainable fisheries development and management. Short-term or tactical operational details in the form of programs/projects have been purposely excluded, with the exception of activities (tackled in the next sections) indispensable to medium- to long-term concerns. This is primarily because the phase and extent of development activities in the fisheries sector rely mainly on available public and private resources and the relative sectoral priorities in their allocation. For instance, a detailed schedule in the expansion of trawler numbers is principally an operational matter while the limit to such expansion is a long-term, strategic concern. The schedule depends on a considerable number of permutations relative to, for example, incentives and financial resources available, while the limit is a permanent, resource-based fixture. In this context, this document sets relatively long-term directions with implementation details left to the executing agency.

Management goal and objectives in capture fisheries

Documents that provide an overview of the long-term objectives of the Government of Brunei Darussalam for the exploitation and management of fisheries resources include legislation (e.g., Fisheries Enactment of 1972, Fishery Limits Enactment of 1982); development plans (e.g., fisheries portion of the Fifth National Development Plan covering 1986-1990); project documents (e.g., Beales et al. 1982; DOTCP 1986; Silvestre et al., in press, b); and internal reports on file at DOF. The available documents reflect a vigorous interest as well as a cautious, conservative approach of local authorities in sustainable fisheries development and management.

Moreover, these documents acknowledge that the local fisheries resources are comparatively small by regional standards. Sustainability of fisheries, however, has been consistently deemed significant over the years for the following reasons:

Current Food Preferences and Long Fishing Tradition. Brunei Darussalam has one of the highest per capita seafood consumption in Southeast Asia, averaging over 35 kg/person/year for the 1985-1989 period. The country's long fishing tradition and early European accounts as far back as the sixteenth century (see, for example, Nicholl 1975) attest to the significance of fisheries as an economic activity and food source.

Dependence on Imported Fresh Food Supply and Attempts at Self-Sufficiency. The nation imports a large part of its fresh food supply from neighboring Sabah and Sarawak. Agriculture "has been steadily declining since 1974, both in terms of its share of non-oil GDP, and of the total labor force" (DOTCP 1987). Considerable gains, however, towards self-sufficiency in poultry and egg production are likewise expected for locally suitable vegetables and fruits, although comparative advantage in other activities (e.g., cattle, rice production) is quite limited. Joint ventures with other countries (e.g., cattle farming in Northern Australia) has been resorted to for commodities not consistent with the country's comparative advantage. As of the present time, over 80% of rice consumed and about 55% of marketed fresh fish in the country are imported.

Economic Diversification From the Dominant Oil and Natural Gas Industry. With regard to fish consumption, the potential yield of 25,700 t/year from coastal waters conceivably provides considerable room for import substitution, employment and hence, economic diversification. Preliminary feasibility studies suggest the financial viability of exploiting these resources (see Cruz et al., in press and references therein). Over the past ten years, at least 75% of the country's annual GDP originated from the oil and natural gas industry. Aware of the problems inherent in an economy based on nonrenewable resources, the government has put particular emphasis on diversification. The development framework and thrusts to this end are discussed in DOTCP (1987) and the five-year development plans for the periods 1986-1990 and 1991-1995.

Based on the documents reviewed, the primary interest and aspiration of the state over the long term may be condensed into this overall goal: "Sustainable development of capture fisheries... towards optimization of

benefits to the nation." In line with and in pursuance of this overall goal, the following specific objectives are consistent with current national development priorities:

- upliftment of the socioeconomic status or well-being of participants in capture fisheries;
- provision of a stable supply of fish and fishery products at reasonable prices; and
- increased production and efficient utilization of capture fishery resources towards greater self-sufficiency.

It is proposed that the Government of Brunei Darussalam formally adopt the above-mentioned overall goal and specific objectives covering fishery resources exploitation and management in the country.

The term "sustainable development" in the goal statement above is used in the context of the definition given in FAO (1991):

> . . . the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development . . . conserves land, water, plant and animal genetic resources, is environmentally nondegrading, technically appropriate, economically viable and socially acceptable.

The goal statement thus recognizes OSY as the appropriate management goal requiring optimum benefits from the specific objectives. These objectives embody all the current government policies on capture fisheries. It is acknowledged that the three objectives taken separately are located at different harvest and fishing effort levels. For instance, increased production and self-sufficiency are more consistent with harvest levels near MSY while considerations of improved socioeconomic well-being (e.g., incomes) may be more consistent with MEY. The balance among the elements in the basket of objectives is resource-specific and dependent on the characteristics of resources, the status of the fisheries on them, and social acceptability.

Proposed Management Guidelines and Implementation Strategies

Two essential management elements are addressed here for possible adoption by DOF, namely:

- resource-based management guidelines which define exploitation patterns and limits consistent with stated objectives, resource characteristics and status of the country's capture fisheries and
- implementation strategies which define key approaches and measures to ensure proper administration and review of stated objectives and guidelines.

The management guidelines were formulated principally to define the extent within which the basket of specific objectives may be attained. They address the main issue of sustainable development consistent with the situational analysis discussed in the previous sections. Note that the guidelines are based on currently available assessments and studies of variable scope and reliability. These are not exhaustive and require continuous review, extension and refinement as an integrated part of the planning process. Strategies that incorporate proper review of management guidelines versus objectives and facilitate implementation were subsequently formulated based on current realities in capture fisheries and the existing institutional structure relevant to fisheries management.

As is evident from available assessments, the fisheries resources are largely lightly fished, except for the heavily exploited shrimps, due to their high market price and more inshore distribution. Overall, Brunei Darussalam is in a unique position among Southeast Asian countries where the overfishing problem appears to be considerable (see IPFC 1987; Chua and Pauly 1989). This unique situation results primarily from the economic opportunities provided by the dominant oil and natural gas industry. Tremendous opportunities exist, therefore, to develop the country's capture fisheries on a sustainable basis minus the difficulties inherent in overcrowded fisheries.

Management guidelines

The guidelines may be broadly categorized according to the concerns they address, as follows: (1) appropriate exploitation levels and patterns for the major resource groups (i.e., shrimps, demersals and pelagics); (2) minimizing sectoral and gear conflicts; and (3) maintenance of environmental quality. Guidelines relevant to the last two concerns involve the various resource groups and are treated separately.

Shrimp Fisheries. Available assessments indicate MSY levels of 350-800 t/year at 500-600 *andang* units under various rainfall regimes (see Fig. 8). The demand for shrimps in the country is high. In 1989, large and small shrimps fetched on the average, over B$12 and B$5, respectively. About 430 t of local shrimps and 665 t of imported shrimps were marketed. This implies that the available local shrimp resources are inadequate to meet even current demand and that the country will continue to import the commodity in the future. Aquaculture may offer some potential for meeting future

demand, but the high input costs, lack of aquaculture tradition and the need to preserve mangroves/wetlands do not give comparative advantage in such activity.

It is recommended that effort levels be limited to a maximum of 500 standard *andang* units. This level gives maximum yield under minimum rainfall conditions but is large enough to give yields close to the maximum under different rainfall regimes. It is proposed that effort reduction be made solely on part-time fishers and that full-time *andang* fishermen be given priority in issuance of licenses. Maximum *andang* effort levels are set based on standard units currently in use. Particular attention should be given to monitoring of gear design and specifications that leads to improved efficiency and the requisite adjustment of the appropriate number of licenses to be issued in this context.

Growth overfishing of *M. brevicornis* due to the use of the *tugu* will not be effectively solved by increasing its cod-end mesh size because of clogging effects from long hours of gear deployment. It is recommended that no new *tugu* licenses be issued and that the existing *tugu* units be phased out gradually via nonreplacement of older units. A five-year phase-out period appears reasonable, giving enough time for operators to recover their investment and other gear to take up the slack in supply.

Demersal Fisheries. Demersal resources have a total potential yield of 15,400 t/year at 130.7 thousand standard trawl hours for "accessible" and exclusive artisanal grounds combined.

Silvestre et al. (in press, b) estimate MEY for "accessible" demersal grounds to be 6,000 t/year at 25.8 thousand standard trawl hours in Stratum I and 2,600 t/year at 35.7 thousand standard trawl hours in Stratum II. For exclusive artisanal grounds, MEY is about 3,300 t/year at 14.2 thousand standard trawl hours (assuming an MEY to MSY and f_{MEY} to f_{MSY} ratio similar to Stratum I). Hence, the MEY level from the demersal resources in "accessible" and exclusive artisanal grounds combined totals 11,900 t/year. It is recommended that harvest levels over the long term from the country's demersal resources not exceed this figure. The effort level corresponding to such harvest is about 75.7 thousand standard trawl hours or 57 standard boats (see Table 2 for definition). Operating around MEY as a limit over the long term avoids the uncertainties associated with harvesting resources near their MSY level; maintains incomes and prices at reasonable levels; and is consistent with supply stability and economic diversification policies.

Demand projections by the year 2000 is placed at a maximum of 14,400 t (see Table 15). Based on current consumption patterns, about 4,300-8,600 t of this consist of demersals. The demand, thus, over the next ten years is bound to be lower than the maximum harvest level recommended above. Demand would vary by fish grade, being higher for the valuable categories. Effort expansion on the demersal resources should be done in phases that allow the resources and market sufficient time to stabilize (e.g., 4-5 boats every 3-5 years). Priority in effort expansion should be given to Stratum I where the catch rates are highest and the MEY of 6,000 t/year combined with the artisanal maximum landings limit of 3,300 t/year should be sufficient to meet demand by the year 2000. Value-added fish processing activities to reduce the volume of discards (particularly in trawling) and thus promote efficient utilization of harvests should be encouraged.

The potential for export of value-added processed fish products consistent with available resources should be studied. If feasible, this would allow for effort expansion on demersals closer to the harvest limit given above at an accelerated phase. However, available studies indicate limited export potential under current conditions. The country's resource base is relatively small by regional standards and local demand for valuable fish grades (e.g., snappers, groupers) is already high. The high production and marketing costs entailed do not give the country comparative advantage in the intensely competitive international market. Currently, the premium paid for freshness combined with low selling cost makes local fish production competitive with fish imports.

The DOF has analyzed the catchability of the principal gear that exploit demersals (Tables 8 and 9) and their equivalent in standard effort units (trawling hours). Similar to recommendations made for the *andang*, monitoring of gear design and specifications of demersal gear that lead to increased catchability must be made and their equivalent in standard effort units periodically assessed.

Growth overfishing of demersal resources cannot be avoided due to the nature of the multispecies mix. The use of the *tugu* and trawl is mainly responsible for this. Phasing out the *tugu* solves part of the problem. It is recommended that a minimum mesh size limit of 4.5 cm for trawl cod ends be adopted, consistent with the available assessments. The use of small-meshed cod-end liners that interfere with escapement through the 4.5-cm cod end should be banned. With the projected expansion of the trawl fleet, these measures would minimize growth overfishing of demersal resources.

Pelagic Fisheries. Available assessments indicate the pelagic resources to be lightly fished overall. Potential yield estimates of 9,800 t/year from onshelf pelagics (7,700 t/year of small pelagics and about 2,100 t/year of large ones) are preliminary and await confirmation by more rigorous assessments. As an initial

step, however, a maximum harvest limit of 7,600 t/year (6,000 t/year of small pelagics and 1,600 t/year of large pelagics) is recommended assuming an MEY to MSY ratio similar to demersals in "accessible" areas.

Growth overfishing of pelagics will not be an issue if the *tugu* in the inshore areas is phased out. The principal pelagic gear are mainly operated farther offshore where the average size of the individuals caught is larger.

Similar to demersals, expansion of effort on the pelagics should be done in phases to allow the resources and market to stabilize. Close monitoring should allow assessment or refinement of resource potential figures. Table 18 gives a summary of potential yield estimates and proposed maximum harvest limits over the long term by major resource group. Note that the proposed maximum harvest level totals 20,000 t/year as opposed to a projected maximum demand of about 14,400 t/year by the year 2000 (see Table 15). The obvious implication is that effort expansion on the pelagic resources should be coordinated with, and made to complement, effort expansion on the demersals. Studies on species/product cross-substitution are clearly in order. Based on current consumption patterns, between 2,900-7,200 t of the projected demand by the year 2000 consist of pelagics. The maximum harvest limit for pelagics of 7,600 t/year is beyond projected demand for human consumption in the next ten years and emphasizes the significance of the above recommendations on effort expansion.

Minimizing Sectoral and Gear Conflicts. Minimizing spatial conflict among sectors and fishing gear assumes importance in view of the projected expansion of the industrial fisheries sector. Sectorally, the main issues are those between the oil and gas sector vis-à-vis the fisheries sector and artisanal versus industrial fisheries.

Table 18. Estimates of potential yield and proposed maximum harvest limit by major resource group from the coastal fisheries resources of Brunei Darussalam.

Resource group	Potential yield estimate (t/yr)	Proposed maximum harvest limit (t/yr)
Shrimps	500[a]	500[a]
Demersals		
"accessible" areas	11,100	8,600[b]
artisanal grounds	4,300	3,300[c]
Small pelagics	7,700	6,000[c]
Large pelagics	2,100	1,600[c]
Total	25,700	20,000

[a]Estimate based on average rainfall conditions.
[b]Estimate of MEY (Silvestre et al., in press, b).
[c]Assuming MEY to MSY ratio similar to demersals in "accessible" areas.

The oil and gas industry is of major importance to the national economy and any expansion of fishing effort must primarily assure the unhampered use and safety of oil and gas structures. Effort expansion will principally stem from the industrial fisheries sector to meet future demand. The number of artisanal fishermen is projected to decline because of increased land-based economic opportunities. The interest of the remaining artisanal fishers, however, would have to be protected. Therefore, it is recommended that DOF continue enforcement of the ban on industrial fishing activities within 3 nm of the shoreline and within a 1-nm radius of any oil industry structure (i.e., platforms, pipelines, etc.) and navigation cautionary areas. In effect, industrial fishing activities are limited to the unshaded areas in Fig. 11. Note that coral/hard grounds are effectively protected as they are treated as navigation cautionary areas.

The main issues on gear/technological conflicts concern (1) trawling versus the use of FADs and (2) trawling versus the use of fish traps by artisanal fishermen. The use of FADs should be limited to the periphery of the 1-nm limit off pipelines (exclusive of oil platforms and other structures) and coral/hard grounds. This gives purse seiners and artisanal fishermen using FADs enough ground to cover without interference to trawling activities. It is recommended that fish traps *(bubu)* be limited to the artisanal grounds within 3 nm of the coast and within 1 nm of coral/hard grounds and pipelines (excluding oil platforms and other structures). Moreover, all fish traps and FADs deployed must be properly marked to avoid any danger to navigation.

Maintenance of Environmental Quality. The issues and measures relevant to long-term maintenance of environmental quality are covered by other papers in this volume. The point here is primarily to reemphasize the need for maintaining environmental quality for sustainable development of the country's fisheries. In this context, the recommendations of the other background papers are endorsed, namely:

- formulation and adoption of water quality standards;
- formulation and adoption of a protocol for the introduction of exotic species into the country (e.g., for research, aquaculture, etc.);
- requirement of environmental impact statements for all development activities; and
- establishment and support of an interagency group to assess impacts of development projects and minimize their adverse effects.

Moreover, it is proposed that the following action plans be supported: (1) Red Tide Contingency, (2) Coral Reef and Island Management, (3) Mangrove Management, (4) Water Quality Management, (5) Oil Spill Contingency and (6) Aquaculture Management.

Accelerated land-based development activities in the past ten years, current development efforts and population growth are bound to increase environmental stresses. The recommendations mentioned are essential to ensure the viability of the country's fisheries.

Implementation strategies

Successful fisheries management experiences imply the need for a clearly defined management entity with appropriate support and capabilities, as well as effective strategies to attain set objectives. In the context of Brunei Darussalam, the fisheries management entity is clearly defined. The DOF has line responsibility for all matters concerning fisheries. The following strategies to facilitate the administration and proper review of the management guidelines are recommended to the department.

Wide Consultation in Management Decisionmaking Process. Establish a fisheries management council with advisory functions to the Director of Fisheries. Artisanal and commercial fishermen's associations, producers, marketing and consumer groups, the academe and concerned agencies (see Table 17) should be represented. This formal consultative process will improve feedback from affected sections, data collection, law enforcement and overall management implementation. Periodic review of the appropriateness of the guidelines vis-à-vis stated objectives and overall goal is best addressed within the framework of the management council.

Efficient Licensing Control and Enforcement Capabilities. Maintain the annual licensing scheme for all gear and industrial vessels to ensure efficient monitoring of effort expansion and trends. Make periodic enforcement visits to the landing sites and base of operations as well as regular patrols in the fishing grounds to assure compliance of individual operators with the terms of their licenses. The programmed boats for DOF in the next five years (exclusive of the capabilities of the Royal Brunei Marine Police and Flotilla) are sufficient to cover the country's coastal waters. For cost-effectiveness, the enforcement checks are best implemented in combination with the data acquisition/monitoring scheme of catches and resource conditions.

Representation of DOF in Maintenance of Environmental Quality. Maintenance of environmental quality is crucial to sustain development of capture fisheries, and requires the most interagency coordination (see Table 17). The DOF should actively participate in the proposed interagency committee that will oversee environmental management.

Efficient Extension and Information Services. Formation of fishing associations and the increase of effort on the resources require expanded extension and information services to the private sector by DOF. The Industrial Fisheries Unit was recently created under the office of the Director of Fisheries to promote and facilitate expansion of the sector. Most of the other units within DOF perform extension functions in various degrees, particularly the Extension and Enforcement Section (EES) (see Fig. 20). The various extension functions should be centralized under a separate Extension and Information Section, manned by qualified extension service officers. Such should emphasize service delivery and attain targets set in the development plan for the sector.

Management Constraints and Program Recommendations

Inputs to management decisionmaking process

The available quantitative fisheries data and studies are of variable scope and reliability and clearly need continuous refinement and/or extension. Two interrelated programs are clearly in order, namely: (1) improvement of available statistical baseline and (2) establishment of a fisheries assessment group.

A reliable statistical system is a basic prerequisite in the assessment and management of fisheries and provides indispensable information in the evaluation of sectoral performance. Subramaniam et al. (1989) detail the nature of the country's fisheries statistics system. Four sections under DOF routinely collect statistical information (see Fig. 20). The Marine Fisheries Section collects catch statistics from full-time artisanal fishermen while the Aquaculture Section monitors aquaculture production by species and culture method. The Marketing Unit of the Post-Harvest Section (PHS) monitors industrial sector landings (via logbook returns from skippers) and fresh fish marketed by stalls in markets throughout the country. Through the annual licensing procedure, EES monitors fishermen numbers and their gear. Only statistics from PHS and EES are published to date in the annual Brunei Darussalam Statistical Yearbook.

The statistical collection system needs improvement. Estimation of total catch statistics is problematic, for three reasons: (1) data from part-time artisanal fishers are unavailable; (2) logbook returns from industrial boat skippers may be unreliable; and (3) it is marketed landings that are published annually. Streamlining the

system may be best accomplished by establishing a small Statistics Unit under the Director of Fisheries with the following activities: publish historical data and annual statistics on fisheries in a suitable format; design and implement a statistical data collection system; and computerize the available statistical data base. The second activity addresses the issue of data reliability and should consider primary data collection in the landing places as these are few and can easily be covered (see Fig. 16). The rest of the activities address the issue of accessibility of information, both those already available in various formats in DOF files and those to be generated by programmed activities.

The establishment of a fisheries assessment group is essential due to: (1) the scope and reliability of existing studies; (2) the inadequacy of current understanding of multispecies resources, particularly their stability at high effort levels; and (3) the lack of socioeconomic studies on the country's capture fisheries. The following activities need particular attention in this context: improve the timeliness and reliability of biological/management advice; monitor and refine assessments on the major resource groups; conduct ecosystem/multispecies fisheries research; address information gaps about the resources; and make socioeconomic studies of consequence to resource allocation, social equity, market efficiency and cross-product substitution.

Availability of specialized manpower

The lack of qualified manpower for specialized tasks in DOF requires reliance on expatriate experts in the immediate future. A program for the development of local expertise is clearly urgent. For management and extension activities, local staff in the following fields (at least masteral level) need to be trained: resource economics, stock/resource assessment, information, fishing gear/boat technology, fish processing technology, extension services and aquatic ecology/ environmental management.

Private sector manpower needs are also a concern due to the projected expansion of the industrial fisheries sector. Currently, most of the crew of trawlers and purse seiners are expatriates from Malaysia and Thailand. A training program by DOF to provide locals with sufficient skills is necessary over the medium term to facilitate programmed industrial sector development. Efforts towards this end have been initiated but require more effective implementation (e.g., screening of trainees) and continuous support.

Quality and seasonality of harvests/landings

Efficient utilization of fisheries resources is constrained by: (1) the disparity of preferred species for human consumption versus species composition of trawl catches (given the projected expansion of this sector) and (2) the high seasonality of shrimp, pelagic and (to a lesser extent) demersal resource catches/ availability and its effect on incomes and fish prices. Reduction of discards through value-added fish processing activities is recommended. Moreover, the feasibility of canning and/or storage facilities should be studied to complement industrial fisheries development.

Increasing cost of labor

The accelerated development activities in other sectors of the economy are bound to reduce manpower availability in the fisheries sector. Currently, the total number of fishermen is on the decline due to more comfortable, land-based alternatives. The effect of rising labor cost and standard of living on the programmed expansion of industrial fisheries needs careful evaluation to formulate remedial measures. The long-term goal is economic efficiency of fishing operations to allow fishing incomes to compare favorably with those in other sectors. Operators need to be organized to ensure that imported inputs (e.g., gear, spare parts) are readily available at reasonable cost. Continued access to skilled expatriate labor for fishing operations, however, will not be a problem in the next ten years or so in the region.

Overall, the prospects for sustainable development of the capture fisheries of Brunei Darussalam are bright despite the constraints. The country is in a very favorable position compared with other countries in the region where overcrowded fisheries are common. The recommendations given here, coupled with proposed measures in the other papers in this volume provide the framework for sustainability of benefits from capture fisheries.

References

Beales, R. 1982. Investigations into demersal resources accessible to trawling in Brunei waters, p. 1-98. *In* R. Beales, D. Currie and R. Lindley (eds.) Investigations into fisheries resources in Brunei. Brunei Museum, Brunei Darussalam.

Beales, R., D. Currie and R. Lindley, editors. 1982. Investigations into fisheries resources in Brunei, p. 1-204. Brunei Museum, Brunei Darussalam.

Beddington, J. and J. Cooke. 1983. The potential yield of fish stocks. FAO Fish. Tech. Pap. (242): 1-47.

Chou, L.M., M.W.R.N. De Silva and A.T. White. 1987. Coral reefs, algae and seagrasses, p. 43-58. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Chua, T.-E. and D. Pauly, editors. 1989. Coastal area management in Southeast Asia: policies, management strategies and case studies. ICLARM Conference Proceedings 19, 254 p. Ministry of Science, Technology and the Environment, Kuala Lumpur; Johore State Economic Planning Unit, Johore Bahru, Malaysia; and International Center for Living Aquatic Resources Management, Philippines.

Chua, T.-E., L.M. Chou and M.S.M. Sadorra, editors. 1987. The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Crocos, P. and J. Kerr. 1983. Maturation and spawning of the banana prawn *Penaeus merguiensis* de Man (Crustacea: Penaeidae) in the Gulf of Carpentaria. Aust. J. Exp. Biol. Mar. Ecol. 69(1): 37-59.

Cruz, A., S. Subramaniam, G. Silvestre and I.K.A. Hamid. Financial and economic analysis of trawling in Brunei Darussalam. *In* G. Silvestre, S. Subramaniam and H.J.H. Matdanan (eds.) The capture fisheries of Brunei Darussalam. ICLARM Tech. Rep. (In press).

Cunningham, S. 1981. The evolution of the objectives of fisheries management during the 1970s. Ocean Manage. 6: 251-278.

Currie, D. 1979. Some aspects of the hydrology of the Brunei Estuary. Brunei Mus. J. (6): 199-239.

Currie, D.J. 1982. Studies on the biology of penaeid prawn and the prawn fishery in the Brunei Estuary, p. 134-187. *In* R.W. Beales, D.J. Currie and R.H. Lindley (eds.) Investigations into fisheries resources in Brunei. Brunei Mus. Monogr. No. 5.

Dalzell, P. and R. Ganaden. 1987. A review of the fisheries for small pelagic fishes in Philippine waters. BFAR Tech. Pap. Ser. 10(1): 1-58.

DOF (Department of Fisheries). 1968. Report on the 1968 trawling survey. Fisheries Department, Ministry of Development, Brunei Darussalam. (Unpublished).

DOF (Department of Fisheries). 1986-1990. Department of Fisheries, Ministry of Industry and Primary Resources, Brunei Darussalam. (Unpublished records).

DOF (Department of Fisheries). 1989. Pelagic resource survey (interim report). Department of Fisheries, Ministry of Industry and Primary Resources, Brunei Darussalam. 26 p. and 4 appendices.

DOTCP (Department of Town and Country Planning). 1986. Negara Brunei Darussalam Master Plan Background Paper No. 5: Fisheries and Aquaculture. Department of Town and Country Planning, Ministry of Development, Brunei Darussalam.

DOTCP (Department of Town and Country Planning). 1987. Negara Brunei Darussalam Master Plan: Main Volume. Department of Town and Country Planning, Ministry of Development, Brunei Darussalam.

EPU (Economic Planning Unit). 1966-1990. Brunei Darussalam statistical yearbook. Statistics Division, Economic Planning Unit, Ministry of Finance, Brunei Darussalam.

EPU (Economic Planning Unit). Fifth National Development Plan (1986-1990). (Unpublished).

EPU (Economic Planning Unit). Sixth National Development Plan (1991-1995). (Unpublished).

FAO (Food and Agriculture Organization). 1991. Reducing environmental impacts of coastal aquaculture. Report of the First Session of the GESAMP Working Group on Environmental Impacts of Coastal Aquaculture, 7-11 January 1991. Kiel, Germany. GESAMP XXI/8. 27 p. and 4 appendices. Food and Agriculture Organization of the United Nations, Rome.

Garcia, S. 1988. Tropical penaeid prawns, p. 219-249. *In* J. Gulland (ed.) Fish population dynamics. Second ed. John Wiley & Sons, New York.

Garcia, S., P. Sparre and J. Csirke. 1989. Estimating surplus production and maximum sustainable yield from biomass data when catch and effort time series are not available. Fish. Res. 8: 13-23.

Gulland, J. 1971. The fish resources of the oceans. Food and Agriculture Organization/Fishing News Books Ltd., Surrey, England.

Gulland, J. 1974. The management of marine fisheries. Scientechnica (Publishers) Ltd., Bristol.

Gulland, J. 1978. Fisheries management: new strategies for new conditions. Trans. Am. Fish. Soc. 107(1): 1-11.

Halidi. H.A.M.S. 1987. A preliminary analysis of catch-per-effort data from demersal trawl surveys off Negara Brunei Darussalam (1979-1986). Report of a training stage at the International Center for Living Aquatic Resources Management, March-April 1987. Manila, Philippines.

IPFC (Indo-Pacific Fisheries Commission). 1987. Proceedings of the Symposium on the Exploitation and Management of Marine Fishery Resources in Southeast Asia held in conjunction with the 22nd Session of the Indo-Pacific Fisheries Commission, 16-19 February 1987. Darwin, Australia. RAPA/Rep. 1987/10. 552 p. Regional Office for Asia and the Pacific, Food and Agriculture Organization of the United Nations, Bangkok, Thailand.

Khoo, H.W., S. Selvanathan and H.A.M.S. Halidi.1987. Capture fisheries, p. 89-109. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Lawson, R. 1978. Incompatibilities and conflicts in fisheries planning in Southeast Asia. Southeast Asian J. Soc. Sci. 6(1-2): 115-136.

Linden, O., B. Ganning and L. Lindeström. 1989. Preliminary studies on plankton, primary production and fish in the Inner Brunei Bay. Malay. Nat. J. 43: 33-52.

Longhurst, A. and D. Pauly. 1987. Ecology of tropical oceans. Academic Press, California, USA.

Loo, M., L. Hsu and J. Paw. 1987. Physical environment, p. 5-27. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Mohammed Shaari, S.A.L., W. Weber, A.K. Lee and W.C. Lam. 1976. Demersal fish resources in Malaysian waters. First trawl survey off the coasts of Sarawak, Brunei and the west coast of Sabah, 27 March-1 May 1972. Fish. Bull. (8): 64 p. Ministry of Agriculture and Rural Development, Kuala Lumpur, Malaysia.

Nicholl, R., editor. 1975. European sources for the history of the Sultanate of Brunei in the sixteenth century. Brunei Museum, Bandar Seri Begawan, Brunei Darussalam.

Panayotou, T. 1982. Management concepts for small-scale fisheries: economic and social aspects. FAO Fish. Tech. Pap. (228): 1-53.

Pauly, D. 1980. Biological overfishing of tropical stocks. ICLARM Newsl. 2(3): 3-4.

Pauly, D. 1984. Fish population dynamics in tropical waters: a manual for use with programmable calculators. ICLARM Studies and Reviews 8, 325 p. International Center for Living Aquatic Resources Management, Manila, Philippines.

Pauly, D. 1988. Some definitions of overfishing relevant to coastal

zone management in Southeast Asia. Trop. Coast. Area Manage. 3(1): 14-15.

Pauly, D., G. Silvestre and I. Smith. 1989. On development, fisheries and dynamite: a brief review of tropical fisheries management. Nat. Resour. Modeling 3(3): 307-329.

Roedel, P., editor. 1975. Optimum sustainable yield as a concept in fisheries management. Am. Fish. Soc. Spec. Publ. (9): 1-89.

Rothlisberg, P., D. Staples and P. Crocos. 1985. A review of the life history of the banana prawn *Penaeus merguiensis* in the Gulf of Carpenteria, p. 125-136. *In* P. Rothlisberg, B. Hill and D. Staples (eds.) Second Australian National Prawn Seminar. Cleveland, Australia.

Rothschild, B.J., editor. 1982. Global fisheries: perspective for the 1980's. Springer-Verlag, New York.

Silvestre, G. 1990. Overexploitation of the demersal stocks of Lingayen Gulf, Philippines, p. 873-876. *In* R. Hirano and I. Hanyu (eds.) The Second Asian Fisheries Forum. Asian Fisheries Society, Manila, Philippines.

Silvestre, G., S. Subramaniam and H.A.M.S. Halidi. Preliminary trophic model of the coastal fishery resources of Brunei Darussalam, South China Sea. ICES C.M. 1990/L: 41, Session Q. 11 p. (In press, a).

Silvestre, G., S. Subramaniam and D. Pauly. Results of demersal fishery resources investigations in the coastal waters of Brunei Darussalam (1989-1990). ICLARM Tech. Rep. (In press, b).

Silvestre, G., S. Subramaniam and H.J.H. Matdanan, editors. The capture fisheries of Brunei Darussalam. ICLARM Tech. Rep. (In press, c).

Silvestre, G., S. Subramaniam and H.A.W. Ranimah. Penaeid shrimp fishery in the Brunei River Estuary and adjacent waters. *In* G. Silvestre, S. Subramaniam and H.J.H. Matdanan (eds.) The capture fisheries of Brunei Darussalam. ICLARM Tech. Rep. (In press, d).

Subramaniam, S., G. Silvestre, H.A.M.S. Halidi, A.K. Rahman and H.A. Abdul Hamid. Design, operation and catch of industrial gear used in Brunei Darussalam. *In* G. Silvestre, S. Subramaniam and H.J.H. Matdanan (eds.) The capture fisheries of Brunei Darussalam. ICLARM Tech. Rep. (In press, a).

Subramaniam, S., G. Silvestre, T. Sujastani, H.A.M.S. Halidi and M. Mohammed. Design, operation and catch of artisanal gear in Brunei Darussalam. *In* G. Silvestre, S. Subramaniam and H.J. Matdanan (eds.) The capture fisheries of Brunei Darussalam. ICLARM Tech. Rep. (In press, b).

Subramaniam, S., H.A.W. Ranimah and H.A.H. Idris. 1989. The current status of fisheries statistics in Brunei Darussalam. Paper presented at the Seventh Regional Workshop on Fishing Statistics, 17-20 October 1989. Bangkok, Thailand.

Teng, S.K. 1971. Observations on certain aspects of the biology of *Metapenaeus brevicornis* (H. Milne-Edwards) and *Penaeus merguiensis* (de Man) in the Brunei estuarine system. University of Singapore, Singapore. 125 p. M.S. thesis.

Valencia, M. 1978. The physical and chemical environment, p. 9-63. In T.-E. Chua and J.A. Mathias (eds.) Coastal resources of West Sabah: an investigation into the impact of oil spills. Universiti Sains Malaysia, Penang, Malaysia.

White, A.T., M.W.R.N. De Silva and P.H.Y. Sharifuddin. 1987. Institutional and legal framework, p. 149-153. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Mangrove Resources of Brunei Darussalam: Status and Management

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Abstract

This paper gives an overview of the status and use of mangrove resources in Brunei Darussalam. Due to its prosperous oil-based economy, the country's mangroves have not been heavily exploited and are among the best preserved in Southeast Asia. Nevertheless, the mangroves' limited areal extent, vulnerability to development pressures and the resulting potential use conflicts call for a sound mangrove resources management. The management strategy involves zoning the mangrove areas into various uses that would preserve, conserve, protect or enhance the mangrove environment for its ecological significance. The management plan elements are presented here for possible adoption and implementation by the government.

Introduction

A 1987 survey of the coastal forests of Brunei Darussalam (Zamora 1987) indicates that the mangroves are not heavily exploited and are among the best preserved in Southeast Asia. However, there are plans (e.g., DOTCP 1987) to convert mangrove areas for rice cultivation, aquaculture, and residential and industrial sites. Moreover, there is a need to allocate mangroves for the following: (1) traditional uses (e.g., charcoal, firewood); (2) construction purposes (e.g., poles for pilings); (3) habitat support to valuable fisheries; (4) protection against coastal erosion; (5) habitat for unique, rare, endangered and/or vulnerable wildlife; (6) reserve areas for protection of biological diversity; and (7) maintenance of water quality. Given these competing requirements, the development of a management plan for the optimal use of the country's mangrove resources is deemed necessary.

Brunei Darussalam's Mangroves

The mangroves of Brunei Darussalam occur in saline soils (pH=3.6-4.7) subject to tidal inundation. Largely in northern Temburong (Selirong Forest Reserve [SFR] and Labu Forest Reserve [LFR]); along the lower reaches of Belait, Tutong and Sungai (or Sg., i.e., river) Brunei; and around Muara (Fig. 1), mangroves occupy a total area of 18,418 ha representing 3.2% of the national land area (Table 1). Despite exploitation of the resource over the past 88 years, there remains a substantial tree stand, with the seedling and sapling component (which represents the replacement pool) making up 78% of the total number of plants per hectare of mangrove forest (Zamora 1987).

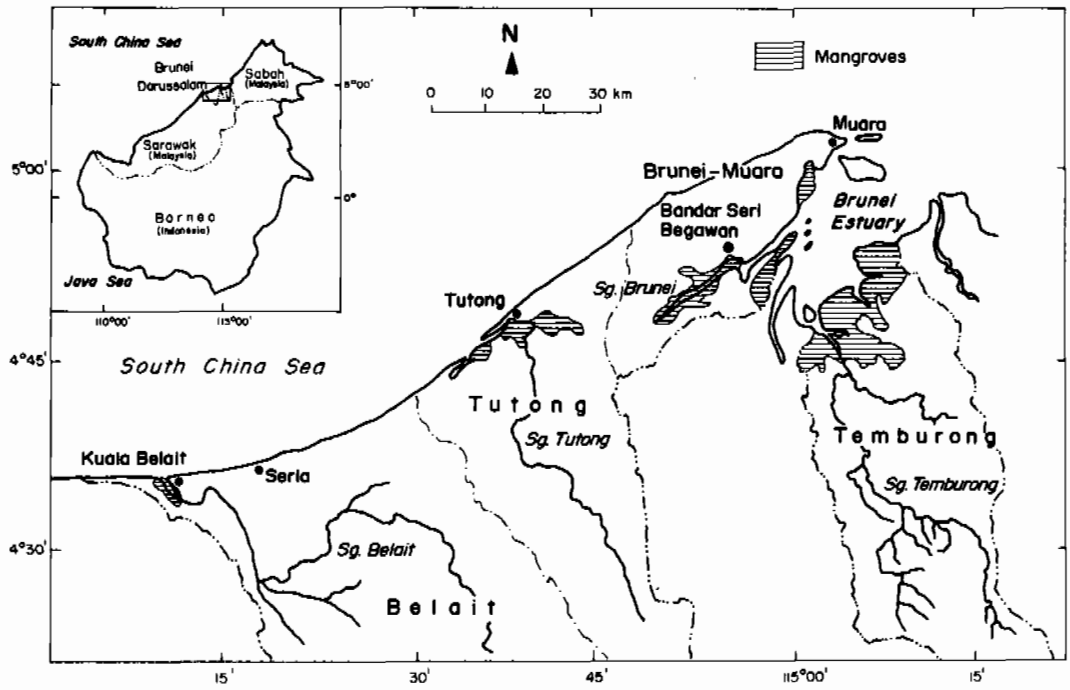


Fig. 1. Distribution of mangrove forests in Brunei Darussalam.

Table 1. Mangrove area relative to total land area in the four administrative districts of Brunei Darussalam.

District	Total land area (ha)	Mangrove area (ha)	% of total mangrove area
Temburong	116,600	12,164	66.0
Brunei-Muara	57,000	3,937	21.4
Tutong	130,300	1,784	9.7
Belait	272,500	533	2.9
Total	576,400	18,418	100.0

Source: Zamora (1987).

Flora and vegetation

Based on field surveys and literature, Zamora (1987) lists 81 species of vascular plants in the country's mangrove swamps. These consist of 47 flowering plants, 1 gymnosperm and 33 ferns and fern allies.

Tomlinson (1986) suggests the classification of "mangrove" plants into four categories, namely: (1) major elements, (2) minor elements, (3) mangrove associates and (4) specialized elements. Major elements occur in mangrove forests, form pure stands, and do not extend into terrestrial communities. They are characterized by morphological and physiological attributes such as aerial roots, vivipary of the embryo and a mechanism for salt excretion that make them specially adapted to their environment. Strict mangroves are separated from their relatives at least at the generic level, and often at the subfamily or family level. Minor elements are distinguished by their inability to form a conspicuous element of the vegetation. They may occupy peripheral habitats and only rarely form a pure community. They are separated from their relatives mostly at the generic level. Mangrove associates are never inhabitants of strict mangrove communities and may occur only in transitional vegetation. Specialized elements include climbers, epiphytes and parasites.

An attempt to classify "mangrove" plants occurring in Brunei Darussalam's mangrove forests is given in Table 2. These categories are not sharply circumscribed and assessment is somewhat subjective given the continuum of possibilities.

Of the major elements of mangroves in the country, the rare species are *Kandelia candel (aleh-aleh)*, *Bruguiera cylindrica (berus ngayong)*, *B. parviflora (berus linggadai)* and *B. sexangula (berus pulut)*, while *Rhizophora apiculata (bakau minyak)* and *Nypa fruticans (nipah)* are the most dominant.

Vegetation Types. The six major mangrove forest types identified in Brunei Darussalam are: (1) undifferentiated mangrove, (2) *Rhizophora*, (3) *Xylocarpus*, (4) *Bruguiera*, (5) *Nypa* formation and (6) *Nypa-Heritiera*.

Undifferentiated mangrove consists of a mixture of species whose components depend on soil composition and degree of inundation. *Rhizophora* mangrove is

Table 2. "Mangrove" plants occurring in Brunei Darussalam based on categories described by Tomlinson (1986).

Major elements	Mangal associates
Avicenniaceae	Acanthaceae
Avicennia alba	*Acanthus ebracteatus*
A. marina	*A. ilicifolius*
A. officinalis	Sapindaceae
Rhizophoraceae	*Allophyllus cobbe*
Bruguiera cylindrica	Myrsinaceae
B. gymnorrhiza	*Ardisia elliptica*
B. parviflora	*Myrsine umbellata*
B. sexangula	Lecythidaceae
Ceriops tagal	*Barringtonia racemosa*
Rhizophora apiculata	Tiliaceae
R. mucronata	*Brownlowia argentata*
Kandelia candel	*B. tersa*
Combretaceae	Apocynaceae
Lumnitzera littorea	*Cerbera manghas*
L. racemosa	*C. odollam*
Arecaceae	Papilionaceae
Nypa fruticans	*Derris trifoliata*
Sonneratiaceae	*Intsia bijuga (Intsia retusa)*
Sonneratia alba	*Pongamia pinnata*
S. caseolaris	Flagellariaceae
S. ovata	*Flagellaria indica*
	Euphorbiaceae
Minor elements	*Glochidion littorale*
Pteridaceae	Anacardiaceae
Acrostichum aureum	*Gluta velutina*
A. speciosum	Malvaceae
Myrsinaceae	*Hibiscus tiliaceus*
Aegiceras corniculatum	*Thespesia populnea*
Euphorbiaceae	Aquifoliaceae
Excoecaria agallocha	*Ilex cymosa*
Sterculiaceae	Rutaceae
Heritiera globosa	*Merope angulata*
H. littoralis	Arecaceae
Rubiaceae	*Oncosperma tigillarium*
Scyphiphora hydrophyllacea	Pandanaceae
Meliaceae	*Pandanus affinis*
Xylocarpus granatum	Verbenaceae
X. moluccensis	*Vitex peralata*

almost completely dominated by *R. apiculata* of the family Rhizophoraceae. *R. mucronata (bakau kurap)* occurs occasionally, in most cases as a riverine species along deltaic channels and creeks. *Xylocarpus* mangrove is characterized by pure stands of *Xylocarpus granatum (nyireh bunga)* of the family Meliaceae. Lobster mounds, usually covered by *Acrostichum aureum (piai fern)* abound in areas occupied by this type. *X. granatum* is also found in association with *R. apiculata*. Pure stands of *B. gymnorrhiza (linggadai)* of the family *Rhizophoraceae* distinguish *Bruguiera* mangrove. Three species *(B. cylindrica, B. parviflora and B. sexangula)* that are abundant and sometimes form pure stands in Sarawak mangroves (Chai 1975; Chan 1986), occur very rarely. *B. gymnorrhiza* also occurs in association with *N. fruticans* and as a constituent of the mixed overstorey above *Nypa*. *Nypa* formation is marked by pure stands of *N. fruticans*. Usually associated with *Heritiera globosa (dungun)*, *Nypa* formation tends to merge with the *Nypa-Heritiera* type and there is rarely a precise boundary between them. *Nypa* is likewise of widespread occurrence in the other mangrove types. The *Nypa-Heritiera (nipah-dungun)* type is characterized by dense stands of *N. fruticans* with *H. globosa* of the family Sterculiaceae emerging above the canopy of *Nypa-H. globosa*. At the downriver limits, *Excoecaria agallocha (buta-buta)* and *B. gymnorrhiza* occur, while towards the upriver limit, *Brownlowia argentata (melapeh), Aegiceras corniculatum (sekang mata)* and *Glochidion littorale (buah kenanang)* are common.

Two minor mangrove types are also recognized: (1) *Sonneratia* mangrove, dominated by *Sonneratia caseolaris (pedada)* of the family Sonneratiaceae and (2) *Oncosperma* formation, identified by a marginal mangrove species, *Oncosperma tigillarium (nibong)*, a tall, spiny plant. It occurs towards the upriver limits of *nipah* swamps and is sometimes found in almost pure clumps.

Occurrence and Distribution. Table 3 gives the distribution of the various types of mangrove forests in Brunei Darussalam. In Temburong District, the undifferentiated mangrove type is absent. The *Rhizophora* mangrove type is the most dominant and virtually covers the whole of SFR and most of LFR. It extends from the seaward fringe to the margins of the peat swamp inland where it borders the transition zone. The other dominant types are the *Nypa* formation and *Nypa-Heritiera* which collectively comprise 4,142 ha and occur mainly along Sg. Temburong, Sg. Pandaruan, Sg. Duwan and their tributaries. The *Xylocarpus* and *Bruguiera* types form only a minor component of the mangrove areas of Temburong. The former is concentrated in the middle of LFR and the latter, in the middle of Pulau (or P., i.e., island) Siarau.

Table 3. Distribution and area of the types of mangrove forests in the four districts of Brunei Darussalam.

District	Mangrove type	Area (ha)
Temburong	1	-
	2	5,572
	3	172
	4	70
	5	1,885
	6	2,257
	7	2,208
		(12,164)
Brunei Muara	1	2,848
	2	60
	3	-
	4	-
	5	303
	6	726
	7	-
		(3,937)
Tutong	1	1,052
	2	74
	3	-
	4	-
	5	301
	6	357
	7	-
		(1,784)
Belait	1	153
	2	-
	3	-
	4	-
	5	273
	6	107
	7	-
		(533)
Grand total		18,418

1 - Undifferentiated
2 - *Rhizophora*
3 - *Xylocarpus*
4 - *Bruguiera*
5 - *Nypa* formation
6 - *Nypa-Heritiera*
7 - Type mixtures
Source: Zamora (1987).

In Brunei-Muara District, undifferentiated mangroves dominate (lining the fringes of Sg. Brunei and its tributaries) while the *Xylocarpus* and *Bruguiera* types are virtually absent. The other mangrove types (i.e., *Rhizophora, Nypa, Nypa-Heritiera*) occur in various small proportions.

Dominating Tutong District is the undifferentiated mangrove type, followed by *Nypa-Heritiera, Nypa* and *Rhizophora.* These are concentrated on the southwestern (Telisay) side.

The *Nypa*, undifferentiated and *Nypa-Heritiera* types dominate the mangrove areas of Belait District, while the *Rhizophora, Xylocarpus* and *Bruguiera* types are practically absent. The undifferentiated mangrove type is concentrated on the lower east and west banks of Sg. Belait.

To sum up, mangrove swamps in Brunei Darussalam are found mainly around the deltaic system of Temburong District and along the northwestern fringes of Brunei Estuary in Brunei-Muara District (see Table 1 and Fig. 1).

Vegetation Zones in Brunei Estuary. Sahat et al. (1986) recognize six distinct vegetation zones in Brunei Estuary, namely: (1) *Avicennia-Sonneratia* formation, (2) *Rhizophora* forest, (3) *Nypa* formation, (4) *Heritiera-Excoecaria* forest, (5) peat swamp forest and (6) in disturbed areas and sandy soils (Table 4 and Fig. 2).

Plankton

Mohamed et al. (1984) and Linden et al. (1989) undertook studies of plankton and other organisms in the vicinity of Brunei Estuary. Linden et al. (1989) record 78 phytoplankton species from two sampling periods (November-December 1984 and April 1985). The dominant genera in November-December 1984 were diatoms *(Bacteriastrum, Chaetoceros* and *Rhizosolenia).* Dominant in April 1985 were species of the blue-green algae, *Oscillatoria.* These results indicate

Table 4. Vegetation zones in the Brunei Estuary area.

Vegetation zone	Location	Dominant species
1. *Avicennia-Sonneratia* formation	Seaward zone within the estuarine system in (a) accreting intertidal mudflats and (b) rivermouths and along banks of lower reaches of tidal rivers.	*A. marina* *S. alba*
2. *Rhizophora* forest	Lower and middle reaches of tidal inundation where coastal erosion had previously taken place.	*R. apiculata*
3. *Nypa* formation	Lower and upper reaches of rivers.	*N. fruticans*
4. *Heritiera-Excoecaria* forest	Landward extension of the *Nypa* formation.	*H. littoralis* *E. agallocha*
5. Peat swamp forest	Upper reaches of tidal influence.	*Dyera* spp. (Apocynaceae)
6. Disturbed areas and sandy soils	a. Areas cleared for agriculture and housing.	*Dillenia suffruticosa*, *Barringtonia asiatica*, *Melastoma malabathrica*, *C. manghas* *Morinda* and *Pandanus*
	b. Areas along exposed coast and offshore islands.	*Casuarina equisetifolia*

Source: Mohd. Jaya et al. (1986).

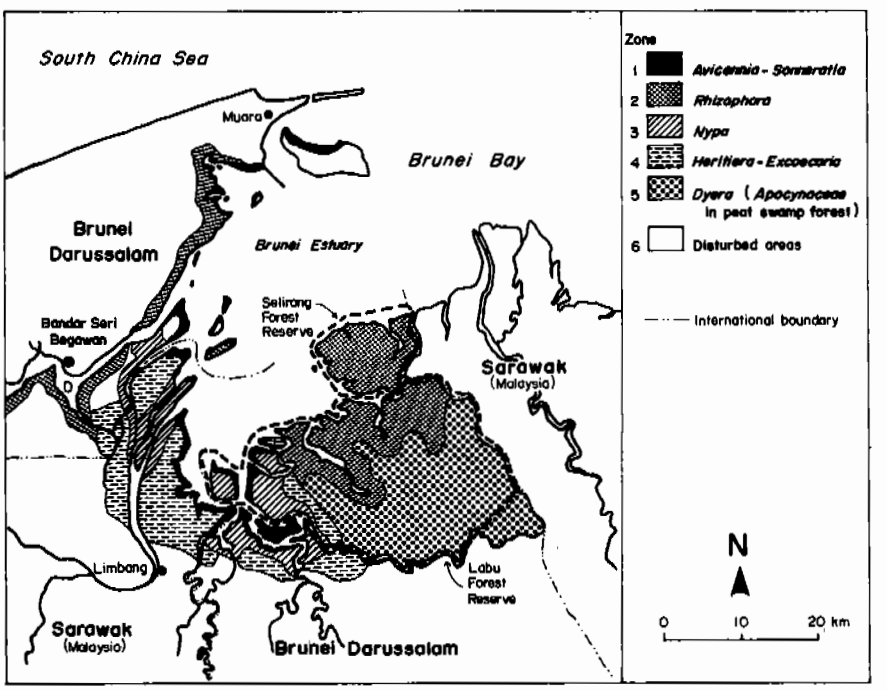


Fig. 2. Distribution of six vegetation zones in the Brunei Estuary area. (Mohd. Jaya et al. 1986).

higher productivity values (chlorophyll a) during the earlier period. For zooplankton, crustaceans were the most common group with copepods frequently found abundant. Shrimp larvae were recorded in most samples. Tunicates and chaetognaths were slightly more common in April 1985 than in November-December 1984.

Fauna

Some of the animals found in the mangrove areas of Brunei Darussalam include protozoans, sponges, bryozoans, coelenterates, ctenophores, worms (nonpolychaetes, polychaetes), crustaceans (barnacles, crabs, shrimps), insects (mosquitos, moths), arachnids, molluscs (bivalves, gastropods, scaphopods), echinoderms, ascidians, fishes, reptiles (crocodiles, lizards, snakes, turtles), amphibians, birds and mammals (bats, monkeys, otters) (see Chua et al. 1987).

Crustaceans. Scylla serrata (mangrove crab) is the most economically important crab in the Brunei Estuary area. Two main commercially important shrimp species found around the mangroves are *Penaeus merguiensis* (white shrimp) and *Metapenaeus brevicornis* (yellow shrimp). *P. indicus* and six other shrimp species occurring in the area are also considered valuable (Currie 1982).

Fishes. In their survey of fishes in mangrove creeks, river channels and the seaward edges of mangrove fringes in Brunei Estuary, Mohd. Jaya et al. (1986) record 79 species belonging to 34 families. Of these, 27 species can also be caught offshore, i.e., in the South China Sea (see Beales 1982). This shows a link between mangroves and offshore fisheries (see Silvestre and Matdanan, this vol.).

Reptiles. A vulnerable and protected species, *Crocodylus porosus* (estuarine crocodile) is found in Brunei Bay (Cox and Gombek 1985; Howes 1986). *Chelonia mydas* (green turtle), a protected species under Part A: First Schedule of the Wildlife Protection Ordinance (Sarawak Cap 128), is claimed to occur in the area, too.

Birds. Mohd. Jaya et al. (1986) report the occurrence of 6 families composed of 17 species of shorebirds and 14 species of waterbirds at 7 intertidal sites in Brunei Estuary. Of these, 14 species are migratory, utilizing the mangrove and mudflat areas of the estuary for short periods each year, while 17 species are residents. The most common migratory shorebirds are *Charadrius mongolus* (Mongolian plover), *Pluvialis fulva* (Asian golden plover), *Tringa totanus* (common redshank) and *Actitis hypoleucos* (common sandpiper). Among the waterbirds, the most common large resident is *Egretta sacra* (Pacific or eastern reef egret) while the most common tern is *Chlidonias hybrida* (white-winged black tern). Based on Mohd. Jaya et al. (1986), the protected waterbirds are *E. sacra, Ciconia stormii* (Storm's stork), *Leptoptilos javanicus* (lesser adjutant stork), *Haliaetus leucogaster* (white-bellied sea eagle), *Pelargopsis capensis* (stork-billed kingfisher), *Halcyon pileata* (black-capped kingfisher) and *Aceros undulatus* (wreathed hornbill). *C. stormii* was formerly distributed throughout Southeast Asia, but large-scale modification of swamp forests has brought this little-known species to the brink of extinction. Two migratory species, *Limnodromus semipalmatus* (Asian dowitcher) and *Egretta eulophotes* (Chinese egret) are considered endangered.

All 31 species reported utilize the mangrove and mudflat areas as foraging grounds and/or roosting sites. Tanjong (or Tg., i.e., cape) Puan, Tg. Api Api, Tg. Kidana, P. Berbunut, P. Baru-Baru, P. Pepatan, P. Muara Besar, Sg. Brunei and Sg. Butir are used as foraging areas during low tide. Kampong (or Kg., i.e., village) Rangau and P. Berbunut are used as roosting sites during high tide. P. Muara Besar is the most important area within Brunei Estuary for shorebirds. Fourteen of the 17 shorebird species (8 residents and 9 migratory species) use it for foraging.

The intertidal zone in Brunei Estuary supports a relatively low benthos biomass. Hence, only a small number of waterbirds use this area compared with those in other Southeast Asian countries (Howes 1986). Shore- and waterbirds known to include a large proportion of crustaceans in their diet are: *C. leschenaultii* (large sandpiper), *Xenus cinereus* (Terek sandpiper), *C. dubius* (Mongolian plover), *Numenius phaeopus* (whimbrel), *T. totanus* and *A. hypoleucos* (Swennen and Marteijn 1985).

The Brunei Bay area is a very suitable wintering or staging site for migrating waders. As Howes (1986) notes, the expansive areas of exposed mudflats and sandflats at low tide; the availability of suitable undisturbed roost sites; and the large, though mostly secondary, mangrove system which provides a rich nutrient flow into the intertidal flats provide suitable conditions for visiting waterbirds. *E. eulophotes* uses the Brunei Bay area as a wintering or stopover site before returning to its breeding grounds in mainland Asia. *C. leschanaultii* is known to "summer", while *P. fulva* is known to breed there (Howes 1986).

Mammals. As in West Malaysia, fruit bats in Brunei Darussalam *(Macroglossus minimus, Eonycteris spelea)* most likely also play an important role in the reproductive biology of *S. caseolaris* and *S. alba (perepat)* by acting as their pollinator (Tomlinson 1986).

A population of large flying foxes *(Pteropus vampyrus)* occurs in P. Siarau, designated as a conservation area for the species (DOTCP 1986b). At dusk, hundreds can be seen over mangrove areas at Kg. Limpaku Pinang, Kg. Rangau and as far inland as Limbang. Dependent on fruit trees, possibly a species of figs *(Ficus)* found in mangrove swamp forest transition areas as well as inland peat swamp and lowland dipterocarp forest, this species is thus vulnerable to clearance of such forest types (Howes 1986).

Nasalis larvatus (proboscis monkey) is one of the endangered species of wildlife that utilizes the mangrove environment. Occurring in the offshore islands of Berambang, Berbunut, Baru-Baru, Pepatan and Bedukang (Mohd. Jaya et al. 1986), it prefers large, undisturbed mangrove forests and feeds on the leaves and fruits of *S. alba*, the young leaves of *B. gymnorrhiza*, palm shoots and fruits (Eimerl and DeVore 1972). Though widely distributed, the proboscis monkey is highly vulnerable. Without protection, the population will be wiped out as unmanaged logging and illegal hunting continue. Currently, it is protected by the Malaysian Government under the First Schedule (Part A: Protected Animals) of the Wildlife Protection Ordinance (Sarawak Cap 128). The Director of the Brunei Museum has proposed the designation of the mangroves of P. Berambang as a conservation area for the proboscis monkey (Zamora 1987).

Two other species, *Macaca fascicularis* (crab-eating or long-tailed macaque) and *Presbytis cristata* (silver leaf monkey), occur in the *nipah*-mangrove islands around the immediate vicinity of Bandar Seri Begawan. *P. cristata* and *M. fascicularis* live almost all over the Sunda Shelf islands. They have a habitat preference for mangrove swamp; upland and lowland tropical rain forest; and monsoon and secondary forest in close proximity to human habitation. *Presbytis* usually live in groups of up to 30 individuals. Ten species of mangroves found edible to *Presbytis* and *Macaca* are *A. alba, A. marina, A. officinalis, S. alba, S. caseolaris (S. acida), A. corniculatum, R. mucronata, R. apiculata, N. fruticans* and *B. gymnorrhiza*. Their diets consist of 58.5% leaves and 41.2% fruits for *Presbytis* and 16.7% leaves, 50% fruits, 16.7% bark and 8.3% cambium for *Macaca* (Supriatna et al. 1989).

Salter and MacKenzie (1981) report that otters *(Lutra)* occur along many mangrove channels in Brunei Bay.

Wildlife at Risk. Due to overexploitation of mangroves in Asia, a number of mangrove-dependent wildlife species have been classified under "at-risk" status (see Saenger et al. 1983), 15 (2 reptiles, 4 mammals and 9 birds) of which occur in Brunei Darussalam (Table 5). Their continued existence is somehow safeguarded by the current status of mangroves in the country.

Table 5. Fauna at risk that utilize the mangrove environment in the Brunei Estuary area.

Class	Species	Status
Mammals	*Nasalis larvatus*	Endemic, protected
	Macaca fascicularis	Protected
	Presbytis cristata	Vulnerable
	Pteropus vampyrus	Protected
Reptiles	*Crocodylus porosus*	Vulnerable, protected
	Chelonia mydas	Protected
Birds	*Limnodromus semipalmatus*	Endangered, migratory
	Egretta eulophotes	Endangered, migratory
	E. sacra	Protected
	Ciconia stormii	Protected, endangered
	Leptotilus javanicus	Protected
	Haliaetus leucogaster	Protected
	Pelargopsis capensis	Protected
	Halcyon pileata	Protected
	Aceros undulatus	Protected

Protected - significant populations are located within reserves which seek to protect them.
Vulnerable - not endangered at present, but at risk over a longer period or could become endangered if current resource use patterns change.
Endangered - in serious risk of disappearing from the wild state within one or two decades if present resource use patterns continue.

Substrate

The soils of mangrove areas in Brunei Darussalam have been characterized in DOTCP (1986a), Zamora (1987) and references therein. In mangrove areas where the natural vegetation cover is mainly *N. fruticans* (i.e., coastal flats in the estuaries of Sg. Temburong, Sg. Brunei and Sg. Tutong), the soils are grey, slightly saline, nearly ripe to half-ripe and poorly drained, clayey, often with potential acid sulfate layers down to a depth of 50-60 cm from the surface. These mangrove areas are low-lying, shallowly flooded by tidal waters and only for a few hours at high spring tides (i.e., about once a month). The largest area occupied by these soils is in the combined estuaries of Sg. Temburong, Sg. Batu Apoi, Sg. Labu and Sg. Pandaruan just north of Bangar Town in Temburong District. Most of the area lies south of Sg. Labu (about 2,700 ha), divided into quite large blocks by the meanderings of the rivers; an additional 600 ha north of Sg. Labu in LFR make up a total area of 3,300 ha. Three other reasonably large areas occur, as follows: (1) 575 ha in southern P. Berambang in Brunei Estuary (some portions had been previously reclaimed and cultivated for rice, rubber, coconuts and vegetables). The island has been proposed as a conservation area for proboscis monkeys; (2) 100 ha along the lower reaches of Sg. Tutong roughly 3 km south of Tutong Town; and (3) 225 ha along the lower reaches of Sg. Bakiau and Sg. Birau about 4 km south-east of Tutong Town.

In mangrove areas where the natural vegetation cover consists of a variety of mangrove types (including *R. apiculata, X. granatum* and *B. gymnorrhiza* and sometimes *N. fruticans*) and in the estuaries of large rivers that are lower-lying and more affected by seawater (e.g., in SFR and LFR in northern Temburong District), the soils are grey, strongly saline, unripe to half-ripe, poorly drained and usually clayey with potential acid sulfate layers often less than 50 cm from the surface.

Overall, soils in Brunei Darussalam mangrove areas can become extremely acidic upon exposure to air and thus, highly unsuitable for conversion to ponds or mangrove regeneration.

Mangrove Resources Utilization

Plant resources

In the past, the mangroves of Brunei Darussalam were a major source of wood for the charcoal industry (Lim and Sharifuddin 1975); firewood for local use and for export mainly to Hong Kong from 1943-1960; and bark for the manufacture of cutch (a dye extract used in the tanning industry from 1901-1952).

Mangrove charcoal is traditionally used by Brunei women for postnatal treatment: "The local women believe that after giving birth, a mother should stay near charcoal fire to warm herself and [...] the heat helps to contract the muscles of the womb" (Lim and Sharifuddin 1975). Mangrove charcoal is also used for cooking native dishes (e.g., *satay* and traditional cakes). Since charcoal is efficient and cheap, coffee shop owners were very slow in changing to gas and electricity (Lim and Sharifuddin 1975). Mangrove charcoal and firewood were used for ironing and daily cooking, respectively, where electricity and gas were unavailable (DOTCP 1986b).

At present, mangroves continue to be exploited for charcoal and firewood on a small scale, and for poles for piling in construction work (Table 6). While charcoal production is declining because of increasing use of gas (Stewart 1986), the demand for mangrove poles has increased markedly in recent years due to the substantial development of the construction industry. Almost all the poles, charcoal and firewood are obtained from SFR and LFR in Temburong District (Table 6). Only *R. apiculata* forest is exploited for charcoal, firewood and pole production. *X. granatum* and *B. gymnorrhiza* forests are not exploited; thus, they attain moderately large diameters of up to 50 cm for the former and up to 40 cm for the latter.

Today, *nipah* has very few uses in Brunei Darussalam. Its leaves are used as roofing material almost negligibly compared to the practice in the rest of

Table 6. Production of firewood, charcoal and poles (a) from permit areas in Labu and Selirong Forest Reserves, 1976-1987 and (b) in Brunei Darussalam, 1974-1987.

	Firewood (m^3)		Charcoal (t)		Poles (pieces)	
Year	(a)	(b)	(a)	(b)	(a)	(b)
1974		48		192.0		4,400
1975		388		173.0		58,100
1976	320	323	330.0	330.0	95,300	95,300
1977	294	294	303.5	303.5	61,200	61,200
1978	270	270	270.5	270.5	55,200	55,200
1979	290	292	291.5	291.1	100,400	100,400
1980	260	260	255.8	255.8	107,600	107,600
1981	260	260	265.1	265.1	91,100	91,100
1982	270	270	196.8	196.8	92,900	92,900
1983	275	275	223.8	223.8	154,200	154,200
1984	297	297	230.6	230.6	176,900	176,900
1985	340	343	275.8	275.8	168,100	168,100
1986	260	260	212.3	212.3	192,200	192,200
1987	240	240	145.2	145.2	164,400	164,400

Source: EPU (1987).

Table 7. Direct socioeconomic uses of mangrove plant species in the Brunei Estuary area.

Species[a]	Local use
R. apiculata	Wood used for (1) house construction (particularly roof, walls and piles); (2) charcoal production for cooking[b]; and (3) construction of fish traps or stakes.
R. mucronata	Wood used for (1) house construction (particularly roof, walls and piles); (2) charcoal production for cooking[b]; (3) construction of fish traps or stakes; and (4) oil extracts to bum in lamps (pre-1940).
B. gymnorrhiza	Wood used for (1) house construction (particularly roof, walls and piles); (2) charcoal production for cooking[b]; and (3) construction of fish traps or stakes.
X. granatum	(1) Wood used for house piles and charcoal for copper smelting to make canons (old use); (2) poles for betel nut trees to climb up in plantations; and (3) seeds boiled and water solution used to treat skin diseases.
N. fruticans	(1) Leaves of mature fronds processed as *atap* and used as roofing material and wall panels for houses; shrimp and fish traps; (2) young leaves used for weaving hats, mats, food containers *(ketupat)* and carrying baskets, and as cigarette wrappers *(rokok daun)*; (3) sap from inflorescence stalks used to make a sweet drink *(gula anau)*; and (4) immature endosperm of fruit eaten.
S. alba	Wood used for (1) construction of boat frames *(tajuk)* and (2) house beams.
S. caseolaris	Fruits eaten (either whole or mixed) with sago sauce.
H. littoralis	Wood used (1) for boat construction (bow section where engine is attached); (2) as a rat guard *(dinnar)* around stilt legs of a rice store; (3) in a wheelless buffalo cart *(kuntol)*; and (4) as a pestle for rice pounding.
I. retusa	Wood (which is very hard) used for cross beams on the floor of houses.
H. tiliaceus	Bark used to make straps and belts.
A. aureum	Fronds used as a thatch *(raba)* to camouflage *bubu* fish traps.

[a]No large-scale forestry practices have been developed; trees are merely cut for local uses.
[b]A small-scale charcoal industry in P. Berbunut operates six kilns utilizing species of *Rhizophora* taken under permit from the forest around Sg. Duwai Kecil. Each burning-cooling cycle takes around one month to complete.
Source: Mohd. Jaya et al. (1986).

Southeast Asia. Nearly all dwellings in the country have tin roofs. Sugar is also extracted from *nipah* and used as an ingredient for a native cake, again on a very limited scale (DOTCP 1986b).

Table 7 lists the traditional uses of mangrove plants and their parts (i.e., wood, bark, leaves, inflorescence stalks, fruits and seeds) by communities living in the Brunei Estuary area.

It is worthy to note the economic potential of exporting an aroid of high ornamental value, *Cryptocoryne ciliata*, from the Temburong mangroves. Found in brackishwater; river mouths; sandy loams, partly submerged by tides; and in *Nypa* formation in sunny places, it is collected from the wild, rarely cultivated by traders and easily propagated vegetatively by rhizome. Useful in aquariums with fresh- or brackishwater, the living rhizomes are sold to hobbyists at US$1-3 each. Annually, about 500,000 specimens are marketed worldwide.

What is considered commercial mangrove forest in Brunei Darussalam includes only stands of pure *R. apiculata* and pure *B. gymnorrhiza* (DOTCP 1986b). These areas total 5,978 ha, 335 ha (5.6%) of which are state lands (outside SFR and LFR) that cannot be used for production. The actual "commercial" mangrove area allocated to production is therefore 5,643 ha. This may be slightly increased if the area occupied by the *R. apiculata* mixture type is added and managed properly. Current mangrove exploitation in SFR and LFR is confined to permits to extract timber for the small charcoal industry and poles for piling in construction work. Zamora (1987) lists 5 permits issued covering 683 ha for the former and 10 permits covering 1,541 ha for the latter.

The current price of mangrove firewood is difficult to estimate since it is harvested and utilized on a household basis. On the other hand, charcoal is produced by three kilns in P. Berbunut and one in P. Baru-Baru. Interviews with the kiln owner at P. Berbunut in April 1987 reveal that his operations produce 200-300 12-kg bags per month; each bag fetching B$10.00.[1] Poles are produced on contract at B$1.30/piece and transported by boat from Temburong to Sg. Belukut (Jalan Kota Batu). They are sold by length as follows: B$3.50-4.50/piece for 5 m, B$6.00-8.00/piece for 6 m and B$12.00-15.00/piece for 9 m. The average rate of production is 10-20 poles/day/worker (DOTCP 1986b).

Since the employment generated by mangrove-based industries is mostly on a piecework basis, it is difficult to calculate the number of full-time workers. However, an estimate of the potential for full-time employment can be derived from production figures, based on the following assumptions: production rates are 11 poles/day/worker and 0.5 t of charcoal/month/worker and full-time work consists of 250 working days/year. Then, pole production (including loading into the boat) employs 54 men; and charcoal production employs 38 men (DOTCP 1986b). Discounting recorded firewood production, which in terms of labor force is minimal, the total direct full-time employment arising from mangrove utilization is 92 workers. With additional handling and transport to point of wholesale, the total probably will not exceed 120 men.

From the foregoing, it can be concluded that the current overall contribution of mangrove exploitation to the national economy is insignificant (see also Fallon-Scura and Dalusung, this vol.).

Animal resources

Scylla serrata is marketed live in Brunei Darussalam. An average of 60 t/year was sold during the 1985-1989 period; 20 t were produced locally and the remaining 40 t imported from Sarawak. The average price in 1989 was B$5.40/kg.

Annual shrimp landings during the 1985-1989 period averaged 385 t, consisting of 60% *M. brevicornis*, 30% *P. merguiensis* and the rest by six other shrimp species. Of the average landing of 385 t, 220 t were large *(udang besar)* and 165 t were small *(udang kecil)* shrimps. Mean shrimp prices per kg in 1989 were B$12.15 and B$5.20 for large and small shrimps, respectively. The main fishing grounds for shrimps are the mangrove creeks, river channels and seaward edges of mangrove fringes in Brunei Estuary. In addition to marine shrimps, the large freshwater prawn *(Macrobrachium rosenbergii)* is of significance. About 45 t of this species worth B$14.70/kg were landed in 1989.

About 50% of the 79 fish species caught during the survey by Mohd. Jaya et al. (1986) are commercially important in Brunei Darussalam. More than 50% of these utilizes the Brunei Estuary mangroves at various stages (spawning, foraging, nursing) during their life cycles.

Fishing grounds for these fishes are mangrove creeks; river channels; and seaward edges of mangrove fringes in Brunei Estuary, Sg. Temburong, Sg. Tutong and Sg. Belait (see DOTCP 1986a and Silvestre and Matdanan, this vol., for details on estuarine-/mangrove-dependent fisheries resources and their exploitation).

Mangrove lands

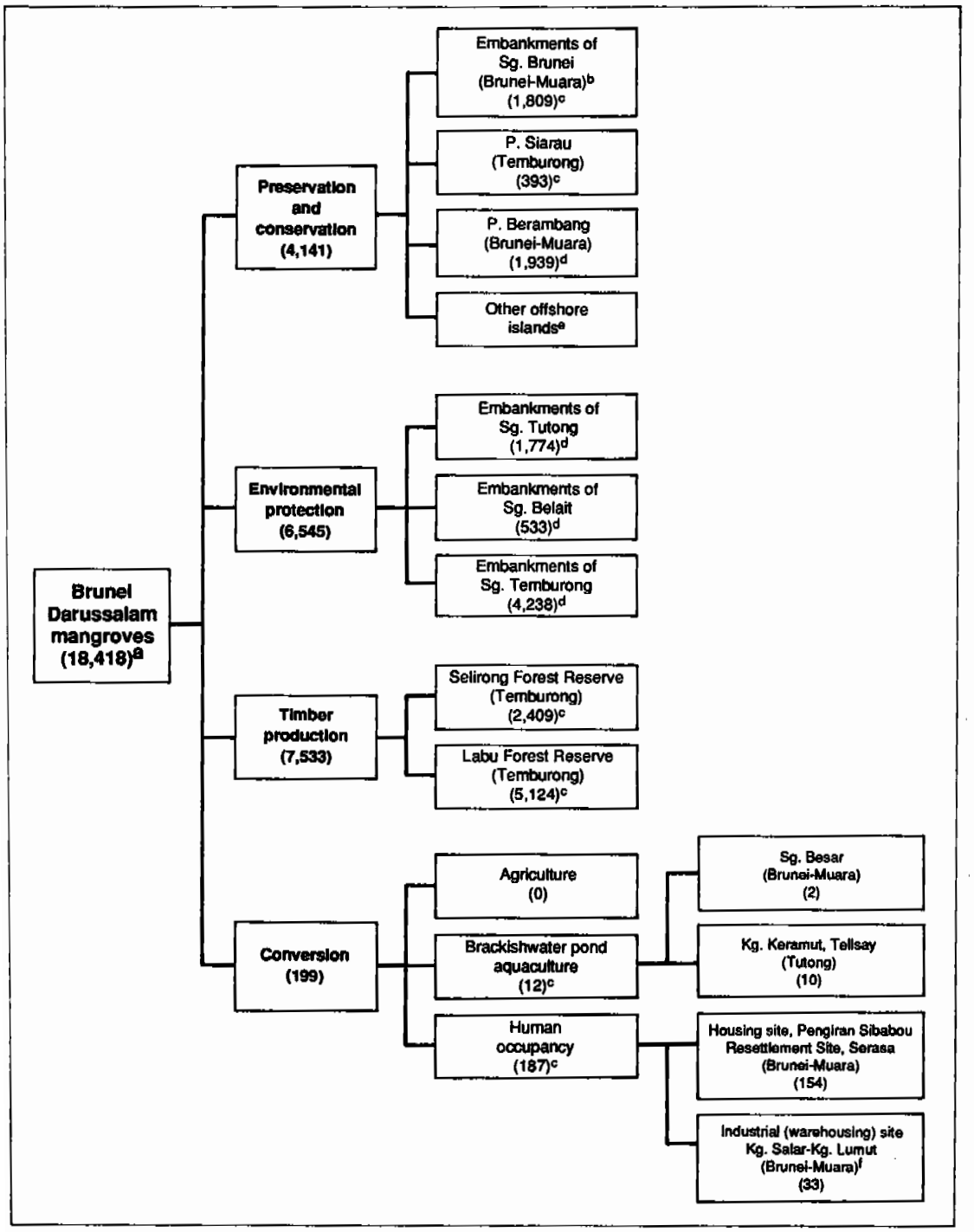
Of the 18,418-ha mangrove areas in Brunei Darussalam, 9,934 ha (54%) are currently committed to specific activities. Fig. 3 gives the distribution of the mangrove areas into various land uses.

Protection or Preservation Areas. The existing protected areas include: the riverine mangroves along the embankments of Sg. Brunei and the mangroves surrounding uninhabited P. Siarau.

Forest Reserve Areas. Two such areas in Brunei Darussalam that contain mangrove lands are SFR and LFR (Fig. 3). The District Forest Office in Bandar Seri Begawan directly administers the mangrove forests in both reserves. The SFR comprises the large tidal island of Selirong on the eastern side of Brunei Estuary (Fig. 2). Ninety-four percent of the reserve's surface area is mangrove forest (Zamora 1987), of which 97% is composed of *R. apiculata*. Thirty-seven percent or 5,124 ha of LFR is mangrove forest consisting of five mangrove types (predominantly *R. apiculata* [63%]) that cover the northern and western portions. The peat swamp forest (8,765 ha, mainly of poor quality) covers the central, eastern and southeastern parts of the reserve (Zamora 1987).

Prior to and since its constitution in 1948, SFR has been exploited for firewood, charcoal and poles, and so has LFR. Charcoal production makes use solely of *R. apiculata*, and firewood production largely consists of the same species. From the production rates in both reserves between 1976 and 1987 (Table 6), the following are explicit: (1) firewood production has remained relatively constant (240-340 m^3) in the last 12 years; (2) annual charcoal production has declined from 330 to 145 t; and (3) pole production has grown since 1978 and is likely to increase further with the high demand from the expansion of the construction industry.

[1]September 1991: B$1.70 = US$1.00.



[a]Consists of 9,934 and 8,484 ha of committed and uncommitted mangrove areas, respectively.

[b]Trees *(Rhizophora apiculata)* are currently being felled illegally for poles and firewood within the 20-m strips of mangrove vegetation lining the embankments of the major rivers (Brunei, Temburong, Tutong and Belait).

[c]Existing, as of 1 June 1990; total area is 9,934 ha.

[d]Proposed; total area is 8,484 ha.

[e]Nonmangrove.

[f]Its development conflicts with its designation as part of a mangrove conservation area (De Silva et al. 1990).

Fig. 3. Existing and proposed land uses of mangrove areas in Brunei Darussalam relative to the proposed mangrove management zonation plan. Figures in parentheses refer to area in hectares.

Brackishwater Pond Aquaculture. Fishpondification is the massive conversion of mangrove swamps into brackishwater ponds for rearing aquatic animals (Zamora 1988a; 1989). There is a 2-ha brackishwater shrimp pond located in Sg. Besar (along Jalan Kota Batu), Brunei-Muara District. Its operator has been successful in two semi-intensive culture trials using *Penaeus monodon* (tiger shrimp) and *P. merguiensis/P. indicus*. Also, about 30 ha in P. Muara Besar are being applied for by a foreign firm to develop into a shrimp farm. In Kg. Keramut, Telisay, Tutong District, private operators are developing two 5-ha shrimp farms.

At present, no mangrove area in Brunei Darussalam is devoted to wet rice cultivation.

Human Occupancy (Residential, Industrial and Commercial Site Development). Some mangrove areas are being developed as residential and industrial sites in Brunei-Muara District. These are the 154-ha Pengiran Sibabou Resettlement Project in Serasa and the 33-ha warehousing site in the Kg. Lumut/Kg. Salar vicinity.

Ecological significance/services

In recent years, a body of literature has grown (see Fortes 1988; Mastaller 1989; Zamora 1990; Paw and Chua 1991) which emphasizes the ecological significance and functions of mangroves: (1) help prevent erosion of riverbanks which, in turn, protect adjacent properties; (2) maintain or improve water quality by taking up suspended solid matter and floating materials; (3) reduce storm surges and associated strong winds; (4) export detritus and nutrients into nearby systems which form the food base of a complex of marine organisms which, in turn, support valuable nearshore fisheries; (5) serve as spawning and nursery grounds of economically important shrimp and fish species; and (6) contain interesting and unusual wildlife (both plants and animals) which provides opportunities for education, scientific study, maintenance of biodiversity and tourism.

The degree of importance of the mangroves' functions varies from one area to another depending upon a complex of factors. The function of dampening storm surges and strong winds can be considered of low importance in Brunei Darussalam since it is outside the typhoon belt, and cyclones are almost unknown. However, prevention of erosion of riverbanks has great significance. Mangroves lining extensive stretches of river embankments (i.e., Belait, Liang, Tutong, Brunei and Temburong) and tributaries aid in preventing unnecessary loss of soil and other resources in the ecosystem caused by the battering effects of wave action. Likewise, the strips of mangroves around small islands and along riverbanks and estuaries are a line of defense against erosion due to water movements caused by passing small crafts carrying passengers and produce. Dense strips of *nipah* lining the embankments of portions of tidal rivers, estuaries and other habitats flooded by brackishwater act as sediment traps and minimize substrate erosion and evaporation loss.

The role of mangroves in supplying nutrients and detritus to the fisheries in estuarine and offshore systems in different countries (see Hamilton and Snedaker 1984; Fortes 1988; Paw and Chua 1991 and references therein) can likewise be presumed to be operational in Brunei Darussalam in some, if not all, respects.

During the course of the surveys in June 1987 and March 1990 in the country's mangrove swamps (see Zamora 1987; Cabahug and Garces, this vol.), great quantities of shrimp and fish fry had been found among the tangled roots of *Rhizophora* plants, indicating the mangroves' function as a nursery habitat. Frusher's (1986) studies in Papua New Guinea similarly reveal that juvenile penaeid shrimps use the mangrove ecosystem as a nursery habitat. Quite a few workers have obtained evidence to support this view (see, for example, Lewis et al. 1985). Also, species of fish have been recorded throughout the estuarine mangrove system. If these fishes are not mangrove-dwellers, they presumably visit the mangrove shore at high tide where they consume mangrove invertebrates, detritus and algae.

The mangroves of Brunei Darussalam provide habitats for many species of animals, some of which are unique and endangered. The *nipah*-mangrove islands in the immediate vicinity of Bandar Seri Begawan harbor substantial populations of *N. larvatus, M. fascicularis, P. cristata* and a variety of birds. P. Siarau, a *nipah*-mangrove island in Brunei Estuary southeast of Bandar Seri Begawan, is the roosting site of an enormous population of *P. vampyrus* (Mittermeier 1980). A species of saturniid moth, new to science, is found in the Temburong mangroves (DOTCP 1986a). Sg. Temburong is home to the aroid *C. ciliata* which is of high ornamental value.

Large quantities of litter collect and form detrital materials on the muddy floor of the swamps in Brunei Darussalam (Zamora 1987). The detritus-derived decomposing plant material (through bacterial, protozoan and fungal action) is utilized by a group of consumer organisms present in the *nipah* palm habitat. Thus, *nipah* palms contribute significantly toward energy flow within the swamp ecosystem. Under favorable conditions, mangroves can have a gross primary productivity of 14 g C $m^{-2}day^{-1}$ (Snedaker and Getter 1985).

The detrital mud is inhabited by numerous crabs, snails and bivalves while the creek and water channels

provide habitats for various estuarine fishes. The mudflats serve as wintering sites of migratory populations of waterbirds (including the endangered Chinese egret) which migrate every winter from breeding grounds in Siberia to Southeast Asia.

Management Plan Elements

Because of Brunei Darussalam's prosperous oil-based economy, good educational system and concern for conservation, its mangrove resources have not been heavily exploited and unduly stressed. No serious conflicts have yet arisen among resource users. However, planned rapid industrialization (see DOTCP 1986a) may lead to varying degrees of conflicts. Mangrove areas designated for conservation purposes but used as housing or industrial sites (DOTCP 1988; De Silva et al. 1990) and the illegal harvesting of poles from mangrove areas declared as protection zones are two emergent examples of use conflicts.

Objectives

The emerging conflicts, limited areal extent of the country's mangroves and their vulnerability to development pressures urgently call for sound mangrove resources management. In this regard, the following management objectives are proposed:

1. to preserve mangrove systems needed for the protection of genetic resources and biological diversity and as resources for restoring areas where management policies may fail or accidents have occurred;
2. to conserve the mangrove resources (plants, animals, physical space or land) for the maximum benefit of the people; and
3. to minimize or avoid conversion uses (e.g., housing development, aquaculture, agriculture) that eliminate the mangrove resources.

Strategy: zones for mangrove areas

A management strategy should be adopted which involves zoning the mangrove areas into various uses based on the mangroves' particular (or combinations of) characteristics. This should integrate existing and proposed land uses that tend to preserve, conserve, protect or enhance the mangrove environment.

Zone 1: Areas for Preservation and Conservation. Existing protected areas. The riverine mangroves along Sg. Brunei are essential to maintain the full potential of Brunei Darussalam's fisheries resources: protect land resources against wave erosion; control sedimentation; and as buffer zones and natural landscape.

Mangroves on the uninhabited P. Siarau at the mouth of Sg. Temburong are needed as roosting sites of *P. vampyrus* and other wildlife species (e.g., endemic saturniid moth).

Proposed wildlife sanctuaries. The offshore islands of Berbunut (inhabited, 112 ha), Baru-Baru (86 ha), Pepatan (39 ha), Bedukang (20 ha) and the mangroves of P. Berambang are useful as habitats of *N. larvatus*, *M. fascicularis* and *P. cristata*, among others (Mohd. Jaya et al. 1986).

Mohd. Jaya et al. (1986) also recommend the 16,914-ha peat swamp forest-mangrove forest-intertidal mudflat area in northern Temburong District (Fig. 4) as a wildlife sanctuary for the following reasons: (1) as an outstanding example of one of the few remaining areas in Asia where a complete biological unit of peat swamp forest, mangrove forest and intertidal mudflat area can be found intact; (2) as a protected area in close proximity to major population centers (e.g., Bandar Seri Begawan, Limbang and P. Labuan), it can be utilized for leisure, tourism, education and scientific study; (3) it harbors wildlife species endangered on a worldwide scale (*E. eulophotes, L. semipalmatus, C. stormii, L.*

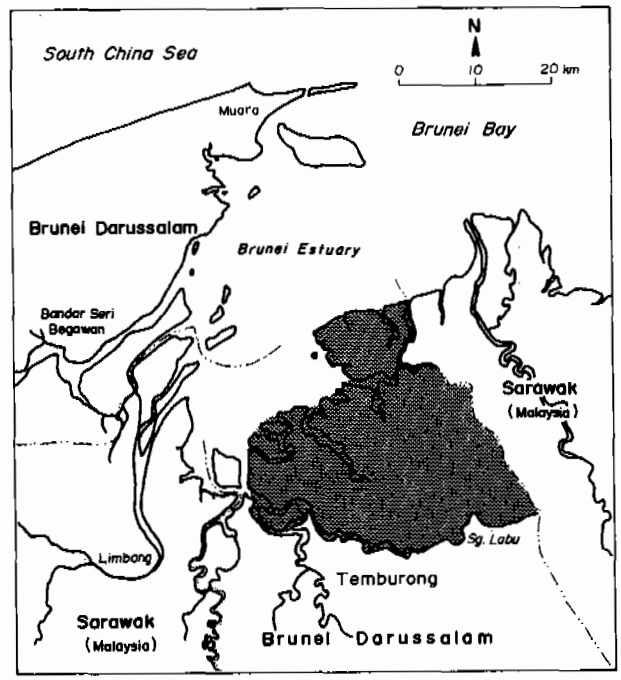


Fig. 4. Peat swamp forest-mangrove forest-intertidal mudflat area in Temburong District recommended as a wildlife sanctuary (adapted from Howes 1986).

javanicus, P. capensis, H. pileata, A. undulatus, N. larvatus, C. porosus, C. mydas) and protected under Part A: First Schedule of the Wildlife Protection Enactment of 1978 (Sarawak Cap 128) *(E. eulophates, E. sacra, H. leucogaster)* and supports a recently discovered species of saturniid moth, endemic to Temburong; (4) the intact mangrove forest contributes to the high productivity of the commercial fisheries industry within Brunei Bay; and (5) the mangroves provide important local and traditional needs of the Bruneians.

Of paramount significance is the proposed International Coastal Resources Conservation Area (ICRCA) conceived as a strategy for international cooperation in coastal resources management (Howes 1986). Since the tidal wetlands in Brunei Darussalam are continuous with those of Malaysia (Sarawak and Sabah), the proposed area will link the former with similar areas in the latter within Brunei Bay (Fig. 5).

Within Brunei Bay, the effects of overexploitation or destruction in one part of the system may adversely affect the people, wildlife (plants and animals) and natural resources productivity. Political boundaries have no control over the movements of commercial fish stock, shrimp stock, wildlife or pollution. The implementation of ICRCA should therefore encompass the coastline of Brunei Darussalam and Malaysia (Sarawak and Sabah).

Such a continuous protected coastal area would offer significant advantages:

1. A bilateral cooperation between Brunei Darussalam and Malaysia will safeguard the natural resources of Brunei Bay and ensure the survival of many wildlife species and future productivity for fishery and forestry and thus enhance the economies of both countries.
2. A fully protected and managed wildlife sanctuary will provide facilities for education, scientific research and recreation, and promote tourism.

Within Southeast Asia, coastal resources are heavily abused, resulting in substantial habitat loss for migratory birds. Without international cooperation to secure a network of protected coastal zones throughout the region, future populations of migratory animals will be endangered due to habitat destruction in their migration routes and winter survival areas.

Implementation of the proposed wildlife sanctuaries by proper authorities would create a protected coastline within Brunei Bay, connecting all existing and proposed conservation areas in both Brunei Darussalam and East Malaysia. The continuity of protected areas is imperative to ensure the free movement of organisms within that system and to prevent fragmentation of the area which could lead to its decreased importance for

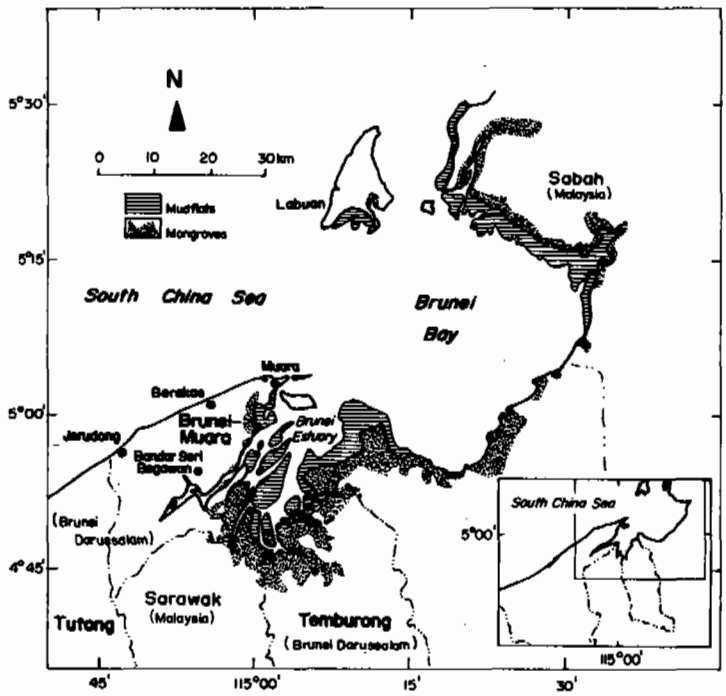


Fig. 5. Distribution of mudflats and mangroves in Brunei Bay.

the people, natural resources and wildlife (Howes 1986).

Mohd. Jaya et al. (1986) and Howes (1986) further recommend that:

1. the current production forests (forest reserves) be included in protected coastal areas (wildlife sanctuaries) and managed on a sustainable basis and
2. the areas of mature or regenerating mangroves currently not included in forest reserves remain part of the protected coastal areas and not be exploited in any way.

Zone 2: Areas for Protection. Like those of Sg. Brunei (and for the same reasons), the mangrove strips lining the embankments of the other major rivers--Belait, Tutong and Temburong (see Fig. 3); associated estuarine systems, including mudflats; and mangrove areas near productive fry and fishing grounds should be protected. These areas also support migratory shorebirds and resident waterbirds. The most important periods when migrant shorebirds use Brunei wetlands are August (for curlew sandpiper) and September (for the Mongolian plover, rednecked stint and common sandpiper). Resident waterbirds use Brunei Estuary as breeding grounds (e.g., *E. sacra, Butorides striatus* or little green heron, *Ardea sumatrana* or Sumatran heron). Moreover, commercially important shrimp and fish species use the mangrove areas, particularly in Brunei Estuary, as nursery and feeding grounds (Mohd. Jaya et al. 1986).

Zone 3: Areas for Wood Production (Firewood, Charcoal, Poles). The SFR and LFR are proposed to constitute areas for wood production on a sustainable basis. Based on the assessment of available data on forest resource conditions, stand and stock, regeneration capacities; estimates of timber volume; and other considerations, Cabahug and Garces (this vol.) note the following:

- Both reserves were extensively subjected to either selective or clearcutting. However, they still harbor sizable old growth stands of economic value.
- Extraction of timber for firewood, charcoal and poles from existing forest stands in said reserves will not bring about denudation of mangrove areas, if done on a sustainable basis.
- There is sufficient timber supply from these reserves to sustain demand for firewood, charcoal and poles and even a 15-30% annual increase in demand (projected over a 20-year period) will not deplete the mangrove resource.
- Although Brunei Darussalam is not foreseen to become heavily dependent on mangroves for future economic needs (hence not posing any real threat of resource depletion), it is still advisable to manage the mangrove reserves for ecological reasons.

While permits are issued for the extraction of timber for firewood, charcoal and poles, there is currently no significant silvicultural management scheme (Zamora 1987). DOTCP (1986b) reports that: "Active control or management is not undertaken because the royalty [uptake] is very low (about B$11,000) and thus, not regarded as cost effective by the Department of Forestry."

Zone 4: Area for Agriculture. In 1987, a 1,000-ha mangrove area west of Lumapas in Temburong District earmarked for pond aquaculture was identified as a possible site for mechanized wet rice cultivation.

Said area consists of a mixture of *R. apiculata, N. fruticans* and *Nypa-Heritiera* types. Except for the small patch of *bakau minyak*, these types are presumed to be without significant economic value but with high ecologic value as: (1) nutrient source for the maintenance of fishery potential; (2) protection of land resources against wave erosion; (3) controller of sedimentation; (4) natural landscape; and (5) feeding, spawning and breeding grounds of wildlife. The estuarine waters of Sg. Temburong near this area are frequented fishing grounds.

The soils of the area are clayey (DOTCP 1986a; 1986b) and can become extremely acidic upon exposure to air. This condition often leads to nutrient and fertilization problems, resulting in stunted growth or reduced productivity of crops such as rice (Hamilton and Snedaker 1984). Also, improvement of such soils is extremely expensive (Singh 1982; Singh and Poernomo 1984). Watts (1969), van der Kevie (1973), Mooreman and Pons (1975) and van Breemen (1976) give further information on the nature and management of acid sulfate soils.

Thus, the proposed conversion of the mangrove area into mechanized wet riceland should be discouraged. When planning to convert mangroves into agricultural ventures, Hamilton and Snedaker (1984) suggest the following: (1) where agricultural development is a sound conversion, some mangrove systems should be left intact to continue their uses and services; (2) since the acid sulfate soil problem has caused the failure of many coastal lowland mangrove conversions to rice and other crops, soil testing and land resource assessment should precede mangrove conversion; (3) intensification of agricultural activities on already cleared land may be a more economical, sustainable and desirable option than pushing agriculture onto saline mangrove lands; and (4) it should be considered that the effects of

agriculture will cross ecosystem boundaries (e.g., pesticides and fertilizers may find their way into neighboring mangroves and cause a series of food chain contamination through biological magnification; acid sulfate soil conditions in converted mangroves may cause fish kills in adjacent estuaries).

Zone 5: Areas for Pond Aquaculture. At present, there are only 12 ha of developed brackishwater aquaculture ponds in Brunei Darussalam (see Fig. 3). A 1,000-ha mangrove area in lower Labu, Temburong District, has been recommended as one of several possible sites for brackishwater pond aquaculture (see, for example, Chua et al. 1987).

Birkenmeier (1969) identifies the said area as "ecologically favorable" for shrimp culture but rules out the venture as uneconomical. These are not consistent with findings that the mangrove forest areas of Lawas District (Sarawak, Malaysia) adjacent to Temburong District, have a high sulfide content (i.e., dry soil, pH = 2.9; wet soil, pH = 5.2) (Tamhane et al. 1964, as cited by Howes 1986). Sulfides in the form of hydrogen sulfide and pyrite sulfur occur in wet soils. When these soils dry out, the sulfides are oxidized and the soils become highly acidic sulfate. Soils become dried out when the frequency of inundation is reduced (e.g., by a rise in ground level or following extensive clear felling). Chai (1974) notes that the oxidation of such soils may affect the rates of mangrove regeneration *(Rhizophora, Bruguiera)* and the formation of high acid sulfate soils leads to brackishwater aquaculture failure. According to Saenger et al. (1983), highly pyritic soils severely inhibit the efficiency of phosphate fertilizers, resulting in inadequate algae growth on which fishponds depend for high yields. High acidity and aluminum concentration kill or weaken the fish so that they become vulnerable to diseases or parasites. When it rains, the sudden influx of these toxins from the sides of the dikes is commonly lethal to a large proportion of the remaining fish. Finely divided ferric hydroxide subsequently appears in the pond water and clogs the gills of the survivors, killing some and weakening the rest. Shrimps grown in aquaculture ponds appear to be even more vulnerable to the toxins from acid sulfate soils. Thus, the mangrove forest areas of Temburong District would most likely be highly unsuitable for aquaculture (Howes 1986).

Despite the foregoing facts, if it becomes necessary to produce shrimps through aquaculture, the following guidelines may be adopted (Zamora 1988b):

- If there is a choice, areas without mangrove cover or with sparse mangrove growth that can be cleared without much difficulty should be utilized before those with dense tree growth or undisturbed mangrove forest. Areas convertible into fishponds need to be scientifically identified.
- Ponds should be of such dimensions that the adjacent mangroves are minimally affected and the supply of fry to coastal fishery areas is not reduced.
- Some undesirable pond culture practices (e.g., use of chemicals to kill weeds and predators aside from nontarget organisms involved in detritus conversion) should be avoided or minimized. Unless the pond culture scheme can improve on the natural productivity and sustain it, then this practice is self-defeating in the long term.

Zone 6: Areas for Human Occupancy. As of 1990, only 187 ha of mangrove areas in two sites in Brunei-Muara District are being developed for human occupancy (see Fig. 3). This is only 1% of the 18,418-ha total mangrove area of the country. Nevertheless, development of the warehousing site conflicts with its designation as a mangrove conservation area (DOTCP 1988). As the report states:

> The successful expansion of the aquaculture industry in the bays south of Serasa depends to a large extent upon the retention of all remaining mangrove areas. It is therefore proposed that no development or felling be permitted to the mangrove forests either side of Sungai Salar and that a strip of mangrove be maintained right up to Serasa Spit to serve as a landscaped edge to the Serasa Resettlement Scheme and adjoining Sewage Treatment Plant and Aquaculture Complex. Another area of mangrove is also retained south of the Industrial Estate which, in addition to its ecological significance, acts as an effective green buffer between industrial and residential/ recreational uses.

Since conversion of mangroves for real estate purposes may bring out significant negative impacts on the surrounding environment (see De Silva et al. 1990), said land use option in mangrove areas should be discouraged or avoided. Should it be unavoidable, the following should be considered (Saenger et al. 1983):

- Interference with water flow should be minimized. Roads and access should always be parallel (not perpendicular) to surface flow patterns. When perpendicular barriers cannot be avoided, they should either follow natural water divides (when present) or contain culverts with sufficient total flow cross-section.
- Houses and facilities should be built on stilts, poles and pilings to allow for continued sur-

Table 8. Distribution by district of mangrove uses in the proposed zonation plan.

District	District area (ha)	Land use (ha)	Land use
Temburong	12,164	393	Preservation and conservation
		4,238	Environmental protection
		7,533	Timber production
Brunei-Muara	3,937	3,748	Preservation and conservation
		187	Human occupancy
		2	Brackishwater aquaculture
Tutong	1,784	1,774	Environmental protection
		10	Brackishwater aquaculture
Belait	533	533	Environmental protection
Total	18,418	18,418	

face water circulation and normal sediment movement.

The mangrove use zonation plan (see Table 8 and Fig. 3) presented here proposes to allocate the 18,418-ha mangroves of the country as follows:

1. 58% (10,686 ha) for preservation and environmental protection (ecologic);
2. 41% (7,533 ha) for wood production (poles, charcoal) on a sustainable basis (economic, ecologic); and
3. 1% (199 ha) for conversion uses, i.e., brackishwater aquaculture and human occupancy (economic).

Indeed, a high proportion of the mangrove resources is earmarked in the present plan for preservation or conservation, in the belief that it is more ecologically and economically beneficial to the country over the long term. However, with the increased need for land (residential, industrial and commercial purposes), more mangrove areas may be sacrificed within the decade (1990-1999) particularly in the rapidly developing Brunei-Muara District. The continued illegal cutting of poles outside the forest reserves (e.g., along and within the 20-m strip of embankment of Sg. Brunei) should be controlled. The clearing of mangroves for housing and industrial development, when inevitable, may be permitted provided guidelines are followed strictly and proper measures are implemented to mitigate the significant harmful effects of conversion on the surrounding environment/resources.

Plan implementation

Administrative Framework. The Ministry of Industry and Primary Resources (MIPR) is the main agency concerned with the development, management and conservation of mangrove resources. Under MIPR are agencies whose functions relate to the utilization of mangrove resources, namely:

1. Forestry Department (planning and management for mangrove forest production; forest protection);
2. Department of Fisheries (fish production in mangrove areas and brackishwater ponds); and
3. Agriculture Department (use of mangroves for wet rice cultivation).

Other agencies belonging to other ministries whose functions and jurisdictions could relate to the utilization of mangrove resources are:

1. Department of Town and Country Planning, Ministry of Development (use of mangroves as sites for residential, industrial and commercial development);
2. Land Department, Ministry of Development (land uses in mangrove areas); and
3. Museums Department (MuD), Ministry of Culture, Youth and Sports (establishment of mangrove areas as reserves, conservation sites and wildlife sanctuaries and for research).

Mangroves are multiple-use resources. Under this concept, resource allocation decisions can be done by competent authorities based in several agencies. With this approach, an efficient referral system to link the concerned agencies is essential.

The most effective administrative view regards each mangrove resource as a component of the coastal zone. Decisions concerning the use of mangrove resources could then be made in the context of their dependency on adjacent watershed areas and on their relationships with estuaries, mudflats, seagrass beds and coral reefs.

The initial activities in plan implementation should be geared towards:

1. monitoring actual or potential threats to the existence of the mangroves;
2. acquiring the necessary baseline data for firming up or revising the management plan;
3. eventually implementing a silvicultural management scheme for the existing forest reserves in accordance with the requirements of the country; and
4. training the required manpower to implement the management plan. (Item 4 can be treated as a component of Item 3.)

Based on the above activities, the programs below are proposed as part of the plan.

Monitoring. At present, these threats to the mangroves of Brunei Darussalam need to be monitored immediately:

1. conversion of mangrove areas (e.g., along Jalan Muara, Brunei-Muara District) into residential and industrial sites and
2. illegal cutting of mangrove trees for poles and firewood within the 20-m strips of embankments of Sg. Brunei and other major rivers.

Uncontrolled or indiscriminately undertaken, the foregoing activities can cause significant undesirable effects on the mangrove and nearby systems and depletion of mangrove resources.

To monitor these practices, periodic inspection surveys by car, speed boat or helicopter should be conducted. A report of the findings after each survey trip must contain data on the location of the mangrove areas inspected, extent of damage (if any), number of trees cut, violation of guidelines, etc. Sufficient budget for equipment, supplies and materials, transportation and personnel services should be set aside for the purpose.

Research and development. Very little research has been done on the biology of mangrove organisms (flora and fauna) and the ecology of the mangrove forests of Brunei Darussalam (see Mohd. Jaya et al. 1986; Tomlinson 1986; Chua et al. 1987). Some studies are now being undertaken or have been planned or proposed by the MuD researchers and the Biology Department, Universiti Brunei Darussalam. However, much more remains to be done. The following are priority areas for research:

1. Basic biological surveys on the whole range of mangrove flora and fauna are necessary in determining the functions of the mangrove ecosystem. Only by discovering and cataloguing these organisms can a thorough understanding of the whole ecosystem be gained.
2. Studies of the structure and dynamics of the mangrove ecosystem should characterize the internal energy cycle; determine the contribution of leaves of mangrove plants, algae, runoff and others to the detrital cycle; and ascertain the types and percent mineralization of nutrients and the latter's residence time in the system.
3. Qualitative and quantitative studies on mangrove-dependent fisheries are needed to assess the contributions of mangroves towards inshore fisheries. This information would help policymakers decide on the extent of mangroves which could make way for development.
4. Comprehensive and systematic surveys should determine the degree of pressure exerted by traditional and other uses on the mangrove ecosystem over time.

Appropriate proposals may be developed and programmed for implementation as part of the management plan. Research work in some areas requires the involvement of a multidisciplinary team made up of a botanist, zoologist, ecologist, resource economist and sociologist.

Education and training. Technical manpower to undertake and implement the management plan is conspicuous by its inadequacy. The training of qualified personnel to study and manage the mangroves of Brunei Darussalam should be conducted as part of the plan. Thus, adequate funding would be urgently required.

For personnel who will be tasked with research work, degree-oriented study programs in: (1) basic biology of economically important mangrove flora and fauna; (2) mangrove ecology; and (3) resource economics with special emphasis on the mangrove ecosystem are appropriate. Short-term, nondegree training programs (e.g., environmental impact assessment) are relevant for those who will be charged with monitoring work.

Information dissemination. Information could be disseminated on the ecologic and economic importance of mangroves; policies, rules and regulations on resource utilization, development and management; and mangrove ecosystem conservation. With an increased level of public awareness, exploitation of resources can be sustained over time for the benefit of a greater number of users. A three-pronged program approach can be employed (Fig. 6). Its intended recipients are communities within and around mangrove areas, resource planners, policy- and decisionmakers, policy implementors and law enforcers.

The first component of the program attempts to increase the level of nature appreciation among the people through presentation of simple devices such as

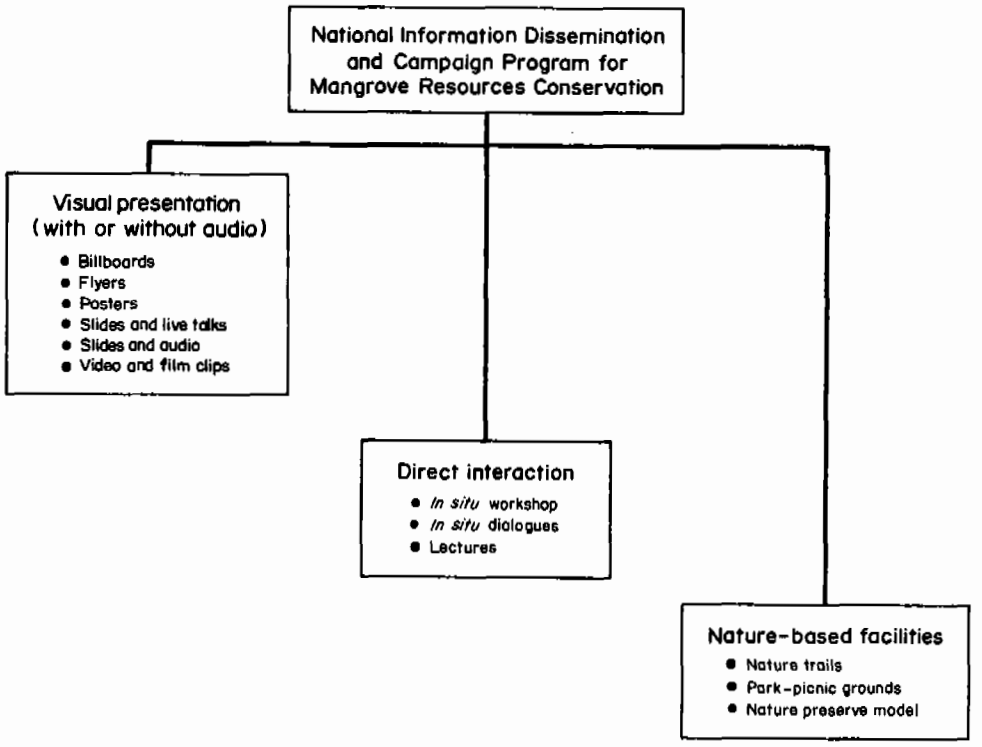


Fig. 6. Elements of a National Information Dissemination and Campaign Program for Mangrove Resources Conservation.

eye-catching posters and billboards dealing with environmental protection, mangrove forest conservation and preservation, and other concerns. Second, the same issues will be covered in-depth by holding *in situ* dialogues and workshops to facilitate people-government interactions on environmental issues. Another form of direct interaction is a lecture series by experts from the government, environmentalists and others. The lectures shall serve as a mechanism for disseminating and updating information on government policies and regulations; current activities relating to mangrove protection and enhancement; people's perceptions of the mangrove environment; and other relevant issues.

The third component of the program is designed to elicit and maintain appreciation of the mangrove environment by providing facilities where people can pursue recreational activities in a natural setting. A parcel of mangrove land may be selected and declared as a nature preserve model.

References

Beales, R.W. 1982. Investigations into demersal resources accessible to trawling in Brunei waters, p. 1-93. *In* R.W. Beales, D.J. Currie and R.H. Lindley (eds.) Investigations into fisheries resources in Brunei. Brunei Mus. Monogr. No. 5.

Birkenmeier, E. 1969. Fisheries development in Brunei. Brunei Mus. J. 1(1): 192-196.

Chai, P.K. 1974. The potential of mangrove forests in Sarawak. Malays. For. 37(4): 284-288.

Chai, P.K. 1975. The mangrove trees and shrubs of Sarawak. Malays. For. 38(3): 187-208.

Chan, H.T. 1986. Country reports: Malaysia, p. 131-150. *In* R.M. Umali, P.M. Zamora, R.R. Gotera, R.S. Jara and A.S. Camacho (eds.) Mangroves of Asia and the Pacific: status and management. JMC Press Inc., Quezon City, Philippines.

Chua, T.-E., L.M. Chou and M.S.M. Sadorra, editors. 1987. The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Cox, J. and F. Gombek. 1985. A preliminary survey of the crocodile resource in Sarawak, East Malaysia. International Union for the Conservation of Nature and Natural Resources-World Wildlife Fund Project No. MAL 74/85. Kuala Lumpur, Malaysia.

Currie, D.J. 1982. Studies on the biology of penaeid prawn and the prawn fishery in the Brunei Estuary, p. 134-204. *In* R.W. Beales, D.J. Currie and R.H. Lindley (eds.) Investigations into fisheries resources in Brunei. Brunei Mus. Monogr. No. 5.

De Silva, M.W.R.N., P.M. Zamora and I. Ariff. 1990. Conversion of mangrove into industrial development site at Kampong Salar/ Kampong Lumut (warehousing area), Brunei-Muara District. Fisheries Department, Ministry of Industry and Primary Resources, Brunei Darussalam. (Unpublished).

DOTCP (Department of Town and Country Planning). 1986a. Negara Brunei Darussalam Master Plan Background Paper No. 5: Fisheries and Aquaculture. Department of Town and Country Planning, Ministry of Development, Brunei Darussalam.

DOTCP (Department of Town and Country Planning). 1986b. Negara Brunei Darussalam Master Plan Background Paper No. 8: Forestry. Department of Town and Country Planning, Ministry of Development, Brunei Darussalam.

DOTCP (Department of Town and Country Planning). 1987. Negara Brunei Darussalam Master Plan: Main Volume. Department of Town and Country Planning, Ministry of Development, Brunei Darussalam.

DOTCP (Department of Town and Country Planning). 1988. Muara Local Plan and Port Study. Vol. 1: Local Plan. Department of Town and Country Planning, Ministry of Development, Brunei Darussalam.

Eimerl, S. and I. DeVore. 1972. The primates. NV: Time-Life International.

EPU (Economic Planning Unit). 1987. Brunei statistical yearbook 1985/86. Statistics Division, Economic Planning Unit, Ministry of Finance, Brunei Darussalam.

FD (Forestry Department). 1987. Annual report 1986. Forestry Department, Ministry of Development, Brunei Darussalam.

Fortes, M.D. 1988. Mangrove and seagrass beds of East Asia: habitats under stress. Ambio 17(3): 207-213.

Frusher, S.D. 1986. Penaeid prawns and their use of the mangrove ecosystems, p. 125-132. Proceedings of the Workshop on Mangrove Ecosystem Dynamics, 27-31 May 1985. Motupore Island Research Station, Port Moresby, Papua New Guinea.

Hamilton, L.S. and S.C. Snedaker. 1984. Handbook for mangrove area management. International Union for the Conservation of Nature and Natural Resources-United Nations Educational, Scientific and Cultural Organization-United Nations Development Programme-East-West Center. East-West Center, Hawaii, U.S.A.

Howes, J.R. 1986. Evaluation of Sarawak wetlands and their importance to waterbirds. Report 4: Limbang/Lawas Districts of Brunei Bay. Interwader, Kuala Lumpur, Malaysia.

Lewis, R.R. III, R.G. Gilmore, Jr., D.W. Crewz and W.E. Odum. 1985. Mangrove habitat and fishery resources in Florida, p. 281-336. *In* W. Seaman, Jr. (ed.) Florida aquatic habitat and fishery resources. Florida Chapter of the American Fisheries Society, Kissimmace, Florida, U.S.A.

Lim, J.S. and P.M. Sharifuddin. 1975. Charcoal production in Brunei. Brunei Mus. J. 3(4): 201-220.

Linden, O., B. Ganning and L. Lindestrom. 1989. Preliminary studies on plankton, primary production and fish in the Inner Brunei Bay. Malay. Nat. J. 43: 33-52.

Mastaller, M. 1989. Literature review on the significance of mangrove resources with emphasis on small-scale fisheries and aquaculture. Federal Republic of Germany.

Mittermeier, R.A. 1980. Conservation in Brunei. Brunei Mus. J. 4(4): 251-257.

Mohamed, M., R. Stanforth and N. Johnston. 1984. Current and plankton studies in Brunei Bay, 8-9 June 1984. Report by Universiti Kebangsaan Malaysia, Sabah Campus, Malaysia. (Unpublished).

Mohd. Jaya, S., S. Nyawa, J.R. Howes, D. Parish, A.H. Samat and J. Jumat. 1986. A study of the littoral ecosystem in Brunei Estuary, Brunei Darussalam. Draft Report of Brunei Museum-Interwader, Kuala Lumpur, Malaysia. (Unpublished).

Mooreman, F.R. and L.J. Pons. 1975. Characteristics of mangrove soils in relation to their agricultural land use and potential, p. 529-547. *In* G.E. Walsh, S.C. Snedaker and J.J. Teas (eds.) Proceedings of International Symposium on Biology and Management of Mangroves, 8-11 October 1974, Hawaii. University of Florida, Gainsville, Florida, U.S.A.

Paw, J.N. and T.-E. Chua. 1991. An assessment of the ecological and economic impact of mangrove conversion in Southeast Asia, p. 201-212. *In* L.M. Chou, T.-E. Chua, H.W. Khoo, P.E. Lim, J.N. Paw, G.T. Silvestre, M.J. Valencia, A.T. White and P.K. Wong (eds.) Towards an integrated management of tropical coastal resources. ICLARM Conference Proceedings 22, 455 p. National University of Singapore, Singapore; National Science and Technology Board, Singapore; and International Center for Living Aquatic Resources Management, Philippines.

Saenger, P., E.J. Hegerl and J.D.S. Davie, editors. 1983. Global status of mangrove ecosystem. Commission on Ecology Pap. No. 3. International Union for the Conservation of Nature and Natural Resources, Malaysia.

Salter, R.E. and N.A. MacKenzie. 1981. Habitat use and behavior of the proboscis *(Nasalis larvatus)* in Sarawak. National Parks and Wildlife Office, Forestry Department, Kuching, Sarawak, Malaysia.

Singh, V.P. 1982. Kinetics of acidification during inundation of previously dried acid sulphate soil material: implications for the management of brackishwater fishponds, p. 331-353. *In* N. Dost and N. van Breemen (eds.) Proceedings of the Bangkok Symposium on Acid Sulphate Soils. International Institute for Land Reclamation and Improvement Publ. 31. Wageningen, The Netherlands.

Singh, V.P. and A.T. Poernomo. 1984. Acid sulphate soils and their management for brackishwater fishponds, p. 121-132. *In* J.V. Juario, R.P. Ferraris and L.V. Benitez (eds.) Advances in milkfish biology and culture: Proceedings of the Second International Milkfish Aquaculture Conference. Southeast Asian Fisheries Development Center, Iloilo City, Philippines.

Snedaker, S.C. and C.D. Getter. 1985. Coastal resources management guidelines. Research Planning Institute, Inc., Columbia, South Carolina, U.S.A.

Stewart, M.B. 1986. A geography of Negara Brunei Darussalam. Dewon Bahasa Daan Pustaka Brunei, Bandar Seri Begawan, Brunei Darussalam.

Supriatna, J., C. Adimuntja, T. Mitrasetia, E. Willy, D. Rufendi and B.O. Manulang. 1989. Chemical analysis of food plant parts of two sympatric monkeys *(Presbytis aurata and Macaca fascicularis)* in the mangrove forest of Muara Gembong, West Java. BIOTROP Spec. Publ. 37: 161-169.

Swennen, C. and E. Marteijn. 1985. Wader feeding ecology studies in the Malay Peninsula. *In* D. Parish and D.R. Wells (eds.) Interwader Annual Report 1984. Interwader Publ. 2. Kuala Lumpur, Malaysia.

Tomlinson, P.B. 1986. The botany of mangroves. Cambridge University Press, Cambridge, England.

van Breemen, N. 1976. Genesis and solution chemistry of acid sulphate soils in Thailand. Agric. Res. Rep. (Versl. Landbouwk. Onderz.) No. 848. Wageningen, The Netherlands.

van der Kevie, W. 1973. Physiography, classification and mapping of acid sulphate soils, p. 204-219. *In* H. Dost (ed.) Acid sulphate soils: Proceedings of the International Symposium 1972. International Institute for Land Reclamation and Improvement Publ. 18. Wageningen, The Netherlands.

Watts, J.C.D. 1969. Phosphate retention in acid sulphate pond muds from the Malacca area. Malay. Agric. J. 47: 187-202.

Zamora, P.M. 1987. Mangroves, p. 28-48. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Zamora, P.M. 1988a. Diversity of flora in the Philippine mangrove ecosystem. Paper presented at the Haribon Foundation-International Institute of Environment and Development Technical Workshop on Biological Diversity, 6 December 1988. University of the Philippines, Diliman, Quezon City, Philippines.

Zamora, P.M. 1988b. Pond aquaculture of shrimps as a possible mangrove area elimination use in Brunei Darussalam. Bakawan 6(4): 6-8.

Zamora, P.M. 1989. Impact of fishpondification on the mangrove ecosystem of the Philippines. BIOTROP Spec. Publ. 37: 21-37.

Zamora, P.M. 1990. Master Plan for Forestry Development (Philippines): Mangroves. Department of Environment and Natural Resources-Asian Development Bank Project, Manila, Philippines.

Assessment of Mangrove Forest Resources in Brunei Darussalam*

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Abstract

An inventory of mangrove forest resources in Brunei Darussalam showed that Brunei-Muara District had the most diverse mangrove stand while Temburong District had the highest stand and stock of mangrove timber. The timber-size trees were mostly 20-40 cm in diameter and largely consisted of *Rhizophora apiculata*, *Xylocarpus* spp. and *Bruguiera* spp.

Selirong and Labu Forest Reserves in Temburong are used for timber production. The projected growing stock of mangrove timber showed a rising trend. A 20-year demand projection revealed a decreasing trend for charcoal and firewood, and the opposite course for poles and piles. Even with an assumed 15% and 30% annual increase in demand for mangrove products in the future, depletion of the resources is not expected. Nonetheless, the formulation of a mangrove forest management plan is recommended for a sustainable exploitation of these resources.

*ICLARM Contribution No. 821.

Introduction

The mangrove forest resources in Brunei Darussalam have an areal extent of 18,418 ha. Of these, the Temburong mangrove forest accounts for 66% (12,167 ha); Brunei-Muara, 21% (3,934 ha); Tutong, 10% (1,784 ha); and Belait, 3% (533 ha). These mangrove resources are now being exploited for firewood and charcoal on a small scale and for poles (for piling in construction work) on a commercial scale. Most of the poles are obtained from Selirong and Labu Forest Reserves in Temburong District. In addition, there is increasing interest to convert mangrove swamps into brackishwater shrimp ponds. This may become a future issue of resource use-conflict due to limited natural resources (Zamora 1987).

This paper assesses the mangrove resources which include timber inventory and mangrove forest condition. The resource-use patterns, wood volume and growth parameter estimates as well as timber stock and demand projections for firewood, charcoal, and poles and piles are also presented. As such, this study is an attempt to provide additional information which may be helpful in the formulation of a management plan for mangrove forests in Brunei Darussalam.

Methodology

The mangrove forest resources in Brunei Darussalam were assessed from May to June 1990 and consisted of three interdependent components.

Forest resource inventory

Available aerial photos covering the mangrove forest were obtained from the Survey Department, Brunei Darussalam. The 1987 photos with a scale of 1:25,000 were interpreted to determine the mangrove forest condition and land uses in Brunei-Muara, Tutong and Belait. The 1982 photos of a similar scale were used for Temburong since these were the latest available ones.

The interpreted information from aerial photos was verified on the ground and used to finalize the delineation of various mangrove land uses and vegetative conditions. The corrected information was transferred to a 1:25,000 base map of the country. The area in each classification was measured using a dot grid and a planimeter. Due to time constraint, only the mangrove forest in Temburong District was thoroughly field-validated. The mangrove forest condition in Temburong District was categorized based on the classes given in Table 1.

Sampling areas with 0.1-ha circular plots were predetermined and located in the 1:25,000 base map. The location and distribution of sampling plots were based on the condition of each mangrove vegetation (e.g., primary-growth, secondary-growth and logged-over areas); species composition--either homogeneous/pure stand or heterogeneous/mixed stand; and intended or existing uses of the area such as for conservation, forest reserve, production and conversion into housing and industrial site and agriculture. The sampling plots were purposely distributed to proportionately represent various mangrove forest conditions laid out in the base map.

A total of 69 sampling plots was established, measured and distributed among the 4 districts as follows: 43 in Temburong, 19 in Brunei-Muara, 4 in Tutong and 3 in Belait.

Trees with a diameter above 15 cm were measured using a diameter tape and a clinometer. The diameter of non-*Rhizophora* species was taken at breast height (Dbh) or about 1.3 m from ground level. For *Rhizophora* species, which have extensive prop or stilt roots, the diameter was taken at 30 cm above the highest bud root (Dab) or from the topmost stilt roots. Total height and height at first major branch were estimated using a clinometer. Branches with diameters of 10 cm and above were also measured.

Table 1. Mangrove forest condition/class in Temburong District as inferred from 1982 aerial photographs.

Condition/ class[a]	Area (ha) Selirong	Labu	Other areas	Total
A	0.5	48.8	0	49.3
B	8.0	0	0	8.0
C	0	31.0	0	31.0
D	135.2	348.2	0	483.4
E	895.5	1,357.8	31.5	2,284.8
1	1,025.5	2,310.8	287.0	3,623.3
2	343.0	767.0	42.8	1,152.8
3	77.0	55.0	7.0	139.0
4	12.5	7.8	0	20.3
X	58.5	45.5	0	104.0
N	0	179.2	969.2	1,148.4
NH	0	101.0	1,438.8	1,539.8
NHR	0	0	96.8	96.8
Total	2,555.7	5,252.1	2,873.1	10,680.9

[a]A - clear-cut areas without regeneration.
B - clear-cut areas with sparse regeneration.
C - clear-cut areas with dense regeneration.
D - selective cutting areas with sparse regeneration.
E - selective cutting areas with dense regeneration.
1 - old growth, low density and volume.
2 - old growth, medium density and volume.
3 - old growth, medium density and high volume.
4 - old growth, high density and volume.
(old growth includes *R. apiculata* and *Bruguiera* spp.)
X - pure stand of *Xylocarpus* spp.
N - pure stand of *Nypa fruticans*.
NH - *N. fruticans* mixed with *Heritiera globosa*.
NHR - *N. fruticans* mixed with *H. globosa* and *Rhizophora* spp.

The regenerations (seedlings and saplings) and pole-size trees were counted, including fern, palms (*Nypa* and *Oncosperma*) and other associated mangrove species. The pole-size trees were classified into class "A" (5-10 cm diameter) and class "B" (>10-15 cm diameter) since the 16-, 20- and 25-ft length pole-size class used in the market in Brunei Darussalam are 5-15 cm in diameter.

Calculation of tree parameter variables

Individual tree volume was computed using the volume equation for each species derived by Cabahug (1986a; 1986b) for Palawan timber-producing mangrove species (Table 2).

A stand and stock table was constructed in each district. The volume by forest condition classification of each compartment block in Selirong, Labu and other areas in Temburong was computed.

Table 2. Equations for various tree parameter variables.

Tree parameter variable	Species	Formula	
Wood volume (V)	*R. apiculata*	$\text{LogV} = -4.029663 + 1.837598\ \text{LogD} + 0.9298366\ \text{LogH}$	where
	R. mucronata	$\text{LogV} = -3.788613 + 1.473822\ \text{LogD} + 1.120277\ \text{LogH}$	V = wood volume (m^3)
	Bruguiera gymnorrhiza	$\text{LogV} = -3.814477 + 1.565084\ \text{LogD} + 1.035151\ \text{LogH}$	D = diameter (cm)
	B. cylindrica	$\text{LogV} = -3.629746 + 1.337198\ \text{LogD} + 1.156924\ \text{LogH}$	H = height (m)
	Lumnitzera littorea	$\text{LogV} = -3.977934 + 1.62143\ \text{LogD} + 0.9805590\ \text{LogH}$	
	Xylocarpus spp.	$\text{LogV} = -3.942941 + 1.676631\ \text{LogD} + 1.01687\ \text{LogH}$	
	Others	$V\ (m^3) = BA \bullet H \bullet ff$	where Ba = basal area (m^2) H = height (m) ff = form factor (average 0.65)
Stand volume (SV)		$SV\ (m^3/ha) = \frac{\Sigma V}{\text{Plot area}}$	
Stand stock per hectare (N)		$N\ (\text{tree/ha}) = \frac{\text{Total no. of live trees on the plot}}{\text{Plot area}}$	
Diameter of the mean basal area of the tree (Dg)		$Dg\ (\text{cm}) = \frac{\Sigma d^2}{\text{No. of trees on the plot}}$	where d = diameter
Stand dominant height (Ho)		$Ho\ (\text{m}) = \frac{\Sigma Dh}{\text{No. of dominant trees on the plot}}$	where Dh = height of dominant trees
Mean diameter of dominant height (Dho)		$Dho\ (\text{cm}) = \frac{\Sigma Dd}{\text{No. of dominant trees on the plot}}$	where Dd = diameter of dominant trees
Stand mean height (H)		$H\ (\text{m}) = \frac{\Sigma Th}{\text{No. of trees on the plot}}$	where Th = tree height
Stand basal area (G)		$G\ (m^2/ha) = \frac{\Sigma Ba}{\text{Plot area}}$	where $Ba = 0.007854\ (Dbh)^2$

Source: Adapted from Cabahug (1986a; 1986b).

Demand and supply projection

As the Temburong mangrove forests are designated for production, analysis of demand and supply of mangrove resources is confined to this district.

An arithmetic straight line projection method was used in projecting the demand (Alder 1980). Historical demand data were taken from actual survey interviews conducted in the area and secondary information from the records of the Forestry Department (FD). These data served as baseline information in establishing the demand trend and were used to derive a coefficient factor.

Results and Discussion

Mangrove forest resources

Mangrove Timber Inventory. Of the 11 mangrove species prevalent in Brunei Darussalam, 9 (81.8%) were distributed in Brunei-Muara, 6 (54.5%) in Temburong, 3 (27.3%) in Tutong and 2 (18.2%) in Belait (Table 3a). *R. apiculata* was consistently found in all of the four study areas/districts and was the most dominant species in terms of number. In Brunei-Muara and Belait, *Xylocarpus* was the co-dominant species while in Temburong and Tutong, it was *B. cylindrica.*

In all the districts, *R. apiculata* had the highest total volume per hectare (Table 3a). *A. officinalis* ranked second, but based on total number of trees per hectare, it was less than *X. granatum.* Although *A. officinalis* trees were fewer than *X. granatum*, quite a number of the former were taller with bigger diameters, thus resulting in a higher volume. This is also the case in Brunei-Muara. Based on total volume, Belait maintained *R. apiculata* and *X. granatum* as the most dominant species. Similarly, Temburong and Tutong retained *R. apiculata* and *B. cylindrica* as the dominant species in volume and number.

Generally, in all the districts, the greatest number of trees belonged to the 20-cm Dbh class numbering 390 trees/ha, of which 282 were *R. apiculata* (Table 3b). This was followed by the 25- and 30-cm Dbh classes, each with 269 trees/ha, then by the 35- and 40-cm Dbh classes with 197 and 178 trees/ha, respectively. Only Brunei-Muara had trees in the 80- to 100-cm Dbh range consisting of *A. officinalis, X. granatum* and *S. caseolaris.*

Mangrove Forest Resource Condition in Temburong District. Table 1 gives the mangrove forest condition of Selirong, Labu and other areas in Temburong District. Both the Selirong and Labu mangrove forests were extensively subjected to cutting, either selectively or totally. The Labu mangrove forest had the largest clear-cut areas (79.8 ha) mostly located along Sungai (or Sg., i.e., river) Bangaw and Sg. Ayam-ayam adjacent to or near the boundary of Sarawak. However, it still had a sizeable intact old-growth mangrove forest of 3,140.6 ha which accounted for 29.4% of the total mangrove forest of Temburong District. Selirong had 1,458 ha of old-growth mangrove forest or 13.6% of the total area. These areas are mostly located in the innermost portions of the forest which are inaccessible by water transport.

The major groupings of mangrove timber-producing species in Temburong were *R. apiculata (bakau), Xylocarpus* spp. *(nyireh), H. globosa* and *Bruguiera* spp.

Table 3a. Stand and stock of mangrove timber resources in Brunei Darussalam.

Species	District: Brunei-Muara N	Brunei-Muara V	Temburong N	Temburong V	Tutong N	Tutong V	Belait N	Belait V	Total N	Total V
R. apiculata	284	107.3	692	370.1	66	26.0	50	8.0	1,092	511.4
R. mucronata	21	2.9	13	4.8	-	-	-	-	34	7.7
B. gymnorrhiza	-	-	24	6.4	-	-	-	-	24	6.4
B. cylindrica	-	-	51	19.1	19	8.2	-	-	70	27.3
Xylocarpus granatum	82	18.9	38	12.2	-	-	8	1.0	128	32.1
Avicennia marina	31	11.8	-	-	-	-	-	-	31	11.8
A. officinalis	47	37.6	-	-	3	0.9	-	-	50	38.5
Sonneratia caseolaris	27	8.9	-	-	-	-	-	-	27	8.9
Heritiera littoralis	1	0.2	4	2.8	-	-	-	-	5	3.0
L. littorea	7	3.8	-	-	-	-	-	-	7	3.8
Excoecaria agallocha	6	4.1	-	-	-	-	-	-	6	4.1
Total	506	195.5	822	415.4	88	35.1	58	9.0	1,474	655.0

N = no. of trees/ha.
V = volume in m^3/ha.

Table 3b. Stand and stock of mangrove timber resources in Brunei Darussalam, per diameter class.

Species	Diameter class (cm) 20 N	20 V	25 N	25 V	30 N	30 V	35 N	35 V	40 N	40 V	45 N	45 V	50 N	50 V	55 N	55 V	60 N	60 V
R. apiculata	282	57.7	195	56.8	210	90.8	167	95.1	153	110.7	38	42.5	22	27.1	13	8.5	3	4.7
R. mucronata	16	2.1	5	0.8	6	1.8	5	1.9	1	0.5	1	0.6	-	-	-	-	-	-
B. gymnorrhiza	12	2.6	5	1.3	3	1.1	4	1.4	-	-	-	-	-	-	-	-	-	-
B. cylindrica	13	4.2	29	7.1	9	3.2	11	8.0	5	1.8	2	1.9	1	1.1	-	-	-	-
X. granatum	45	5.0	26	4.2	22	6.4	5	1.8	10	3.8	3	1.2	5	2.4	4	1.9	1	0.7
A. marina	13	3.7	7	2.6	7	3.2	2	0.9	1	0.6	1	0.8	-	-	-	-	-	-
A. officinalis	1	0.1	1	0.2	8	1.3	1	0.3	2	0.8	-	-	1	0.8	4	3.6	2	1.8
S. caseolaris	3	0.3	1	0.2	2	0.7	-	-	-	-	-	-	1	0.2	-	-	-	-
H. littoralis	1	0.2	-	-	-	-	1	0.5	3	2.3	-	-	-	-	-	-	-	-
L. littorea	2	0.3	-	-	1	0.2	1	0.6	2	1.6	1	1.1	-	-	-	-	-	-
E. agallocha	2	0.3	-	-	1	0.5	-	-	1	0.7	-	-	2	2.6	-	-	-	-
Total	390	76.5	269	73.2	269	109.2	197	110.5	178	122.8	46	48.1	32	34.2	21	14.0	6	7.2

Species	Diameter class (cm) 65 N	65 V	70 N	70 V	75 N	75 V	80 N	80 V	85 N	85 V	90 N	90 V	95 N	95 V	100 N	100 V	Total N	Total V
R. apiculata	9	17.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,092	511.4
R. mucronata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34	7.7
B. gymnorrhiza	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24	6.4
B. cylindrica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	70	27.3
X. granatum	1	1.1	1	0.8	1	1.2	-	-	-	-	-	-	4	1.6	-	-	128	32.1
A. marina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	31	11.8
A. officinalis	1	1.0	2	2.2	-	-	-	-	-	-	3	2.3	-	-	24	24.1	50	38.5
S. caseolaris	-	-	-	-	-	-	3	0.9	-	-	-	-	6	2.0	11	4.6	27	8.9
H. littoralis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	3.0
L. littorea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	3.8
E. agallocha	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	4.1
Total	11	19.6	3	3.0	1	1.2	3	0.9	-	-	3	2.3	10	3.6	35	28.7	1,474	655.0

(linggadai) (Table 1). *R. apiculata* thrived abundantly and was homogeneously dominant in Selirong and Labu. *N. fruticans* was the most abundant nontimber producing species which existed homogeneously in continuous tracts along Sg. Temburong, Sg. Labu, Sg. Panderuan and Sg. Kibi. A mixed stand of associated mangrove species was usually sited toward the innermost portion considered as a landward zone or ecotone. *H. littoralis, Hibiscus tiliaceus, Intsia bijuga (Intsia retusa), E. agallocha, Acrostichum aureum* and *L. littorea* were the frequently observed associated species. However, a large tract of a heterogeneous tree mangrove stand consisting of 1,438.8 ha of *N. fruticans* and *H. globosa* was also found in other areas in the Temburong mangrove forests. A mixture of *N. fruticans, H. globosa* and *Rhizophora* spp. was also frequently observed.

Floristic Composition of Mangrove Forest. Mangrove regeneration. Table 4 shows that two mangrove regeneration species, namely, *R. apiculata* and *N. fruticans*, occurred in all the four study areas. This may indicate that these species were physiognomically dominant in the entire Brunei Darussalam region.

Percentage contribution in terms of the number of species in each of the districts signifies that Brunei-Muara was the most diverse; almost all of the representative regeneration species were found there. Species exclusively recorded in the transect of Brunei-Muara were *R. mucronata, A. officinalis, S. caseolaris, S. alba, L. littorea* and *E. agallocha.* On the other hand, *C. tagal* was found growing only in Belait.

Of the 43 sampling areas measured in Temburong District, *R. apiculata* and *X. granatum* had the highest degree of occurrence. *R. apiculata* and *N. fruticans* grew most frequently in the sampling plots of Brunei-Muara, Belait and Tutong.

Mangrove timber-size vegetation. In terms of mangrove timber-size vegetation, *R. apiculata* dominated the four areas followed by *B. cylindrica* and *X. granatum* which both fall in presence class 3 category (Table 5). Among the four districts, Brunei-Muara had the highest percentage of 71.4 which meant that most of the representative timber-size mangrove vegetation was observed there. Common species found in Temburong and Brunei-Muara were *R. apiculata, R. mucronata, X. granatum* and *H. littoralis.* The species exclusively

Table 4. Floristic composition of mangrove regeneration in Brunei Darussalam.

Species	Degree of occurrence at the four study areas/districts				
	Temburong	Brunei-Muara	Belait	Tutong	Presence class*
Rhizophoraceae					
R. apiculata	p	p	p	p	4
R. mucronata	a	p	a	a	1
B. gymnorrhiza	p	p	a	p	3
B. cylindrica	p	p	a	a	2
B. parviflora	p	p	p	a	3
Ceriops tagal	a	a	p	a	1
Avicenniaceae					
A. officinalis	a	p	a	a	1
Sonneratiaceae					
S. caseolaris	a	p	a	a	1
S. alba	a	p	a	a	1
Meliaceae					
X. granatum	p	p	p	a	3
Combretaceae					
L. littorea	a	p	a	a	1
Sterculiaceae					
H. littoralis	p	a	a	a	1
Rubiaceae					
Scyphiphora hydrophyllacea	a	p	p	a	2
Arecaceae					
N. fruticans	p	p	p	p	4
Euphorbiaceae					
E. agallocha	a	p	a	a	1
Total no. of species	7	13	6	3	
% contribution	46.7	86.7	40.0	20.0	

a = absent

p = present

*Indicates the number of occurrence of mangrove species regeneration in the four districts.

Table 5. Floristic composition of timber-size mangroves in Brunei Darussalam.

Species	Degree of occurrence at the four study areas/districts				
	Temburong	Brunei-Muara	Belait	Tutong	Presence class*
Rhizophoraceae					
R. apiculata	p	p	p	p	4
R. mucronata	p	p	a	a	2
B. gymnorrhiza	p	a	a	p	2
B. cylindrica	p	a	p	p	3
B. parviflora	p	a	a	a	1
Avicenniaceae					
A. officinalis	a	p	a	p	2
A. marina	a	p	a	a	1
Sonneratiaceae					
S. caseolaris	a	p	a	a	1
S. alba	a	p	a	a	1
Meliaceae					
X. granatum	p	p	p	a	3
Combretaceae					
L. littorea	a	p	a	a	1
Sterculiaceae					
H. littoralis	p	p	a	a	2
Arecaceae					
N. fruticans	a	a	a	p	1
Euphorbiaceae					
E. agallocha	a	p	a	a	1
Total no. of species	7	10	3	5	
% contribution	50.0	71.4	21.4	35.7	

*Indicates the number of occurrence of mangrove species regeneration in the four districts.

recorded in Brunei-Muara were *A. marina, S. caseolaris, S. alba, L. littorea* and *E. agallocha.* Likewise, *B. parviflora* and *N. fruticans* were found solely in Temburong and Tutong, respectively.

Assessment of Mangrove Reproduction/Regeneration. Regeneration species in the study areas composed of true mangrove and some associated species were grouped into seedlings, saplings, pole-size "A" and pole-size "B" (Table 6).

Of the 15 species of true mangroves, *R. apiculata* had the greatest number of regeneration of 3,540/ha, most of which belonged to the seedling group, particularly in Brunei-Muara, Temburong and Belait Districts. This was followed by *X. granatum, B. cylindrica, A. marina* and *H. littoralis* with an average total regeneration count of 282, 143, 93 and 92/ha, respectively. The rest of the representative species occurred in less number/abundance.

A large number of the regeneration species in Brunei Darussalam were made up of associated species. *N. fruticans* topped the list with an average of 928/ha. Other species such as *A. aureum* and *B. racemosa* contributed 245 each. *Melastoma malabathricum (Kudok-kudok)* gave 223, *H. tiliaceus* 169 and the rest were of less number. *N. fruticans* and *A. aureum* were consistently growing in all of the four study areas although they did not always exhibit the highest total number. The dominant associated species based on total number in each of the study areas/districts varied as follows: *H. tiliaceus* in Brunei-Muara, *A. aureum* in Temburong, *M. malabathricum* in Belait and *N. fruticans* in Tutong.

Tree growth parameter estimates

Wood Volume and Growth Parameter Estimates. Table 7 lists the mean values of tree growth parameters in Brunei Darussalam. In terms of natural stand, the Temburong study area had the highest average total volume of 177.3 m^3/ha owing to its highest Ho of 14.0 m. Although the trees measured inside the sampling plots of Temburong were the tallest with an H of 12.2 m, they were the least dense among the study areas with an average stocking of 200 trees/ha and a corresponding G of 14.6 m^2/ha.

The Brunei-Muara study area ranked second in average stand volume of 125.2 m^3/ha but first in trunk dimension. It had a Dg of 32 cm and a Dho of 37.3 cm. This area also had the highest average stocking of 330 trees/ha occupying 18.9 m^2/ha.

Table 6. Mean regeneration count (no./ha) of true mangrove and associated species in Brunei Darussalam.

Species	Seedling	Sapling	Pole size "A"	Pole size "B"	Miscellaneous	Total
True mangrove species						
R. apiculata	1,938	700	674	228		3,540
R. mucronata	8	6	8	10		32
B. gymnorrhiza	15	0.75	1	0.75		17.5
B. cylindrica	44	15	47	37		143
B. parviflora	18	8	6	8		40
S. caseolaris	0.5	0.25				0.75
S. alba			0.25			0.25
A. officinalis	26	13	10	13		62
A. marina	16	16	26	35		93
X. granatum	72	91	75	44		282
H. littoralis	27	24	25	16		92
L. littorea		1	8	8		17
S. hydrophyllacea	0.5	1				1.5
E. agallocha	2	2	1	5		10
C. tagal		9				9
Subtotal	2,167	887	881.25	404.75		4,340
Associated species						
Pandanus tectorius	7	21	7		35	70
N. fruticans	48	64	31	15	770	928
A. aureum	81	26	6		132	245
Acanthus ebracteatus	5	1	4	1	69	80
Camptostemon philippinensis (?)	0.75	4	1			5.75
Calophyllum inophyllum		0.25				0.25
I. bijuga (I. retusa)	14	9	8	3		34
Euphoria didyma	2	4	0.75			6.75
H. tiliaceus	6	10	0.75		152	168.75
Ficus balete	18	8	10	6		42
Derris indica	11	6	0.15	0.25		17.4
Dolichandrone spathacea	3	0.75				3.75
Barringtonia racemosa	168	58	11	8		245
Caesalpinia nuga					7	7
Anacardia spp.	0.5	0.75	2	1	6	10.25
M. malabathricum	204				19	223
Oncosperma tigillarium	4	4	1	26	3	38
Fern					17	17
Miscellaneous	69	49	27	18	10	173
Subtotal	641.25	265.75	109.65	78.25	1,220	2,314.9
Grand total	2,808.25	1,152.75	990.9	483	1,220	6,654.9

Table 7. Mean values of tree growth parameters in Brunei Darussalam.

Parameter	Temburong	Brunei-Muara	Belait	Tutong
Dg (cm)	30.6	32.0	22.4	38.1
Dho (cm)	32.1	37.3	21.8	40.2
H (m)	12.2	8.8	8.6	10.0
Ho (m)	14.0	11.1	10.1	11.4
G (m^2/ha)	14.6	18.9	11.9	25.2
N (trees/ha)	200.0	330.0	235.0	215.0
SV (m^3/ha)	177.3	125.2	45.3	125.0

Tutong ranked third in volume with 125 m^3/ha attributed to a Dg of 38.1 cm and a Dho of 40.2 cm, which, along with a G of 25.2, were the highest among the four districts.

The Belait study area had the lowest average volume of 45.3 m^3/ha, attributed to the lowest trunk diameter of 22.4 cm and shortest height of 8.6 m. The trees were quite dense, though, with an average stocking of 235/ha, the second among the four study areas.

Growth Parameter Estimates for Temburong District. Tree growth was assessed only in Temburong because sampling in the other districts was statistically insufficient to represent their overall situation. Moreover, the Temburong mangroves were designated for production forest while those of Brunei-Muara, Tutong and Belait were considered protection forest (see Zamora, this vol.).

The trees in each of the 43 sampling plots in Temburong were measured based on the following parameter variables: Dg, Dho, Ho, H, G, N and SV (Table 8). In terms of Dg, the highest was recorded in plot P-K-2 with 41.0 cm and the least was in S-34 with 20.3 cm. Old-growth trees from plot S-28 have the highest value of Dho with 40.8 cm. The highest Ho of 20.7 m was contributed by plots C-20-1 and C-6-3 while the highest H of 19 m came from C-6-3. The highest G was given by S-28 plot at 40.4 m^2/ha. Among the 43 plots, it appeared that S-32 was the most dense with a total stocking of 510 trees/ha.

Wood Volume Estimates for Temburong District. High volume (>200 m^3/ha). In the old-growth stands of Temburong District, most trees with high volume were found in sampling plots S-28 and S-35 with an average of 232.2 m^3/ha (Table 8). Younger growth in these plots was mostly composed of saplings with an average of 600 trees/ha, followed by those categorized as Class B poles with an average of 410 trees/ha and the least were the Class A poles recording an average of 355 trees/ha (Table 9).

Medium volume (101-200 m^3/ha). The total volume registered for the old-growth trees in the medium category was 2,066.5 m^3, or an average of 137.8 m^3/ha for 15 plots in the Temburong study area (Table 9). Sampling plot S-32 obtained the highest volume of 184.7 m^3/ha and the least was exhibited by plot C-16-2-b with 103.9 m^3/ha (Table 8).

In terms of the composition of the younger vegetation, saplings displayed the greatest number, followed by Class A, then Class B with corresponding averages of 720,287 and 139 trees/ha, respectively.

Low volume (50-100 m^3/ha). For the low volume old-growth trees, 10 sampling plots gave a total volume of 732.4 m^3/ha with an average of 73.2 m^3/ha (Table 9). Among these 10 plots, S-31a plot had the highest volume of 93.4 m^3/ha and plot C-15-2 had the least with 59.6 m^3/ha (Table 8). The younger growth in these plots was mostly saplings, followed by Class A and lastly by Class B, with respective averages of 238, 136 and 86 trees/ha.

Selective cutting areas (volume <50 m^3/ha). Thirteen sampling plots made up the selective cutting areas. Trees in these plots contributed a total volume of 440.2 m^3/ha with an average of 33.9 m^3/ha. The highest volume was given by plot S-29 with 48.9 m^3/ha while the smallest came from C-20-2 which had 12.1 m^3/ha (Table 8).

The younger stands in these selective cutting areas were mostly pole-size under Class A, which averaged 1,347 trees/ha, followed by 1,218 for saplings and 253 under Class B (Table 9).

Clear-cut areas. Temburong District had three plots, namely, C-7-2, 4th Plot and S-40, undergoing regeneration, classified as reproduction, logged-over area and clear-cut area, respectively. These plots were mostly composed of saplings and pole-size trees, hence, no data for volume of older trees/growth had been recorded. On the average, these plots gave 487 saplings/ha, 83 pole-size Class A and 47 pole-size Class B stands (Table 9).

Demand and supply analysis for Temburong forests

A 20-year supply and demand projection showed an increasing trend for supply of charcoal, firewood and poles/piles. For firewood and charcoal, the supply-demand gap is increasing (Tables 10-11), and through time there would still be available resources to sustain the demand. For poles and piles, the supply-demand gap is more than twice the demand (Table 12). Extraction of these mangrove products from the existing mangrove stands in the area would not bring about denudation of the mangrove forest.

Nevertheless, it is foreseen that people would not depend much on mangroves for economic needs. Thus, there is no real threat of dwindling resources. However, it is still advisable to efficiently manage the mangrove areas and their resources for ecological reasons.

Annual increases of 15% and 30% in the demand were assumed to test the sensitivity of the supply-demand gap. It was projected that even for a 20-year period of 15% or 30% increase in the demand for mangrove products (firewood, charcoal, poles and piles), supply would still be enough to accommodate the demand (Tables 13-15). At these rates, therefore, depletion of the resources is not expected to occur.

Table 8. Growth and yield parameters in Temburong District.

Compartment plot no.	Dg (cm)	Dho (cm)	Ho (m)	H (m)	G (m^2/ha)	N (trees/ha)	SV (m^3/ha)	Volume class
C-24-1	26.4	30.1	13.0	11.8	4.4	90	33.9	d
C-24-2	34.3	36.9	14.9	11.4	28.6	310	177.7	b
C-26-1	26.8	23.6	11.1	9.8	7.8	130	44.4	a
C-26-2	29.2	34.1	11.8	10.8	18.0	270	111.2	b
C-10-1	32.0	29.0	11.5	9.6	16.3	230	92.5	c
C-10-2	28.3	35.3	12.0	10.1	4.8	70	25.3	d
C-16-1-a	30.6	32.0	11.5	10.2	6.3	90	23.4	d
C-16-2-a	34.5	27.1	19.2	15.0	18.3	190	155.7	b
C-9-1	28.8	36.0	12.9	11.0	11.8	160	71.8	c
C-9-2	30.4	33.8	19.8	16.4	6.5	90	59.8	c
C-15-1	27.1	23.1	12.8	10.2	10.4	180	65.9	c
C-15-2	29.8	36.0	15.5	13.0	9.8	140	59.6	c
C-16-1-b	30.3	29.4	15.0	14.7	10.8	150	68.4	c
C-16-2-b	31.0	37.8	16.4	14.4	13.6	180	103.9	b
C-19-1	29.2	31.3	17.3	14.0	5.9	90	36.9	d
C-19-2	32.1	35.6	20.1	17.0	19.2	240	184.0	b
C-7-1	29.2	31.2	16.5	14.5	10.1	110	61.3	c
C-7-2	-	Reproduction		-	-	-	-	e
C-7-3	30.7	36.0	18.2	14.8	7.4	100	38.9	d
C-20-1	30.3	35.2	20.7	17.9	10.1	150	104.1	b
C-20-2	30.9	36.0	14.0	8.5	2.3	30	12.1	d
C-20-3	33.5	38.5	19.0	17.4	8.8	90	79.5	c
C-6-1	32.5	23.0	15.8	16.6	9.1	110	80.2	c
C-6-2	23.3	25.5	21.0	14.0	5.1	130	46.9	d
C-6-3	31.6	31.3	20.7	19.0	12.7	160	123.4	b
P Kibi-1	30.4	36.3	8.7	7.4	5.1	70	35.0	d
P-K-2	41.0	37.7	13.1	11.3	31.1	287	183.6	b
S-28	35.0	40.8	10.9	8.7	40.4	500	255.2	a
S29	31.4	29.0	10.7	11.4	13.2	120	48.9	d
S-30	30.5	30.1	12.4	11.9	21.9	210	110.0	b
4th Plot	-	Logged area		-	-	-	-	e
S-31	31.2	34.8	8.3	15.4	24.5	300	148.4	b
S-31a	-	-	-	-	-	-	93.4	c
S-32	30.8	32.8	11.4	11.0	37.0	510	184.7	b
S-33	25.4	23.4	11.9	10.3	21.2	420	115.0	b
S-34	20.3	24.1	9.4	8.0	5.4	170	29.7	d
S-35	27.7	34.4	16.3	14.5	29.7	370	209.2	a
S-36	32.8	27.7	8.6	7.0	12.6	150	45.0	d
S-37	35.1	38.4	14.0	11.7	17.8	250	127.0	b
S-38	32.4	28.0	7.3	6.0	7.1	70	19.8	d
S-39	31.6	35.9	13.9	12.0	18.8	260	121.5	b
S-40	-	Clear-cut area		-	-	-	-	e
S-41	33.5	29.4	10.5	8.5	27.4	350	116.3	b

Volume class	m^3/ha
a - high volume	>200
b - medium volume	101-200
c - low volume	50-100
d - selective cutting areas	<50
e - clear-cut areas	

Table 9. Total and average wood volume estimates in Temburong mangrove forests.

Category	Volume (m^3/ha)		Sapling (trees/ha)		Class A (trees/ha)		Class B (trees/ha)	
	Total	Average	Total	Average	Total	Average	Total	Average
Old growth forest								
High volume	464.4	232.2	1,200	600	710	355	820	410
Medium volume	2,066.5	137.8	10,800	720	4,310	287	2,080	139
Low volume	732.4	73.2	2,380	238	1,360	136	860	86
Selective cutting areas	440.2	33.9	15,830	1,218	17,510	1,347	3,290	253
Clear-cut areas	-	-	1,460	487	250	83	140	47

Conclusion and Recommendations

The following were the salient findings of the study:

- Brunei-Muara District had the most diverse mangrove stand while Temburong District had the most homogeneous one in terms of species composition. *R. apiculata* was the physiognomically dominant species throughout Brunei Darussalam in terms of abundance, distribution and volume while *Xylocarpus* spp. was second in abundance. *N. fruticans* was the most abundant nontimber mangrove species.
- The timber-size trees were mostly 20-40 cm in diameter and largely consisted of *R. apiculata* followed by *Xylocarpus* spp. and *Bruguiera* spp. in terms of number and volume.
- *R. apiculata* thrived extensively in homogeneous dense or sparse formation in the Labu and Selirong Forest Reserves. In terms of standing stock, mean basal area, mean diameter, mean height and mean volume, the species gave the highest value. *Xylocarpus* and *Bruguiera* also grew in pure stands but in limited areas and were usually mixed with *R. apiculata*. *Nypa* grew extensively in Temburong, either in pure or mixed stands. *H. globosa* mixed with *Nypa* were found in the middle to the innermost part of the mangrove forest. *Oncosperma* thrived abundantly in the transition zone/ecotone up to the peat swamp forest.
- Based on the 1982 aerial photo information and the ground verification done in May 1990, the Labu and Selirong mangrove reserves had been subjected to extensive clear-cutting. However, they still had a sizeable area of pristine mangrove stands located in the innermost portions of the mangrove forest and thus mostly inaccessible by water transport. On the other hand, most of the clear-cut or logged-over areas were located along the rivers and near or adjacent to the boundary of Sarawak and Brunei Darussalam.
- Natural regeneration was quite profuse in selective cutting areas with *R. apiculata* having a high density of seedlings. The openings provided a favorable environmental condition for the growth and development of seedlings, saplings, poles and piles. The trees left during

Table 10. Supply and demand projection for firewood.

Year	Area (ha)			Yield/ha (m^3)[a]			Total AAC (m^3)[b]			Total potential supply (m^3)	Effective demand (m^3)	Supply-demand gap (m^3)
	1[c]	2[d]	3[e]	1[c]	2[d]	3[e]	1[c]	2[d]	3[e]			
1991	178.00	54.16	5.92	73.24	134.93	232.19	200.44	135.24	27.58	363.25	163.79	199.46
1992	178.00	54.16	5.92	76.74	138.43	235.39	214.28	139.45	28.00	381.73	162.89	218.84
1993	178.00	54.16	5.92	80.24	141.93	238.59	228.13	143.66	28.42	400.21	161.99	238.22
1994	178.00	54.16	5.92	83.74	145.43	241.79	241.97	147.87	28.84	418.69	161.09	257.60
1995	178.00	54.16	5.92	87.24	148.93	244.99	255.82	152.08	29.26	437.16	160.19	276.97
1996	178.00	54.16	5.92	90.74	152.43	248.19	269.66	156.30	29.68	455.64	159.29	296.35
1997	178.00	54.16	5.92	94.24	155.93	251.39	283.51	160.51	30.10	474.12	158.39	315.73
1998	178.00	54.16	5.92	97.74	159.43	254.59	297.35	164.72	30.52	492.60	157.49	335.11
1999	178.00	54.16	5.92	101.24	162.93	257.79	311.20	168.93	30.94	511.07	156.59	354.48
2000	178.00	54.16	5.92	104.74	166.43	260.99	325.04	173.15	31.37	529.55	155.69	373.86
2001	178.00	54.16	5.92	108.24	169.93	264.19	338.88	177.36	31.79	548.03	154.79	393.24
2002	178.00	54.16	5.92	111.74	173.43	267.39	352.73	181.57	32.21	566.51	153.89	412.62
2003	178.00	54.16	5.92	115.24	176.93	270.59	366.57	185.78	32.63	584.99	152.99	432.00
2004	178.00	54.16	5.92	118.74	180.43	273.79	380.42	190.00	33.05	603.46	152.09	451.37
2005	178.00	54.16	5.92	122.24	183.93	276.99	394.26	194.21	33.47	621.94	151.19	470.75
2006	178.00	54.16	5.92	125.74	187.43	280.19	408.11	198.42	33.89	640.42	150.29	490.13
2007	178.00	54.16	5.92	129.24	190.93	283.39	421.95	202.63	34.31	658.90	149.39	509.51
2008	178.00	54.16	5.92	132.74	194.43	286.59	435.80	206.85	34.73	677.38	148.49	528.89
2009	178.00	54.16	5.92	136.24	197.93	289.79	449.64	211.06	35.15	695.85	147.59	548.26
2010	178.00	54.16	5.92	139.74	201.43	292.99	463.48	215.27	35.58	714.33	146.69	567.64

[a]Growth rates: (1) 3.5/yr (2) 3.5/yr (3) 3.2/yr
[b]Annual allowable cut
[c]50-100 m^3/ha
[d]101-200 m^3/ha
[e]>200 m^3/ha

Table 11. Supply and demand projection for charcoal.

Year	Area (ha) 1[c]	Area (ha) 2[d]	Area (ha) 3[e]	Yield/ha (m^3)[a] 1[c]	Yield/ha (m^3)[a] 2[d]	Yield/ha (m^3)[a] 3[e]	Total AAC (m^3)[b] 1[c]	Total AAC (m^3)[b] 2[d]	Total AAC (m^3)[b] 3[e]	Total potential supply (m^3)	Effective demand (m^3)	Supply-demand gap (m^3)
1991	3,382.00	1,029.04	112.58	73.24	134.93	232.19	3,808.36	2,569.47	524.43	6,902.25	269.28	6,632.97
1992	3,382.00	1,029.04	112.58	76.74	138.43	235.39	4,071.40	2,649.50	532.44	7,235.34	264.53	6,988.81
1993	3,382.00	1,029.04	112.58	80.24	141.93	238.59	4,334.45	2,729.54	540.44	7,604.43	259.78	7,344.65
1994	3,382.00	1,029.04	112.58	83.74	145.43	241.79	4,597.49	2,809.58	548.45	7,955.51	255.03	7,700.48
1995	3,382.00	1,029.04	112.58	87.24	148.93	244.99	4,860.54	2,889.61	556.45	8,306.60	250.28	8,056.32
1996	3,382.00	1,029.04	112.58	90.74	152.43	248.19	5,123.58	2,969.65	564.46	8,657.69	245.53	8,412.16
1997	3,382.00	1,029.04	112.58	94.24	155.93	251.39	5,386.62	3,049.69	572.46	9,808.77	240.78	8,767.99
1998	3,382.00	1,029.04	112.58	97.74	159.43	254.59	5,649.67	3,129.72	580.47	9,359.86	236.03	9,123.83
1999	3,382.00	1,029.04	112.58	101.24	162.93	257.79	5,912.71	3,209.76	588.48	9,710.95	231.28	9,479.67
2000	3,382.00	1,029.04	112.58	104.74	166.43	260.99	6,175.76	3,289.80	596.48	10,062.03	226.53	9,835.50
2001	3,382.00	1,029.04	112.58	108.24	169.93	264.19	6,438.80	3,369.83	604.49	10,413.12	221.78	10,191.34
2002	3,382.00	1,029.04	112.58	111.74	173.43	267.39	6,701.85	3,449.87	612.49	10,764.21	217.03	10,547.18
2003	3,382.00	1,029.04	112.58	115.24	176.93	270.59	6,964.89	3,529.90	620.50	11,115.29	212.28	10,903.01
2004	3,382.00	1,029.04	112.58	118.74	180.43	273.79	7,227.94	3,609.94	628.50	11,466.30	207.53	11,258.85
2005	3,382.00	1,029.04	112.58	122.24	183.93	276.99	7,490.98	3,689.98	636.51	11,817.47	202.78	11,614.69
2006	3,382.00	1,029.04	112.58	125.74	187.43	280.19	7,754.02	3,770.01	644.52	12,168.55	198.03	11,970.52
2007	3,382.00	1,029.04	112.58	129.24	190.93	283.39	8,017.07	3,850.05	652.52	12,519.64	193.28	12,326.36
2008	3,382.00	1,029.04	112.58	132.74	194.43	286.59	8,280.11	3,930.09	660.53	12,870.73	188.53	12,682.20
2009	3,382.00	1,029.04	112.58	136.24	197.93	289.79	8,543.16	4,010.12	668.53	13,221.81	183.78	13,038.03
2010	3,382.00	1,029.04	112.58	139.74	201.43	292.99	8,806.20	4,090.16	676.54	13,572.90	179.03	13,393.87

[a]Growth rates: (1) 3.5/yr (2) 3.5/yr (3) 3.2/yr
[b]Annual allowable cut
[c]50-100 m^3/ha
[d]101-200 m^3/ha
[e]>200 m^3/ha

Table 12. Supply and demand projection for poles and piles.

Year	Area (ha) 1[b]	2[c]	3[d]	Yield/ha (m^3) 1[b]	2[c]	3[d]	Total AAC (m^3)[a] 1[b]	2[c]	3[d]	Total potential supply (m^3)	Effective demand (m^3)	Supply-demand gap (m^3)
1991	88.25	2,736.75	4,573.50	91.00	1,120.00	346.50	535.38	204,344.00	105,647.85	310,527.23	24,589.80	285,937.43
1992	88.25	2,736.75	4,573.50	158.45	1,246.70	407.03	932.21	227,460.42	124,101.92	352,494.55	25,179.60	327,314.95
1993	88.25	2,736.75	4,573.50	222.53	1,367.07	464.52	1,309.20	249,421.01	141,633.29	392,363.50	25,769.40	366,594.10
1994	88.25	2,736.75	4,573.50	283.40	1,481.41	519.15	1,667.34	270,283.57	158,288.09	430,239.01	26,359.20	403,879.81
1995	88.25	2,736.75	4,573.50	341.23	1,590.04	571.04	2,007.58	290,103.01	174,110.15	466,220.74	26,949.00	439,271.74
1996	88.25	2,736.75	4,573.50	396.17	1,693.24	620.34	2,330.80	308,931.47	189,141.11	500,403.38	27,538.80	472,864.58
1997	88.25	2,736.75	4,573.50	448.36	1,791.28	667.17	2,637.86	326,818.52	203,420.52	532,876.89	28,128.60	504,748.29
1998	88.25	2,736.75	4,573.50	497.94	1,884.41	711.66	2,929.56	343,811.21	216,985.96	563,726.73	28,718.40	535,008.33
1999	88.25	2,736.75	4,573.50	545.05	1,972.89	753.93	3,206.69	359,954.26	229,873.13	593,034.07	29,308.20	563,725.87
2000	88.25	2,736.75	4,573.50	589.79	2,056.95	794.08	3,469.95	375,290.16	242,115.93	620,876.05	29,898.00	590,978.05
2001	88.25	2,736.75	4,573.50	632.30	2,136.80	832.23	3,720.05	389,859.27	253,746.60	647,325.93	30,487.80	616,838.13
2002	88.25	2,736.75	4,573.50	672.69	2,212.66	868.47	3,957.65	403,699.92	264,795.74	672,453.31	31,077.60	641,375.71
2003	88.25	2,736.75	4,573.50	711.05	2,284.73	902.89	4,183.37	416,848.54	275,292.42	696,324.32	31,667.40	664,656.92
2004	88.25	2,736.75	4,573.50	747.50	2,353.19	935.60	4,397.80	429,339.73	285,264.26	719,001.79	32,257.20	686,744.59
2005	88.25	2,736.75	4,573.50	782.13	2,418.23	966.67	4,601.51	441,206.36	294,737.51	740,545.38	32,847.00	707,698.38
2006	88.25	2,736.75	4,573.50	815.02	2,480.02	996.19	4,795.04	452,479.65	303,737.10	761,011.79	33,436.80	727,574.99
2007	88.25	2,736.75	4,573.50	846.27	2,538.72	1,024.23	4,978.88	463,189.29	312,286.71	780,454.88	34,026.60	746,428.28
2008	88.25	2,736.75	4,573.50	875.96	2,594.48	1,050.87	5,153.54	473,363.44	320,408.84	798,925.82	34,616.40	764,309.42
2009	88.25	2,736.75	4,573.50	904.16	2,647.46	1,076.17	5,319.46	483,028.88	328,124.86	816,473.21	35,206.20	781,267.01
2010	88.25	2,736.75	4,573.50	930.79	2,697.79	1,100.21	5,477.09	492,211.05	335,455.09	833,143.22	35,796.00	797,347.22

[a]Annual allowable cut
[b]50-100 m^3/ha
[c]101-200 m^3/ha
[d]>200 m^3/ha

Table 13. Sensitivity analysis for firewood.

Year	Effective demand (m^3)	Demand (m^3) 15% annual increase	Supply-demand gap (m^3)	Demand (m^3) 30% annual increase	Supply-demand gap (m^3)
1991	163.79	188.36	174.89	212.93	150.32
1992	162.89	187.32	194.41	211.76	169.97
1993	161.99	186.29	213.92	210.59	189.62
1994	161.09	185.25	233.44	209.42	209.27
1995	160.19	184.22	252.94	208.25	228.91
1996	159.29	183.18	272.46	207.08	248.56
1997	158.39	182.15	291.97	205.91	268.21
1998	157.49	181.11	311.49	204.74	287.86
1999	156.59	180.08	330.99	203.57	307.50
2000	155.69	179.04	350.51	202.40	327.15
2001	154.79	178.01	370.02	201.23	347.07
2002	153.89	176.97	389.54	200.06	366.72
2003	152.99	175.94	409.05	198.89	386.37
2004	152.09	174.90	428.56	197.72	406.01
2005	151.19	173.87	448.07	196.55	425.66
2006	150.29	172.83	467.59	195.38	445.31
2007	149.39	171.80	487.10	194.21	464.96
2008	148.49	170.76	506.62	193.04	484.61
2009	147.59	169.73	526.12	191.87	504.25
2010	146.69	168.69	545.64	190.70	523.63

Table 14. Sensitivity analysis for charcoal.

Year	Effective demand (m^3)	Demand (m^3) 15% annual increase	Supply-demand gap (m^3)	Demand (m^3) 30% annual increase	Supply-demand gap (m^3)
1991	269.28	309.67	6,592.58	350.06	6,552.19
1992	264.53	304.21	6,949.13	343.89	6,909.45
1993	259.78	298.75	7,305.68	337.71	7,266.45
1994	255.03	293.28	7,662.23	331.54	7,623.97
1995	250.28	287.82	8,019.49	325.36	7,981.24
1996	245.53	282.36	8,375.33	319.19	8,338.50
1997	240.78	276.90	8,731.87	313.01	8,695.76
1998	236.03	271.43	9,088.43	306.84	9,053.02
1999	231.28	265.97	9,444.98	300.66	9,410.29
2000	226.53	260.51	9,801.52	294.49	9,767.54
2001	221.78	255.05	10,158.07	288.31	10,124.81
2002	217.03	249.58	10,514.63	282.14	10,482.07
2003	212.28	244.12	10,871.17	275.96	10,839.33
2004	207.53	238.66	11,227.72	269.79	11,196.59
2005	202.78	233.20	11,584.27	263.61	11,553.86
2006	198.03	227.73	11,940.82	257.44	11,911.11
2007	193.28	222.27	12,297.37	251.26	12,268.38
2008	188.53	216.81	12,653.92	245.09	12,625.64
2009	183.78	211.35	13,010.46	238.91	12,982.90
2010	179.03	205.88	13,367.02	232.74	13,340.16

Table 15. Sensitivity analysis for poles and piles.

Year	Effective demand (m^3)	Demand (m^3) 15% annual increase	Supply-demand gap (m^3)[a]	Demand (m^3) 30% annual increase	Supply-demand gap (m^3)
1991	24,589.80	28,278.27	282,248.96	31,966.74	278,560.49
1992	25,179.60	28,956.54	323,538.01	32,733.48	319,761.07
1993	25,769.40	29,634.81	362,728.69	33,500.22	358,863.28
1994	26,359.20	30,313.08	399,925.93	34,266.96	395,972.05
1995	26,949.00	30,991.35	435,229.39	35,033.70	431,187.04
1996	27,538.80	31,669.62	468,733.76	35,800.44	464,602.94
1997	28,128.60	32,347.89	500,529.00	36,567.18	496,309.71
1998	28,718.40	33,026.16	530,700.57	37,333.92	526,392.81
1999	29,308.20	33,704.43	559,329.64	38,100.66	554,933.41
2000	29,898.00	34,382.70	586,493.35	38,867.40	582,008.65
2001	30,487.80	35,060.97	612,264.96	39,634.14	607,691.79
2002	31,077.60	35,739.24	636,714.07	40,400.88	632,052.43
2003	31,667.40	36,417.51	659,906.81	41,167.62	655,156.70
2004	32,257.20	37,095.78	681,906.01	41,934.36	677,067.43
2005	32,847.00	37,774.05	702,771.33	42,701.10	697,844.28
2006	33,436.80	38,452.32	722,559.47	43,467.84	717,543.95
2007	34,026.60	39,130.59	741,324.29	44,234.58	736,220.30
2008	34,616.40	39,808.86	759,116.96	45,001.32	753,924.50
2009	35,206.20	40,487.13	775,986.08	45,768.06	770,705.15
2010	35,796.00	41,165.40	791,977.82	46,534.80	786,608.42

[a]Please refer to Table 12 for total potential supply.

cutting served as seed trees which provided seeds/propagules to invade the open areas. Likewise, saplings and pole-size trees were more profusely dominant in selective cutting areas than in the close canopy or densely formed stands. There is a great chance that these areas will be adequately stocked by *R. apiculata* in the future since most of the natural regeneration has already established itself. However, in areas where *A. aureum* and *A. ebracteatus* grew abundantly, the regeneration of *Rhizophora* spp. was hindered. *Xylocarpus* spp. and *Bruguiera* spp. followed *R. apiculata* in natural regeneration count. *Nypa* had the highest occurrence of regeneration in nontimber or associated mangrove species. It was evident that a relationship existed between the density of timber-size trees and the number of regeneration/nontimber size trees in the areas surveyed.

Biomass production followed a similar trend as volume production. Apparently, the most productive area was the pristine mangrove forest which contained high wood volume.

Selirong and Labu Forest Reserves are used for timber production. The FD issues and periodically renews permits for extraction of poles, piles and firewood and charcoal production.

- The 20-year projection of mangrove timber demand showed a decreasing trend for charcoal and firewood, and the reverse course for poles and piles. Likewise, the projected growing stock of mangrove timber for firewood, charcoal, poles and piles showed an increasing trend. Even with 15% and 30% increase in demand for mangrove timber in the future, depletion of the resource will not occur.

Based on the foregoing, the following are the initial recommendations:

- Formulate a management plan to prescribe the appropriate silvicultural system and harvesting method to optimize the future development of the mangrove forest, considering the limitation, instability and fragility of mangrove ecosystems.
- Adopt a modified selective cutting scheme with retention of 40 seed trees/ha strategically located or evenly distributed throughout the area to enhance natural regeneration. If the latter will not be sufficient after two years, supplementary planting will be necessary.
- Adopt a 45-year and a 15-year cutting cycle for timber and pole and pile production, respectively.
- Consider the biological, social and economic factors and existing harvesting practice in

formulating a workable and appropriate Mangrove Silvicultural Management Plan particularly in Selirong and Labu mangrove wood production forests.

- Examine the entire mangrove ecosystem before utilization and land-use patterns are changed, in view of the various goods and services ascribed to it (e.g., coastal protection, direct and indirect benefits to fisheries) as demonstrated in recent studies.

References

Alder, D. 1980. Forest volume estimation and yield prediction. Vol.1. Food and Agriculture Organization, Rome.

Cabahug, D.M., Jr. 1986a. Tree volume functions of selected timber-producing mangrove species. Department of Environment and Natural Resources, Quezon City, Philippines. (Unpublished).

Cabahug, D.M., Jr. 1986b. Integrated Mangrove Forestry Research Project - Progress Report. Department of Environment and Natural Resources, Quezon City, Philippines. (Unpublished).

Zamora, P. 1987. Mangroves, p. 28-43. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Fish Communities in Natural Reef and Artificial Habitats in the Coastal Waters of Brunei Darussalam

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CHOU, L.M., G.S.Y. LIM and C.B. LENG. 1992. Fish communities in natural reef and artificial habitats in the coastal waters of Brunei Darussalam, p. 75-90. *In* G. Silvestre, H.J.H. Matdanan, P.H.Y. Sharifuddin, M.W.R.N. De Silva and T.-E. Chua (eds.) The coastal resources of Brunei Darussalam: status, utilization and management. ICLARM Conference Proceedings 34, 214 p. Department of Fisheries, Ministry of Industry and Primary Resources, Bandar Seri Begawan, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Abstract

The fish communities in artificial reef structures in the coastal waters of Brunei Darussalam were assessed by comparison of results from visual censuses of fish populations at the natural patch reefs and tire reef at Two Fathom Rock, two oil rig structures at Champion Oilfield and a marker buoy line. Emphasis was given on fish diversity, size and abundance. The results show that artificial structures support a greater diversity and abundance of food fishes of high market demand and larger sizes compared to natural reefs. These structures, therefore, play potentially important roles in contributing to increased fish production in the country. Proper management is necessary for artificial reefs to be effective in serving their purpose over the long term.

Introduction

One of the tasks carried out under the Association of Southeast Asian Nations/United States Coastal Resources Management Project (ASEAN/US CRMP) in Brunei Darussalam involves the assessment of artificial reef fisheries resources. The activity, which includes development and monitoring of artificial reefs, is intended as an input to the proposed coastal area management plan of the country.

Artificial reefs in Brunei Darussalam consist of tire reefs and petroleum-related structures, e.g., drilling platforms and submarine pipelines. In 1987, CRMP conducted underwater observations of the fish fauna at the tire reef at Two Fathom Rock and an oil well-jacket (CPWJ-30) at Champion Oilfield (Chou and White 1987). These gave some indications of encrusting marine communities and the function of these artificial structures as fish habitats. After this initial study, the Department of Fisheries (DOF) continued the monitoring efforts through observations of fish catch using hook and line and fish trap *(bubu)*. The data indicate encouraging catch results at these structures (De Silva 1989). In May 1990, further underwater surveys of fish communities (with particular emphasis on fish diversity, size and abundance) at randomly selected natural patch reefs, offshore oil rigs/structures and an artificial tire reef were initiated. Conducted under the auspices of the ASEAN/US CRMP, the study intended to help evaluate the potential of the structures to enhance fisheries production in the country. This paper presents the results of the survey.

Materials and Methods

Estimation of fish populations at selected natural reefs and artificial reef structures was made by visual

census using scuba equipment. At each survey site, the abundance of each species was recorded. Actual counts were made for all fishes, except for the more numerous families of Labridae and Pomacentridae, for which Log 4 abundance categories were used. Size estimates (total length in cm) were made for target (i.e., food fish) species. Other marine communities were also noted, but not quantitatively. Detailed methodology varied between the natural reefs and artificial reef structures.

Tire and natural patch reefs

Due to the horizontal extent of these reefs, the censuses were conducted using six 100-m transects. At each site, a 100-m measuring tape was laid on the substratum along which divers swam. Fishes observed within 5 m on either side and above the divers were recorded (Fig. 1). This corresponds to a habitat space of 5,000 m^3 per transect.

The artificial tire reef established by DOF at the basin of Two Fathom Rock in 1985 has over 16,000 tires to date, with 5,000 tires a year randomly deposited at the southern basin (Figs. 2 and 3). The reef consists of 100 to 300 tire units strung loosely together by a rope (thus forming a low profile) and anchored at both ends by concrete blocks. Due to their random deployment, the units have taken a variety of configurations on the seafloor. Single tires of various sizes are also scattered around. Efforts have been taken recently to concentrate the tires within a more confined area. The reef extends over approximately 35,000 m^2 of the sandy basin and is surrounded by a few small low natural patch reefs which are still unmapped. Two transects were done on the tire reef. A third one, the control transect starting from the edge of the tire reef, was laid out in the area of the basin without tire modules.

Three 100-m line transects were done on patch reefs surrounding the tire reef. Two of these were located north and south of the tire reef, at 8.5-m and 14-m depth, respectively. The third transect was a small (30 m across) patch reef situated 15 m from the tire reef, with 70 m of this transect laid over the sandy substrate beyond the tire modules.

Oil rigs

Operational oil well-jackets in offshore oilfields, as well as two condemned oil rigs donated by Brunei Shell Petroleum Co. (BSP) to DOF and sunk at Two Fathom Rock, also function as artificial reefs. Operational well-jackets (CPWJ-30 and CPWJ-28) at Champion Oilfield surveyed for this study are located on Champion Shoal approximately 30 km north of Tanjong (or Tg., meaning cape) Punyit (Fig. 2). Each well-jacket consists of a rectangular tower of tubes (12.5 x 8 m) reinforced by crossbraces, standing on the seafloor (Fig. 4). The main shafts are more than 1 m in diameter; the other tubes are 0.5 m in diameter. CPWJ-30 stands in deeper waters of 27 m while CPWJ-28 is located in shallower waters of 15 m, with the volumes enclosed by each oil well-jacket equivalent to 2,700 m^3 and 1,500 m^3, respectively.

CPWJ-30 and CPWJ-28 were surveyed by gradually ascending from the seafloor to the surface. Visual censuses were made of fishes found within the water column enclosed by the rig framework and within 5 m of

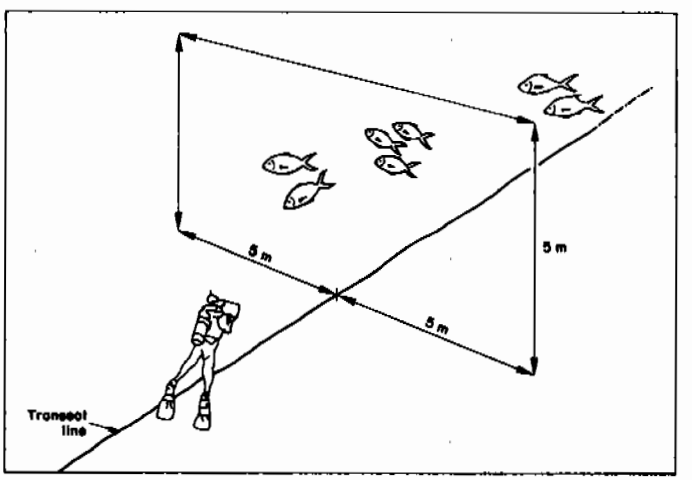

Fig. 1. Schematic representation of the 100-m fish visual census technique used in the study.

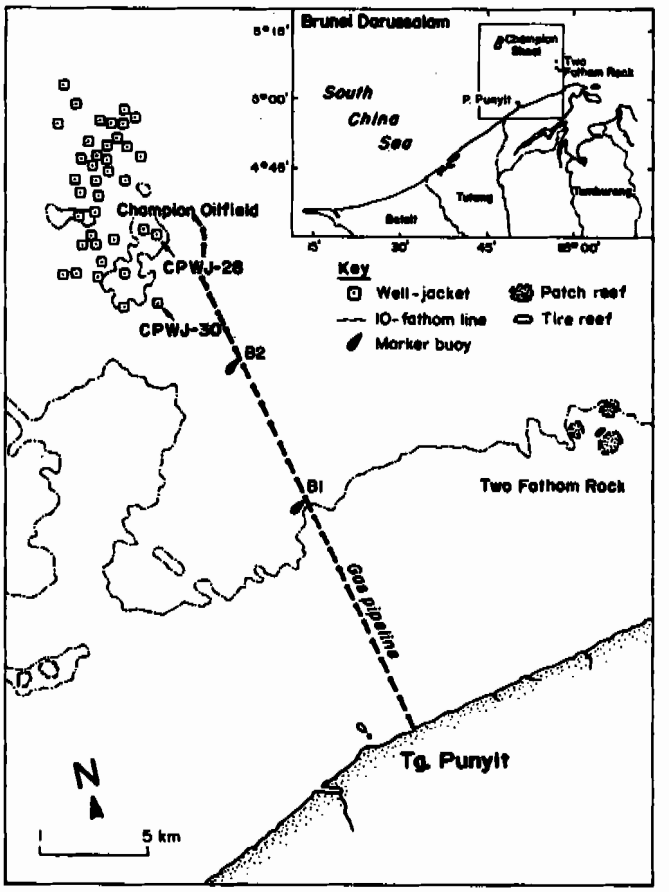

Fig. 2. Location of artificial reef structures in the coastal waters of Brunei Darussalam.

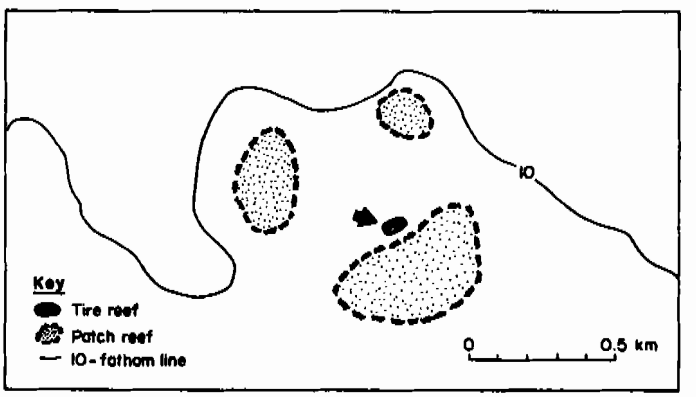

Fig. 3. Location of the tire reef at Two Fathom Rock.

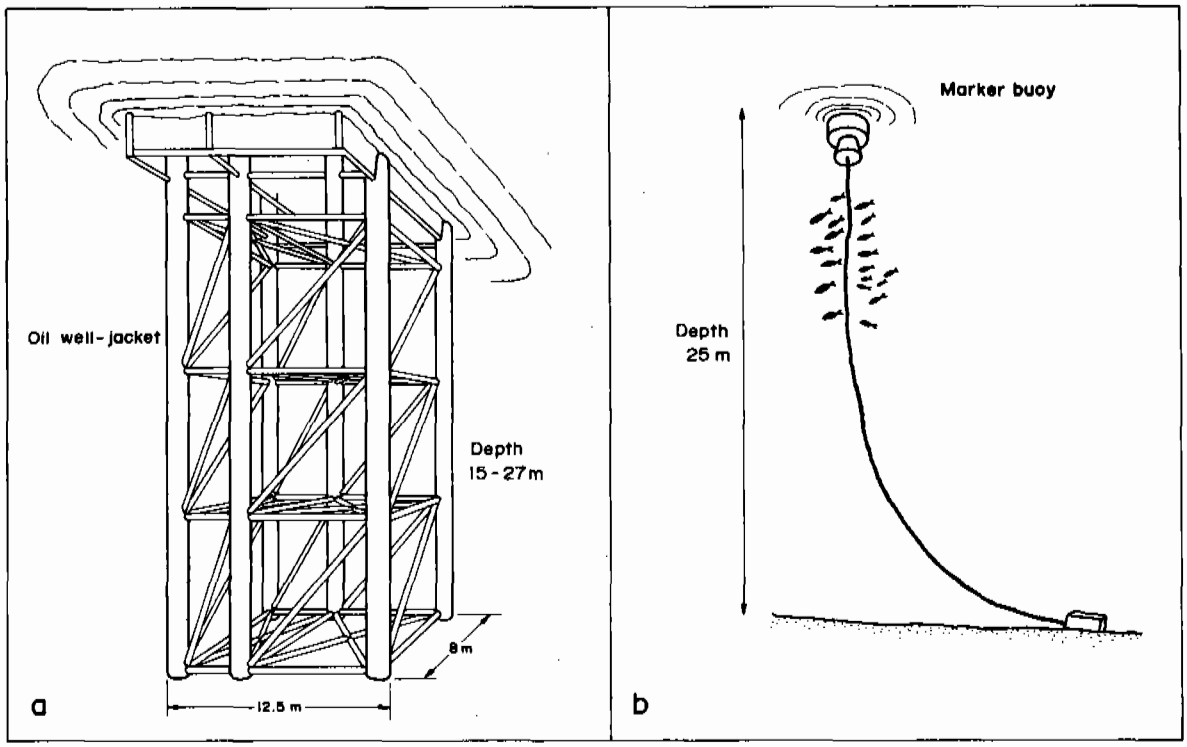

Fig. 4. Underwater view of the oil well-jacket (a) and market buoy chain (b) surveyed (by vertical fish census) during the study.

the rig. The vertical stratification of fishes was also noted. The volume of sea space surveyed for CPWJ-30 and CPWJ-28 was 8,910 m^3 and 6,075 m^3, respectively.

Two redundant oil rigs, SWA-58 (53 m long) and SWA-45 (46 m long), were placed horizontally on the seabed at Two Fathom Rock in August 1988 (De Silva 1989). Attempts to locate these structures during the study were unsuccessful.

Marker buoy line

A large number of submarine oil and gas pipelines link the offshore oilfields to onshore installations (see Silvestre and Matdanan, this vol.). A 30-km gas pipeline, which runs from Champion Oilfield to the shore near Tg. Punyit, was initially chosen for study. Two buoys, B_1 and B_2, situated 12.4 km and 20 km, respectively, from the shore mark the location of this pipeline (Fig. 2). These buoys are anchored to massive concrete blocks on the seafloor by thick iron chains (Fig. 4). An attempt was made to survey the pipeline from the buoy nearer to the shore, B_1, to B_2 (see Fig. 2). However, the pipeline could not be located due to very poor water visibility (less than 1 m) below a thermocline located 3 m from the seafloor. Instead, a vertical fish census (similar to that at the oil rigs) was conducted at B_1 by ascending towards the water surface from the bottom (Fig. 4). All fishes aggregating within 10 m of the marker buoy line were recorded. The volume of sea space surveyed for the 25-m buoy was 7,854 m^3.

A total of nine visual censuses was conducted--six on the 100-m fish transects on the tire and natural reefs at Two Fathom Rock and three vertical censuses at the oil well-jackets and buoy line of the submarine pipeline (Table 1).

Results

A total of 144 species of fishes from 31 families was recorded for natural reefs, tire reef, oil rigs and buoy line. Most of these were coral reef-associated species, including several midwater pelagics (Table 2). Damselfishes (Pomacentridae) and wrasses (Labridae) were among the most abundant and diverse families, with 26 and 22 species, respectively. Fourteen families recorded at the artificial reef structures (tires and oil rigs) were food fishes sold in the markets of Brunei Darussalam. Based on the grading system of marketable fishes (Khoo et al. 1987), 38 species belonged to Grade I, 3

Table 1. Summary of transect observations in the coastal waters of Brunei Darussalam in May 1990.

Transect no.	Habitat type	Date	Location	Depth (m)	Remarks
1	Natural patch reef	5/12	Two Fathom Rock (North patch reef)	14	100-m transect
2	Small natural patch reef (30 m across)	5/12	Two Fathom Rock	14	100-m transect (70 m over sand)
3	Natural patch reef	5/15	Two Fathom Rock (South patch reef)	9	100-m transect
4	Tire reef	5/10	Two Fathom Rock (30°E)	17	100-m transect[a]
5	Vicinity of tire reef	5/10	Two Fathom Rock (180°E)	17	100-m transect[a] (control: no tire modules)
6	Tire reef	5/12	Two Fathom Rock	17	100-m transect
7	Oil rig (CPWJ-30)	5/16	Champion Oilfield	22	vertical fish census[a]
8	Oil rig (CPWJ-28)	5/16	Champion Oilfield	15	vertical fish census
9	Buoy line (B1)	5/14	Along gas pipeline from Champion Oilfield to Tg. Punyit (12.4 km from shore)	25	vertical fish census[a]

[a]Thermocline present.

Table 2. Summary of fish composition, size range and abundance as observed during visual censuses in the coastal waters of Brunei Darussalam on 10-16 May 1990. (Values indicate actual counts; estimated lengths are shown in parentheses [cm]; "+" indicates presence.)

Habitat type	Natural patch reef			Tire reef			Oil rig		Buoy line
Location	Two Fathom Rock			Two Fathom Rock			(CPWJ-30)	(CPWJ-28)	(B1)
Date	5/12	5/12	5/15	5/10	5/10	5/12	5/16	5/16	5/14
Group/family/species Transect no.	1	2	3	4	5	6	7	8	9
A. Target food species									
Serranidae									
Cephalopholis argus	2(15-30)	3	-	-	-	-	-	-	-
C. boenack	+	3	-	-	-	1(30)	-	-	-
C. pachycentron	6(7-10)	3	12(8-15)	2(14,15)	-	1(13)	2(15)	-	-
Cephalopholis sp. 1	-	-	3(10-15)	-	-	-	-	-	-
Cromileptes altivelis	-	-	-	-	-	-	1(35)	-	-
Epinephelus caeruleopunctatus	-	-	-	+	-	1(35)	-	-	-
E. fasciatus	2	-	4(15,20)	-	-	-	2(40)	2(22,15)	-
E. morrhua	-	-	-	-	-	-	2(50)	-	-
E. tauvina	-	-	+	+	-	1(40)	-	-	-
Epinephelus sp. 1	-	-	-	-	-	-	1(100)	-	-
Plectropomus maculatus	16(18-30)	1	1(30)	-	-	-	1(40)	4(20-35)	-
Labracinus cyclophthalma	2	-	-	-	-	-	-	-	-
L. melanotaenia	3	-	9	-	-	-	-	-	-
Lutjanidae									
Lutjanus bohar	-	-	-	-	-	-	16(20-45)	-	-
L. carponotatus	1(15)	-	-	-	-	2(20-22)	-	-	-
L. decussatus	4(20)	2(25)	7(15-25)	-	1(20)	-	-	4(30)	-
L. ehrengergii (?)	-	-	-	-	-	-	5(25-30)	-	-
L. fulviflamma	-	4(40)	-	-	-	-	-	-	-

Continued

Table 2 (continued)

Habitat type	Natural patch reef			Tire reef			Oil rig		Buoy line
Location	Two Fathom Rock			Two Fathom Rock			(CPWJ-30)	(CPWJ-28)	(Bl)
Date	5/12	5/12	5/15	5/10	5/10	5/12	5/16	5/16	5/14
Group/family/species Transect no.	1	2	3	4	5	6	7	8	9
L. johnii (?) (*monostigmata*)	-	1(40)	-	-	-	6(20)	-	-	-
L. kasmira	-	-	-	-	-	-	10	-	-
L. madras	-	55(15-20)	-	11(15-20)	-	-	400(20)	-	500+
L. gibbus	-	-	+	-	-	-	-	-	-
Lutjanus sp. 1	-	3(30)	-	1(40)	3(25)	1(30)	-	-	-
Caesionidae									
Caesio teres	150+	18(25-30)	-	100+	15(30)	55(14-18)	12	150+	-
Pterocaesio diagramma	200+	-	-	20+	-	18(15-20)	600+	300+	100+
P. tile	-	-	+	-	-	-	-	-	-
Carangidae									
Atule mate	-	-	-	-	-	-	1	-	300+
Caranx sexfasciatus	-	-	-	-	-	-	-	-	500+
Carangoides ferdau	-	-	-	-	-	+	2(60)	-	-
C. fulvoguttatus	-	-	-	-	1(60)	+	1(50)	-	-
Elagatis bipinnulata	-	-	-	-	-	-	6(40)	-	-
Gnathodon speciosus	-	6(20-25)	-	-	-	-	9(50-60)	-	-
Selaroides leptolepis	-	-	-	-	-	-	-	-	200+
Siganidae									
Siganus corallinus	-	3	-	-	-	-	-	-	-
S. guttatus	-	-	-	-	+	14(20-30)	7(30)	-	-
S. javus	-	-	-	-	-	-	4(25)	-	-
S. virgatus	+	2	4	-	-	-	-	2(25)	-
Latidae									
Lates calcarifer	-	-	-	1(15)	-	-	1(30)	-	-
Sphyraenidae									
Sphyraena barracuda	-	-	1(100)	2(80)	-	-	2(80)	-	-
S. flavicauda	-	-	-	700(20-30)	-	-	-	-	-
Haemulidae									
Plectorhynchus diagrammus	-	-	-	-	-	-	2(35)	-	-
P. picus	-	5(30-35)	-	9(20-45)	-	11(20-30)	1(25)	1(40)	-
P. pictus	-	-	-	-	-	1(30)	16(25-50)	5(30-40)	-
Nemipteridae									
Pentapodus caninus	-	-	-	-	-	-	-	2	-
Scolopsis bilineatus	6	-	10	-	-	-	-	-	-
S. ciliatus	6	5	19	2	1	4	-	-	-
S. dubiosus	-	-	4	-	-	-	-	-	-
S. vosmeri	-	-	-	-	-	1	-	-	-
Mullidae									
Parupeneus indicus	+	-	-	-	-	-	-	-	-
P. multifasciatus (?) (*trifasciatus*)	-	-	8	-	-	-	1	2	-
P. tragula	-	-	-	+	-	-	-	-	-
Parupeneus sp. 1	1(40)	-	-	-	-	-	-	-	-
Pomacanthidae									
Pomacanthus annularis	2	2	-	1	1	-	-	-	-
P. sexstriatus	+	1	-	-	-	-	-	-	-
Centropyge vroliki	1	-	-	-	-	-	-	-	-
Ephippididae									
Platax orbicularis	-	-	-	-	-	-	60	-	10
P. pinnatus	-	-	-	-	-	-	2	-	-
Dasyatidae									
Taeniura lymma	-	-	-	-	-	1(20)	-	-	-
Carcharhinidae	-	-	-	-	-	-	1	-	-
Kyphosidae									
Kyphosus bigibbus	-	-	-	-	-	-	-	19(25-30)	

Continued

Table 2 (continued)

Group/family/species	Habitat type / Location / Date / Transect no.	Natural patch reef Two Fathom Rock 5/12 1	5/12 2	5/15 3	Tire reef Two Fathom Rock 5/10 4	5/10 5	5/12 6	Oil rig (CPWJ-30) 5/16 7	(CPWJ-28) 5/16 8	Buoy line (Bl) 5/14 9
B. Indicator species										
Chaetodontidae										
Chaetodon baronessa		1	-	-	-	-	-	-	-	-
C. kleinii		3	-	5	-	-	-	-	-	-
C. octofasciatus		2	3	1	-	-	-	-	-	-
C. speculum (?)		-	-	2	-	-	-	-	-	-
C. trifascialis		1	-	1	-	-	-	-	-	-
C. vagabundus		-	-	-	-	-	-	-	2	-
Chelmon rostratus		2	2	3	2	-	2	-	-	-
Coradion chrysozonus		2	-	1	+	-	-	-	3	-
Heniochus acuminatus		-	5	-	3	-	1	2	-	-
C. Common families										
Labridae										
Anampses melapterus		-	-	3[a]	-	-	-	-	-	-
Bodianus diana		-	-	-	-	-	-	+	2[a]	-
B. hirsutus		+	-	-	-	-	-	-	-	-
B. mesothorax		2[a]	-	3[a]	+	-	2[a]	-	-	-
Cheilinus diagramma		1	-	3[a]	-	-	-	-	-	2[a]
C. fasciatus		+	-	-	-	-	-	-	-	-
C. chlorourus		2[a]	-	3[a]	-	-	-	-	1	-
Choerodon anchorago		-	-	2[a]	-	-	-	-	-	-
C. shoenleinii		-	2[a]	-	-	-	3[a]	-	-	-
Coris gaimard		1	-	3[a]	-	-	-	-	-	-
C. variegata		-	-	3[a]	-	-	-	2[a]	-	-
Gomphosus varius		1	-	2[a]	-	-	-	-	-	-
Halichoeres dussumieri		-	-	-	+	-	-	-	-	-
H. hortulanus		-	-	3[a]	-	-	-	2[a]	2[a]	-
H. melanochir		3[a]	-	4[a]	-	-	-	-	-	-
H. melanurus (hoeveni)		2[a]	1	3[a]	3[a]	-	+	-	-	-
H. poecilopterus (?)		-	-	-	6[a]	+	-	-	2[a]	-
Hemigymnus melapterus		3[a]	-	2[a]	-	-	-	-	-	-
Labroides bicolor		+	-	-	-	-	-	-	-	-
L. dimidiatus		3[a]	2[a]	4[a]	3[a]	1	2[a]	3[a]	-	-
Stethojulis sp.		-	-	-	2[a]	-	-	-	-	-
Thalassoma lunare		4[a]	3[a]	6[a]	3[a]	1	3[a]	7[a]	7[a]	-
Pomacentridae										
Abudefduf bengalensis		-	-	1	-	-	-	-	1	-
A. coelestinus		-	-	-	-	-	-	-	2[a]	-
A. saxatilis		-	3[a]	-	-	-	-	-	3[a]	4[a]
Ambyglyphidodon aureus		-	2[a]	-	-	-	-	-	-	-
A. leucogaster		-	-	-	-	-	-	-	3[a]	-
Amphiprion clarkii		2[a]	3[a]	3[a]	-	-	-	-	-	-
A. ocellaris		-	-	2[a]	-	-	-	-	-	-
A. perideraion		2[a]	-	-	-	-	-	-	-	-
Chromis margaritifer		3[a]	5[a]	6[a]	-	-	-	-	-	-
C. weberi		-	-	5[a]	-	-	-	-	-	-
Chromis sp. 1		5[a]	5[a]	-	4[a]	-	-	-	-	-
Chrysiptera cyanea		2[a]	-	-	1	4[a]	-	-	-	-
Dascyllus reticulatus		4[a]	4[a]	5[a]	-	-	-	-	-	-
D. trimaculatus		-	-	2[a]	-	-	-	-	-	-
Neopomacentrus taeniurus		-	-	-	6[a]	-	5[a]	7[a]	7[a]	-
Neopomacentrus spp.		-	-	-	-	-	-	7[a]	7[a]	3[a]
Paraglyphidodon melas		3[a]	-	4[a]	-	-	-	-	-	-
P. nigroris		3[a]	3[a]	3[a]	2[a]	-	3[a]	-	-	-
Pomacentrus albimaculus		3[a]	2[a]	5[a]	4[a]	-	3[a]	-	-	-
P. coelestis		4[a]	4[a]	5[a]	+	-	-	4[a]	-	-
P. lepidogenys		3[a]	-	2[a]	-	-	-	-	-	-

Continued

Table 2 (continued)

Group/family/species	Habitat type / Location / Date / Transect no.	Natural patch reef, Two Fathom Rock, 5/12, 1	Natural patch reef, Two Fathom Rock, 5/12, 2	Natural patch reef, Two Fathom Rock, 5/15, 3	Tire reef, Two Fathom Rock, 5/10, 4	Tire reef, Two Fathom Rock, 5/10, 5	Tire reef, Two Fathom Rock, 5/12, 6	Oil rig (CPWJ-30), 5/16, 7	Oil rig (CPWJ-28), 5/16, 8	Buoy line (Bl), 5/14, 9
P. littoralis		1	-	-	-	-	-	-	-	-
P. moluccensis		2[a]	2[a]	3[a]	-	-	-	-	-	-
P. philippinus		+	-	-	-	-	-	-	-	-
unidentified sp. 1		3[a]	-	3[a]	-	-	-	-	-	-
unidentified sp. 2		4[a]	-	3[a]	-	-	-	-	-	-
unidentified sp. 3		-	-	+	-	-	-	-	-	-
D. Other families										
Acanthuridae										
Acanthus dussumieri		-	-	-	-	-	-	3	-	-
A. mata		-	34	-	2	-	5	-	-	-
A. olivaceus		1	-	-	-	-	-	-	-	-
Ctenochaetus striatus		5	-	9	5	-	-	-	1	-
Naso annulatus		-	3	-	-	7	-	-	-	-
Naso brevirostris		-	-	-	-	-	7	-	-	-
Apogonidae										
Apogon cyanosoma		-	-	-	+	-	7	-	-	-
A. compressus		-	-	-	+	-	300	-	-	-
Cheilodipterus macrodon		-	-	-	+	-	-	-	-	-
Apogon spp.		-	-	-	50	-	1,000	+	+	+
Balistidae										
Sufflamen chrysoptera		-	-	5	-	-	-	-	-	-
Balistid sp. 1		+	-	-	-	-	-	2	2	-
Blennidae										
Meicanthus grammistes		-	-	1	-	-	-	-	-	-
Grammistidae										
Diploprion bifasciatus		-	-	2	-	-	-	-	-	-
Monacanthidae										
Aluterus scriptus		-	-	-	-	-	-	-	1(50)	-
Mugiloididae										
Perapercis sp.		7	-	4	+	-	1	-	-	-
Pempheridae										
Pempheris sp.		+	-	-	-	-	-	-	+	-
Scaridae										
Scarus gibbus		+	-	4	-	-	-	1	-	-
S. ghobban		+	-	-	-	2	1	2	-	-
S. schlegeli		3	-	11	-	-	-	-	-	-
S. prasiognathus		+	-	1	-	2	-	-	-	-
S. bowersi (?)		-	-	2	-	-	-	-	-	-
Scarus spp.		-	3	-	-	-	-	-	-	-
Scorpaenidae										
Pterois sp.		-	-	-	-	-	-	-	-	1
Synodontidae										
Synodus spp.		-	-	2	+	-	-	-	-	-
Tetradontidae										
Arothron stellatus		-	-	-	-	-	-	1	1	
A. inconditus (?)		-	-	1	-	-	-	-	-	-
Canthigaster valentini		-	-	-	1	-	-	-	-	-
Zanclidae										
Zanclus cornutus		-	-	-	-	-	-	-	-	13
Unidentified juveniles		-	-	-	-	6[a]	-	-	-	-

[a]In log 4 abundance categories, as follows:

Category	No. of individuals
1	1
2	2-4
3	5-16
4	17-64
5	65-256
6	257-1,024
7	1,025-4,096

species to Grade II, 6 species to Grade III and 4 species to Grade IV (Table 3). Other families of food fishes recorded were the seachubs (Kyphosidae), parrotfishes (Scaridae) and surgeonfishes (Acanthuridae).

Natural patch reefs

Hard coral communities of the larger patch reefs north and south of the tire reef were observed to be generally rich in diversity, with a live coral cover of about 30-40%. A wide range of other reef organisms was also recorded, including coelenterates (soft coral, gorgonians, hydroids, anemones), echinoderms (starfishes, crinoids), algae, sponges and tunicates. The reef profile was generally low and flat, with few coral outcrops present. The third small patch reef was covered mostly by soft corals and gorgonians, with only a few isolated colonies of hard coral.

The combined number of fish species recorded at the patch reefs was 88 (Table 2), composed largely of the families Pomacentridae and Labridae. Pomacentrids of genera *Chromis* and *Pomacentrus* were particularly dominant, and the common wrasses were *Thalassoma lunare* and *Halichoeres* species. Seven indicator species of butterflyfishes (Chaetodontidae) were recorded.

Among the more abundant target fishes were fusiliers (Caesionidae), groupers (Serranidae) and snappers (Lutjanidae). The most numerous, the fusiliers *Pterocaesio diagramma* and *Caesio teres* (*cuning*), were seen in schools of hundreds, usually in midwater over the reef. The common snapper found was *Lutjanus decussatus*, though generally small (20-25 cm). The groupers consisted mostly of smaller species like *Cephalopholis pachycentron*, *C. boenack* and *C. argus*. A few larger individuals of *Plectropomus* spp. were also encountered. The less important food fishes found were parrotfishes, threadfin breams (Nemipteridae) and rabbitfishes (Siganidae). Large carangids were also spotted near the transects.

Species that remained closely associated with the reef substratum were pomacentrids, labrids, serranids and nemipterids, while snappers, rabbitfishes, parrotfishes and surgeonfishes were seen to swim around the general area. There were fewer species of pelagic fishes like the carangids and barracudas. The remaining 70 m of the third transect, which included the 30-m patch reef, was generally devoid of fish.

Tire reef

The tires were observed to be lightly encrusted with algae, tunicates, sponges, hydroids and gorgonians.

Table 3. Target species of food fish recorded at artificial reef structures categorized according to the grading system[a] for market fishes in Brunei Darussalam.

Grade I	Grade II
Serranidae	Haemulidae
Cephalopholis argus	*Plectorhynchus diagrammus*
C. boenack	*P. picus*
C. pachycentron	*P. pictus*
Cephalopholis sp. 1	
Cromileptes altivelis	
Epinephelus caeruleopunctatus	
E. fasciatus	Grade III
E. morrhua	
E. tauvina (?)	Mullidae
Epinephelus sp. 1	*Parupeneus indicus*
Plectropomus maculatus	*P. multifasciatus* (*trifasciatus* [?])
Lutjanidae	*P. tragula*
Lutjanus bohar	*Parupeneus* sp. 1
L. carponotatus	
L. decussatus	
L. ehrengergii (?)	Pomacanthidae
L. fulviflamma	*Pomacanthus annularis*
L. johnii (?) (*monostigmata*)	*P. sexstriatus*
L. kasmira	
L. madras	
L. gibbus	
Lutjanus sp. 1	Grade IV
Carangidae	Ephippididae
Atule mate	*Platax orbicularis*
Caranx sexfasciatus	*P. pinnatus*
Carangoides ferdau	
C. fulvoguttatus	Dasyatidae
Elagatis bipinnulata	*Taeniura lymma*
Gnathodon speciosus	
Selaroides leptolepis	Carcharhinidae
Siganidae	
Siganus corallinus	
S. guttatus	
S. javus	
S. virgatus	
Latidae	
Lates calcarifer	
Sphyraenidae	
Sphyraena barracuda	
S. flavicauda	
Caesionidae	
Caesio teres	
Pterocaesio diagramma	
P. tile	

[a]Fish grade prices in 1986 (Khoo et al. 1987).

Grade	Price range/kg (B$)
I	3.55 - 9.50
II	2.79 - 6.21
III	2.25 - 4.78
IV	1.16 - 7.06

Several colonies of hard coral (Scleractinia) have also been reported (De Silva, pers. comm.). Fishfeeding scrape marks were evident on some tire surfaces. Other free-living reef organisms were also present, mainly anemones and echinoderms (crinoids, asteroids and holothurians). On two of the three fish transects in the area, thermoclines were experienced at 1-1.5 m above the seafloor and water in this cooler base layer was turbid, with considerable reduction in visibility.

A total of 40 species of fishes was recorded in the tire reef (Table 2). Five families of fishes were particularly abundant: (1) small barracudas (Sphyraenidae) from a single species, *Sphyraena flavicauda*, of which a school of about 500 was observed hovering 2 m above the tire reef, always above the thermocline; (2) fusiliers which consisted mostly of *Caesio teres*; (3) 21 sweetlips (Haemulidae) mostly *Plectorhynchus picus*, with sizes ranging from 20 to 45 cm; and as with most natural reefs, (4) damselfishes and (5) wrasses (Category 7 of the log 4 abundance categories: 1,025-4,096 individuals), with the dominant species being *Neopomacentrus taeniurus* and *Halichoeres* sp. Juvenile fishes, too small to be identified, were also present in large numbers of about 1,000.

A significant number of target species were recorded. Besides fusiliers and sweetlips, groupers, snappers, rabbitfishes and threadfin breams were also well represented (Table 2).

The damselfishes, wrasses, cardinalfishes (Apogonidae) and groupers were noted to stay within the tire framework, while target species, namely, snappers *(Lutjanus madras, L. johnii* and *L. carponotatus)*, rabbitfishes *(Siganus guttatus)* and threadfin breams *(Scolopsis* sp.) were observed to swim around the general area, occasionally moving away and returning to the tire reef.

Along the 100-m control fish transect, a thermocline similar to that in the tire reef was observed. The bottom substrate was sandy and water below the thermocline was turbid. Only nine species of fishes were sighted along the transect, all within the first 10 m of the transect line, i.e., the tire reef. Among these were 15 *Caesio teres*, 7 surgeonfishes *(Naso annulatus)* and 4 snappers *(Lutjanus* spp.). No resident species of the sandy substrate was apparent over the remaining length of the transect.

Oil rigs

The structure of the oil well-jackets provides surfaces for the attachment of a wide variety of benthic organisms. The vertical columns and crossbraces were completely and thickly encrusted with barnacles, hard corals, soft corals *(Dendronephthya* sp.), tunicates, hydroids, seafans *(Melithaea* sp.), seawhips and algae. Crinoids, a sea urchin *(Echinometra calamaria)*, a cushion-star *(Culcita novaeguineae)*, crabs, an octopus and a lobster were also sighted in or around the immediate vicinity of the well-jackets. Both rigs surveyed stood on similar substratum of basically coral rubble, with limited growth of hard corals and other reef organisms. As a result, the profile of the shoal is very low and affords very little shelter. More hard coral colonies were observed on the seafloor near the shallower rig CPWJ-28, while a thermocline 2 m from the seafloor was evident at the deeper rig CPWJ-30. Fish communities at both rigs were different in terms of the species present and abundance.

In CPWJ 30, 41 species of fishes were recorded, with damselfishes and wrasses as the most abundant families. These occurred in large numbers (Category 7 of the log 4 abundance categories: 1,025-4,096 individuals) among the encrusting growth on the well-jacket.

The most abundant food fishes were the fusiliers consisting of about 500 *Pterocaesio diagramma* generally confined to the upper 15 m of the water column, and some *Caesio teres*. Large carangids, composed of *Gnathodon speciosus, Carangoides ferdau, C. fulvoguttatus* and rainbow runners *(Elagatis bipinnulata)* were also sighted. Other midwater species encountered were 2 large barracudas (approximately 1 m long) and 60 batfishes *(Platax orbicularis and P. pinnatus)*. The remainder of the target species were concentrated in the lower portion of the water column, 12 m above the seafloor. A large school (approximately 400) of snappers, *Lutjanus madras*, 16 large *L. bohar* and other *Lutjanus* species were observed. Among the sweetlips, *Plectorhynchus pictus* was most abundant, with a count of 16 large individuals 25-50 cm long; *P. picus* and *P. diagrammus* were also present. The groupers ranged from small species like *Cephalopholis pachycentron*, found even on the rig framework, to larger species like *Epinephelus fasciatus, Cephalopholis argus, Plectropomus maculatus* and *Chromileptes altivelis*, which moved around the rig nearer the seafloor. Large species like *Epinephelus morrhua* (50 cm long) and an unidentified *Epinephelus* species (at least 1 m long), were also observed, as well as two species of the siganids *Siganus guttatus* (30 cm long) and *S. javus* (25 cm long), and the seabass *Lates calcarifer* (25 cm long).

In CPWJ-28, the fish population was different and generally poorer, with a total of only 25 species. The dominant families were damselfishes and wrasses which swarmed over the encrusted surface of the rig. Generally, fewer target species were recorded.

Fusiliers, mainly *Pterocaesio diagramma*, made up the bulk of the midwater species. These appeared to be

larger individuals than those in CPWJ-30. There were also greater numbers of *Caesio teres*. Six sweetlips of the species *Plectorhynchus pictus* and *P. picus* (30-40 cm long), the groupers *Plectropomus maculatus* (20-35 cm long) and *Epinephelus fasciatus*, and snappers of the species *Lutjanus decussatus* (20-25 cm long) were observed in the lower portion of the water column. Nineteen seachubs *(Kyphosus bigibbus*, 30 cm long*)*, were also seen grazing off encrustations on the rig. Other fishes sighted were rabbitfishes *(Siganus virgatus)*, a large puffer *(Arothron stellatus*, about 70 cm*)*, 13 moorish idols *(Zanclus cornutus)*, 2 species of chaetodontids and a large filefish *(Aluterus scriptus)*.

Marker buoy line

This habitat consisted essentially of an encrusted length of chain stretching between a marker buoy on the surface and an anchor point on the seafloor 25 m below, passing through a thermocline at 18 m depth. Below the thermocline, visibility was reduced to less than 1 m. The chain was heavily encrusted with barnacles, hydroids, tunicates and algae; several crabs and gobies were observed to live among these.

Fishes aggregating around the chain appeared to be in two distinct strata, with a mixed school of carangids remaining above a school of about 500 small snappers of the species *Lutjanus madras* (approximately 20-25 cm long). The carangids consisted of an estimated 300 individuals of *Caranx sexfasciatus* (30 cm long), 300 *Atule mate* and 200 *Selaroides leptolepis* (25 cm long). The school of snappers seemed to stay below the larger carangids at all times, even when the latter swam below the thermocline. A group of 10 large batfishes *(Platax orbicularis)* was also encountered in midwater. Nearer the surface, the damselfishes *Abudefduf saxatilis* and *Neopomacentrus* spp. were closely associated with the large buoy structure.

Discussion

The foregoing preliminary data showed that 14 species were common among natural reefs, tire reef and oil rigs. These fishes included two species each of snappers *(Lutjanus decussatus* and *L. madras)*, fusiliers *(Caesio teres* and *Pterocaesio diagramma)*, butterflyfishes and labrids, and one species each of groupers *(Cephalopholis pachycentron)*, sweetlips *(Plectorhynchus picus)*, parrotfishes, damselfishes, barracudas and surgeonfishes. Thirty-two species (36.4%) recorded at the natural reefs were also present at the tire reef, and 27 (30.7%) were also at the oil rigs. Twenty-two species of fishes were common between the tire reef and oil rigs, of which eight species were not sighted at the natural patch reefs. Five out of the eight species recorded at the buoy were also at the rigs. These comprised schooling pelagics. Thirty-seven species of fishes recorded at natural reefs were not at the artificial reefs and structures. Most of these were chaetodontids, wrasses, damselfishes, threadfin breams and parrotfishes. Twenty-one species appeared to be "exclusive" to the oil rigs, consisting mainly of food fishes like snappers, groupers and carangids, as well as typical reef families of wrasses and damselfishes. The transects or sections of transects over the sandy substrate of Two Fathom Rock showed that the area was generally devoid of fish.

Whether on natural or artificial substrata, each reef fish community has its distinct composition of resident, semiresident and transient species. An attempt to classify the fishes into these categories was made from this one-time observation.

The fishes that appeared as resident species belonged to the following families: damselfishes, wrasses, cardinalfishes, groupers and seabasses (Latidae). Damselfishes and wrasses generally have very widespread distribution and are found in most shallow marine habitats. As expected, they were most diverse in the natural patch reefs than all the other artificial structures surveyed. However, several species had been successful in establishing themselves on artificial reef structures (tire reef, oil rigs and buoy) as seen by their large numbers and the presence of both adult and juvenile individuals. These are important for the increase of fish productivity, especially the herbivorous pomacentrids, as they are a food source for other larger species at the artificial structures. The dominant damselfishes at each habitat surveyed consisted of one or two genera/species and were generally distinct. For pomacentrids, the dominant species on the natural reefs were *Chromis* spp. and *Pomacentrus* spp., while those at the tire reef and oil rigs were *Neopomacentrus* spp. For labrids, *Thalassoma lunare* was very abundant at the patch reef and oil rigs, but less so at the tire reef, where the dominant labrid was an unidentified *Halichoeres* species. The cardinalfishes were mostly *Apogon* spp. and occurred in larger numbers at the artificial structures than at the patch reef. The high shelter requirement of this family may explain this. Groupers, too, require much shelter space, provided for by the artificial structures. Like the damselfishes, their territorial behavior suggests their establishment as resident species on the artificial structures.

The semiresident fishes on the artificial reefs are identified by their movement in a larger "territory"

which might have included the artificial reef. Most of the target fishes (snappers, sweetlips, goatfishes (Mullidae), rabbitfishes) and others like surgeonfishes, parrotfishes, angelfishes (Pomacanthidae), seachubs and several species of wrasses are likely to belong to this category.

Several fishes were observed to swim in and out of the artificial reef area, probably using it as a temporary refuge and/or a point of reference. These included the larger fishes like the barracuda *Sphyraena barracuda*, trevallies *(Caranx* spp., *Carangoides* spp. and *Gnathodon speciosus)* and a shark; and pelagics *(Pterocaesio diagramma, Caesio teres, Atule mate* and *Elagatis bipinnulata)*, batfishes *(Platax* spp.*)* and snappers *(Lutjanus madras)*. It is still unclear if these are semiresident or transient fishes.

Tire and natural patch reefs

The tire reef appears to be a form of extension of the surrounding patch reefs, "colonized" by a considerable number of natural reef species. The low profile of the tire modules simulates a similar environment as the patch reefs, with its own source of food and shelter. However, the fish community, though similar, does not represent a complete spillover from the natural reefs, as seen in the lower abundance and diversity of smaller resident reef fishes like the damselfishes, wrasses and indicator butterflyfishes. The tire reef seems to provide a habitat for more target species like groupers, snappers, fusiliers and sweetlips of larger sizes, than natural reefs. The larger crevices afforded by the tires appear to have attracted larger species, especially groupers and snappers. Encrustations of algae and other marine organisms on the tires, large numbers of small fishes (especially *Apogon* spp., damselfishes, small wrasses and other juveniles) and other free-living invertebrates serve as an important food source to both herbivores (parrotfishes and rabbitfishes) and carnivores (snappers, carangids and groupers).

The earlier data collected at the then 5,000-tire reef (Chou and White 1987) permit only superficial and qualitative comparisons with the results of this study. Slight differences in the species composition can be seen. An evident increase in *Plectorhynchus* species (sweetlips) was observed in this study and the species of snappers and rabbitfishes seemed to have been replaced by others. Fusiliers, however, remained the most abundant target fishes.

The tire reef appears to have substantially increased the standing stock of fish in the basin area of Two Fathom Rock, judging from the complete lack of fish over the open sandy areas (Transects 2 and 5). However, more information is required to permit comment on the stability of the community structure over the tire reef.

Oil rigs

The oil well-jackets at Champion Oilfield serve as additional substrata for shoaling reef fishes to settle on. Their extent from the bottom to the top of the water column may simulate vertical substrate stratification provided by natural reefs. Productivity on the rig structure is higher than that of the surrounding shoal, particularly with the colonization by a wide variety of reef organisms, including algae and invertebrates which are important sources of food for fish. In addition, the ample shelter provided by the huge structure is effective in attracting both resident and pelagic species.

Several species appeared to have settled at the rigs as these species were distinctly more abundant on the rig structure than the seafloor of the shoal, and both adults and juveniles were present. These included the groupers, damselfishes, wrasses and cardinalfishes.

As with the tire reef, a high number of target fishes, probably semiresidents, were also found here. The rigs, particularly the deeper one, CPWJ-30, attract a greater diversity of larger-sized individuals than those at the tire reef. An earlier discussion attributed this to the clearer waters and the absence of thermoclines (Chou and White 1987). However, a thermocline was present 3 m above the seafloor at CPWJ-30 during this survey, indicating that thermoclines may not affect fish abundance as previously thought. It is possible that other factors like the bigger shelter space of the rig structure, high productivity and low fishing pressure have contributed to this.

Some changes have occurred in the fish community structure at CPWJ-30 since the Chou and White study, with a shift in dominance from pelagics *(Caesio* sp. and carangids*)* to more permanent species. The diversity and abundance of groupers have increased, while snappers, not previously recorded, are present in considerable numbers (e.g., *Lutjanus madras*) and in large sizes. The number of sweetlips (between 20-45 cm) and batfishes *(Platax orbicularis)* has also increased significantly. *Siganus* species have been replaced by *Siganus guttatus* and *S. javus*. The difference in fish fauna of the deep and shallow oil well-jackets is surprising. Besides the obvious factor of depth, no inference can be made at this point.

Marker buoy lines and submarine pipelines

Pelagic fishes have been known to aggregate around drifting objects and midwater structures (Klima and

Wickham 1971). The marker buoy and its anchor chain evidently serve as a similar fish aggregating device (FAD). Although the surface of the chain was heavily encrusted with barnacles and other invertebrates, these were probably not a source of food, as none of the fishes was seen feeding off the buoyline. Although fish diversity was low, a high biomass was observed. No conclusions can be made, however, on how effective the FAD is from this one-time observation. Although the pipeline was not surveyed, large groupers had been reported along the sides of these pipelines during the monitorings conducted by DOF staff.

Possible physical factors affecting fish communities at artificial reef structures

The different artificial reef structures seem to support similar, yet distinct, fish communities. From this survey, the following are possible physical factors affecting the composition (species, size and abundance) at each habitat type:

- Depth - areas deeper than 16 m tend to aggregate more target species.
- Shelter - the size and degree of cover created by the artificial structures and the different profiles (high/low) may also affect size and type of fish settling in.
- Food - its availability and abundance--algae, encrusting forms, small invertebrates and fishes.
- Location - the productivity of the area surrounding the artificial reef structure is important. Locating the artificial reef in a more barren area will encourage more permanent resident species to settle in rather than use it only as an occasional refuge (Murdy 1979).
- Thermocline - its effects on fish distribution in these waters are not established. Thermoclines observed at the tire reef and the oil rigs limit sediments to the lower depths, enabling clearer visibility in the water layer above the thermocline. While several species of fish (barracudas, fusiliers, batfishes and carangids) are found to stay above the thermocline at all times, other fishes (snappers, sweetlips, damselfishes and wrasses) are not affected by them.

Implications for Research

Brunei Darussalam relies more on imported fish than on local fisheries. In 1989, imports amounted to 3,489 t, while local fisheries supplied only about half of this at 1,826 t. The total value of fish consumed was B$34.6[1] million, only 33% of which constituted fish from local sources.

From the fish census data collected in this study and unpublished preliminary fish catch data (hook and line and fish trap), it can be seen that sought-after families of fishes (groupers, snappers, fusiliers, mullets, carangids, trevallies, sweetlips, barracudas and others) are present in significantly larger numbers at artificial reef structures than at natural reefs. In addition, those structures which occupy the entire water column tend to attract pelagic fishes, especially the schooling species and batfishes. The fish data in this study were not expressed in numbers per unit volume as these values would not be comparable, due to the difference in the extent and profiles of the habitat types (e.g., the habitat at the oil rigs embraces the entire water column, whereas that at the tire reef extends only 1 m above the seafloor).

The artificial reefs in the waters of Brunei Darussalam are potentially important in contributing to fish production, especially food fishes of high demand. At present, they appear to serve three functions: (1) as an extension of the surrounding patch reefs by providing refuge and food for fishes which have found these habitats suitable and have taken up more permanent residency; (2) as a FAD, at least temporarily, for semi-resident species, which includes many food species; and (3) as a point of orientation for transient/nomadic, especially midwater pelagics.

The artificial tire reef and oil rig structures that were surveyed apparently contribute effectively to fish productivity. These structures support a higher diversity, greater abundance and larger sizes of food fishes of high demand compared to the natural reefs.

However, this one-time study is insufficient to determine if fish productivity at artificial reef structures has actually increased, with the establishment of stable, self-propagating fish communities, or if fishes are merely being drawn from surrounding areas. Although comparisons with a previous survey (Chou and White 1987) have shown a trend towards more stable communities at both the tire reef and CPWJ-30, and juveniles and other resident species have been observed in this study, long-term monitoring is needed to fill the data gap.

Estimation of productivity requires understanding the dynamics of the fishes, especially food fishes, at the artificial reef structures. Many questions about their recruitment patterns are still not answered although

[1]September 1991: B$1.70 = US$1.00.

observations of juveniles and adults indicate that recruitment of some species has taken place. Similarity of species among natural patch reefs, tire reef and oil rigs confirms that coral reefs are a source of colonizers of artificial reefs, either in the emigration of adult fishes or indirectly through the supply of juveniles. Movement of fishes and, consequently, their dependence on the artificial structures, especially semiresident and transient species, are still not established. The trophic relationships within the artificial reef are still to be further understood. All efforts should be made to directly observe fishes and other organisms at the sunken, condemned oil rigs SWA-58 and SWA-45 at Two Fathom Rock to determine the community structure of the animals, especially fishes, they support and attract.

Implications for Management

Artificial structures in the sea can and do attract fish. In the initial stages, fish from surrounding areas will aggregate around the structures, resulting in no actual fish biomass increase in the area. From the survey results, it is apparent that the different structures all serve as fish aggregators, with varying degrees of success. Given a longer term, colonization of these structures and ecological succession by a variety of encrusting organisms will develop these structures into proper marine habitats serving the needs of fishes for food, shelter and reproduction. Only then can artificial structures contribute significantly towards the generation of fish biomass as they become fully established, newly created marine habitats (White et al. 1990).

The tire reef at Two Fathom Rock indicates that such can be developed in other areas with similar features and at the same or even shallower depths of 11 m (6 fathoms) which will bring them closer to the shore (average of 6 km from the shoreline). New areas to be developed should preferably be located near patch reefs such as at Pelong Rocks, Scout Patches and Victoria Patches, so that they serve as extensions of reef habitat space and in the long term, can support settlement and growth of hard corals as well. Other patch reefs farther offshore can also be used, but because of the distance, cost must be taken into account.

The use of vehicle tires should therefore continue as long as their disposal on land poses a potential problem and they could be obtained free of charge. The size of the tire reef at Two Fathom Rock can easily be increased further as there is still a large expanse of suitable seafloor space. The increase in the number of tires from 5,000 in 1987 to over 16,000 at present has contributed to a larger and more diverse fish population there. The use of tire pyramids, which will provide a higher profile and extend above the thermocline, should be considered.

Condemned oil rigs, which make excellent fish aggregators because of their size and configuration, should also be used if the petroleum industry could provide them free of charge. They can be located in depths of 18 to 22 m and with the broader size resting on the seafloor extending up to 8 m above it. Sites selected will have to be away from navigational channels. Their size and structure allow them to be sited away from existing patch reefs as they are excellent substrata for quick settlement and rich growth of encrusting organisms within a short time, which serve to attract many fish species. However, it is important to directly observe the sunken oil rigs at Two Fathom Rock to determine their role in contributing to fish productivity. The present study extrapolates from the standing rigs and may miss out on factors which direct observations can identify. Such information will be important in determining future locations. The placement of disused oil rigs within the 3-mile limit from the shore, where trawling activities are prohibited, will also discourage errant trawlers from operating in this zone.

Data from DOF reveal that the great majority of fishermen (both full- and part-time) operate from the Brunei-Muara District. It would thus be logical to establish artificial reefs closer to this district initially. Site selection studies are required to determine suitability for artificial reef establishment.

Since fishing pressure has not reached intense levels, Brunei Darussalam has the unique opportunity to allow newly deployed artificial reef structures time to develop stable communities. In this way, the artificial reefs become newly established habitats that can support healthy fish populations, instead of serving as an aggregator of fish from the surrounding areas. This situation allows the country to use artificial reefs as a long-term management tool.

For such artificial structures to be effective in fish production, proper and capable management is important. Without any form of management, these structures will only facilitate the depletion of the fishery stocks of the area since the aggregation of fish towards them will require much less effort to catch and remove fish at an efficient rate.

A management plan should include restrictions on the type of fishing gear used. It is suggested that only hook-and-line fishing be permitted and that all other methods be prohibited from artificial reef structures until further investigations have been conducted. The operational oil rigs have a rich fish population because of the restrictions on fishing there.

The results of the present study have indicated that the artificial structures in the waters of Brunei Darussalam contribute towards fish productivity and that 38 of the 53 species found there belong to Grade I (most popular) in the grading system of marketable fishes. They, therefore, play a role in the enhancement of fishes in the high demand category.

However, it must be emphasized that the present study, which gives fish abundance, diversity and biomass estimates of the artificial structures, is based on one-time observations. This cannot provide information on the dynamics of the fish populations. Feeding habits and dietary preferences, recruitment rate, seasonal fluctuations and the optimum rate at which fish can be harvested from these structures are additional data needed to refine a management plan. A monitoring program (Table 4) has been designed to yield such inputs from which decisions can be made on issues like the need for open and closed seasons and whether other fishing methods apart from hook and line may be allowed.

Table 4. Proposed activities for the artificial reef monitoring program in Brunei Darussalam.

I. Detailed mapping of the natural and tire reefs at Two Fathom Rock including small patch reefs and buoys.
- Objective:
  - to provide useful inputs to plans to establish other tire reefs.

II. Regular monitoring of artificial reef structures.
- Fish visual census:
  - tire and patch reefs: two 100-m fish transects each, fixed by permanent markers;
  - oil rigs, CPWJ-30 and CPWJ-28;
  - to include length estimation of food fishes;
  - recommended frequency: once in four months.
- Objectives:
  - to identify resident, semiresident and nomadic/transient species;
  - to establish the role of the artificial reef in the life cycle (spawning, recruitment, growth) of the fishes, especially food species.

III. Fish catch data monitoring

A. Hook and line
- Additional data requirement that could be included in the present sportfishing survey form of DOF:
  - specific identification by scientific name;
  - the time fishing commenced and ended (this should be noted even if no fishes were caught);
  - number of persons fishing;
  - whether fish caught is a tagged fish (see tagging experiment below);
  - gut contents of fish caught by hook and line around artificial reef structures.
- Objectives:
  - to calculate fish catch effort per man-hour (in kg/person/hr);
  - to compute species weight-length correlation for use in the estimation of fish biomass according to Brock (1954);
  - data of gut contents of fish caught are required to determine trophic relationships of fishes at the artificial reef.

B. Fish traps *(bubu)*
- Present monitoring to be continued
  - recommended frequency: once in six months;
  - specific identification by scientific name.
- Tag and release experiment
  - fish caught using *bubu*, especially food species, to be tagged and released;
  - recapture by *bubu* or hook and line to be recorded, including information on scientific name, weight and length, date tagged, gear used and location.
- Objectives:
  - to determine fish yield/productivity of tire reef/rig, and the effectiveness of fish traps in harvesting artificial reef fishes (this is important for management plans to permit or prohibit *bubu* in artificial reef areas);
  - tagging experiments would yield valuable information on growth rate and movement of fish, especially food fish, from the artificial reef area.

IV. Monitoring of other benthic organisms at artificial structures
- Encrusting forms - removal and collection of unit area of encrusting organisms on reef substrate for wet weight measurement and composition (identification) analysis.
- Free-living forms - actual counts of invertebrates found in artificial reefs.
- Objective:
  - to monitor the biomass changes of organisms colonizing artificial reef structures, which constitute food sources for fishes.

One may argue against the need to establish artificial reefs to support fishing, as such fishing can be carried out at the natural reefs. However, Chou et al. (1987) pointed out that the waters of Brunei Darussalam are not well endowed with coral reefs and coral communities. Their studies also indicated that fishing pressure on the reefs at Pelong Rocks, although not intense, has led to a drop in abundance of food species compared to the reefs at Two Fathom Rock, where fishing pressure was considerably less. The present investigations show that food fishes are larger, more abundant and more diverse in the artificial reefs than in the natural reefs. The artificial reef habitats, therefore, are more effective for food fishes. Nevertheless, aside from food fishes, the marine communities of an artificial reef can never match the diversity found on a natural reef.

It is therefore recommended that the long-term strategy for artificial reef development in Brunei Darussalam be aimed at enhancing recreational more than artisanal fishing. Preliminary catch per unit effort observations using hook and line, together with fish trap trials at the artificial structures (unpublished data from DOF; De Silva 1989) demonstrate their potential for recreational fishing. Moreover, data from DOF show a steady decline in the number of full-time artisanal and part-time fishermen since 1986 to 311 and 893 in 1989, respectively. The trend, especially for the full-time artisanal fishermen, is unlikely to be reversed due to reasons identified by Selvanathan (1989), which included the attraction of government positions and other vocations on land.

Thus, with an artificial reef development program to serve the needs of recreational fishermen, restrictions on fishing off the natural reefs can eventually be introduced. Natural reefs are few in Brunei waters, with those currently subjected to fishing pressures having smaller populations of food fish. The natural reefs can then be effectively managed, allowed to develop to retain their high biodiversity and be tapped as a tourist attraction to scuba divers (as well as sport fishing in artificial reefs) when tourism plays a more significant role in the country's economy.

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References

Brock, V.E. 1954. A preliminary report on a method of estimating reef fish populations. J. Wildl. Manage. 18(3): 297-308.

Chou, L.M. and A.T. White. 1987. Artificial habitats, p. 60-63. *In* T.-E. Chua, L.M. Chou and M.S.M Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Chou, L.M., M.W.R.N. De Silva and A.T. White. 1987. Coral reefs, algae and seagrasses, p. 43-58. *In* T.-E. Chua, L.M. Chou and M.S.M Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

De Silva, M.W.R.N. 1989. Artificial reefs: a practical means of enhancing living marine resources, p. 173-180. *In* T.-E. Chua and D. Pauly (eds.) Coastal area management in Southeast Asia: policies, management strategies and case studies. ICLARM Conference Proceedings 19, 254 p. Ministry of Science, Technology and the Environment, Kuala Lumpur; Johor State Economic Planning Unit, Johore Bahru, Malaysia; and International Center for Living Aquatic Resources Management, Manila, Philippines.

Khoo, H.W., S. Selvanathan and H.A.M.S. Halidi. 1987. Capture fisheries, p. 89-108. *In* T.-E. Chua, L.M. Chou and M.S.M Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Klima, E.F. and D.A. Wickham. 1971. Attraction of coastal pelagic fishes with artificial structures. Trans. Am. Fish. Soc. (1): 86-90.

Murdy, E.O. 1979. Fishery ecology of the Bolinao artificial reef. Kalikasan: Philipp. J. Biol. 8(2): 121-154.

Selvanathan, S. 1989. Biophysical resource and environment of Brunei Darussalam: fisheries. Department of Fisheries, Brunei Darussalam. 32 p. (Unpublished).

White, A.T., L.M. Chou, M.W.R.N. De Silva and F.Y. Guarin. 1990. Artificial reefs for marine habitat enhancement in Southeast Asia. ICLARM Education Series 11, 45 p. International Center for Living Aquatic Resources Management, Philippines.

Water Quality in the Coastal Areas of Brunei Darussalam: Status, Management Issues and Recommendations

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Abstract

The status of water quality in the rivers and coastal waters of Brunei Darussalam was assessed based on available information augmented by field studies. Results indicate no major water pollution problems to date, existing water quality being largely consistent with current beneficial uses. Of particular concern, however, is the status of Brunei River which has shown increased suspended solids throughout its length and high coliform concentration, especially in the vicinity of the village (Kampong or Kg.) of Ayer. Major pollution sources are domestic wastes and surface runoff which contribute 50% and 29%, respectively, to the load discharged into watercourses nationwide. Increased population and accelerated economic development hold potential adverse impacts on water quality in the near future.

Recommendations to mitigate existing and potential negative effects focus on: (1) improved domestic waste treatment and disposal (particularly for Kg. Ayer); (2) proper classification, siting and zoning of industries and appropriate waste treatment; (3) adoption and/or implementation of land development measures, oil spill contingency, environmental impact assessment (EIA), monitoring program and discharge standards; and (4) appropriate legal measures and institutional arrangements.

Introduction

Brunei Darussalam is in an enviable position compared with its ASEAN neighbors as it has no major environmental pollution problems to date. Nonetheless, proper management of the quality of river and coastal waters is essential in view of population growth, urbanization and industrial development.

Kuntjoro (1987) estimated the annual population growth rates in coastal and inland areas of Brunei-Muara District during the 1971-1981 period at 6.7% and 4.1%, respectively. This exceeded the national average of 3.5% for the same period. The average rate of 3.7% for coastal areas nationwide far exceeded the 2.1% for inland areas. With rapid population increase in Brunei-Muara and coastal areas, the consequent increase in the discharge of untreated and partially treated sewage and sullage water is bound to place greater stress on the environment.

The government is committed to develop the "non-oil" industrial sector to diversify the economy which has traditionally been dependent on the oil and gas industry. In line with this, the Ministry of Industry and Primary Resources (MIPR) has identified 23 industrial development sites (see De Silva et al., this vol.), almost all of which are in the coastal zone, including ecologically sensitive estuarine areas. Industries to be promoted in the industrialization program include food processing and manufacture of chemicals. Discharge of effluents from these, as well as activities such as onshore oil refining and livestock farming could have adverse impacts on receiving watercourses. Degradation in water quality of rivers and coastal waters would result in increased economic costs. This may take the form of loss of revenue from sectors such as fisheries and tourism and the added expense of treating water for beneficial uses. Appropriate management and control measures are therefore necessary to mitigate potential water quality deterioration as a result of rapid economic development.

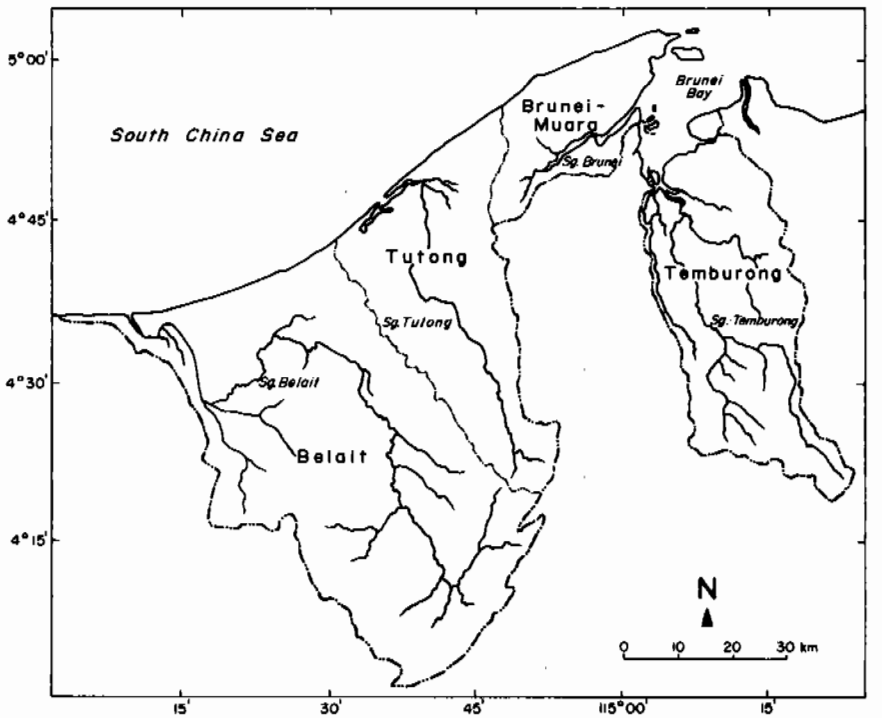

Fig. 1. Location of river systems in Brunei Darussalam.

Water Quality Status and Beneficial Uses of Rivers and Coastal Waters

There are four major rivers (Sungai or Sg.) in Brunei Darussalam: Belait, Tutong, Brunei and Temburong (Fig. 1). The drainage basins of these rivers cover a catchment area of 4,260 km^2, approximately 75% of the country's land area. The four rivers affect the quality of coastal waters; Sg. Belait and Sg. Tutong discharge into South China Sea while Sg. Brunei and Sg. Temburong drain into Brunei Estuary leading to Brunei Bay. All the rivers are subject to tidal influence for considerable distances inland (Loo et al. 1987).

Available water quality data

To date, there is no systematic collection of water quality data for rivers and coastal waters except in Sg. Brunei and Serasa Bay. Given the importance of Sg. Brunei (which drains most of the catchment area of Brunei-Muara District where over 60% of the population resides), the Public Works Department (PWD) conducted a study (1987b) to assess its water quality and pollution status. A total of 16 sampling stations was identified along a 15-km stretch of the river from its upstream branching with Sg. Damuan downstream to Brunei Estuary (Fig. 2). Subsurface and "bottom" water samples were collected from these stations and analyzed for the following parameters: suspended solids (SS), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), organic nitrogen (Org-N), total phosphorus (TP), chlorophyll "a", total plate count, total coliform (TC) and *E. coli*. In addition, *in situ* measurements of salinity, pH, temperature, redox potential and dissolved oxygen (DO) were conducted for various depths at these stations. A total of 16 sampling runs was done from August 1984 to June 1985.

Arising from this study, the Sewerage Section of PWD started water quality monitoring for Sg. Brunei in 1988. Sampling stations were similar to those chosen in 1987 except that Stations H and K were dropped and one station (Q) located at Sg. Damuan was added. The scope of work and experimental design are described in Yau (1991), while a summary of trends is given in Yau (1990). Water quality monitoring for Serasa Bay (east of the sand spit) was also initiated in early 1988 to gather baseline data before commissioning the Muara Sewage Treatment Plant (STP) to discharge treated sewage into the bay through an outfall. The eight sampling stations are shown in Fig. 3. Monitoring is conducted twice a month during high and low tides. Water

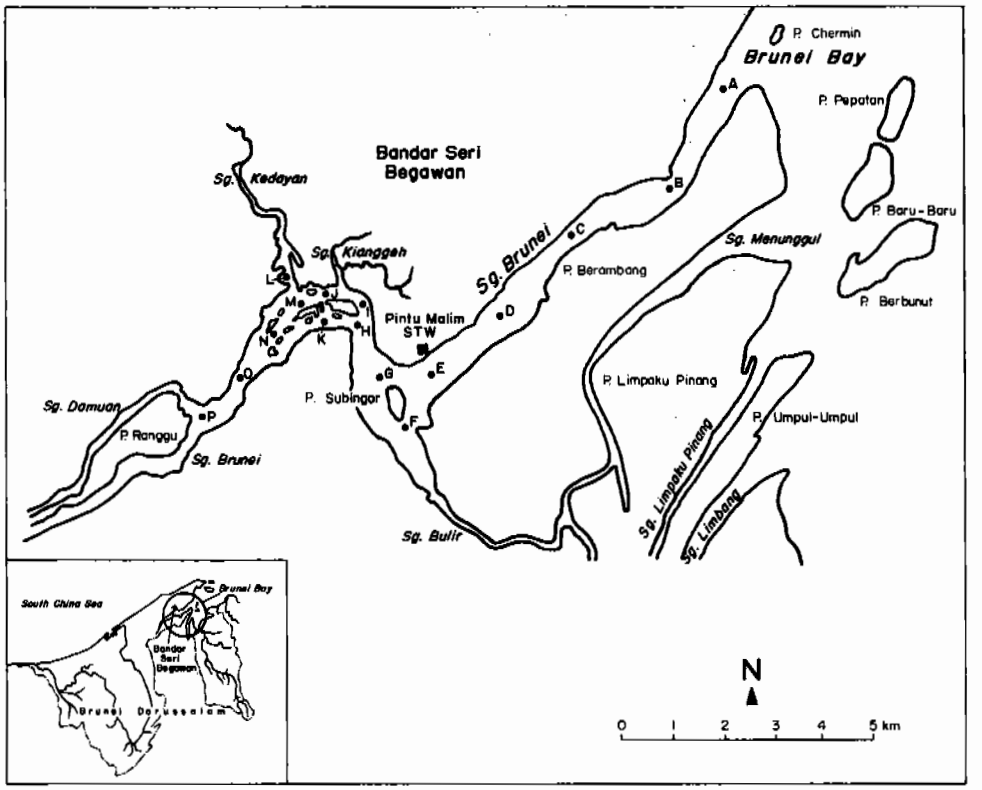

Fig. 2. Location of 16 sampling stations (A-P) distributed along a 15-km stretch of Sg. Brunei during the PWD (1987a) study.

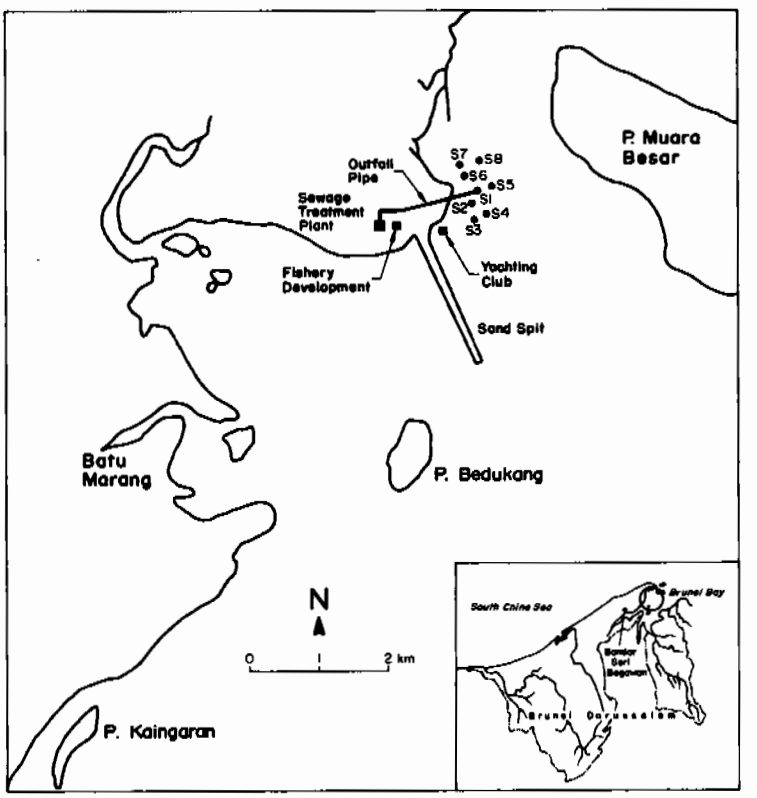

Fig. 3. Water quality sampling stations in Serasa Bay (east of sand spit).

quality parameters monitored include pH, TC, fecal coliform (FC), SS, volatile SS (VSS), 5-day biological oxygen demand (BOD_5), salinity, DO and temperature.

Under the auspices of the Association of Southeast Asian Nations/United States Coastal Resources Management Project (ASEAN/US CRMP), the water quality of Sg. Belait, Sg. Tutong, Sg. Temburong and the coastal waters was investigated to augment available information. Sampling stations for the rivers and coastal waters are illustrated in Fig. 4 and their locations are described in Tables 1 and 2. River stations were selected using the following criteria (WHO 1978): abstraction points for public water supply; areas downstream of industrial effluent and sewage discharge; areas of confluence of main river and important tributary; and areas where water is in the natural state (baseline station). Coastal water stations were chosen in areas where water is used for fisheries and recreation. For practical reasons, site accessibility was also considered. In the case of river water samples, salinity, temperature, pH, DO, SS, TC, BOD_5, hydrocarbon (HC) and FC were determined. For coastal waters, TC, FC and HC were measured. Laboratory analyses for BOD_5, SS, TC and FC were conducted using facilities of the PWD Sewerage Section and the DOF Marine Section. The HC measurements were done in the BSP Production Chemistry Laboratory. Other parameters were measured *in situ*. Three sampling trips during ebb tide were carried out from mid-June to the end of July 1990.

Sg. Brunei

Changes in the water quality of Sg. Brunei are indicated in the annual mean values of SS, DO and TC for 1984-1985 (PWD 1987b), 1988 and 1989 (Fig. 5a-d). In the case of FC, only 1984-1985 data are available. Fig. 5a and b show clearly that the river's water quality has deteriorated over the years in terms of SS and DO. The drastic increase of over 100% in SS concentrations for the entire length of the river is most likely due to increased sediment and silt from land development within the catchment area of Sg. Brunei. The DO profiles exhibit a general trend of decline, especially

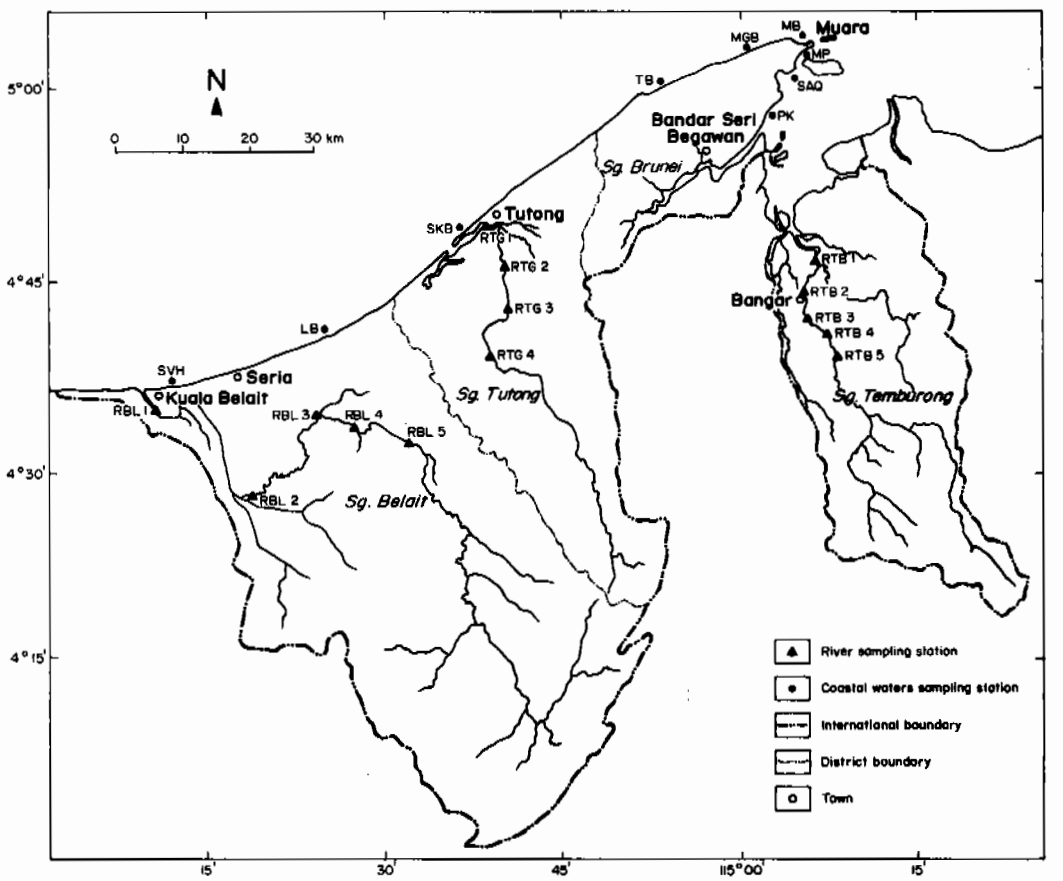

Fig. 4. Location of river and coastal water sampling stations used in the CRMP study in June-July 1990.

Table 1. River sampling stations used in the CRMP study in June-July 1990.

River	Station code	Description of location	Remarks
Temburong	RTB 1	Confluence of Sg. Temburong and Sg. Batu Apoi	Significant tidal influence
	RTB 2	Downstream of Bangar	Fresh water during ebb tide
	RTB 3	Midpoint of Bangar and Biang	Fresh water during ebb tide
	RTB 4	Downstream of gravel loading and washing works near Biang	Fresh water
	RTB 5	Upstream of Biang	Fresh water
Belait	RBL 1	Seria Bypass Bridge and downstream of Brunei Shell Petroleum Co. (BSP) sewage discharge point	Significant tidal influence
	RBL 2	Downstream of Kuala Balai	Fresh water during ebb tide
	RBL 3	Barrage at Badas	Fresh water during ebb tide
	RBL 4	Bridge near Bukit Puan	Fresh water
	RBL 5	Bukit Sawat	Fresh water
Tutong	RTG 1	Downstream of Tutong Town (Tutong Bridge)	Significant tidal influence
	RTG 2	Tanjong Maya	Fresh water during ebb tide
	RTG 3	Layong water intake point	Fresh water
	RTG 4	Rambai	Fresh water

Table 2. Coastal water sampling stations used in the CRMP study in June-July 1990.

Station	Station code	Description of location
P. Keingaran	PK	Mid-channel between P. Keingaran and mainland near mussel raft culture site
Serasa Bay	SAQ	Department of Fisheries' (DOF) experimental aquaculture site
Muara Port	MP	Off deepwater wharves
Muara Beach	MB	Wading zone, recreational use
Merangang Beach	MGB	Wading zone, recreational use
Tungku Beach	TB	Wading zone, recreational use
Sri Kenangan Beach	SKB	Wading zone, recreational use
Lumut Beach	LB	Wading zone, recreational use
Belait Beach	SVH	Wading zone behind Sea View Hotel at Kuala Belait, recreational use

upstream, but do not indicate any distinctive drop due to the discharge of organic pollutants from the Pintu Malim Sewage Treatment Works (STW), Kg. Ayer, Sg. Kianggeh and Sg. Kedayan. A sharp increase in TC and FC levels in 1984-1985 as well as in the 1989 TC profile are shown in the vicinity of Kg. Ayer and the confluence with Sg. Kedayan and Sg. Kianggeh tributaries (Fig. 5c-d). Thus, there is strong indication that direct discharge of sewage and sullage water from Kg. Ayer and discharges from Sg. Kedayan and Sg. Kianggeh have increased the bacterial contamination of Sg. Brunei.

Salinity data varying from 8 to 24 ppt (Yau 1990) indicate that Sg. Brunei is brackish at all times. As such, no suitable single value index can be employed to characterize the river's water quality. Sg. Brunei is thus treated like coastal and marine waters for the purpose of comparing existing water quality with beneficial uses. Thus, the classification given by the National Pollution Control Commission of the Philippines (NPCC 1978) is used. The available data (PWD 1987b; Yau 1990, 1991) are compared with NPCC standards (Table 3) and classified according to appropriate beneficial uses (Table 4). The results of this exercise for stations where the parameters BOD_5, DO, SS, FC and TC are available, and the uses of the river as observed during the CRMP study, are provided in Table 5. The evident incompatibility of the existing water quality of Sg. Brunei with its uses requires upgrading of water quality to the status commensurate with usage. The

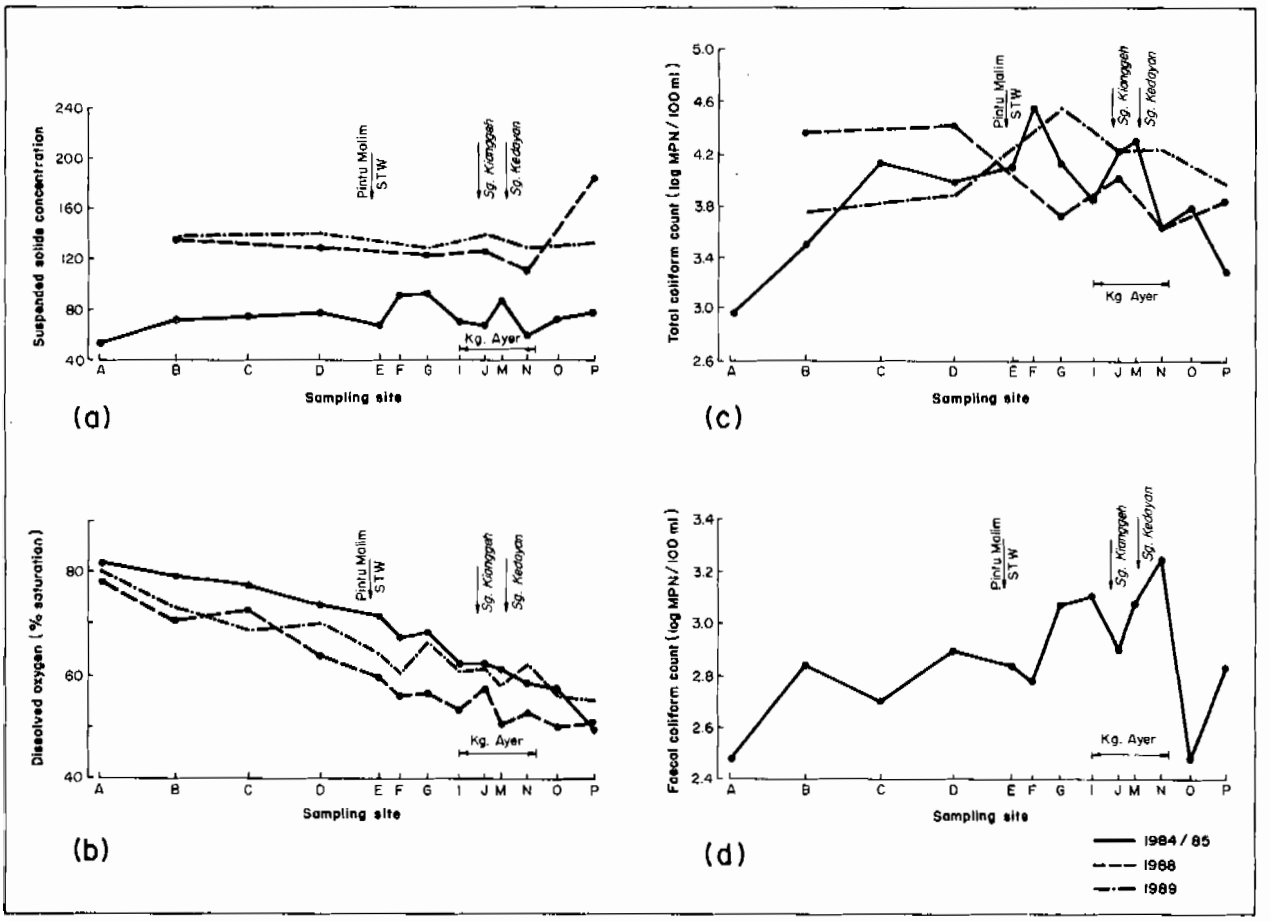

Fig. 5. Distribution of (a) mean SS concentrations, (b) mean DO levels, (c) log mean TC and (d) log mean FC by station for Sg. Brunei based on data from PWD.

Table 3. Marine water quality standards for selected parameters prescribed by NPCC (1978). See Table 8 for corresponding beneficial uses.

Parameter	Unit	Water quality class SA	SB	SC	SD
BOD_5	mg/l	3	5	7	-
DO	mg/l	5	5	5	2
	% saturation	70	70	70	50
SS	mg/l	[a]	[b]	[b]	[c]
FC[d]	MPN/100 ml	nil	200	-	-
TC[d]	MPN/100 ml	70	1,000	5,000	-

[a]Not over 30% increase.
[b]Not over 30 mg/l increase.
[c]Not over 60 mg/l increase.
[d]Geometric mean.

Table 4. Marine water quality classes and beneficial uses applicable to Sg. Brunei (NPCC 1978).

Class	Beneficial use
SA	Waters suitable for the propagation, survival and harvesting of shellfish for commercial purposes; Tourist zones and national marine parks and reserves; Coral reef parks and reserves.
SB	Recreational Waters Class I (bathing areas regularly used by the public); Fishery Waters Class I.
SC	Recreational Waters Class II (e.g., boating); Fishery Waters Class II (commercial and sustenance fishing); Marshy and/or mangrove areas declared as fish and wildlife sanctuaries.
SD	Industrial Waters Class II; Other uses not belonging to SA, SB and SC.

Table 5. Comparison of water quality classes for Sg. Brunei based on existing water quality and beneficial uses.

Station	Class	
	Water quality	Use
B	SD	SC, SD
D	SD	SC, SD
G	SD	SC, SD
J	SD	SB. SD
N	SD	SB, SD
P	SD	SC, SD
Q	SD	SC, SD

main pollution problems of the river, namely, high bacterial load and SS levels, are mainly responsible for categorizing its water quality under Class "SD".

Sg. Tutong, Sg. Belait and Sg. Temburong

Table 6 gives the mean values of selected water quality parameters measured in the CRMP study for stations in Sg. Tutong, Sg. Belait and Sg. Temburong. Ideally, a water quality index reflecting the composite influence of various parameters should be employed to indicate the general water quality status of a river. However, this approach cannot be adopted here due to limited available data.

Salinity values indicate that the three rivers are subject to tidal influence along the downstream stretch near their respective estuaries. Sg. Tutong has the lowest water quality among the three rivers since FC levels at all stations exceed the United States Environmental Protection Agency (USEPA 1976) limit of 200 MPN/100 ml for bathing waters and SS concentrations are highest. The river's aesthetic quality is poor with many visible floating materials. In general, there is no distinctive change in water quality along Sg. Tutong and Sg. Belait. In Sg. Temburong, however, the impact of human settlements on water quality is discernible from data at Station RTB 2, located immediately downstream of Bangar Town, where FC and BOD_5 values are markedly higher than those at the other stations.

Brunei Darussalam has yet to establish water quality standards for various beneficial uses of river and coastal waters. It is therefore necessary to consult standards developed in other countries, particularly in the ASEAN region, to assess and compare existing water quality with beneficial uses. For the three rivers mentioned above, the proposed water quality standards per class and corresponding beneficial uses for rivers in Malaysia (DOE 1986) are adopted (Tables 7 and 8). The parameters used for classification are again limited to five to suit the situation where comprehensive water quality data are unavailable. Comparison of values in Table 6 with standards in Table 7 allows classification of the stations in the three rivers based on the kinds of beneficial uses described in Table 8. Results of this procedure are provided in Table 9 where existing water quality is compared with existing uses observed during the CRMP study. Note that existing beneficial uses are consistent with the prevailing water quality of the three rivers.

Coastal waters

Fewer types of beneficial uses are associated with coastal waters and a specific use rather than a combination of uses is often observed. As such, the classification procedure used here differs somewhat from those discussed previously. Brunei's coastal waters are assessed based on their suitability for recreation and fisheries. The merit of this procedure is that fewer parameters need to be compared with the standards to come up with a conclusion. This suits the condition in Brunei Darussalam as comprehensive water quality data for coastal waters are currently not available.

The water quality standard for recreation (bathing or primary contact) used here follows the USEPA (1976) FC log mean bacterial limit of 200 MPN/100 ml, based on a minimum of five samples over a 30-day period. The standard for fisheries (aquaculture), is also based on a microbial content indicator. As the main concern is human health protection, the selected USEPA (1976) recommendation for shellfish-harvesting waters stipulates a median FC bacterial concentration limit of 14 MPN/100 ml.

Table 6. Mean values of selected water quality parameters for stations in Tutong, Belait and Temburong Rivers.

River	Station code	Temperature (°C)	Salinity (ppt)	pH	DO (mg/l)	BOD_5 (mg/l)	SS (mg/l)	HC[a] (ppm)	TC[a] (MPN/100 ml)	FC[a] (MPN/100 ml)
Tutong	RTG 1	28.6	18.7	7.1	4.9	< 1	107	2	1.7×10^4	3.5×10^3
	RTG 2	28.7	3.7	5.6	3.8	< 1	89	1	7.0×10^3	3.0×10^3
	RTG 3	29.2	0	5.6	4.9	1.0	85	< 1	7.0×10^3	2.2×10^3
	RTG 4	28.5	0	5.8	5.4	< 1	120	7	8.0×10^3	6.0×10^2
Belait	RBL 1	28.8	20.3	6.1	4.5	< 1	90	<1	5.0×10^2	5.0×10^1
	RBL 2	-	-	-	-	< 1	119	-	-	-
	RBL 3	29.2	0	5.9	4.6	< 1	43	< 1	1.7×10^3	2.1×10^2
	RBL 4	29.3	0	6.1	4.9	-	61	< 1	7.0×10^3	1.7×10^2
	RBL 5	30.5	0	5.5	5.3	-	37	< 1	3.0×10^3	5.0×10^2
Temburong	RTB 1	27.7	0.5	6.4	5.7	< 1	10	-	1.7×10^4	7
	RTB 2	28.4	0	6.1	6.0	1.4	46	-	3.5×10^4	5.0×10^2
	RTB 3	27.8	0	6.1	5.4	1.0	84	-	1.7×10^4	9.0×10^1
	RTB 4	28.2	0	6.1	5.3	1.0	86	-	3.5×10^4	9
	RTB 5	27.9	0	6.2	5.2	< 1	31	-	5.0×10^4	2

[a]Only one determination conducted.

Table 7. Proposed river water quality standards for Malaysia based on selected parameters (DOE 1986). See Table 8 for corresponding beneficial uses.

Parameter	Unit	Water quality class I	IIA	IIB	III	IV	V
BOD_5	mg/l	1	3	3	6	12	>12
DO	mg/l	7	5-7	5-7	3-5	<3	<1
SS	mg/l	25	50	50	150	300	>300
FC[a]	MPN/100 ml	10	100	400	5,000-20,000	5,000-20,000	-
TC	MPN/100 ml	100	5,000	5,000	50,000	50,000	>50,000

[a]Geometric mean.

Table 8. Proposed river water quality classes and beneficial uses for Malaysia applicable to Sg. Tutong, Sg. Temburong and Sg. Belait (DOE 1986).

Class	Beneficial use
I	Conservation of natural environment
	Water Supply I - practically no treatment necessary
	Fishery I - very sensitive aquatic species
II	Water Supply II - conventional treatment required
	Fishery II - sensitive aquatic species
	Recreational use with body contact
III	Water Supply III - extensive treatment required
	Fishery III - common and tolerant species
	Livestock drinking
IV	Irrigation
V	Other uses (e.g., navigation)

Table 9. Comparison of existing water quality and beneficial uses for rivers in Brunei Darussalam. See text and Tables 6-8.

River	Station	Class	
		Water quality	Use
Temburong	RTB 1	II	III, V
	RTB 2	III	III, V
	RTB 3	III	III, V
	RTB 4	III	III, V
	RTB 5	II	III
Belait	RBL 1	III	III, V
	RBL 2	III	III, V
	RBL 3	III	III, V
	RBL 4	III	III, V
	RBL 5	II	III, V
Tutong	RTG 1	III	III, V
	RTG 2	III	III, V
	RTG 3	III	III, V
	RTG 4	III	III, V

Table 10 gives the mean values of selected parameters for stations in coastal waters. The water quality of Serasa Bay (west of the sand spit) and that of coastal waters off Meragang, Tungku, Sri Kenangan and Lumut Beaches (except Muara and Belait Beaches) satisfy the standard for bathing waters. Table 11 shows the suitability of coastal waters at the identified sites for recreational and aquaculture uses. Both the island (Pulau or P.) of Keingaran and Serasa Bay (west of the sand spit) do not satisfy the standard for shellfish-harvesting waters. As this microbial criterion may be too stringent for other marine species which are not filter feeders, the two sites may still be suitable for finfish and prawn culture at existing FC levels. If aquaculture activities (such as mussel raft culture) are to be revived in the waters off P. Keingaran, management measures need to be introduced to improve water quality. This could only be achieved by upgrading the water quality of Sg. Brunei since it drains into Brunei Estuary where P. Keingaran is located.

Major Sources of Pollution

Domestic waste

Indiscriminate discharge of untreated or semitreated sewage and sullage water into rivers and coastal waters results in environmental pollution due to their high organic and bacterial loads. The estimated BOD load of 6.1 t/day (Table 12) contributed by domestic waste (about 50% of the total discharged to the environment) is certainly low as waste discharged into septic tanks is assumed to have been treated to zero BOD load. Effluent data from PWD (1987a) indicate very poor treatment efficiency for septic tanks. Despite this, the figures in Table 12 clearly show that domestic waste is the largest organic pollution source in Brunei Darussalam. Whether the BOD load of domestic waste will increase or decrease depends on a number of factors such as population growth rate and the adequacy of treatment facilities.

Based on data from the Department of Town and Country Planning (DOTCP 1986), Table 13 gives the proportional usage of various forms of sanitation in Brunei Darussalam. Proportional usage of sewerage is expected to be higher in the future, especially in Brunei-Muara once sewerage schemes such as those for Gadong and Muara Towns are completed and commissioned. Direct discharge of domestic waste to the environment constitutes a very significant proportion of the means of waste disposal in all districts. Of major concern is the situation in Kg. Ayer. The water village, located near the city center with a population of approximately 25,000, generates about 11% of total BOD load contributed by domestic waste. However, since all domestic waste is discharged directly into Sg. Brunei or Sg. Kedayan, Kg. Ayer effectively contributes about 30% of BOD load from domestic waste or about 10% of total BOD load discharged to the environment.

Table 10. Mean values of selected water quality parameters for stations in coastal waters.

Sampling station	Station code	TC (MPN/100 ml)	FC (MPN/100 ml)	HC (ppm)
P. Keingaran	PK	4.9×10^2	2.6×10^2	2
Serasa (west of sand spit)	SAQ	2.7×10^2	3.0×10^1	1
Muara Port	MP	-	-	2
Muara Beach	MB	6.6×10^3	5.0×10^2	1
Meragang Beach	MGB	3.6×10^2	4.6×10^1	4
Tungku Beach	TB	3.7×10^2	1.9×10^1	3
Sri Kenangan Beach	SKB	2.7×10^2	6	1
Lumut Beach	LB	3.0×10^2	5.5×10^1	2
Belait Beach	SVH	5.2×10^3	1.7×10^3	1

Table 11. Suitability of coastal waters for recreational and aquaculture uses.

Location	Beneficial use	Water quality status	Action
P. Keingaran	Aquaculture (mussel culture)	N	Improvement of water quality
Serasa Bay	Aquaculture (fish culture)	Y	Maintenance of water quality
	Recreation (primary contact)	Y	Maintenance of water quality
Muara Beach	Recreation (primary contact)	N	Improvement of water quality
Tungku Beach	Recreation (primary contact)	Y	Maintenance of water quality
Sri Kenangan Beach	Recreation (primary contact)	Y	Maintenance of water quality
Lumut Beach	Recreation (primary contact)	Y	Maintenance of water quality
Belait Beach	Recreation (primary contact)	N	Improvement of water quality

Y = Consistent with usage.
N = Not consistent with usage.

Table 12. Estimated BOD load (t/day) generated and discharged to the environment by various types of wastes.

	Type of waste			
	Domestic	Industrial	Livestock	Surface water runoff
BOD load generation	12.2[a]	2.7[b]	12.4[c]	3.5[d]
Percentage (%)	40	9	40	11
BOD load into watercourses	6.1[e]	1.4[f]	1.2[g]	3.5
Percentage (%)	50	11	10	29

[a]Based on 1985 population (PWD 1987a).
[b]Based on BSP Aqueous Waste Inventory of 1986 and assuming that other industrial waste discharges are negligible.
[c]Mean of PWD (1987a) estimates.
[d]PWD (1987a, 1987b).
[e]Sum of BOD loads contributed by direct discharge, effluent from Pintu Malim STW (assuming BOD = 100 mg/l) and untreated sewage from Belait District. Assumes no sludge discharge from Pintu Malim STW.
[f]Based on BSP's effluent quality standards for produced formation water.
[g]Assuming that only 10% of the load reaches watercourses.

Table 13. Existing levels of sanitation service. See text.

District/area	Form of sanitation				
	Pit latrine	Bucket	Septic tank	Sewerage	Direct discharge to watercourses
Brunei-Muara District					
Bandar Seri Begawan	0%	0%	37%	47%	16%
Kg. Ayer	0%	0%	3%	0%	97%
Brunei-Muara	0%	0%	74%	3%	23%
Tutong District	0%	1%	40%	0%	59%
Belait District	0%	4%	22%	54%	20%
Temburong District	1%	0%	30%	0%	69%

The STWs are part and parcel of modern-day sewerage systems other than those which employ marine outfall as a mode of disposal. These treatment works (such as the Pintu Malim STW in Bandar Seri Begawan, the new Gadong STW in Brunei-Muara District and the new Kg. Pandan STW in Kuala Belait) normally serve a good section of the urban population. However, small package-type STPs are usually located on-site and used to treat waste from government institutions and industrial establishments. Except for the Pintu Malim STW which only provides primary treatment, the other STWs and STPs provide secondary treatment. The most popular treatment employed in STW is the oxidation pond system while extended aeration process is normally used in STP.

Industrial wastewater

Brunei Darussalam's industrial activities have been dominated by the oil-based sector. Onshore and offshore oilfield operations produce various types of liquid wastes. According to the 1986 aqueous waste inventory of BSP, the largest quantity of wastewater generated is produced formation water. This is being discharged at the rate of 5×10^6 m^3/year into Sg. Bera at a point close to the river's discharge into South China Sea. Other liquid wastes generated are comparatively insignificant in terms of volume or pollution load. Non-oil-based industries identified as polluting and generating wastewater are softdrink manufacturing, abattoirs and gravel mining. However, these are small-scale and limited in number and their pollution load would not be significant at present. Estimated BOD load from industrial waste is low compared to that of domestic waste (Table 12). This would change considerably in the near future due to the government's effort to promote the non-oil industrial sector.

Livestock waste

In Brunei Darussalam, livestock farming includes buffalo, cattle, goat, poultry and pig. Livestock manure is highly polluting. The BOD load generation from livestock waste is comparable to that of domestic waste (Table 12). At present, other than poultry farming, very few large-scale commercial operations involve large numbers of animals. For most farms, the animals are allowed to graze freely on land. Hence, only a small proportion of generated pollution load reaches watercourses. However, effluent from the anticipated increase in commercial-scale production farms could cause very serious water pollution problems, if not properly treated.

Surface water runoff

Surface water runoff includes runoff from urban areas and from uncontrolled land development, the pollution loads of which are difficult to quantify. Nonetheless, estimates have been made of nonpoint pollution loads contributed by surface runoff in the Sg. Brunei catchment area (PWD 1987b) and in other principal urban areas (PWD 1987a). The total estimated contribution by surface runoff to the BOD load discharged to the environment is very significant at 29% (Table 12). Unlike other discharges, the control of pollution resulting from surface runoff is much more difficult because of the diffused nature of contributing pollution sources. Principal pollutants carried in urban runoff include semitreated and untreated domestic wastes, effluents from scattered small industries and discharges from garages, petrol stations and workshops. Pollutants found in nonurban runoff are mainly sediments, agricultural wastes and agrochemical residues.

Management Issues

Inadequacies in domestic waste disposal

With a high population growth rate of 3.5% per annum, domestic waste load generation is expected to increase substantially. Inadequately treated or untreated domestic waste can cause the following pollution problems: (1) hazard to human health from pathogens in coastal waters and shellfish; (2) oxygen depletion, eutrophication and contamination of watercourses caused by BOD loading, release of nutrients and heavy metals and other toxic substances, respectively; and (3) deterioration of aesthetic quality.

Despite the government's allocation of financial resources for the construction of sewerage systems and STWs/STPs in recent years, about 50% of the residents in Bandar Seri Begawan and Belait District, and almost the entire population in Tutong and Temburong Districts as well as Kg. Ayer are not serviced by such facilities.

At present, three sewerage systems in Brunei Darussalam provide either partial treatment or no treatment at all. One serves the central business area of Bandar Seri Begawan and government establishments along Jalan Berakas and Jalan Tutong. Domestic waste is conveyed by trunk sewers to the Pintu Malim STW for primary treatment before being discharged into Sg. Brunei. Two other systems are found in Belait District for Kuala Belait and BSP. In both cases, untreated sewage is conveyed by sewers and discharged into Sg. Belait. A new

STW is being constructed at Kg. Pandan to treat the sewage from existing BSP housing areas and new housing projects.

Septic tanks constitute a very important sewage disposal system given their high usage in Brunei-Muara, Bandar Seri Begawan, Tutong, Temburong and Belait (Table 13). The predominantly clay soils do not allow the use of soakaways in general; consequently, septic tank outlets are connected directly to monsoon drains. Since septic tanks are not desludged regularly, the quality of effluents is usually very poor. Effluents have BOD values greater than 100 mg/l (DOTCP 1986) and contribute significantly to the pollution load carried by surface runoff.

Industrial siting and zoning

With the government's commitment to promote non-oil industrial development, the major issue which needs to be addressed is the siting and zoning of industries. Proper industrial siting and zoning are essential to ensure that coastal beneficial uses are compatible and adverse consequences on the surrounding natural systems are minimized. In general, the coastal zone is attractive to industries because of economic considerations, such as proximity to population centers and port facilities. In fact, almost all of the 23 industrial development sites identified by MIPR are located in the coastal zone.

Wastewater from industries in the coastal zone has potential impacts on watercourses ranging from relatively minor disturbances, such as temporary and localized increase in turbidity, to major water pollution caused by the discharge of toxic materials. The problem is made more acute if wastewater is discharged into ecologically sensitive estuarine areas. A case in point is the Muara Industrial Development Site in the Brunei Estuary area which is near residential areas, the Serasa Aquaculture Development Site of DOF and the recreational beaches of Muara and Serasa. Even if treated, the discharge of industrial effluents into the Brunei Estuary area would have potential ill effects on fisheries and recreational activities there.

Inappropriate land development

Recent land clearing activities in Brunei Darussalam due to industrial and residential development have removed natural ground vegetation and exposed soils to the erosional forces of wind and water. Unprotected soils are eroded in due course and washed into rivers and coastal waters as silt and sediment. Higher SS concentrations in Sg. Brunei increase its turbidity which interferes with normal biological processes. Silt and sediment brought down by runoff from land development sites may contain heavy metals and other toxic materials which pollute the watercourses.

Lack of an oil spill contingency plan

The potential for oil spill incidents along the coastal waters of Brunei Darussalam is high considering the large-scale petroleum exploration and production activities as well as tanker traffic in the area. Four potential sources of oil spill could occur in the waters of Brunei Darussalam and neighboring Sabah and Sarawak, namely:

1. release of oil from oil wells and underwater pipelines due to faults developed during operation;
2. maritime accidents due to collision, fire, explosion or grounding of ships;
3. discharge of oil or oily waste from pumping of bilges, deballasting of cargo tanks and tank washings; and
4. accidental spillage on board ships or at oil terminals, or while transferring cargo from ship to shore or vice versa.

Currently, Brunei Darussalam does not have a national oil spill contingency plan, although a draft is under consideration. What is available and operational is that developed by BSP. The urgency of developing and adopting such a plan cannot be overemphasized in view of the potential negative impacts of oil pollution on the marine environment (including important coastal fisheries and ecologically sensitive areas such as coral reefs and mangroves), as well as high cleanup and social costs.

Legal and institutional issues

Laws that relate to water quality and pollution in Brunei Darussalam include the following: Water Supply Act, Fisheries Act, Land Code, Forest Act, Ports Act, Mining Act, Municipal Boards Act, Petroleum Mining Act, Minor Offences Act and Penal Code. All except the Penal Code and the Minor Offences Act empower administrators to make rules or regulations to control water pollution. Among the eight acts, by-laws had been issued only for the Municipal Boards Act (see Tobin, this vol.).

In the absence of water quality criteria, it is difficult to ascertain the beneficial uses commensurate with the quality of a body of water. Without effluent standards,

no legal instruments can be employed by authorities without ambiguity in prosecuting polluters. The resulting indecision of enforcement agencies would lead to inaction and defeat the purpose of having laws.

Having many laws concerning water quality and pollution may create overlaps in the jurisdiction of various government departments and enforcement agencies. For instance, under the Municipal Boards Act and Fisheries Act, the jurisdiction of Municipal Boards and DOF overlaps in controlling the discharge of night soil or excrement into water bodies. A likely consequence is that different sets of effluent standards may be prescribed by regulations under two acts and enforced by agencies for the same type of pollutant discharge. This will create legal and administrative problems.

Lack of effluent and water quality monitoring

Systematic and up-to-date data on the quality of waste discharges and watercourses are essential for designing and implementing an effective water quality management program. Monitoring produces data which make it possible to gauge water and effluent quality and their changes with time. Water quality data are essential for classification of river and coastal waters into beneficial uses. Data on effluent quality are important for ensuring legal compliance.

As previously mentioned, there exists a comprehensive set of water quality data for Sg. Brunei but none for the other major rivers and coastal waters. The two ongoing water quality monitoring programs for coastal waters are each confined to a relatively small area and for a very specific purpose. The Sewerage Section of PWD is monitoring Serasa Bay east of the sand spit (Fig. 3) to gather baseline data before commissioning the Muara STW. The DOF is monitoring selected water quality parameters of Brunei Estuary and the coastal waters off Muara as part of the ongoing red tide watch program.

The Sewerage Section of PWD is monitoring the quality of sewage effluents from STWs/STPs. The BSP is also monitoring a number of locations (BSP 1989). Of particular importance are the daily monitoring for oil content of holding basin discharges from the tank farm at Seria and the quarterly monitoring of the quality of sewage at the Sg. Belait discharge point. Other than those mentioned in PWD (1987a, 1987b), there are no monitoring data on effluent quality of non-oil-based industries, though admittedly the pollution load currently contributed by these industries is not significant.

Management Strategies and Actions

Domestic waste management

Sewage Treatment and Disposal. Due to its location and the significant BOD and bacterial loads being discharged into the Brunei Estuary area, the Pintu Malim STW should be upgraded to provide secondary treatment of domestic waste to achieve the effluent quality of 20 mg/l BOD and 30 mg/l SS. Maturation ponds for effective fecal bacteria reduction must also be installed.

Several STWs sited along the South China Sea coast discharge treated effluents into the sea. Because of the proximity of these STWs to recreational areas, it is recommended that long submerged sewage outfalls be built to convey and discharge treated effluents far out from shore for rapid dilution and dispersal, thus reducing the risk of water quality degradation.

Direct discharge of domestic waste to watercourses still constitutes a very significant proportion of the means of waste disposal in Brunei Darussalam. These are normally rural and semi-rural areas where sewerage is economically not justified. The government should initiate an education program for residents on the importance of hygiene and sanitation and provide incentives for the installation of appropriate sewage treatment facilities. Where the water table is low and soil characteristics are suitable, septic tanks should be the treatment system since it is simple and economical.

Septic tanks and similar private sewage treatment facilities should be regularly inspected by the relevant authorities to ensure proper working order and adequate treatment. Specifically, a regular desludging service should be introduced as a long-term measure.

Sewage sludge should be treated so that it can be disposed of with minimal adverse environmental impacts. The most commonly used treatment method involves anaerobic digestion of the sludge which converts some of the organic matter to gaseous end products. The digested sludge can be used as a soil conditioner or disposed of in some suitable landfill.

Waste Management for Kg. Ayer. Since Kg. Ayer as a single source contributes 10% of the total BOD load discharged into waterways, it is imperative to treat its domestic wastes. The Kg. Ayer waste management study (PWD 1986) has recommended a sewerage system which will collect and convey primarily toilet wastes (human feces and urine) from areas located north of Sg. Brunei for treatment at Pintu Malim STW and wastes from south of Sg. Brunei to be treated at a new treatment facility in Lumapas. Sullage water will not be treated as it is contended that the bulk of BOD and bacterial loads comes from toilet wastes. Transport

of collected wastes from dwellings to treatment facilities will be by a combination of gravity, pressure and vacuum systems.

The proposed sewerage scheme will make possible complete cessation of direct discharge of toilet wastes into Sg. Brunei and Sg. Kedayan. As a consequence, the pollutant load will be effectively reduced, the water quality of the two rivers will improve and potential health problems associated with activities in Kg. Ayer (e.g., fishing, swimming, and house construction and maintenance) will be diminished. These improvements will certainly have a positive impact on fishing activities in Sg. Brunei and tourism.

Industrial development

Classification of Industries. Based on their potential for causing pollution, industries should be classified into: (1) light (nonpolluting), (2) general (polluting) and (3) special (highly polluting). De Silva and Taha (1990) and De Silva et al. (this vol.) identify the various types of industries under these three groups and recommend classification guidelines and a screening procedure (including a questionnaire).

Siting and Zoning of Wastewater-Producing Industries. Sites for wastewater-producing industries should be away from areas where the requirement for good water quality is essential (e.g., aquaculture and ecologically sensitive areas). It is recommended that no polluting industries be allowed in the Sg. Brunei catchment basin and estuarine area. Heavy and polluting coastal industries should be concentrated on fixed areas rather than be allowed to spread so that less of the coast is affected. It may be desirable to locate new industries in areas with existing industrial development or other land alteration provided that adjacent areas are not ecologically vulnerable. For example, shoreline location which has been used as a refuse disposal site may safely be developed for industrial use. Siting alternatives should be incorporated in an EIA for any proposed industrial development.

Green spaces at least 50 m wide should be provided between zones. Within an industrial estate, similar types of industries (e.g., food industries) should be sited in the same zone so that centralized wastewater treatment facilities can be set up. It will not be economically viable for small-scale industries to provide their own treatment facilities.

Industrial Waste Treatment. Industries should provide treatment facilities, either private or centralized systems, to ensure that effluents discharged into the environment are properly treated. Since the composition of industrial wastewater is typically different from that of domestic sewage, it is better to avoid treating industrial waste together with sewage in STWs. Some pollutants in raw industrial wastewater may pass through STWs unchecked. Industrial wastewater may contain sufficiently high concentrations of toxic substances to "poison" microorganisms in biological processes and, as a result, reduce the treatment efficiency of STWs. If industrial wastewater is to be treated in STWs, pretreatment processes must be introduced to remove all pollutants that will not be completely eliminated by STWs or may interfere with biological treatment processes.

Land development measures

Brunei Darussalam has a high annual rainfall with an average of over 2,800 mm/year. Rains commonly come in the form of thunderstorms with rather high intensity. This type of rainfall always brings about accelerated erosion of exposed land if proper control measures in land development are not taken. Two categories of erosion and sediment control measures suggested are vegetative and mechanical control (PWD 1987a). Vegetative control involves provision of vegetated buffer strips to trap sediments, and temporary cover using rapidly growing plants (such as small grains and grasses) to protect cleared areas against erosion. Mechanical control includes the use of detention basins to trap sediments and reduce runoff peaks, as well as construction of diversions or troughs to intercept and divert runoff around exposed areas. Another category not mentioned in PWD (1987a) which may prove to be effective is administrative control. This includes restriction of earthwork activities to drier months and imposition of limits on cleared land area and duration of exposure.

Development and implementation of a national oil spill contingency plan

The primary objective in responding to an oil spill is to minimize environmental damage by limiting the spread of oil and removing it from the water. Development and implementation of a national oil spill contingency plan requires the following information for contingency planning and emergency response: existing marine meteorological, marine ecological and physical oceanographic data; inventory of likely oil pollution sources; inventory of coastal sensitive areas where oil spill impact may be critical; possible oil trajectories in case of oil spill; procedures for identification, containment, dispersal, removal and disposal of oil and haz-

ardous substances; and inventory of response equipment and materials in the country and the region.

Development of the contingency plan requires a multidisciplinary team consisting of one or more marine ecologist(s), meteorologist(s), chemist(s), oceanographer(s), petroleum engineer(s) and others in related fields. These specialists are usually found in universities, research institutions, consultancy firms and the petroleum industry. However, plan implementation involving field operations such as spill containment and cleanup requires personnel with special training and experience. Considering the extensive experience of the petroleum industry in the development of oil spill contingency plans and control operations, the expertise and response resources of BSP should be fully utilized.

Legal framework

Environmental Laws and Discharge Standards. None of the laws of Brunei Darussalam on water quality and pollution specifically addresses the protection of water quality. Further, legally enforceable discharge standards are yet to be made under these laws. Since existing laws are not effective legal instruments to protect environmental quality, it is timely to enact a law specifically for the protection of the country's waters. The proposed law, to be entitled "Prevention of Water Pollution Act" as suggested in PWD (1987a), should be administered by one government agency. It is recommended that regulations with prescribed discharge or effluent standards be made under the new act for a more effective and unambiguous control of water pollution.

The PWD (1987a) has proposed four standards for direct discharges to the environment, each of which applies to a different situation, as follows: (1) discharge to inland watercourses affecting a potable water abstraction point; (2) discharge to inland watercourses at a point not influencing abstraction of potable water; (3) discharge to the estuary; and (4) discharge to the sea. Given various constraints (such as lack of laboratory facilities, skilled manpower and monitoring data), a simplified approach using only the first two standards is proposed. In this connection, discharge standards recommended by PWD (1987a) were modified (Table 14) for possible adoption by the government. However, amendments should be made from time to time to make the standards more responsive and effective in controlling water pollution.

Institution of EIA. The EIA, resource planning and regulatory control are the most effective tools for environmental management. The objectives of EIA are to: examine alternatives and select the best for a proposed development; identify and predict the potential significant environmental impacts; recommend appropriate mitigation measures; and identify the environment costs and benefits of the proposed development. Thus, EIA is essentially a preventive process which seeks to avoid or minimize harmful environmental effects of a proposed activity or development.

In view of Brunei Darussalam's industrialization drive, it is timely to pass regulations mandating EIA, together with the discharge standards, to safeguard the environment in the process of development. The EIA regulations should include, among others, a schedule of the activities requiring an EIA and a procedure for preparing an EIA which is tailored specifically to the country's needs. In the interim, EIA procedures adopted by some ASEAN members can be used (see Alcances et al. 1983 and references therein).

Institutional arrangement

Currently, no single agency in Brunei Darussalam has the sole responsibility for environmental matters, including enforcement of environment-related laws. Such responsibility rests with different ministries, departments and units. Undoubtedly, the existing institutional arrangement is not conducive to an effective implementation of water quality management measures, among others. If a new environmental law (with accompanying regulations and standards) for the protection of Brunei's environment and waters is promulgated, then the creation of a single environmental authority with a capable water quality unit is necessary, with the following jurisdiction and responsibilities: monitor regularly the quality of rivers and coastal waters, and effluents from STWs/STPs, industries and other point sources; enforce the proposed environmental law, regulations and standards related to water quality; provide advice in preparing EIAs and set up a panel to review the EIA for a proposed development; implement the oil spill contingency plan; and serve as the lead agency in fostering better cooperation and coordination among government departments in water pollution control. It has been suggested (see Tobin, this vol.) that the environmental authority be placed under the Prime Minister's office to be assured of effective political support and an independent base of authority. Recommended staff composition for the proposed water quality unit, when fully operational, is presented in Table 15.

Table 14. Proposed effluent/discharge standards for Brunei Darussalam.

Parameter	Discharge area	
	Affects potable water abstraction	Does not affect potable water abstraction
pH	6-9	6-9
Temperature (°C)	40	40
Color	No change	Not objectionable
BOD_5	20	20
Chemical oxygen demand (COD)	150	150
SS	30	30
Total dissolved solids	2,000	2,500
Aluminum (as Al)	5	5
Arsenic (as As)	0.1	0.5
Barium (as Ba)	2	5
Beryllium (as Be)	0.5	1
Cadmium (Cd)	0.05	0.1
Chromium (as Cr^{3+})	0.5	1
Chromium (as Cr^{6+})	0.1	0.2
Chloride (as Cl^-)	500	750
Free chlorine (as (Cl_2)	0.5	0.5
Cobalt (as Co)	0.1	0.2
Copper (as Cu)	0.5	0.5
Cyanide (as CN^-)	0.1	0.2
Synthetic detergents	1	1
Fluoride (as F^-)	1.5	2
Grease and oil	2	5
Hydrocarbons (as HC)	5	5
Iron (as Fe)	1	5
Lead (as Pb)	0.1	0.5
Lithium (as Li)	5	5
Manganese (as Mn)	1	5
Mercury (as Hg)	0.005	0.005
Molybdenum (as Mo)	0.5	1
Ammonia nitrogen (as NH_3-N)	5	50
Nickel (as Ni)	0.2	0.5
Nitrate nitrogen (as NO_3-N)	10	20
Nitrite nitrogen (as NO_2-N)	0.5	1.0
Total nitrogen (as N)	50	50
Phenols	0.1	0.5
Total phosphorus (as P)	30	30
Radioactive material	In accordance with limits and regulations laid down by the International Atomic Energy Agency.	
Selenium (as Se)	0.05	0.1
Sulfate (as SO_4^{2-})	200	400
Sulfide (as S^-)	0.5	1
Vanadium (as V)	0.1	0.2
Zinc as (Zn)	1	2

All limits are given in mg/l except pH, temperature (°C), color and radioactive material.
Source: Modified from PWD 1987a.

Environmental monitoring program

A monitoring program on the water quality of major rivers (i.e., Brunei, Tutong, Belait and Temburong) and coastal waters as well as the effluent quality from major point sources (STWs/STPs, septic tanks and industries) need to be instituted. The basic parameters to be monitored are summarized in Table 16. The recommended monitoring frequencies are: weekly for STWs/STPs, septic tanks and coastal waters, and monthly for industries and rivers. Water quality monitoring stations (WQMS) for Sg. Brunei have already been identified in PWD (1987b) and Yau (1991) (see Fig. 2). This CRMP study has also identified WQMS for Sg. Tutong, Sg. Belait, Sg. Temburong and the coastal waters (see Fig. 4). As the monitoring program progresses, new WQMS may be added if necessary.

Table 15. Recommended staff composition for the water quality unit under the proposed environmental authority.

Staff	River and coastal water monitoring	Source monitoring	EIA	Oil spill contingency plan	Enforcement	Laboratory analysis	Total
Head	-	-	-	-	-	-	1
Senior executive officer	1	1	1	1	1	-	5
Chemist	-	-	-	-	-	2	2
Technician[a]	1	1	-	2	-	1	5
Inspector[b]	-	-	-	-	2	-	2
Laboratory assistant[c]	-	-	-	-	-	4	4
Field assistant	2	2	-	-	-	-	4
Clerk/typist	-	-	-	-	-	-	2

[a]Supervised by a senior executive officer or chemists.
[b]Supervised by a senior executive officer.
[c]Supervised by chemists.

Table 16. Basic parameters to be monitored for various sources and receiving waters.

Source/receiving water	BOD	COD	SS	VSS	NH_3-N	NO_3-N	NO_2-N	TP	Cl^-	Temperature	pH	TC	FC	HC	Heavy metals
STWs/STPs	x	x	x	x	x	x	x	x	x	x	x	x	x	+	+
Septic tanks	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-
Industrial wastewaters	x	x	x	-	+	+	+	+	+	x	x	-	-	+	+
Watercourses (rivers)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	+
Coastal waters	-	-	x	-	-	-	-	-	-	-	-	x	x	x	-

x = Routine analysis.
+ = Analysis only if suspected to be present.
- = Analysis not required.

At present, several government laboratories attached to various departments are equipped for specific functions, but are fully utilized. New laboratory facilities have to be provided specifically to conduct environmental monitoring and enforce proposed discharge standards, and be capable of determining all the parameters listed in Table 16. The new facilities should be placed under the proposed environmental authority.

References

Alcances, R.P., A.D.D. Supetran and M.B. Anderson. 1983. Environmental impact assessment handbook. National Environmental Protection Council, Quezon City, Philippines.

BSP (Brunei Shell Petroleum). 1989. Environmental management plan 1989-1993. Brunei Shell Petroleum Co. Sdn Bhd., Seria, Brunei Darussalam.

De Silva, M.W.R.N. and H.M.T. Sabri. 1990. Environmental consideration for new industries. Department of Fisheries, Ministry of Industry and Primary Resources, Brunei Darussalam. (Unpublished).

DOE (Department of Environment). 1986. Water quality criteria and standards for Malaysia. Final Report. Department of Environment, Malaysia.

DOTCP (Department of Town and Country Planning). 1986. Negara Brunei Darussalam Master Plan. Background Paper 16: sanitation and sewerage. Department of Town and Country Planning, Ministry of Development, Brunei Darussalam.

Kuntjoro, K.D. 1987. Population profile, p. 67-78. *In* T.E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Loo, M., L. Hsu and J. Paw. 1987. Physical environment, p. 5-27. *In* T.-E. Chua, L.M. Chou and M.S.M Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

NPCC (National Pollution Control Commission). 1978. Rules and regulations of the National Pollution Control Commission. NPCC, Manila, Philippines. Off. Gaz. 74(23): 4453-4486.

PWD (Public Works Department). 1986. Kampong Ayer Waste Management Study. Final Report. Prepared by Scott and Furphy Consulting Group. Public Works Department, Ministry of Development, Brunei Darussalam.

PWD (Public Works Department). 1987a. National Water Quality Standards Study. Draft Final Report. Public Works Department, Ministry of Development, Brunei Darussalam.

PWD (Public Works Department). 1987b. Sungai Brunei Water Quality and Pollution Study. Final Report. Public Works Department, Ministry of Development, Brunei Darussalam.

USEPA (United States Environmental Protection Agency). 1976. Quality criteria for water. United States Environmental Protection Agency, Washington D.C.

WHO (World Health Organization). 1978. Global environmental monitoring system: water operational guide. World Health Organization, Geneva.

Yau, K.H. 1990. Review of water quality of Sungai Brunei. Sewerage Section, Public Works Department, Brunei Darussalam. (Unpublished).

Yau, K.H. 1991. Water quality of Brunei River and estuary, p. 189-193. *In* L.M. Chou, T.-E. Chua, H.W. Khoo, P.E. Lim, J.N. Paw, G.T. Silvestre, M.J. Valencia, A.T. White and P.K. Wong (eds.). Towards an integrated management of tropical coastal resources. ICLARM Conference Proceedings 22, 455 p. National University of Singapore, Singapore; Science Council of Singapore, Singapore; and International Center for Living Aquatic Resources Management, Philippines.

Benthos Composition and Diversity in the Coastal Waters of Brunei Darussalam

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Abstract

A total of 165 genera of benthos was identified from the coastal waters of Brunei Darussalam with major phyla consisting of Polychaeta, Mollusca, Arthropoda, Nematoda, Echinodermata and Protozoa. The dominant group was Polychaeta contributing 103 genera or 62.4% of the total. The most common polychaetes were from the families Capitellidae, Eunicidae, Glyceridae and Spionidae.

The abundance of benthos was significantly higher at subtidal stations of 5 m than those of 0, 1, 2 and 3 m, and benthos diversity was highly correlated to the sediments. There was an obvious decreasing diversity gradient from 5 around Brunei Estuary to 2-3 along a stretch of beaches from Tutong to Berakas as compared to 1 at Seria, the major oil terminal in the country. The Brunei Estuary transects had high Shannon-Wiener diversity indices, an indication of sediment enrichment by organic matter. Mangrove habitats were similarly rich in benthos. Transects which had sandy substrata with low organic matter had low diversity.

Introduction

Brunei Darussalam is an oil-producing nation and part of its exclusive economic zone (EEZ) lies within the major tanker shipping route between the Far East and the Indian Ocean. Increasing oil extractions are taking place offshore at 10- to 60-m depth in Brunei Darussalam (Chua et al. 1987) and other countries in the region. Despite advances in loading and unloading designs and procedures for oil tankers and oil extraction installations (Abecassis 1976), oil spills and related environmental disasters occur along the major tanker routes of the world. In the event of an oil spill, available information on the chemical and physical properties of the oil, methods of disposal, aquatic resources, habitats and amenities in the vicinity of the spill site, among others, would be needed (IMO 1980).

Oil spilled on the water surface undergoes several weathering processes, such as evaporation, natural dispersion in the water column and the formation of mousse and tar balls. A tiny fraction dissolves in the water but a substantial amount drifts with the current and eventually pollute beaches and sediments in shallow waters (Fingas et al. 1979). By virtue of their adaptation to intertidal and subtidal habitats, benthos may be used as indicator organisms to evaluate the biological impact of oil spills.

Mackay et al. (1982) estimate the theoretical depth or "diffusion floor" of dispersed oil at 10 m of the aqueous medium. In the natural environment, however, oil penetrates only to a depth of about 3 m. Thus, the present study is confined mainly to the shallow coastal waters of Brunei Darussalam. In fact, most of its mangrove-fringed estuaries are not more than 5 m deep.

On a sensitivity index scale of 1-10 for coastal habitats, Gundlach and Hayes (1978) rank mangrove

swamps as the most vulnerable (10) and rocky shores and sandy beaches as the least sensitive (1). This index is of course biased towards aquatic resources and gives less weight to contamination of beaches and related amenities. Lai and Feng (1984) report on the impact of various petroleum products on mangrove fauna and flora.

This study aims to assess the composition and diversity of the benthic fauna in the intertidal and subtidal zones of Brunei Darussalam as an input in the formulation of an oil spill contingency plan.

Materials and Methods

Sampling sites

Ten transect lines (X, Y, Z, P, Q, R, S, T, U and V) were established along the coast of Brunei Darussalam (Fig. 1). Each transect line consisted of three to five sampling stations depending on the water depth. In places where the water depth exceeded 5 m, five sampling stations were used, e.g., Y0, Y1, Y2, Y3 and Y5. The number following the letter denotes the depth of water (m). This means that the first three stations were intertidal while the last two were subtidal based on a tidal range of 2.7 m at Muara Harbour.

Transects X (south of Kampong [or Kg., i.e., village] Pelompong), Y (west of Pulau [or P., i.e., island] Muara Besar) and Z (east of Kg. Batu Marang) were located in the vicinity of Muara Harbour while Transects P (off Berakas) and Q (off Jerudong) were exposed sandy habitats fringing the South China Sea coast. Transect R was situated on the north coast of Tanjong (or Tg., i.e., cape) Danau in the lower reaches of Sungai (or Sg., i.e., river) Tutong while Transect S was a mixed mangrove-*nipah* swamp opposite P. Selawat about 2 km upstream. Transects T (west coast of P. Pepatan) and U (Tg. Selirong) were also shallow mangrove habitats at the mouths of Sg. Manunggul and Sg. Selirong, respectively, while Transect V was sited on the north coast of P. Siarau west of Sg. Temburong.

A quadrant of 0.33 m^2 was randomly laid on the beach at the first station of every transect. Three random soil samples were collected down to a depth of about 10 cm within the quadrant. All the samples were pooled and sieved with two layers of 5-mm and 0.2-mm sieves. Benthos retained by the 5-mm sieve were preserved in 4% formaldehyde. The partially sorted sample in the 0.2-mm sieve was kept in a three-layered plastic bag, preserved in 4% formaldehyde and dyed with a few crystals of Rose Bengal for sorting in the laboratory.

The remaining intertidal and subtidal samples were collected with a 15-cm^2 Edmund-Berge grab. Five random samples were collected from each station. These samples were pooled and treated similar to those from the first station of every transect. In addition to the ten transects sampled in June 1989, data from an eleventh transect (marked L in Fig. 1) done by Leong et al. (1984) were also used in this study.

Identification of benthos

Benthos were sorted out in the laboratory under a dissecting microscope. Identification of benthos, mostly to the generic level, followed various keys, as follows: Day (1967) and Fauchald (1977) for polychaetes; Lincoln (1979) for amphipods; Naylor (1972) for isopods; Lovett (1981) for decapods; Tetsuaki (1962), Tadashige (1964) and Morris (1973) for molluscs; and Clark and Rowe (1971) for echinoderms. In the case of molluscs, only specimens with internal organs clearly dyed with Rose Bengal were counted. Fragments or empty shells were ignored to minimize allochthonicity in the counts. For fragmented polychaetes, only those with head segments were identified and counted. Specimens of obscure affinities were also dissected and mounted on polyvinyl lactophenol for further examination. All nematods and nemerteans were collectively counted as such due to uncertainties in identification.

The counts were expressed as number/0.1 m^2, i.e., the total area of soil (after pooling) sampled by the Edmund-Berge grab. If the specimens were estimated to be too abundant, the pooled samples were divided into two portions. Only one portion was sorted for counting and identification and the counts were raised accordingly. Following enumeration, an analysis of variance (ANOVA) of benthos versus transects and sampling stations was done. Data files for computation included four variables, namely, transects (1-10), sampling stations (1-5), types of benthos (1-165) and counts.

Diversity, dominance and similarity of benthos

Diversity of the benthic fauna was assessed using three indices (Dick 1976), namely:

Shannon-Wiener index

$$H = \Sigma p_i \log_2 p_i$$

where

$p_i = n_i/N$,

n_i = number of that particular species and

N = total number of individuals of all species.

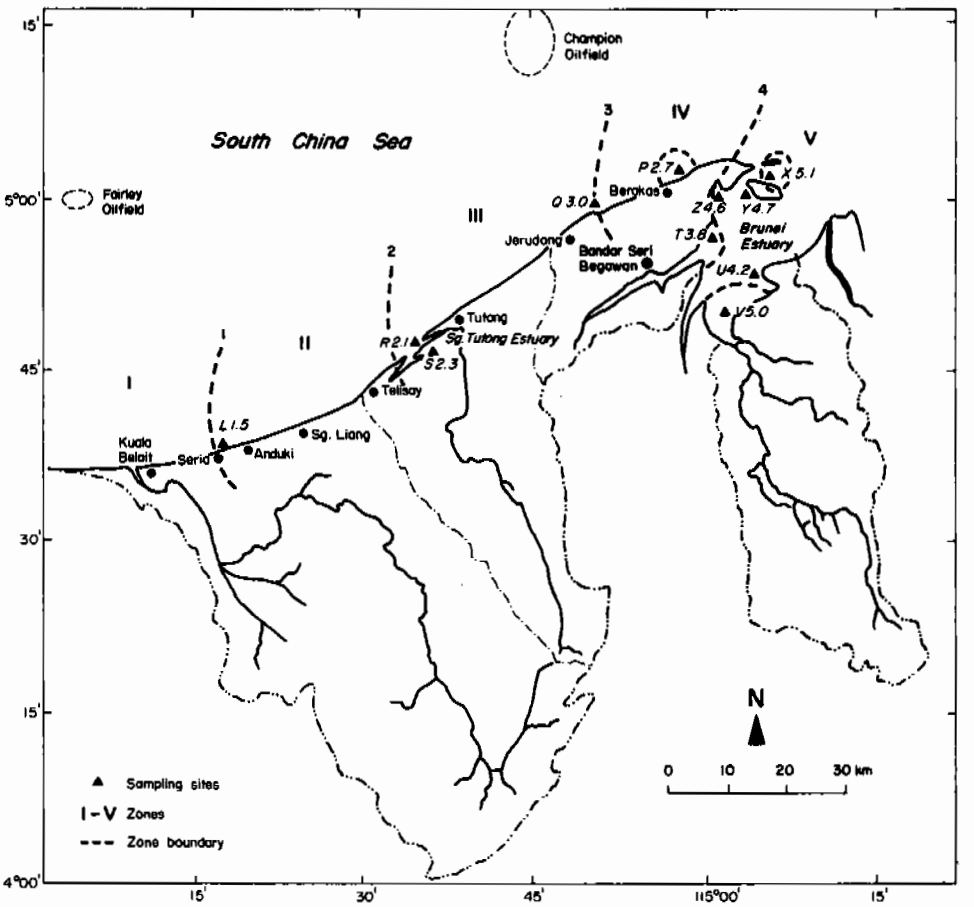

Fig. 1. Sampling sites in Brunei Darussalam. Each site in the form of a transect consists of 3-5 sampling stations. Numbers refer to Shannon-Wiener diversity indices.

Gleason index

$$D = (s - 1)/\log_e N$$

where

s = number of species and
N = number of individuals.

Menhinick index (Menhinick 1964)

$$D = s/(N)^{1/2}$$

where

s = number of species and
N = number of individuals.

These three indices were then compared using Spearman's rank correlation procedure (Zar 1984).

Species dominance in the various transects was assessed with the Simpson index (Odum 1975):

$$D = 1 - \Sigma(p_i)^2 \cdot F$$

where

p_i = % of a particular species and
F = number of species having the same probability p_i.

The dominance of certain groups/species in a habitat is frequently expressed as 1-D, which implies that if its value is low, then certain groups dominate.

The evenness index was also evaluated (Odum 1975):

$$E = H/\log_2 s$$

where

H = Shannon-Wiener index and
s = number of species.

The occurrence of benthos over a wider range of habitats was compared with the Sørenson similarity index (Odum 1975):

$$S = 2C/(A + B)$$

where

A = number of species in transect 1,
B = number of species in transect 2 and
C = number of species in both transects.

Soil analysis

Particle size analysis was done with the hydrometer method (Day 1965) using sodium hydroxide instead of Calgon solution. Soil samples weighing 40 g were oven-dried at 105°C to constant weight and 100 ml of H_2O_2 was added and allowed to stand overnight. The mixture was soaked in 1 N NaOH for 10 minutes. The volume was filled up to 1 l in a measuring cylinder with distilled water and thoroughly mixed. Hydrometer readings were taken at 0.5, 1, 3, 10 and 30 minutes, and 4, 12, 24 and 48 hours after mixing.

The percentage of particle size was determined from a plot of P versus X values:

$$P = 100 \cdot (C/C_o)$$

where

$C = R - 1$

C_o = the oven-dried weight of the soil in 1 l of suspension and

R = the hydrometer reading.

$$X = O/(t)^{1}/_{2}$$

where

O = sedimentation parameter and

t = sedimentation time in minutes.

Only three fractions, namely, sand (>20 μ), silt (2-20 μ) and clay (2 μ) were considered in this analysis. The soil types were then determined according to the United States Department of Agriculture soil texture triangle (Kohnke 1968).

Organic matter was determined by the Walkey-Black method (Black et al. 1965). The air-dried soil was ground, sieved through a 0.5-mm mesh and 10 ml of 1 N $K_2Cr_2O_7$ was added to 0.5 g of this soil. Then 20 ml of concentrated H_2SO_4 containing Ag_2SO_4 was quickly added and allowed to stand for about 20 minutes, followed by 200 ml of distilled water. This mixture was titrated with 0.5 N $FeSO_4$ using o-phenanthroline as indicator.

Results

Benthos composition and distribution

A total of 12 phyla and 165 genera of benthos was found in the coastal habitats of Brunei Darussalam (Table 1), stretching for 100 km from Sg. Tutong Estuary in the west to Sg. Temburong in Brunei Estuary (Inner Brunei Bay). The major phyla included Polychaeta, Mollusca, Arthropoda, Nematoda, Echinodermata, Protozoa and unsegmented worms such as Nemertea, Brachiopoda, Sipunculata and Nematomorpha.

The bulk of the benthos consisted of polychaetes of 103 genera (in 29 families) or 62.4% of the total genera encountered. The most common families, Capitellidae, Eunicidae, Glyceridae and Spionidae, occurred mainly in sediments of most transects rich in organic matter. Some congeneric species observed included 2 species each for *Ancistrosyllis*, *Aricidea*, *Glycera*, *Neonotomastus*, *Lysilla*, *Lumbrineris*, *Sternaspis* and *Ceratonereis*, 3 for *Prionospio*, 4 for *Nephtys* and 5 for *Nereis*. But these congeneric species were treated as one unit (genus) for statistical analyses. Loo et al. (1987) also listed 21 benthos species in Serasa Bay, 17 in the lower reaches of Sg. Temburong and 10 in the vicinity of Sg. Tutong, though most of the species were unidentified.

A total of 31 genera of Crustacea was accounted for in the soil samples. Among them were 4 main orders, namely, Amphipoda (comprising 14 genera), Isopoda (5), Decapoda (7-8) and Tanaidacea (3).

Only 18 genera of Mollusca were recorded of which 10 were Bivalvia, 7 Gastropoda and 1 Scaphopoda.

Four genera of Echinodermata were observed but their numbers were very small and restricted to transects in Brunei Bay and Temburong Estuary.

Nematoda were particularly abundant in Transects X, Y, Z and U located in the western portion of Brunei Estuary (Inner Brunei Bay).

Abundance of benthos

The two-way ANOVA showed an interaction between sampling stations and transects in influencing the benthos counts ($p<0.05$). Individually, these two factors differ in that the abundance of benthos was not significantly different among the transects ($p>0.05$) but was otherwise ($p<0.05$) at various sampling stations (water depths). The latter result was further reinforced by Duncan's t-test (Table 2) which showed that the abundance of benthos at the subtidal stations of 5 m was significantly higher ($p<0.001$) than those of 0, 1, 2 and 3 m.

Nevertheless, being less stringent (since counts from all stations for each transect were pooled), Duncan's test (Table 3) revealed that Transect R was significantly different ($p<0.05$) from the sandy Transects P and Q and Transects X and Z, but was not significantly different ($p>0.05$) from Transects T, U, S, Y and V.

Based on the pooled mean counts there appeared to be two distinct substrata within Brunei Estuary itself, viz., X, Z, T and U on one part (with lower mean

counts) and V and Y on the other (higher mean counts). This may be attributed to the highly diverse and complex soil substrata in the Brunei Estuary area, of which the first four habitats consisted mainly of sandy loam while the latter two were made up of loamy sand (Table 4).

The one-way Duncan test (Table 5) also revealed that *Cossura* and *Ctenodrilus* were significantly ($p<0.0001$) more abundant than the other benthos, based on 42 compressed generic clusters. These two dominant genera occurred mainly in Transects R and S with low salinity.

Benthos diversity

The Shannon-Wiener diversity index which favors the rare genera fluctuated from about 2-3 at Transects P, Q, R and S to approximately 4 and above at other transects (Table 6). The values obtained in the Gleason index (which is biased towards the increase in generic numbers) were higher than those of the corresponding Shannon-Wiener index values. The Gleason index ranged from 2.7 in S to about 3 and sandy habitats P and Q to well above 8 at the estuarine habitats X, Y, U and V while those in the less saline habitats R, T and Z had intermediate values of about 6-7. Being more sensitive to both numerical and generic changes, the Menhinick index was lower, ranging from 1 at Transect S to 4.7 at Transect X.

These three diversity indices appeared to have the same order of ranking except Transect R which gave a high Gleason but low Shannon-Wiener and Menhinick index values. Spearman's rank correlation test showed that the Shannon-Wiener index was positively correlated to both the Gleason ($p<0.02$) and the Menhinick ($p<0.001$) indices (Table 6). This suggested the adequacy of using the three indices to describe the benthos distribution and abundance in the study areas. Similarity in ranked values of the three indices is attributed to the wider geographical range covered in this study.

There was a steep diversity gradient (Table 6) from the apex center in the vicinity of Muara Harbour (Transects X, Y, Z, T and U) or near the mouth of Sg. Temburong (V) through the less diversified sandy shoreline habitats at Berakas (P) and Jerudong (Q), and riverine ones at Tutong (R and S), to the least diversified polluted habitats in the vicinity of Seria (L) (Fig. 1).

Dominance and evenness

Dominance of benthos, as defined by a low value (≤0.85) of the Simpson dominance index (1-D), was not apparent in most transects except P, Q, R and S (Table 6). These were characterized by a few dominant genera such as the amphipod *Urothoe* and isopod *Eurydice* in transects P and Q, and polychaetes *Heteromastus/Parheteromastus/Ctenodrilus* or *Cossura/Ancistrosyllis* in the varied loamy but less saline Transects R and S. The remaining transects had high values which ranged from 0.88 to 0.96. In essence, the higher the values of 1-D, the less likelihood that the habitat is dominated by a few groups and vice versa.

A high 1-D index value goes hand-in-hand with a high evenness index. Calculated evenness index generally agreed with the Simpson dominance index except Transects Q and R (Table 6). Transect Q was characterized by a low number of genera which were not clumped, hence a low Simpson index (0.59) but a high evenness index (0.9). Conversely, Transect R was dominated by a few rare genera such as the polychaetes *Heteromastus, Parheteromastus* and *Ctenodrilus* confined mainly to stations 3 and 5, though the total number of genera was high.

Similarity

There were three main transect clusters, namely, X, Y and Z; R, S, T, U and V; and Q and P at the 26% similarity level in the intertidal and subtidal habitats of Brunei Darussalam (Fig. 2). All the transects in the entire project area may be linked at the 10% similarity level.

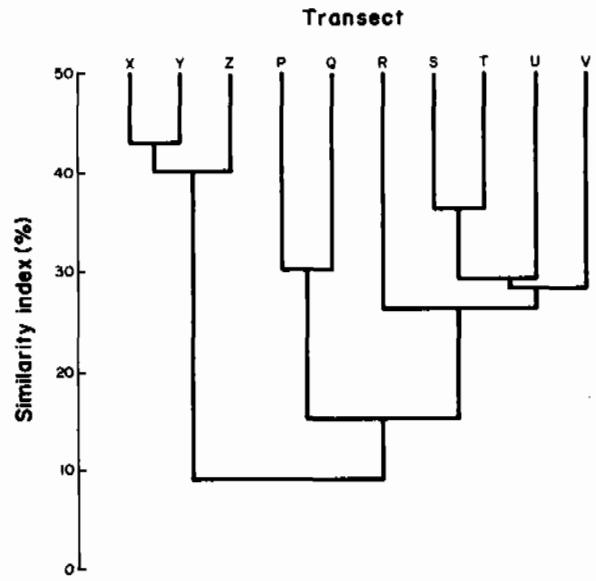

Fig. 2. Benthos similarity index of the various transects.

Table 1. Number of benthos/0.1 m^2 at each station of the 10 transects. The number following the letter refers to the water depth (m).

Benthos	Station X0	X3	X5	Y0	Y1	Y2	Y3	Y5	Z0	Z1	Z3	P0	P1	P3	P5	Q1	Q3	R0	R1	R2	R3
Polychaeta																					
Ampharetidae																					
Ecamphicteris	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Isolda	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
Melinna	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphinomidae																					
Pseudeurythoe	-	1	-	-	2	5	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paramphinome	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aphroditidae																					
Parahalosydna	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paralepidonotus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Malmgrenia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scalisetosus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polyodontes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pholoe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Sthenelais	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-
Capitellidae																					
Capitella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Capitomastus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Heteromastus	-	3	-	-	-	2	-	2	2	-	-	-	-	-	-	-	-	-	3	2	89
Mediomastus	-	-	-	-	-	1	-	-	4	2	-	-	-	-	-	-	-	-	-	-	-
Neontomastus	-	2	2	-	-	6	2	-	-	-	2	-	-	-	-	-	-	-	-	-	-
Neomediomastus	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Parheteromastus	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	7
Cirratulidae																					
Tharyx	-	2	-	-	-	10	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cirriformia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cossuridae																					
Cossura	-	-	-	-	-	-	1	2	-	-	10	-	-	-	-	-	-	-	-	-	1
Ctenodrilidae																					
Ctenodrilus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eunicidae																					
Arabella	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
Drilonereis	-	-	-	-	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Dorvillea	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Protodorvillea	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Ophryotrocha	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eunice	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Marphysa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lumbrineris	-	5	2	-	-	11	4	8	2	-	2	-	-	-	-	-	-	-	-	-	6
Ninoe	-	1	-	-	-	7	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diopatra	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-
Epidiopatra	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Onuphis	-	-	-	-	-	1	-	-	2	-	-	-	-	-	-	-	-	-	-	-	1
Flabelligeridae																					
Flabelligera	-	-	1	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-
Glyceridae																					
Glycera	-	-	-	-	2	2	1	6	-	-	-	-	-	-	2	-	1	-	2	2	-
Glycinde	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Goniada	-	-	-	-	2	6	2	-	2	-	-	-	-	-	-	-	-	-	-	-	-
Goniadella	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
Progoniada	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hesionidae																					
Micropodarke	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17	-	-
Ophiudromus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lacydonidae																					
Paralacydonia	-	4	-	-	4	7	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Magelonidae																					
Magelona	-	-	-	-	-	1	2	-	-	-	5	-	-	-	-	-	1	-	-	-	-
Maldanidae																					
Clymenella	-	-	-	-	-	1	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
Euchymene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unidentified maldanid-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Continued

Table 1 (continued)

Benthos	Station R5	S0	S1	S2	S3	T0	T1	T2	T3	T5	U0	U1	U2	U3	U5	V0	V1	V2	V3	V5	Total
Polychaeta																					
Ampharetidae																					
Ecamphicteris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Isolda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Melinna	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Amphinomidae																					
Pseudeurythoe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9
Paramphinome	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Aphroditidae																					
Parahalosydna	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	4
Paralepidonotus	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1
Malmgrenia	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	2
Scalisetosus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Polyodontes	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Pholoe	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	7
Sthenelais	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
Capitellidae																					
Capitella	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	5
Capitomastus	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Heteromastus	62	-	-	-	2	-	-	-	-	-	-	11	2	-	1	-	-	-	6	1	188
Mediomastus	-	1	-	4	2	-	-	-	-	-	-	3	-	1	-	-	-	-	-	-	18
Neomediomastus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14
Neomediomastus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Parheteromastus	47	-	-	6	2	-	-	-	2	-	-	-	1	-	-	-	-	-	9	-	78
Cirratulidae																					
Tharyx	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13
Cirriformia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	3
Cossuridae																					
Cossura	-	4	-	-	136	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	155
Ctenodrilidae																					
Ctenodrilus	149	-	-	-	-	4	-	4	2	-	-	-	-	-	-	-	-	7	2	-	168
Eunicidae																					
Arabella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	4
Drilonereis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Dorvillea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	4
Protodorvillea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Ophryotrocha	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	3
Eunice	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Marphysa	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
Lumbrineris	-	-	-	-	1	-	1	-	-	-	-	-	-	1	1	-	-	-	-	4	48
Ninoe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
Diopatra	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	4
Epidiopatra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2
Onuphis	-	-	-	-	-	-	-	-	-	-	-	2	6	1	-	-	-	-	-	-	13
Flabelligeridae																					
Flabelligera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Glyceridae																					
Glycera	5	-	-	-	-	-	-	-	-	-	-	3	1	-	-	-	-	-	3	2	32
Glycinde	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	2	5
Goniada	1	-	-	-	-	-	-	2	-	1	-	5	3	1	2	-	-	-	1	-	28
Goniadella	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	4
Progoniada	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Hesionidae																					
Micropodarke	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	19
Ophiudromus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Lacydonidae																					
Paralacydonia	-	-	-	-	-	-	1	-	-	1	-	1	1	-	-	-	-	1	1	-	24
Magelonidae																					
Magelona	-	-	-	2	-	1	11	8	6	2	-	2	1	1	-	-	1	-	1	-	45
Maldanidae																					
Clymenella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Euchymene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	5
Unidentified maldanid-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0

Continued

Table 1 (continued)

Benthos	Station X0	X3	X5	Y0	Y1	Y2	Y3	Y5	Z0	Z1	Z3	P0	P1	P3	P5	Q1	Q3	R0	R1	R2	R3
Nephtyidae																					
Nephtys	-	3	-	-	-	9	-	2	-	-	3	-	-	-	-	-	-	-	-	-	2
Micronephtys	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Nereidae																					
Ceratonereis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Dendronereis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Namalycastis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Namanereis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nereis	1	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	34	7
Neanthes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Platynereis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Leonnates	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laeonereis	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Micronereides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Opheliidae																					
Armandia	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Haploscoloplos	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phylo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Orbiniidae																					
Scolaricia	-	1	-	-		1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scoloplos	-	2	-	-	-	-	2	-	-	-	-	-	-	-	-	-	1	-	2	2	9
Nainereis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palmyridae																					
Bhawania	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palmyra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paraonidae																					
Aedicira	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
Aricidea	-	1	-	-	-	7	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
Paraonides	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paraonis	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pectinariidae																					
Pectinaria	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Petta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Phyllodocidae																					
Eteone	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
Eulalia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Protomystides	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pilargidae																					
Ancistrosyllis	-	1	-	-	-	3	-	8	-	-	3	-	-	-	-	-	-	-	-	-	3
Loandalia	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sabellidae																					
Laonome	-	1	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Megaloma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Spionidae																					
Laonice	-	-	-	-	-	-	3	6	-	-	1	-	-	-	-	-	-	-	-	-	-
Polydora	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
Prionospio	-	4	1	-	-	-	-	-	4	2	4	-	-	-	-	-	-	-	1	-	-
Pygospio	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Scolelepis	-	-	-	11	-	-	-	-	-	-	-	-	1	-	-	3	-	-	1	-	-
Spio	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Spiophanes	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Sternaspidae																					
Sternaspis	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Syllidae																					
Alluandella	-	-	-	-	-	-	-	-	2	2	-	-	-	-	-	-	-	-	-	-	-
Exogonella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Exogonides	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Exogone	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Syllis	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amblyosyllis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eusyllis	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pinosyllis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Continued

Table 1 (continued)

Benthos	Station R5	S0	S1	S2	S3	T0	T1	T2	T3	T5	U0	U1	U2	U3	U5	V0	V1	V2	V3	V5	Total
Nephtyidae																					
Nephtys	-	2	12	-	1	2	42	-	-	-	-	-	-	-	-	-	-	1	2	-	81
Micronephtys	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Nereidae																					
Ceratonereis	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	1	4	8
Dendronereis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Namalycastis	-	-	-	-	-	1	-	-	-	2	-	-	-	-	-	-	-	-	-	-	3
Namanereis	-	-	-	-	1	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	3
Nereis	-	-	-	2	-	-	-	-	-	1	-	7	-	2	-	-	-	-	-	-	64
Neanthes	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-	-	-	-	-	4
Platynereis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Leonnates	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	2
Laeonereis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Micronereides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4	5
Opheliidae																					
Armandia	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Haploscoloplos	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1
Phylo	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
Orbiniidae																					
Scolaricia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Scoloplos	19	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	1	2	2	44
Nainereis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Palmyridae																					
Bhawania	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	2
Palmyra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	3
Paraonidae																					
Aedicira	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	4
Aricidea	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	12	-	-	24
Paraonides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2
Paraonis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2
Pectinariidae																					
Pectinaria	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Petta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	3
Phyllodocidae																					
Eteone	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	6
Eulalia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1
Protomystides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Pilargidae																					
Ancistrosyllis	-	1	-	2	40	-	4	-	-	-	-	2	1	-	-	-	-	1	1	2	72
Loandalia	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	3
Sabellidae																					
Laonome	4	-	-	-	6	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	22
Megaloma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Spionidae																					
Laonice	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	3	4	18
Polydora	-	-	-	-	-	-	-	-	-	-	-	-	1	3	-	-	1	-	4	12	23
Prionospio	-	-	-	-	-	-	14	-	-	1	-	-	-	2	3	-	-	1	10	6	53
Pygospio	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Scolelepis	-	-	-	-	-	-	-	-	-	-	-	3	2	1	-	-	-	-	-	-	22
Spio	-	1	-	-	2	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	7
Spiophanes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2
Sternaspidae																					
Sternaspis	-	1	-	-	-	-	2	-	-	-	-	6	-	-	-	-	-	-	1	-	12
Syllidae																					
Alluandella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
Exogonella	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	2
Exogonides	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	3
Exogone	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Syllis	-	-	-	-	-	-	-	-	-	-	-	-	1	3	-	-	-	-	-	-	5
Amblyosyllis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Eusyllis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Pinosyllis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	2

Continued

Table 1 (continued)

Benthos	Station																				
	X0	X3	X5	Y0	Y1	Y2	Y3	Y5	Z0	Z1	Z3	P0	P1	P3	P5	Q1	Q3	R0	R1	R2	R3
Terebellidae																					
Lysilla	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Terebella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Terebellides	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scalibregmidae																					
Hyboscolex	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trochochaetidae																					
Dosima	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poecilochaetidae																					
Poecilochaetus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Crustacea																					
Amphipoda																					
Amphithoe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ampelisca	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Lembos	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Argissa	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hyale	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Urothoe	-	-	-	-	-	-	-	-	-	-	-	-	5	3	-	-	-	-	-	-	-
Jassa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Listriella	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oedicerotid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Arrhis	-	3	1	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monoculodes	-	-	-	27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Periculodes	-	1	-	-	-	2	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Westwoodilla	-	-	-	65	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phoxocephalid	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Isopoda																					
Cyathura	-	3	3	-	-	7	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Eurydice	5	-	-	-	-	-	-	-	2	-	-	1	4	-	-	3	-	-	-	-	-
Sphaeroma	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Campecopea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grathia	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-
Tanaidacea																					
Apseudes	-	1	1	-	6	2	4	-	-	-	-	-	-	-	-	-	-	1	-	-	4
Tanaid a	-	1	-	-	-	1	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Tanaid b	-	2	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-
Decapoda																					
Caridea	-	-	-	-	2	3	1	-	2	-	-	-	-	-	-	-	-	-	-	-	-
Rhynchocinetid	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Brachyurid	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plagusia	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Xanthid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hippa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Porcellara	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Megalop larvae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oratosquilla	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Insecta																					
Diptera																					
Chironomid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Mollusca																					
Bivalvia																					
Cardid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
Corbula	-	-	-	-	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Donax	1	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-
Nuculana	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-
Lucinid	1	-	-	-	2	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Semelid	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
Tellinid	1	-	-	-	2	1	1	2	-	-	-	-	2	2	-	-	1	-	-	-	-
Venerid	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-
Unidentified bivalve	-	-	-	-	-	-	-	-	-	6	-	-	-	-	1	-	-	-	-	-	3
Barbatia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gastropoda																					
Unidentified gastropod	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Continued

Table 1 (continued)

Benthos	Station R5	S0	S1	S2	S3	T0	T1	T2	T3	T5	U0	U1	U2	U3	U5	V0	V1	V2	V3	V5	Total
Terebellidae																					
Lysilla	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	2
Terebella	-	-	-	-	-	-	-	-	-	-	-	-	-	9	-	-	-	-	-	-	9
Terebellides	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Scalibregmidae																					
Hyboscolex	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Trochochaetidae																					
Dosima	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Poecilochaetidae																					
Poecilochaetus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	5	-	6
Crustacea																					
Amphipoda																					
Amphithoe	-	-	-	-	-	-	4	-	-	-	-	-	-	75	-	-	-	-	-	-	79
Ampelisca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	2	-	9
Lembos	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	10	-	15
Argissa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Hyale	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1
Urothoe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
Jassa	-	-	-	-	-	1	5	-	-	-	-	-	2	24	-	-	-	-	-	-	34
Listriella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	3
Oedicerotid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Arrhis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
Monoculodes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	29
Periculodes	-	-	-	-	-	-	2	-	-	7	-	-	-	-	-	-	-	-	-	-	13
Westwoodilla	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-	-	-	-	-	-	68
Phoxocephalid	21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24
Isopoda																					
Cyathura	-	-	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	-	-	-	19
Eurydice	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15
Sphaeroma	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	2
Campecopea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	3
Grathia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
Tanaidacea																					
Apseudes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	14	34	68
Tanaid a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
Tanaid b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
Decapoda																					
Caridea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
Rhynchocinetid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Brachyurid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Plagusia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Xanthid	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
Hippa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Porcellara	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
Megalop larvae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	3
Oratosquilla	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Insecta																					
Diptera																					
Chironomid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Mollusca																					
Bivalvia																					
Cardid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Corbula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Donax	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
Nuculana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
Lucinid	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	6
Semelid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Tellinid	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13
Venerid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	5
Unidentified bivalve	-	-	-	-	-	-	9	-	-	-	-	-	3	-	-	-	-	-	24	20	66
Barbatia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	2
Gastropoda																					
Unidentified gastropod	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	6

Continued

Table 1 (continued)

Benthos	Station X0	X3	X5	Y0	Y1	Y2	Y3	Y5	Z0	Z1	Z3	P0	P1	P3	P5	Q1	Q3	R0	R1	R2	R3
Arcularia	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tricolia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ringicula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	-	-	-	-	-
Umbonium	-	-	-	-	-	-	-	-	-	-	-	1	1	34	1	-	-	-	-	-	-
Scaphopoda																					
Laevidentalium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-
Echinodermata																					
Echinodiscus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
Amphioplus	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphiura	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unidentified ophiurid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Protozoa																					
Foraminifera	1	-	-	-	-	-	-	-	-	-	-	1	2	1	-	-	-	2	22	-	-
Miscellaneous																					
Nemertean	-	3	1	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Nematodes	-	1	-	-	20	-	-	10	2	2	-	-	-	-	-	-	-	-	-	-	5
Lingula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sipunculid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	3
Nematomorpha	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Obelia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Calanoid[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Lucifer[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sagitta[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No. of ind./station	11	52	33	103	46	109	52	76	28	32	42	3	16	40	14	7	6	3	54	48	162
No. of genera/station	7	27	20	3	11	32	28	19	11	10	16	3	7	3	7	4	6	2	12	7	28
No. of genera/transect	<-47-->				<------58------>				<---31--->				<---13--->			<10>		<-------46------->			
No. of Polychaete genera/station	1	18	12	1	5	23	17	8	9	5	15	0	2	0	1	1	5	0	8	7	17
No. of Crustacea genera/station	2	7	4	2	2	6	9	5	2	2	2	1	1	1	1	1	0	1	0	0	4
No. of Mollusca genera/station	3	0	0	0	3	1	2	6	3	3	1	1	1	2	5	1	1	0	0	0	1
No. of other genera/ station	1	2	2	0	1	1	0	1	1	1	0	0	1	1	1	0	0	1	3	0	4

[a]Incidental pelagic species.

Continued

Table 2. Summary of ANOVA and Duncan multiple comparison test between the abundance of benthos and sampling stations.

Source	DF	Sum of squares	Mean squares	F ratio	P
Between groups	4	296.7749	74.1937	6.1330	<0.001
Within groups	6,760	81,778.5369	12.0974		
Total	6,764	82,075.3118			

Continued

Table 1 (continued)

Benthos	Station R5	S0	S1	S2	S3	T0	T1	T2	T3	T5	U0	U1	U2	U3	U5	V0	V1	V2	V3	V5	Total
Arcularia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Tricolia	-	4	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16
Ringicula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Umbonium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	37
Scaphopoda																					
Laevidentalium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Echinodermata																					
Echinodiscus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Amphioplus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	2
Amphiura	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	28	-	33
Unidentified ophiurid	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	3
Protozoa																					
Foraminifera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29
Miscellaneous																					
Nemertean	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	-	31
Nematodes	-	-	-	-	-	-	-	-	-	-	-	1	-	2	-	-	-	-	12	-	55
Lingula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	5	2	-	8
Sipunculid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	5	4	16
Nematomorpha	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	6
Obelia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Calanoid[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	6	-	11
Lucifer[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	4
Sagitta[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
No. of ind./station	313	15	24	18	193	9	109	16	14	22	3	53	31	142	13	4	9	56	229	103	2,313
No. of genera/station	12	8	2	6	10	5	16	4	5	13	2	18	18	25	9	2	6	22	52	16	
No. of genera/transect			<-----16---->				<-------29------->					<-------46------->					<-------63------->				
No. of Polychaete genera/station	9	7	1	6	10	4	12	4	4	11	1	15	14	19	7	1	1	14	38	11	
No. of Crustacea genera/station	1	0	0	0	0	1	3	0	1	2	1	2	2	4	0	0	2	4	5	2	
No. of Mollusca genera/station	1	1	1	0	0	0	1	0	0	0	0	0	2	0	1	0	0	1	1	2	
No. of other genera/ station	1	0	0	0	0	0	0	0	0	0	0	1	0	2	1	1	3	3	9	1	

[a]Incidental pelagic species.

Table 2 (continued)
Duncan multiple comparison test.

Mean (No./0.1 m²)	Sampling station	Sampling station 0	1	2	3	5
19.9	0					
38.9	1					
46.0	2					
82.3	3					
93.2	5	a				

[a]Denotes pairs of sampling stations significantly different from one another at the 0.05 level.

Table 3. Summary of ANOVA and Duncan multiple comparison test between the abundance of benthos and transects.

Source	DF	Sum of squares	Mean squares	F ratio	P
Between groups	9	240.2622	26.6958	2.2036	0.0191
Within groups	6,755	81,835.0496	12.1147		
Total	6,764	82,075.3118			

Duncan multiple comparison test.

Mean (No./0.1 m²)	Transect	Transect Q	P	X	Z	T	U	S	Y	V	R
2.6	Q										
14.6	P										
19.2	X										
20.4	Z										
34.0	T										
48.8	U										
49.6	S										
77.2	Y										
80.2	V										
116.0	R	*	*	*	*						

*Denotes pairs of transects significantly different at the 0.05 level.

Table 4. Particle size analysis (%) of soil samples from the coast of Brunei Darussalam.

Sampling station	Organic matter	Clay (2μ)	Silt (2-20μ)	Sand (>20μ)	Type of sediment
XO	0.35	2.50	2.50	95.00	Sand
X3	1.28	7.50	25.00	67.50	Sandy loam
X5	3.31	5.00	31.00	63.00	Sandy loam
Mean	(1.65)	(5.00)	(19.50)	(75.20)	(Sandy loam)
Y0	3.71	0	2.50	97.50	Sand
Y1	2.30	1.00	4.00	95.00	Sand
Y2	0.71	6.50	16.00	77.50	Loamy sand
Y3	1.40	20.00	22.50	57.50	Sandy clay loam
Y5	3.47	7.50	22.50	70.00	Sandy loam
Mean	(2.32)	(7.00)	(13.50)	(79.50)	(Loamy sand)
Z0	5.00	10.25	9.25	80.50	Sandy loam
Z1	1.00	6.25	6.00	87.50	Loamy sand
Z2	3.51	6.00	11.50	82.50	Loamy sand
Z3	2.54	17.00	41.00	42.00	Loam
Mean	(3.01)	(9.95)	(15.40)	(73.10)	(Sandy loam)
P0	0.63	0	2.50	97.5	Sand
P1	0.59	0	0	100.00	Sand
P3	0.99	2.50	2.50	95.00	Sand
P5	0.43	1.25	1.25	97.50	Sand
Mean	(0.66)	(0.94)	(1.56)	(97.50)	(Sand)
Q1	0.28	0	0	100.00	Sand
Q2	0.24	2.50	0	97.50	Sand
Q3	0.12	2.50	0	97.50	Sand
Q5	0.40	2.50	2.50	95.00	Sand
Mean	(0.26)	(1.88)	(0.63)	(97.50)	(Sand)

Continued

Table 4. (continued)

Sampling station	Organic matter	Clay (2μ)	Silt (2-20μ)	Sand (>20μ)	Type of sediment
R0	0.04	0	2.50	97.50	Sand
R1	0.21	1.25	0	98.75	Sand
R2	2.54	17.50	7.50	75.00	Sandy loam
R3	3.91	5.00	22.50	72.50	Sandy loam
R5	0.04	2.50	0	97.50	Sand
Mean	(1.35)	(5.25)	(6.50)	(88.25)	(Loamy sand)
S0	4.87	8.00	22.00	70.00	Sandy loam
S1	2.30	20.00	37.50	42.50	Clay loam
S2	1.39	7.50	10.00	82.50	Loamy sand
S3	2.09	5.00	50.00	45.00	Silt loam
Mean	(2.66)	(10.10)	(30.00)	(67.50)	(Sandy loam)
T0	4.34	5.00	22.50	72.50	Sandy loam
T1	3.83	13.50	14.50	72.00	Sandy loam
T2	2.59	7.50	7.50	85.00	Loamy sand
T3	2.07	15.00	14.00	71.00	Sandy loam
T5	3.67	25.00	19.50	55.50	Sandy clay loam
Mean	(3.30)	(13.20)	(15.60)	(71.20)	(Sandy loam)
U1	0.14	2.50	5.00	92.50	Sand
U2	0.29	7.00	3.00	90.00	Sand
U3	3.62	15.00	15.00	70.00	Sandy loam
U5	1.59	20.00	24.00	56.00	Sandy clay loam
Mean	(1.41)	(11.13)	(17.75)	(77.10)	(Sandy loam)
V0	0.20	5.00	0	95.00	Sand
V1	0.84	10.00	5.00	85.00	Loamy sand
V2	0.48	5.00	8.75	86.25	Loamy sand
V3	1.12	12.00	5.00	83.00	Loamy sand
V5	0.75	3.75	25.25	71.00	Sandy loam
Mean	(0.58)	(7.15)	(8.80)	(84.10)	(Loamy sand)

Table 5. Summary of ANOVA and Duncan multiple comparison test on the abundance of various benthos clusters.

Source	DF	Sum of squares	Mean squares	F ratio	P
Between clusters	41	1,535.0132	37.4393	3.1252	<0.0001
Within clusters	6,732	80,540.2985	11.9798		
Total	6,773	82,075.3118			

Continued

Table 5 (continued)
Duncan multiple comparison test.

Mean count/genus	Generic clusters	Generic clusters 1	2	3	4	5	6	7	8.....42
0.0407	1								
0.1341	2								
0.0767	3								
1.0662	4								
0.1951	5								
3.7805	6	*	*	*	*	*			**********
4.0976	7	*	*	*	*	*			**********
0.1931	8								
.	.								
.	.								
.	.								
.	.								
0.3525	42								

Note: Clusters 6 and 7 represent *Cossura* and *Ctenodrilus*, respectively, in the total (42) recorded clusters.

Table 6. Diversity indices of benthos in the coastal waters of Brunei Darussalam and summary of correlation test between Shannon-Wiener and Gleason, and Shannon-Wiener and Menhinick indices. See text.

No.	Transect	Shannon-Wiener index (SW)	Gleason index (G)	Menhinick index (M)	No. of genera (S)	Simpson dominance index (1-D)	Evenness index
1	X	5.1	9.9	4.7	47	0.96	0.91
2	Y	4.7	9.6	3.0	58	0.95	0.80
3	Z	4.6	6.5	3.1	31	0.96	0.93
4	P	2.7	3.0	1.6	13	0.73	0.73
5	Q	3.0	3.1	2.5	10	0.59	0.90
6	R	2.1	7.1	1.9	48	0.85	0.38
7	S	2.3	2.7	1.0	18	0.65	0.55
8	T	3.8	5.5	2.2	29	0.88	0.78
9	U	4.2	8.2	3.0	49	0.88	0.76
10	V	5.0	10.3	3.2	63	0.95	0.84

Summary of Spearman's rank correlation test

Between SW and G indices

$r_s = 0.780$
$(r_s)0.05(2),10 = 0.648$
$r_s > (r_s)0.05(2),10$
Reject H_o: $P_s = 0$, $0.01<p<0.02$.

Between SW and M indices

$r_s = 0.924$
$(r_s)0.05(2),10 = 0.648$
$r_s > (r_s)0.05(2),10$
Reject H_o: $P_s = 0$, $p<0.001$.

Sediments

The sediments along Transects P and Q were sand from the shoreline down to the subtidal depth with organic matter constituting less than 1% (Table 4). The same was true for the soil samples at 0- to 2-m depth in Transects X, Y, R and U. Sediments from the remaining transects were primarily either loamy sand or sandy loam which contained higher organic matter ranging from 0.5-5.0%. Generally, soil samples were more clayey or silty (and less sandy) at the intermediate or subtidal depth which favors colonization by benthos (Table 2).

Conclusion

The substrata of the coastal habitats of Brunei Darussalam were highly varied from mainly sandy in the northern coast to loamy sand or sandy loam in the estuaries.

In this regard, the abundance and diversity of the dominant group of organisms, the polychaetes, were closely correlated to the sediment characteristics of each station studied. Flint and Rabalais (1980) show that the predominant variables of discriminant factors which characterize polychaete niches are % sand, % silt, sand/silt ratio, bottom water salinity and water depth. Sandy areas in Berakas (Transect P) and Jerudong (Transect Q) had low Shannon-Wiener diversity index (H = 2-3) and abundance of polychaetes but more molluscs. This can be attributed to the fact that coarse sediments such as sand are unlikely to trap substantial detritus while periodic scouring of fine sediments by currents will create an environment too harsh for soft-bodied worms. Only in areas with higher % clay enriched with organic matter and subtidal stations with a more stable bottom environment was there a higher diversity of benthos, e.g., Transects X, Y, Z, U and V.

Although Transects R and S were also mainly sandy habitats with low diversity index, the abundance of polychaetes in some stations could be quite high. Station S3, the only one with a silt loam substratum, was exclusively dominated by *Cossura*, a polychaete known to prefer very silty bottoms and which tend to segregate its niche space from others (Flint and Rabalais 1980). Transect R had the lowest diversity index of 2.1 with low water salinity due to its location in the lower reaches of Sg. Tutong. Gage (1972) suggests that brackishwater reduces species diversity through the elimination of the pelagic larvae which are more sensitive to the fluctuation of salinity, assuming that recruitment of benthos populations is mostly dependent on the availability of larvae. However, it is presumed that either the polychaete *Ctenodrillus* has a higher tolerance for low salinity or that station R5 has a relatively stable salinity to enable the species to colonize there in large numbers.

Benthos diversity may also reflect the extent of pollution by petroleum hydrocarbons. Based on Brewer's scheme (1979), a high diversity index indicates non-pollution. The benthos diversity at the study sites was well above those in petroleum-contaminated habitats like Ekofisk Field in the North Sea (Dick 1976) and Sg. Bera in Seria (Leong et al. 1984). The indicator of oil pollution, *Capitella*, was either absent or occurred in small numbers, together with other genera, in some of the sites. In severely polluted areas, *Capitella* was the only abundant Polychaete (Reish 1979).

There is a gradient of benthos diversity from Sg. Bera through Sg. Tutong Estuary, the coast in Berakas and Jerudong, and the vicinity of Brunei Estuary (Fig. 1). This gradient reflects local conditions such as pollution, salinity, geographic features and soil types which either enhance or reduce benthos diversity as well as species dominance.

The benthos diversity gradient correlated well with the observation that Brunei Estuary and its bifurcate channels, Temburong and Brunei, are major nursery grounds and migratory routes for fish and shrimp (Currie 1982). The findings also reinforced the belief that mangrove forests contribute significantly to the primary (Gong 1983), secondary (Sasekumar 1983) and tertiary (MacNae 1974) productivity of adjacent waters. The combined mangrove swamps in the Brunei Estuary area account for about 87% of the total mangrove areas in Brunei Darussalam (Zamora 1987). Being mainly shallow and semi-enclosed, Brunei Estuary and its adjacent mangrove swamps presumably represent the most productive area, followed by other minor estuaries such as Tutong. As such, these estuaries should be accorded priority in the country's oil spill contingency plan.

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References

Abecassis, D.W. 1976. Marine oil pollution. Occas. Pap. No. 6. 123 p. University of Cambridge, Cambridge.

Black, C.A., D.D. Evans, J.L. White, L.E. Ensminger and F.E. Clark. 1965. Part 2. Chemical and microbiological properties, p. 1372-1376. *In* C.A. Black (ed.) Methods of soil analysis. American Society of Agronomy, Inc., Madison.

Brewer, R. 1979. Principles of ecology. Saunders College Publishing, Philadelphia.

Chua, T.-E., L.M. Chou and M.S.M. Sadorra, editors. 1987. The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Clark, A.M. and F.W.E. Rowe. 1971. A monograph of shallow-water Indo-West Pacific echinoderms. Trustees of the British Museum (Natural History), London.

Currie, D.J. 1982. Studies on the biology of penaeid prawns and the prawn fishery in the Brunei Estuary, p. 134-187. *In* R.W. Beales, D.J. Currie and R.H. Lindley (eds.) Investigations into fisheries resources in Brunei. Brunei Museum, Brunei Darussalam.

Day, J.H. 1967. A monograph on the Polychaeta of South Africa. Part I. Errantia. Part II. Sedentaria. British Museum (Natural History), London.

Day, P.R. 1965. Particle fractionation and particle-size analysis, p. 545-567. *In* C.A. Black (ed.) Methods of soil analysis. Part 1. Physical and mineralogical properties including statistics of measurement and sampling. American Society of Agronomy, Inc., Madison.

Dick, B. 1976. Offshore biological monitoring, p. 325-440. *In* J.M. Baker (ed.) Marine ecology and oil pollution. Applied Science Publishers Ltd., Essex, England.

Fauchald, K. 1977. The polychaete worms: definitions and keys to the orders, families and genera. Sci. Ser. No. 28. 108 p. Natural History Museum of Los Angeles County.

Fingas, M.F., W.S. Duval and G.B. Stevenson. 1979. The basics of oil spill cleanup with particular reference to Southern Canada. Environment Canada, Ottawa.

Flint, R.W. and N.N. Rabalais. 1980. Polychaete ecology and niche patterns: Texas continental shelf. Mar. Ecol.(Prog. Ser.) (3): 193-202.

Gage, J. 1972. Community structure of the benthos in Scottish sealochs. (I) Introduction and species diversity. Mar. Biol. (14): 281-297.

Gong, W.K. 1983. Mangrove primary productivity, p. 10-19. *In* J.E. Ong and W.K. Gong (eds.) Productivity of the mangrove ecosystem: management implications. Universiti Sains Malaysia, Malaysia.

Gundlach, E.R. and M.O. Hayes. 1978. Classification of coastal environments in terms of potential vulnerability to oil spill impact. Mar. Technol. Soc. J. (12): 18-27.

IMO (International Maritime Organization). 1980. Manual on oil pollution. Section IV (revised). Practical information on means of dealing with oil spillages. International Maritime Organization, London.

Kohnke, H. 1968. Mechanical composition of the soil. *In* Soil physics. McGraw-Hill, New York.

Lai, H.C. and M.C. Feng. 1984. Fate and effects of oil in the mangrove environment. Universiti Sains Malaysia, Malaysia.

Leong, T.S., Y.K. Leong, S.C. Ho, K.H. Khoo, S.P. Kam, H. Sulaiman, T.M. Wong and R.S. Legore. 1984. An environmental baseline study of the macrobenthos in the vicinity of the crude oil terminal, Seria, Brunei. Sinaran Bros. Sdn. Bhd., Penang, Malaysia.

Lincoln, R.J. 1979. British marine Amphipoda: Gammaridea. British Museum (Natural History), London.

Loo, M., L. Hsu and J. Paw. 1987. Physical environment, p. 5-27. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Lovett, D.L. 1981. A guide to the shrimps, prawns, lobsters, and crabs of Malaysia and Singapore. Occas. Publ. No. 2. 156 p. Universiti Pertanian Malaysia, Malaysia.

Mackay, D., S. Chong and P.G. Wells. 1982. Calculation of oil concentrations under chemically dispersed slicks. Mar. Pollut. Bull. (13): 278-283.

MacNae, W. 1974. Mangrove forests and fisheries. Indian Ocean Fishery Commission, Indian Ocean Programme, United Nations Development Programme, Rome.

Menhinick, E.F. 1964. A comparison of some species-individual diversity indices applied to samples of field insects. Ecology (45): 859-861.

Morris, P.A. 1973. A field guide to shells of the Atlantic and Gulf Coasts and the West Indies. Third ed. Houghton Mifflin Co., Boston.

Naylor, E. 1972. British marine isopods. Keys and notes for the identification of the species. The Linnean Society of London, London.

Odum, E.P. 1975. Ecology. Second ed. Holt, Rhinehart and Winston, New York.

Reish, D.J. 1979. Bristle worms (Annelida: Polychaeta), p. 77-125. *In* C.W. Hart and S.L.H. Fuller (eds.) Pollution ecology of estuarine invertebrates. Academic Press, New York.

Sasekumar, A. 1983. Mangrove secondary productivity, p. 20-28. *In* J.E. Ong and W.K. Gong (eds.) Productivity of the mangrove ecosystem: management implications. Universiti Sains Malaysia, Malaysia.

Tadashige, H. 1964. Shells of the Western Pacific in color. Vol. 2. Hoikusha Publishing Co. Ltd., Osaka, Japan.

Tetsuaki, K. 1962. Shells of the Western Pacific in color. Vol. 1. Hoikusha Publishing Co. Ltd., Osaka, Japan.

Zamora, P. 1987. Mangroves, p. 28-43. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Zar, J.H. 1984. Biostatistical analysis. Second ed. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Simulation of Oil Slick Movement in Brunei Darussalam

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Abstract

This paper presents a simulation model of the potential trajectory and speed of offshore oil slicks in Brunei Darussalam. The model incorporates specific properties of the spilled oil relevant to its spreading, evaporation and dilution, as well as seasonal variations in wind and current vectors in the country's coastal waters. A simulation of hypothetical spills from existing oil fields (Champion, Fairley, Southwest Ampa, Magpie and Semarang) was conducted and probabilities of oil slick landfall along the Brunei coastline are given. The results are useful in the identification of high-risk areas for oil spills, the design of an oil spill contingency plan and overall coastal resources management (CRM) planning for Brunei Darussalam.

Introduction

The development of offshore oil resources increases the risk of oil pollution and the potential damage to adjoining coastal land areas. Oil may be inadvertently released to the marine environment as a result of shipping accidents, offshore well blow-outs, or pipeline fractures and leakages. In order to mitigate environmental damage that may result from an oil spill, containment measures are formulated and contingency response mechanisms are put in place. However, sufficient lead time is needed before contingency measures can be effectively activated. Hence, a timely prediction of the trajectory of an oil slick is necessary for appropriate action (BSP 1988).

To properly predict the trajectory of an oil slick, the processes of oil spreading and transport must be simulated in some manner. This paper deals with the development of a model for the simulation of the spread and movement of a hypothetical oil slick in the offshore areas of Brunei Darussalam. The model is designed as an input to an oil spill contingency plan for the country. The paper further describes the application of the model in identifying potentially high-risk coastal areas as far as offshore well blow-outs are concerned. This has special relevance to the evolution of a CRM plan for the country (see, for example, Lim, this vol.).

Oil Spill Modeling

When oil is spilled on the ocean, it immediately spreads over the water surface at a rate determined by specific properties of the oil (such as specific gravity, surface tension and viscosity) and environmental parameters that govern physical conditions prevailing over the ocean surface. The oil mass also undergoes a process of decay, which includes evaporation, dissolution, emulsification, precipitation and biodegradation.

From its initial impact area, the oil slick is transported by the combined effects of (1) large-scale wind flow; (2) local wind circulations (such as land and sea

breezes if the slick happens to be within 50 km from the coastline of a large island); (3) surface ocean currents; and (4) tidally induced currents. The final trajectory of the slick is also influenced by the Coriolis effect due to the rotation of the earth. The Coriolis effect, however, is less pronounced in equatorial regions.

Spreading

The mathematical model used in this study considers spreading of the slick in three distinct stages, namely: (1) the gravity-inertia regime which takes place during the initial hour after a spill; (2) the gravity-viscous regime; and (3) the surface tension regime which governs the final radius of the slick. The equations employed in this model to calculate the slick radius at various phases of spreading are discussed in detail in Fay (1971) and given in Table 1.

Transport

The movement of an oil slick is generally considered the result of a linear combination of the wind vector and the ocean current vector. The wind vector at the slick position is treated as the sum of the prevailing (seasonal) synoptic wind and the meso-scale (local) wind, which is taken as the land and sea breezes in this study. In the same manner, the total ocean current vector is treated as the sum of the large-scale (seasonal) current and the oscillating, tidally induced component. Thus, the instantaneous slick velocity is computed as follows:

$$\vec{V}_o = a\,[\vec{W}_s + b\,\vec{W}_l] + [\vec{C}_s + \vec{C}_t] \quad \ldots [1]$$

where

- $\vec{V}_o$ - instantaneous oil slick velocity,
- $\vec{W}_s$ - seasonal wind vector,
- $\vec{W}_l$ - land or sea breeze vector,
- $\vec{C}_s$ - seasonal ocean current vector,
- $\vec{C}_t$ - tidal current component vector,
- a - constant (assumed to be 0.033 in this study) and
- b - constant that linearly decreases from 1 at the shoreline to 0 at 50 km from the shore.

The centroidal location of the oil slick is obtained by integrating equation (1) using a discrete time step, t. Hence,

$$\vec{P}(t+\Delta t) = \vec{P}(t) + \{a\,[\vec{W}_s + b\,\vec{W}_l] + [\vec{C}_s + \vec{C}_t]\}\,\Delta t \quad \ldots [2]$$

where P(t) and P(t+Δt) is the position vector of the oil slick centroid at time t and t+Δt, respectively.

Table 1. Equations that measure spreading of oil spill as used in the simulation model.

Stage of oil slick spreading	Slick radius	Time at which spreading shifts
Gravity-inertia regime	$R = K_i\,[\Delta\, g\, V\, t^2]^{0.25}$ where R - radius of oil slick, K_i - nondimensional coefficient experimentally determined to be 1.14 (Fay 1971), Δ - ratio of the absolute difference between densities of seawater and oil, and that of seawater, g - gravitational acceleration, V - original volume of oil spilled and t - time.	From gravity-inertia to gravity-viscous regime $t_{i\text{-}v} = [K_v\, K_i^{-1}]^4\,[V\,\Delta^{-1}\, g^{-1}\, \upsilon^{-1}]^{0.99}$
Gravity-viscous regime	$R = K_v\,[\Delta\, g\, V^2\, t^{0.67}\, \upsilon^{-0.5}]^{0.167}$ where K_v - nondimensional coefficient determined to be 1.45 (Fay 1971) and υ - kinematic viscosity of water.	From gravity-viscous to surface tension regime $t_{v\text{-}t} = [K_v K_t^{-1}]^2\,[\rho\, \sigma_0^{-1}]\,[\Delta\, g\, \upsilon]^{0.33}\, V^{0.67}$ where σ_0 is the spreading coefficient for oil.
Surface tension regime	$R = K_t\,[\sigma^2\, t^9\, \rho^{-2}\, \upsilon^{-1}]^{0.25}$ where K_t - nondimensional constant experimentally determined to be 2.05 (Fay 1971), σ - surface tension and ρ - density of water.	

Table 2. Mean distribution of wind direction and speed in Brunei Darussalam.

Direction	Wind regime season: Northeast monsoon (January-March) % frequency	Mean speed (m/s)	Southwest monsoon (May-November) % frequency	Mean speed (m/s)	April transition % frequency	Mean speed (m/s)	December transition % frequency	Mean speed (m/s)
Calm	36.6	-	43.9	-	42.1	-	39.9	-
North	24.3	3.4	6.2	2.3	14.6	2.7	13.3	2.8
Northeast	16.9	3.0	1.7	1.5	3.9	2.0	9.2	2.8
East	3.1	1.9	1.6	1.5	1.9	1.7	3.5	1.7
Southeast	1.0	1.3	1.7	1.3	1.5	1.2	1.8	1.3
South	4.4	1.4	11.2	1.7	7.4	1.2	10.1	1.6
Southwest	5.6	1.3	16.4	2.0	12.4	1.4	11.5	1.8
West	2.0	1.7	7.4	2.3	4.2	1.9	3.8	2.0
Northwest	6.2	2.6	9.8	2.0	12.0	2.4	6.7	2.3

The present model requires previous specification of the large-scale wind and current vectors. The meso-scale (land and sea breeze) wind circulation as well as the tidally induced changes in ocean currents are used as parameters.

Wind climatology

The monthly distribution of surface wind speed and direction observed at Brunei Airport from 1969 to 1988 was obtained from the Department of Civil Aviation, Brunei Darussalam. The average seasonal wind distribution in Brunei as synthesized from the data are given in Table 2 and Fig. 1. The table reveals the dominance of the northeast monsoon during January to March and that of the southwest monsoon from May to November. The two transition periods fall around April and December between these main wind regimes. The data show a large percentage of calm conditions in all seasons, especially during the southwest monsoon and the April transition period. The average wind speed is stronger during the northeast monsoon season compared with that of the rest of the year.

Land and sea breezes are caused by the differential heating of land and sea (Neumann and Pierson 1966). The sea breeze (onshore wind) occurs at daytime when the land surface is warmer than that of the sea while the land breeze (offshore wind) takes place at night when the land gets colder than the sea surface. Hence, the land-sea breeze system can be regarded as an oscillatory wind component with an amplitude dependent on that of the temperature difference between land and sea surfaces. In most cases, this amplitude amounts to about 5 m/second in tropical areas (Pielke 1974, 1984; Estoque 1990). The seaward extent of this circulation is, however, generally limited to about 50 km. The prevailing wind is therefore modified by the presence of land and sea breezes.

Surface currents

Surface current patterns in the offshore areas of Brunei Darussalam are generally wind-driven. With prevailing winds predominantly blowing along the northeast and southwest directions, the dominant surface currents are also expected to be along these directions. The surface currents, however, are generally weak, seldom exceeding 25 cm/second. Fig. 1 shows the seasonal surface current patterns as synthesized from various float track records and current meter observations by Brunei Shell Petroleum Co. (BSP 1986).

Analysis of current meter observations at various offshore locations reveals the average amplitude of tidally induced currents at less than 50 cm/second. Tidal currents flow towards the southwest during floods and in the opposite direction during ebb tide.

Oil Spill Simulations

Model simulations of oil spill accidents resulting from hypothetical offshore well blow-outs that released 5,000 barrels of crude oil were performed. The crude oil was assumed to have a density of 867 kg/m^3 and a surface tension of 0.0057 Newtons/m. The computations used prevailing ocean current patterns during the northeast and southwest monsoons and the April and December transition months. All possible wind conditions (i.e., eight points of the compass), including calm winds, were considered in each case. A total of 36 simulations per oil field (or 180 computer runs) was considered for the 5 offshore oil fields, namely, Champion, Fairley, Southwest Ampa, Magpie and Semarang, Malaysia (Table 3).

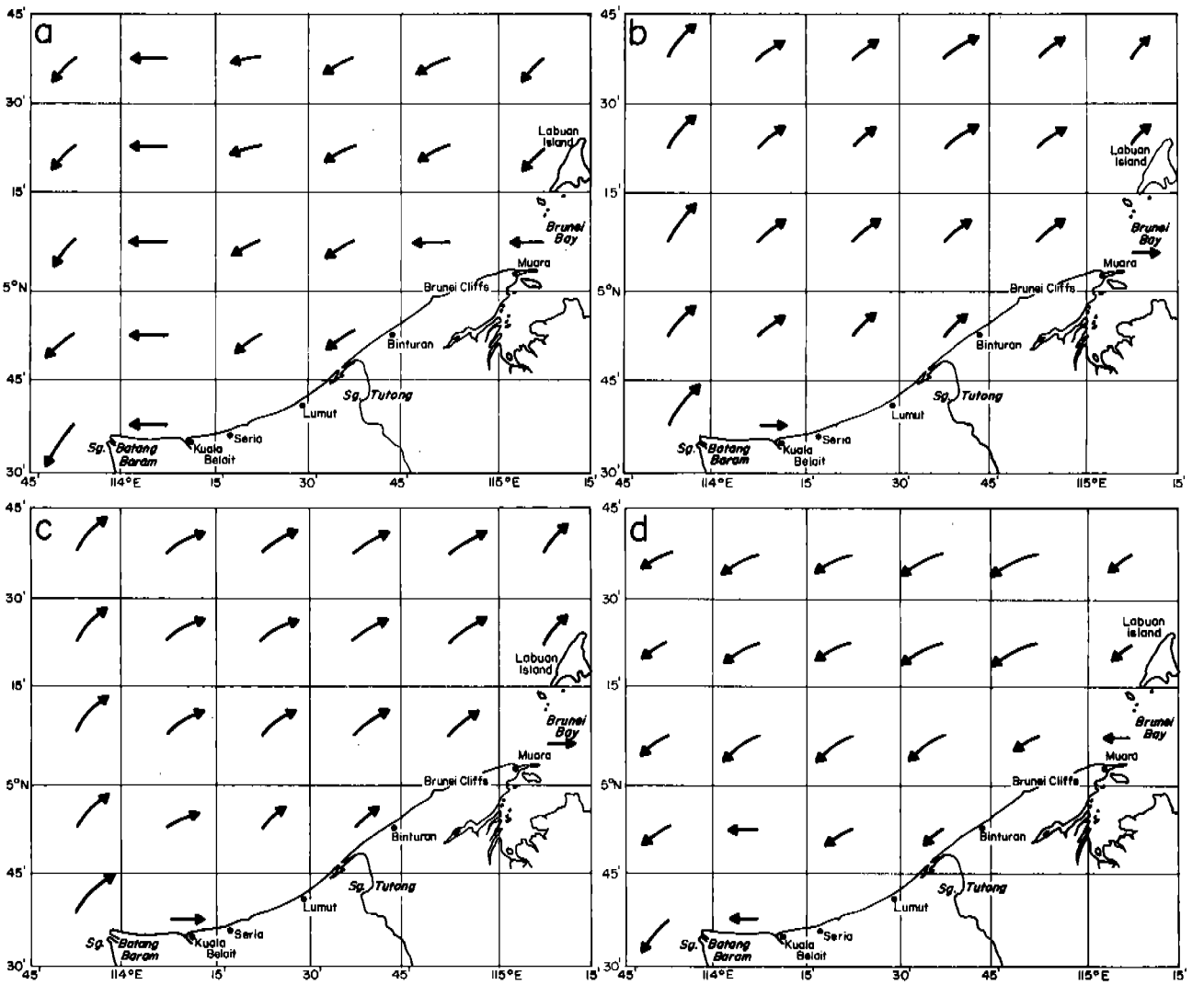

Fig. 1. Surface currents for: (a) January-March, (b) April, (c) May-November and (d) December.

Champion Field

The simulated spill assumed to originate from the middle of Champion Field (Fig. 2a-c) from a well blow-out during the northeast monsoon (January-March) has a 43.2% probability of landfall and a 56.8% chance of not hitting any of the country's shores. The most probable landfall is at the coastal area between the BSP air field in Seria and about 5 km west of Kuala Belait, when the prevailing winds are generally northerly (i.e., north, northeast and northwest). The slick is expected to make a landfall 75-114 hours after the blow-out.

In April, the simulated slick from this same source will not hit land in any part of Brunei Darussalam but has a 14.6% probability of entering Brunei Bay, passing very close to Muara and probably making a landfall in the Sunda, Sarawak area (Fig. 2d). In this event, the slick may be assumed to affect the entire Brunei estuarine area, and will probably take 93 hours to travel from its origin to the mouth of the estuary.

If the Champion well blow-out happens during the southwest monsoon season (May-November), the oil slick is not expected to make a landfall in Brunei Darussalam. However, an 18.0% probability of landfall at Labuan Island may also threaten Brunei Bay. During the December transition period, the simulation shows a 22.5% probability of the oil slick making a landfall between Sungai or Sg. Tutong (i.e., river) and Seria in approximately 73 hours (Fig. 2e-f).

Table 3. Summary of oil slick simulation for Brunei Darussalam.

Slick origin	Month	Location of landfall	Landfall probability (%)	Remarks
Champion	January-March	Between Seria and Kuala Belait	43.2	
	April	None		14.6% chance of entering Brunei Bay
	May-November	None	-	18.0% chance of landfall at Labuan Island
	December	Between Sg. Tutong and Seria	22.5	-
Fairley	December-March	None	-	-
	April	Between Penanjong and Muara	16.5	-
	May-November	None	-	18.1% chance of entering Brunei Bay
Southwest Ampa	December-March	None	-	Will threaten Sg. Batang Baram in Sarawak
	April	Between Lumut and Binturan	16.5	-
	May-November	Between 5 and 15 km west of Muara	18.0	2.0% chance of entering Brunei Bay
Magpie	December-March	None	-	39.6% chance of threatening Sg. Batang Baram
	April	Vicinity of Brunei Cliffs	14.6	-
	May-November	None	-	16.4% chance of entering Brunei Bay
Semarang	December-March	West border between Brunei and Sarawak	21.6	-
	April-November	None	-	-

Fairley Field

Simulations during the northeast monsoon season and the December transition month show a negligible probability of landfall in any part of Brunei Darussalam. However, during the April transition month, there is a 16.5% probability that the slick will make a landfall along the Brunei coast approximately between Penanjong and the western limit of Muara (Fig. 3a-b). During the southwest monsoon season, the slick will not hit land in the country but has an 18.1% chance of entering Brunei Bay (Fig. 3c).

Southwest Ampa Field

The December transition period and the northeast monsoon simulations show that the hypothetical slick from Southwest Ampa will not hit land in any part of Brunei Darussalam but will affect the mouth of Sg. Batang Baram in Sarawak (Fig. 4a-b). There is a 16.5% probability of the slick making a landfall between Lumut and Binturan during the April transition period (Fig. 4c-d). During the southwest monsoon season, the model shows an 18% probability of the slick making a landfall along the coast between 5 and 15 km west of Muara (Fig. 4e-f) and a 2% chance of entering Brunei Bay.

Magpie Field

From December to March, the slick originating from Magpie will have a tendency to move west and southwest, thus missing the Brunei coastline (Fig. 5a-b). However, there is a distinct probability (39.6%) of it threatening the mouth of Sg. Batang Baram. In the April transition period, there is a 14.6% probability that the slick will make a landfall in the vicinity of Brunei Cliffs (Fig. 5c). During the southwest monsoon season, the slick will not directly threaten any part of Brunei Darussalam but there is a 16.4% chance that it will enter northern Brunei Bay (Fig. 5d).

Semarang Field

Any oil spill originating from Semarang Field in Malaysia (longitude 114°55'E, latitude 5°35'N) will not directly pose a threat to the coastal areas of Brunei

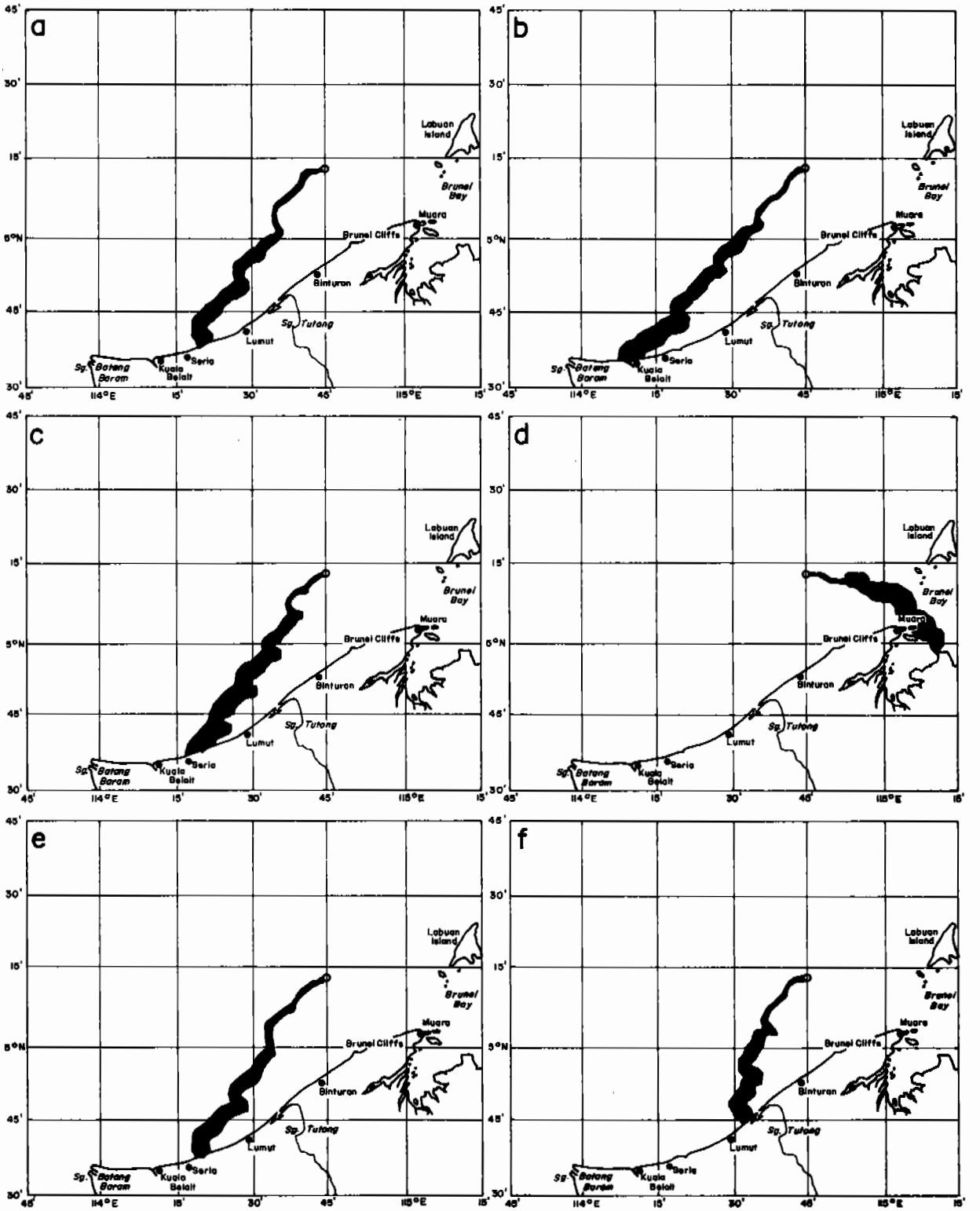

Fig. 2. Predicted oil slick trajectory from a Champion well blow-out during the: (a) January-March season with N winds, (b) January-March season with NE winds, (c) January-March season with W winds, (d) April transition period, (e) December transition period with N winds and (f) December transition period with NE winds.

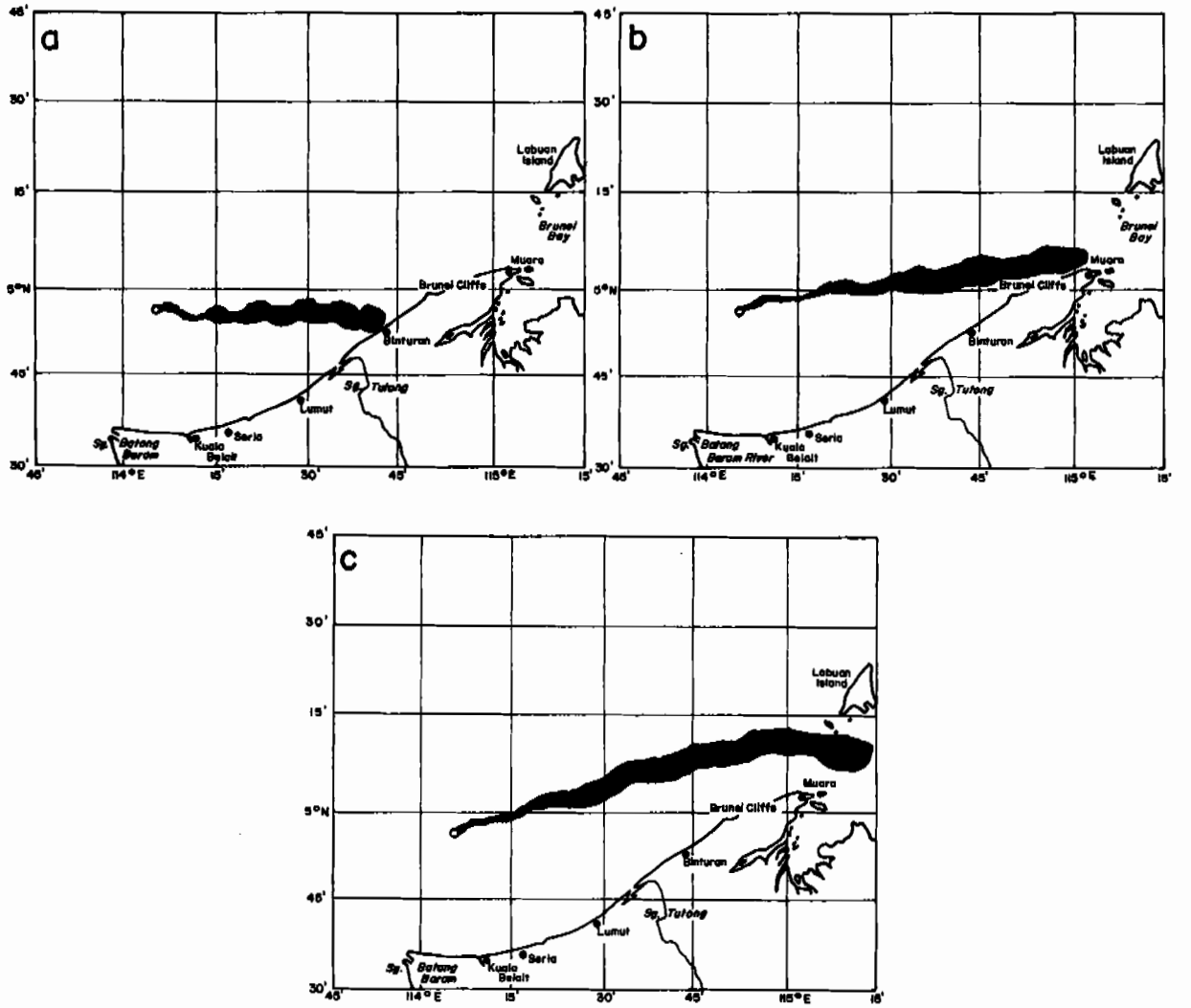

Fig. 3. Predicted oil slick trajectory from a Fairley well blow-out during the: (a) April transition period with N winds, (b) April transition period with E winds and (c) May-November season.

Darussalam except during December to March when there is a 21.6% probability of landfall from the western border between Brunei and Sarawak up to the mouth of Sg. Batang Baram.

Available Software Package

A software package, SPOILS (Simulation and Prediction of Oil Spills) developed for implementation of the routines described here, is available from the Coastal Area Management Program of the International Center for Living Aquatic Resources Management. The software is graphics-oriented, user-friendly and adapted to the existing "data availability environment" in Brunei Darussalam. Designed primarily for identification of high-risk oil spill areas, the software package is extremely useful in the formulation of an oil spill contingency plan (as well as during actual oil spill accidents) and an overall CRM plan. The model used in the package relies highly on the input parameters for accuracy. While available meteorological (e.g., wind) data may be sufficient, oceanographic (e.g., surface current) information on Brunei coastal waters needs upgrading.

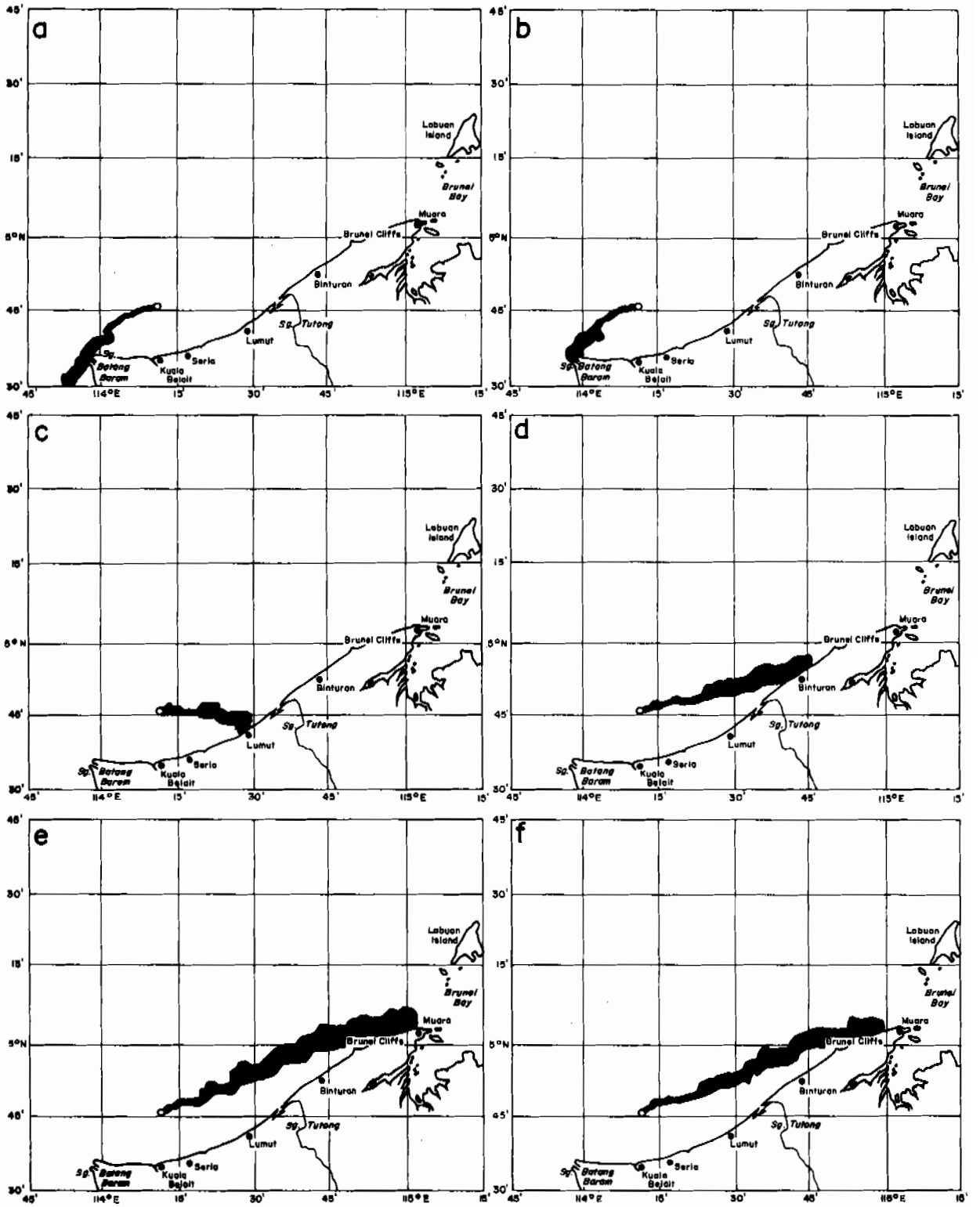

Fig. 4. Predicted oil slick trajectory from a Southwest Ampa well blow-out for: (a) the January-March season, (b) March, (c) April with N winds, (d) April with E winds, (e) the May-November season with SW winds and (f) the May-November season with SE winds.

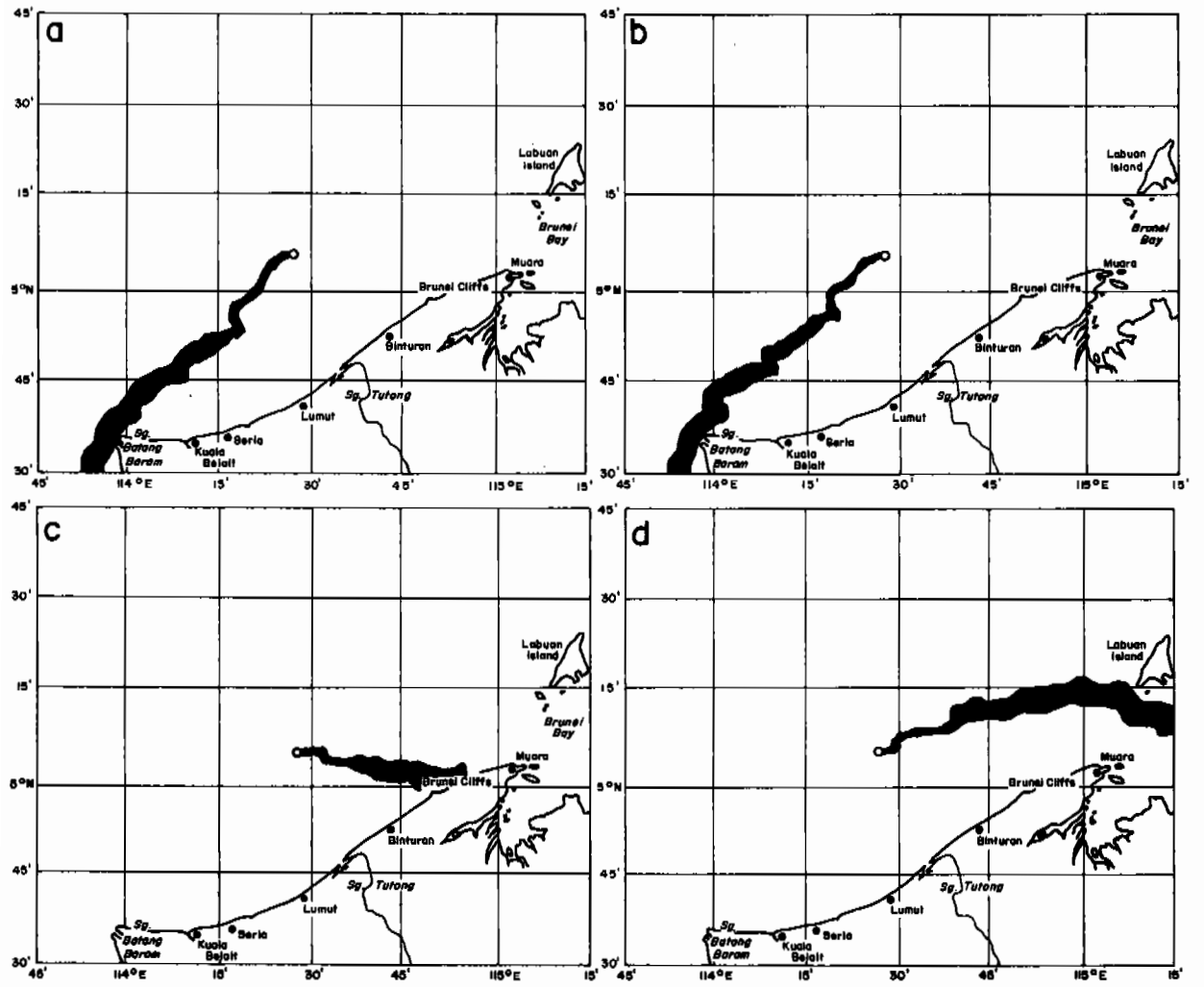

Fig. 5. Predicted oil slick trajectory from a Magpie well blow-out for: (a) December, (b) January-March, (c) April and (d) May-November.

References

BSP (Brunei Shell Petroleum Co.). 1986. Surface currents offshore Brunei: a summary of float tracks observed between March 1984 to December 1985. Brunei Shell Petroleum Co., Seria, Brunei Darussalam.

BSP (Brunei Shell Petroleum Co.). 1988. Oil spill contingency plan. Brunei Shell Petroleum Co., Seria, Brunei Darussalam.

Estoque, M.A. 1990. A surface mesoscale model for complex terrain. Atmosfera 3: 203-216.

Fay, J.A. 1971. Physical processes in the spread of oil on a water surface, p. 463-467. *In* API Proceedings of the Joint Conference on Prevention and Control of Oil Spills. American Petroleum Institute, New York, U.S.A.

Neumann, G. and W.J. Pierson, Jr. 1966. Principles of physical oceanography. Prentice-Hall, Englewood Cliffs, California, U.S.A.

Pielke, R.A. 1974. A three-dimensional numerical model of the sea breezes over South Florida. Monthly Weather Review 102: 115-139.

Pielke, R.A. 1984. Mesoscale meteorological modelling. Academic Press, Inc., Orlando, Florida, U.S.A.

A Composite Sensitivity Index for the Coastal Zones of Brunei Darussalam

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Abstract

The coastal waters of Brunei Darussalam were partitioned into five zones based on benthos diversity. A composite sensitivity index was developed for each zone using ten economic/ecological parameters (e.g., extent of mangroves, benthos diversity, fisheries resources/activities, shoreline population, beachfront length) and an arbitrary grading of these parameters. The system devised used a composite index rank of 1 to 5 in ascending order of sensitivity/vulnerability; as such, those zones abundant in natural resources and fisheries were the most sensitive to the impact of an oil spill or other external stresses. The results indicated that the most vulnerable zone was the Brunei Estuary area (Inner Brunei Bay) with a composite index score of 76% (rank = 5); followed by east Tanjong (or Tg., i.e., cape) Danau/east Jerudong (68%; rank = 4); Kuala Belait/west of Seria (48%; rank = 3); east Jerudong to Pelompong Spit (46%; rank = 2); and east of Seria/west Tg. Danau (44%; rank = 1).

Introduction

The rationale for a composite sensitivity index for various zones in a given coastal area is twofold: (1) to effectively reflect the underlying economic/ecological importance of the various zones in relative terms and (2) to provide a general estimate of their respective sensitivity to external stresses (such as oil spills and large-scale development). The index provides useful background information in the event of an environmental disaster (e.g., the 1979 IXTOC I blowout in the Gulf of Mexico) (GURC 1980).

Some indices are straightforward ratings of the shoreline vegetation and substrata (Gundlach and Hayes 1978; Ridzwan and De Silva 1983), while others may elaborately take into account a multitude of components such as existing recreational activities, potential amenities, hydrology and resources (FEC 1976). Many of these indices are fairly subjective and depend

very much on the availability of data. All environmental indices, however, need to be continuously refined and modified as new data are made available.

This brief contribution represents a preliminary attempt to develop a composite index to assess the sensitivity of various zones in the coastal area of Brunei Darussalam and help make its oil spill contingency plan more effective.

Materials and Methods

The composite sensitivity index for the coastal area of Brunei Darussalam was developed from existing information (Tate 1970; Chua et al. 1987; Lai et al., this vol.). The coastal waters were partitioned into five zones according to benthos diversity which reflected the conditions of the substrata in these areas (Fig. 1) (Lai et al., this vol.). Zone 1 stretched from the western tip of Brunei Darussalam, a short distance from Kuala Belait, to Seria; Zone 2 from Seria to west Tg. Danau, the lowest reaches of Sungai (or Sg., i.e., river) Tutong; Zone 3 from east Tg. Danau to east Jerudong; Zone 4 from east Jerudong to the excavated channel at Pelompong Spit; and Zone 5, the whole portion of Brunei Estuary (Inner Brunei Bay). Except Zone 5, each of the other 4 zones covered the adjoining inshore as well as offshore waters up to the 100-fathom (183-m) isobath.

Ten parameters were considered for each zone, namely: number of fishing gear deployed; area of mangrove swamps; area of *nipah* swamps; number of potential aquaculture sites; benthos diversity (Shannon-Wiener index); number of coral patches; number of fishermen; coastal/riverine population; area of trawling grounds; and length of sandy beachfront.

The first parameter, the number of fishing gear used by full-time fishermen in each of the five zones, was summed up (Table 1) and entered in Table 2, together with the values obtained for the rest of the parameters.

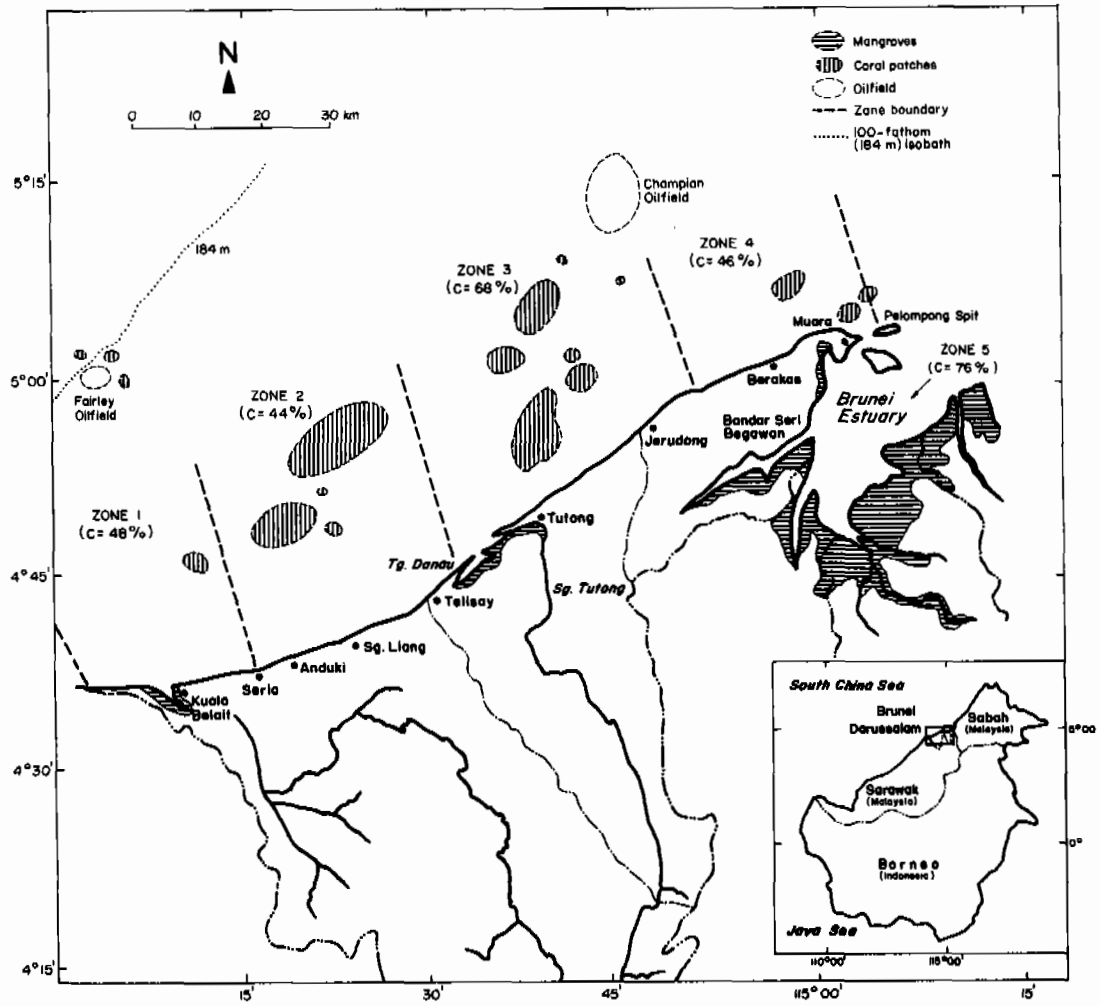

Fig. 1. Zone boundaries for the coastal waters of Brunei Darussalam and their composite sensitivity index (C) scores.

Table 1. Distribution by zone of various fishing gear used by full-time fishermen in Brunei Darussalam.[a]

Gear	Zone 1	2	3	4	5
Ancau (ring net)	4	9	2	-	6
Andang karan (trammel net)	8	9	13	4	143
Andang jaran (gill net)	16	7	15	-	10
Bubu (trap)	12	7	6	1	14
Jaul (handline with sinker)	-	-	-	-	22
Kabat (intertidal fish trap)	-	-	-	-	1
Kilong (deepwater palisade trap)	-	-	-	-	2
Lingkong (purse seine)	-	-	-	-	4
Lintau (shallow water palisade trap)	-	-	-	-	5
Panau (ring net)	5	8	-	-	3
Pancing (handline without sinker)	30	9	8	-	2
Pukat kikis (beach seine)	1	-	-	-	1
Pukat tunda (trawl net)	-	-	-	-	3
Rambat (cast net)	-	2	1	-	12
Rantau (drift gill net)	6	-	6	-	4
Rawai (longline)	-	-	-	-	1
Tugu (conical tidal trap)	-	-	-	1	62
Total	82	51	51	6	295

[a]No attempt was made to differentiate the catch effectiveness of these gear.

Table 2. Estimate of the various parameters by zone in the coastal waters of Brunei Darussalam.

Parameter	Zone 1	2	3	4	5	Source
Gear (no.)	82	51	51	6	295	Chua et al. 1987
Mangrove swamps (ha)	533	-	1,784	-	16,101	-do-
Nipah swamps (ha)	380	-	658	-	1,687	-do-
Potential aquaculture sites (no.)	5	-	8	-	21	-do-
Benthos diversity (Shannon-Wiener index)	<1	1-2	2-3	3-4	4-5	Lai et al., this vol.
Coral patches/shoals (no.)	-	2	4	3	-	Chua et al. 1987; Wright 1988
Fishermen (no.)	130	-	135	-	1,860	Chua et al. 1987
Coastal/riverine population	31,008	18,123	14,660	22,757	72,476	-do-
Trawling grounds (km^2)	777	1,748	1,975	1,295	-	Modified from Halidi 1987
Beachfront (km)	25	45	35	33	5	1:50,000 topographic map

Based on the grading system in Table 3, each parameter was given a grade of 1 to 5 according to its area, length, abundance or number in ascending order. The grading of each parameter was rather subjective, and depended much on the availability and accuracy of data.

The grades were entered into a final composite tabulation and each zone was then ranked accordingly (Table 4). The maximum possible score was 50 while the lowest was 10. In reality, however, no zone could yield a perfect score because some of the parameters are mutually exclusive, e.g., sandy beaches and mangrove swamps seldom go hand-in-hand. The total score (t_i) for each zone was divided by the maximum score (t_m) and multiplied by 100 resulting in a composite sensitivity index (c) ranging from 20% (least sensitive) to 100% (most sensitive). The maximum score (C = 100%) is considered the reference index. In terms of oil spill contingency planning, the higher the index for a particular zone, the greater priority it should be given.

As various types of sand respond differently to the impact of an oil spill, the particle sizes of the sediments from each zone were analyzed using a series of sieves

Table 3. Grading system for each parameter as used in the present study.

Parameter	Value range	Grade
Gear (no.)	≤50	1
	51-100	2
	101-150	3
	151-200	4
	>200	5
Mangrove swamps (ha)	<500	1
	500-1,000	2
	1,001-1,500	3
	1,501-15,000	4
	>15,000	5
Nipah swamps (ha)	≤50	1
	51-150	2
	151-500	3
	501-1,500	4
	>1,500	5
Potential aquaculture sites (no.)	≤1	1
	2-5	2
	6-9	3
	10-19	4
	≥20	5
Benthos diversity (Shannon-Wiener index)	0-0.99	1
	1.00-1.99	2
	2.00-2.99	3
	3.00-3.99	4
	≥4	5
Coral patches/shoals (no.)	≤1	1
	2	2
	3	3
	4	4
	≥5	5
Fishermen (no.)	≤50	1
	51-100	2
	101-500	3
	501-1,000	4
	>1,000	5
Coastal/riverine population	≤10,000	1
	10,001-20,000	2
	20,001-30,000	3
	30,001-40,000	4
	>40,000	5
Trawling grounds (km^2)	≤50	1
	51-500	2
	501-1,000	3
	1,001-1,500	4
	>1,500	5
Beachfront (km)	<10	1
	10-20	2
	21-30	3
	31-40	4
	>40	5

Table 4. Ranking matrix for all the parameters considered and composite sensitivity index by zone in the coastal waters of Brunei Darussalam.

Parameter	Zone 1	2	3	4	5
Gear (no.)	2	2	2	1	5
Mangrove swamps (ha)	2	1	4	1	5
Nipah swamps (ha)	3	1	4	1	5
Potential aquaculture sites (no.)	2	1	3	1	5
Benthos diversity (Shannon-Wiener index)	1	2	3	4	5
Coral patches/shoals (no.)	1	2	4	3	1
Fishermen (no.)	3	5	5	4	1
Coastal/riverine population	3	5	4	4	1
Trawling grounds (km^2)	3	1	3	1	5
Beachfront (km)	4	2	2	3	5
Total score (t_i)	24	22	34	23	38
$t_m = 50$					
Composite sensitivity index (%) ($C = t_i/t_m$)	48	44	68	46	76
Rank	3	1	4	2	5

with mesh sizes of 0.50, 0.212 and 0.106 mm. Each fraction was weighed and their percent weight noted (Table 5).

Results and Discussion

The composite sensitivity index scores for the five zones used in this study are given in Table 4 and Fig. 1. The results reflected the criteria chosen for the formulation of the composite sensitivity index which gave heavy weight to natural resources and fisheries while beachfront length was the only recreation parameter included. Zone 5, the Brunei Estuary area, with its extensive mangrove and *nipah* swamps, muddy substratum, densely populated shoreline and enormous artisanal fishing activities, was declared the most sensitive/vulnerable zone in Brunei Darussalam with a composite index of 76% (rank = 5). Its vulnerability in the event of an oil spill would be further accentuated by the semi-enclosed configuration of the estuary area.

Zone 3, east Tg. Danau including the whole of Tutong Estuary and east Jerudong, with a composite index of 68%, was ranked fourth. This zone was characterized by medium benthos diversity, a large hectarage of both mangrove and *nipah* swamps, and considerable offshore coral patches.

Table 5. Particle size distribution (%) of sediments in various coastal sites in Brunei Darussalam. Standard deviation in parentheses; average values underlined.

Particle size of sediments (mm)	Location					
	Kuala Belait[a]	Seria[b]	Tutong[c]	Jerudong[c]	Berakas[c]	Pulau Muara Besar[c]
<0.11	-	51.4 (1.8)	17.5 (13.6)	7.5 (10.2)	5.3 (6.8)	<u>46.8</u>
0.11-0.20	-	<u>32.4</u> (13.0)	33.9 (6.7)	40.9 (25.7)	37.7 (13.2)	13.1
0.21-0.50	-	15.9 (8.0)	<u>35.4</u> (17.6)	<u>48.7</u> (32.8)	<u>54.9</u> (19.9)	10.8
>0.50	-	0.3 (0.1)	13.2 (10.7)	2.9 (1.2)	2.1 (0.8)	29.3

Sources:
[a]Mean particle size of 0.15 mm obtained from Tate (1970).
[b]Leong et al. (1984).
[c]Sediments obtained during the benthos study of Lai et al. (this vol.).

Zone 1, west of Seria including the whole of Kuala Belait Estuary and offshore waters, was accorded the third rank (48%) by virtue of its modest hectarage of mangrove and *nipah* swamps.

Zone 4 covered a stretch of slightly elevated sandy beach and occasional coastal outcrops and promontories in the Jerudong/Pelompong Spit area. The sediments were composed mainly of coarser-grained sand. This zone had a lower composite index of 46% which partly reflected its limited mangrove/*nipah* area and trawling grounds, and slightly higher wave energy. The longshore drift in the area had resulted in a lengthening of Pelompong Spit of as much as 69 m/year prior to the excavation of an access channel (Tate 1970). However, accretion of sand bar is continually taking place on the western flank of the access channel, the result of a net gain of sandy material estimated at about 59,200 t/year from the eastward longshore drift. The weaker longshore drift turns westward at approximately the promontories of Brunei Bluff. The bifurcating longshore drift may promote dispersal in the event of an oil spill which could result in a slight lowering of its vulnerability despite the contention of more oil entrapment by coarser-grained sandy particles.

Zone 2, east of Seria to west Tg. Danau, was the least sensitive/vulnerable zone. This stemmed primarily from its limited mangrove/*nipah* area, artisanal fishing activity and potential aquaculture site.

Among the sandy beaches from Kuala Belait to Pelompong Spit, there was a gradual increase in the particle sizes of the sediments towards the easterly direction (Table 5). Gundlach and Hayes (1978) classified fine sandy beaches as less sensitive to oil impact compared to coarse-grained sand. This is because fine sand tends to entrap less oil droplets by virtue of its smaller interstitial spaces. Although particle size of the substratum was not one of the parameters considered for the development of the composite index, the sensitivity ranking of the zones somewhat matched those of Gundlach and Hayes (1978). In this study, for instance, Zone 2 (from Seria to west Tg. Danau) had a composite index of 44% (rank = 1) and was therefore less sensitive to oil impact than Jerudong-Berakas (part of Zone 4) which had an index of 46% (rank = 2). The particle size of the substratum at Kuala Belait-Seria was finer than that at Jerudong-Berakas (Table 5). It is thus plausible to deduce that Seria would also be less sensitive based on the classification of Gundlach and Hayes (1978).

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References

Chua, T.-E., L.M. Chou and M.S.M. Sadorra, editors. 1987. The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports

18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

FEC (Fisheries and Environment Canada). 1976. An environment risk index for the siting of deep water oil ports. Department of Fisheries and Environment, Ottawa, Canada.

GURC (Gulf Universities Research Consortium). 1980. Field evaluation of the effectiveness of Corexit 9527 chemical dispersant on the IXTOC I oil spill, Bay of Campeche, Mexico. Gulf Universities Research Consortium, Houston, Texas.

Gundlach, E.R. and M.O. Hayes. 1978. Vulnerability of coastal environments to oil spill impacts. Mar. Technol. Soc. J. 12(4): 18-27.

Halidi, H.A.M.S. 1987. A preliminary analysis of catch/effort data from demersal trawl surveys off Negara Brunei Darussalam. Department of Fisheries, Ministry of Industry and Primary Resources, Brunei Darussalam.

Leong, T.S., Y.K. Leong, S.C. Ho, K.H. Khoo, S.P. Kam, S. Hanapi, T.M. Wong and R.S. Legore. 1984. An environmental baseline study of the macrobenthos in the vicinity of the crude oil terminal, Seria, Brunei. Sinaran Brothers Sdn. Bhd., Penang, Malaysia.

Ridzwan, A.R. and M.W.R.N. De Silva, editors. 1983. Coastal resources of Cukai-Dungun coastline sensitive to impacts of oil spills. Universiti Pertanian Malaysia/Petronas, Malaysia.

Tate, R.B. 1970. Longshore drift and its effect on the new Muara Port. Brunei Mus. J. 2(1): 238-252.

Wright, R.A.D. 1988. Brunei Shell Petroleum Co. Oil Spill Contingency Plan. Safety and Environmental Department, Brunei Shell Petroleum Co., Brunei Darussalam.

Island Management Strategy for Brunei Darussalam

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Abstract

Of the 33 recorded islands in Brunei Darussalam, 2 are located offshore; the rest are in Inner Brunei Bay or the major rivers. All but 3 islands are uninhabited, the majority of them in a pristine state. The islands are fringed with mangroves and swamps, some are covered with undisturbed primary forest and several areas have been cleared for agriculture. Generally, the islands support few flora and fauna, but some harbor endangered species or provide undisturbed breeding sites.

Based on the degree of protection each needs to maintain sustainability, the islands have been classified into three groups: general use, conservation and protection. From their research and studies, the Biology Department of the Universiti Brunei Darussalam (UBD) and the Department of Town and Country Planning (DOTCP) propose that most of the islands be designated as nature reserves or wildlife sanctuaries. Some islands have the potential for ecotourism and for recreational, educational and research purposes. A working group on island management (WGIM) could be formed to coordinate the efforts of the relevant government bodies until a single authority responsible for overall management of the islands and their resources is established.

Introduction

There are 33 recorded islands in Brunei Darussalam, 2 of which are found offshore; the rest are situated either in the Inner Brunei Bay or the major rivers. Of the 20 islands in Brunei-Muara District, 13 are located in the Brunei Bay area (Fig. 1), 5 in Sungai or Sg. (i.e., river) Brunei (Fig. 2) and 2 off the coast of Muara. In Temburong District, there are 10 islands (Fig. 3a-b). All of the 3 islands in Tutong District are situated in the Tutong River System (Fig. 4). There are no known islands in Belait District. Many of the islands are situated in areas of active sedimentation and as a consequence are increasing in size (DOTCP 1986).

The islands occupy a land area of 7,939 ha, or 1.4% of the country's land area. Almost all the islands are totally uninhabited other than a few with one or two human settlements along the banks. These inhabited islands (Pulau or P.), namely, Berambang, Baru-Baru and Berbunut, can mainly be found around the vicinity of Bandar Seri Begawan in Brunei-Muara District. They make up 1,137 ha, or around 14% of the total area of the country's islands.

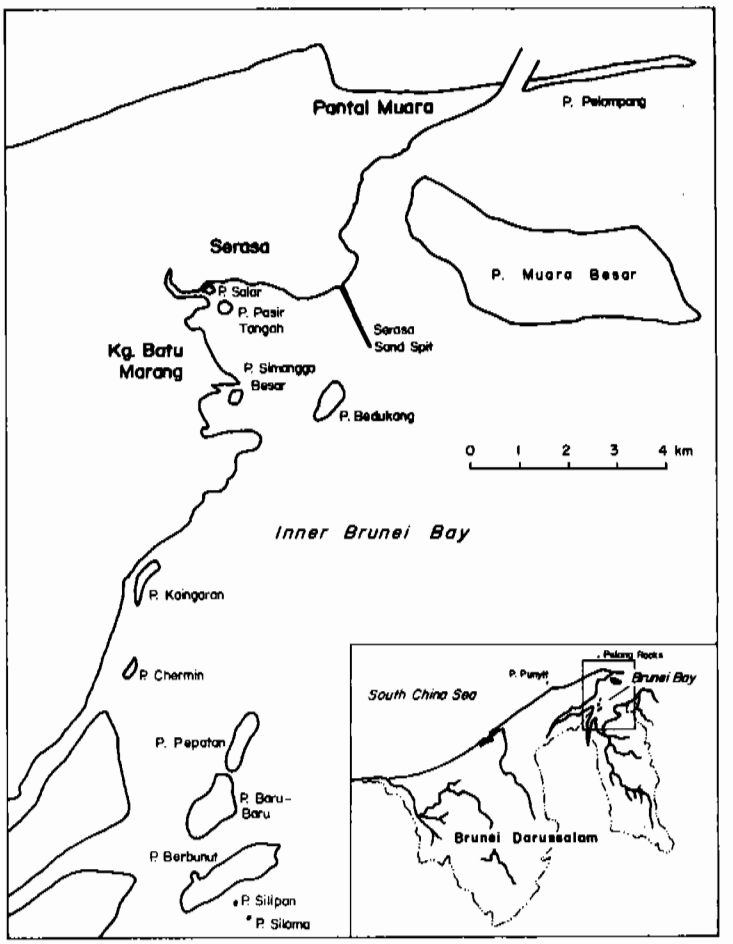


Fig. 1. Islands in Brunei Bay and offshore islands, Brunei-Muara District.

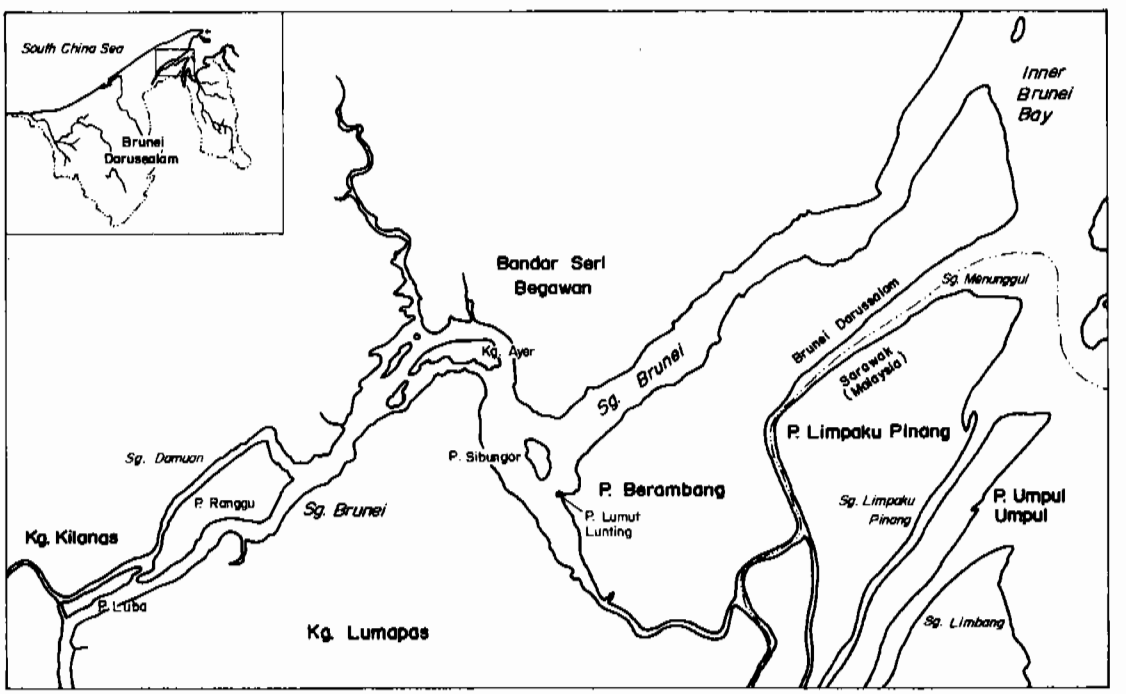


Fig. 2. Islands in the Sg. Brunei area, Brunei-Muara District.

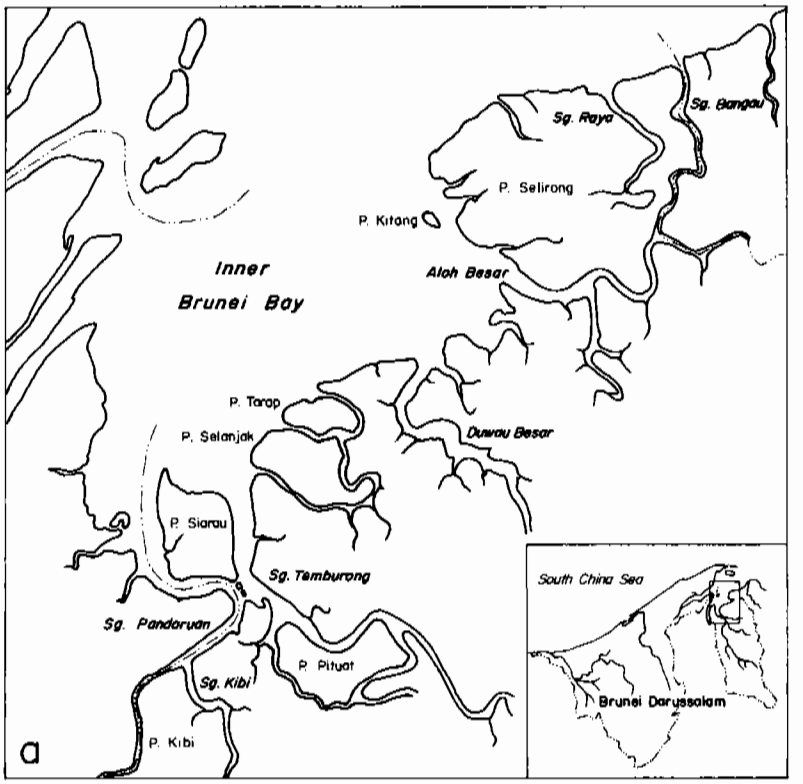
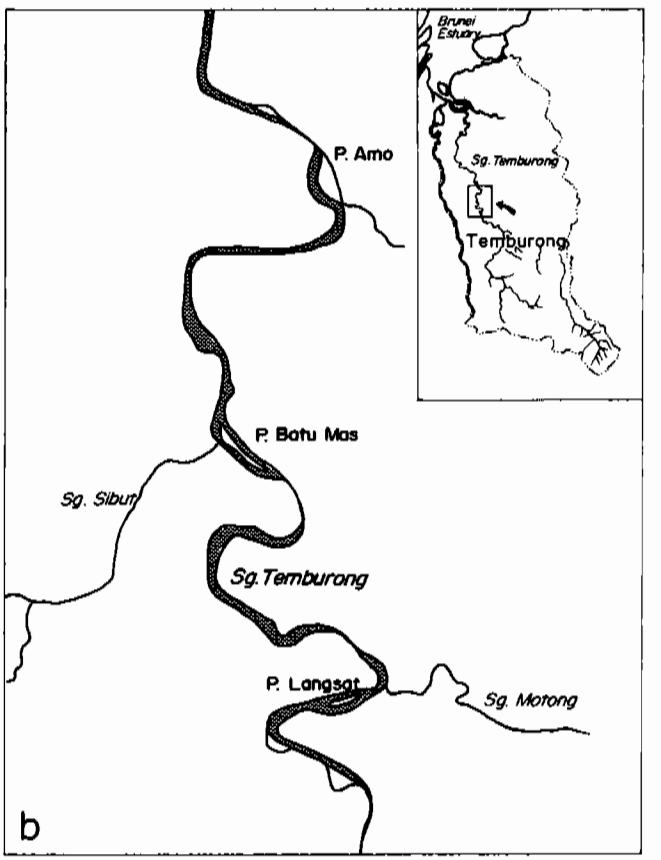


Fig. 3a. Islands in Temburong District.

Fig. 3b. Islands in Temburong District.



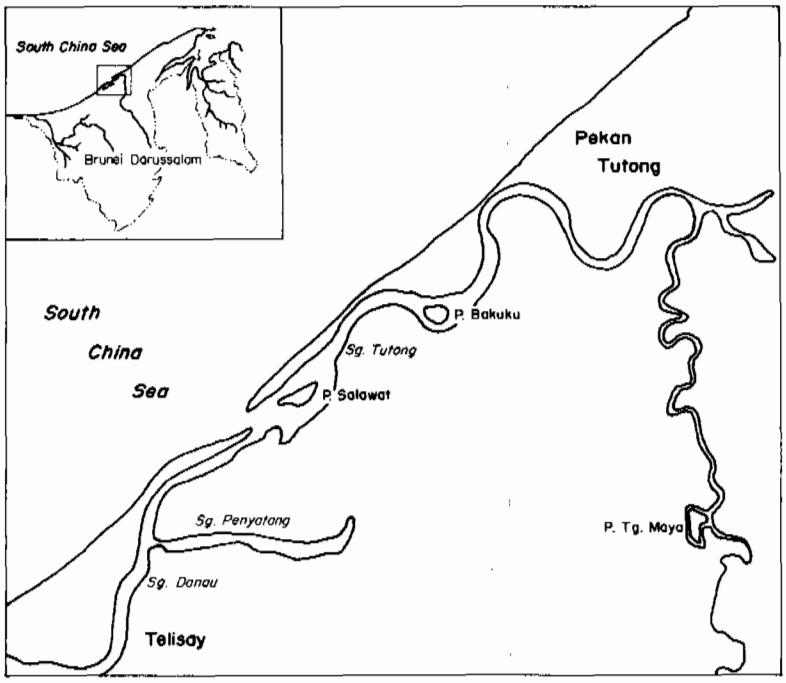


Fig. 4. Islands in Tutong District.

The rest of the islands are virtually untouched. Generally, they support very few flora and fauna, but some harbor endangered species or provide undisturbed breeding sites. Turtle nesting on a few islands with sandy beaches has been reported. The composition of the flora and fauna of the islands is significantly different from that of the adjacent mainland. This may be due to the relative isolation of the islands (DOTCP 1986).

Very few studies have been carried out on the islands. A brief survey (Mittermeier 1980) of the *nipa* and mangrove islands in the immediate vicinity of Bandar Seri Begawan reveals that the islands have very similar characteristics. All have a substantial population of proboscis or long-nosed monkeys *(Nasalis larvatus)*, referred to as *orang belanda* or *bangkatan* in Malay; crab-eating or long-tailed macaques *(Macaca fascicularis)*; silver leaf monkeys *(Presbytis cristata)*; and a wide variety of birds.

The proboscis monkey is herbivorous and prefers to live in undisturbed mangrove areas. It is considered a vulnerable or endangered species by the International Union for the Conservation of Nature and Natural Resources, and the Conservation on International Trade in Endangered Species of Wild Flora and Fauna. It is found only in the island of Borneo (Malaysia, Indonesia and Brunei Darussalam). In Brunei Darussalam, it is predominant in the islands of Berambang, Berbunut, Pepatan, Baru-Baru and Bedukang (Mohd. Jaya and Howes 1986) and several other islands. P. Siarau, the roosting site of an enormous population of large flying foxes or fruit bats *(Pteropus vampyrus)*, is also a natural habitat of the proboscis monkey (Mittermeier 1980).

Among other adverse effects, the destruction of the mangroves on the islands could result in the extinction of the flying fox and the proboscis monkey from a part of Borneo. For this reason, Mittermeier (1980) recommends the establishment of several wildlife sanctuaries and possibly a mangrove national park in the Brunei Bay area. The Negara Brunei Darussalam Master Plan (NBDMP) of 1986 proposes that most of the islands in the entire country be designated either as reservation or conservation areas.

Status of the Islands

Brunei-Muara District

Inner Brunei Bay Area

P. Muara Besar. One of the largest islands of Brunei Darussalam at 940 ha, Muara Besar is in the Inner Bay area about a kilometer southeast of the International Port of Muara. It is the site of the only livestock quarantine station in the country, built in 1984, but has up to now not been utilized. At present, there is no source of fresh water in the island but electricity supply will soon be connected (DOTCP 1988). Despite its size and

proximity to the International Port, Muara Besar is uninhabited. The island is made up of sand in excess of 10 m deep. The land is flat, fringed with isolated strips of mangroves and swamp forest with some shifting cultivation being practised northeast of the island. The mangrove forests consist mainly of *Avicennia marina* and *Sonneratia alba* on the south coast and *bakau (Rhizophora apiculata)* along the west coast. The middle western portion of the island consists of grasslands while the middle eastern portion has primary forest growth. There is a wide band of sandflats at the northern side where some 14 species of migratory shorebirds have been observed (Mohd. Jaya and Howes 1986). The most abundant species is the Asian golden plover *(Pluvialis fulva)*, followed by the whimbrel *(Numenius phaeopus)*.

The southern and western coasts are more sheltered, with a muddy foreshore. Their apparent stability offers a potential for deepwater berths (Fig. 5), because of ready accessibility to deep water and favorable current conditions, probably second only to Muara in the whole of Brunei Darussalam (DOTCP 1988). However, strong currents have eroded Ujong Sapo at the eastern end of the island by more than 100 m in the last ten years, thus threatening the navigation light situated here.

P. Pelompong (Pelompong Sand Spit). Originally connected to the mainland, 64-ha Pelompong is a natural spit located north of Muara Besar. It is mainly uninhabited primary forest.

In 1963, a channel was cut across the spit to provide easy access to Muara Port, resulting in the creation of this island. In 1968, the channel separating the island from the mainland was dredged and a breakwater known as Muara Cut was constructed to prevent siltation of the channel. Since then, the natural supply of beach material to the spit has been severed, causing extensive erosion on its northern coast. To alleviate the problem, 12 headland breakwaters were constructed but did not extend to the entire length of the frontage, leaving the easternmost 1,000 m unprotected. As a result, the spit breached in 1985. In 1987, the island was covered by the sea. Five more headlands were constructed in 1988 to restore the spit to its pre-1985 length. Although the headlands succeeded in protecting the beaches, they should be regularly monitored to detect possible weakening.

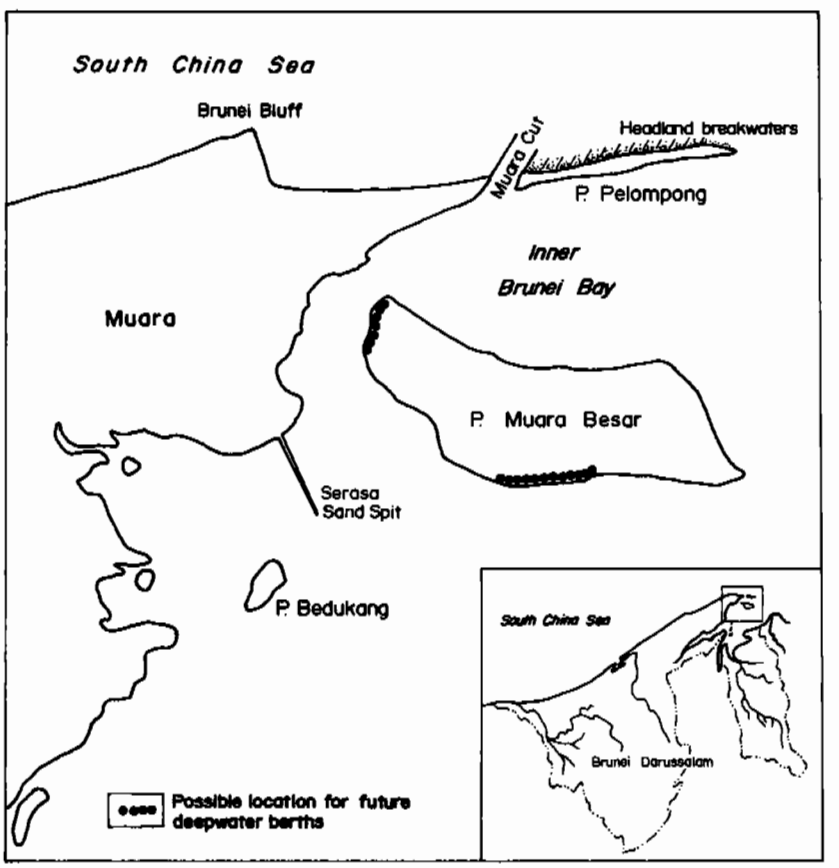


Fig. 5. Proposed areas for deepwater berths in P. Muara Besar.

Though the southern shore of the spit appears to be stable, the eastern end adjacent to Muara Cut experienced some erosion after the initial dredging of the cut. To remedy this, three rock groins were built to the east. In 1987, the seawall and groins appeared to be in fair condition (DOTCP 1988). The Biology Department of UBD (1990) recommends that this island be "protected for hydrological reasons although the navigational channels around the spit may have to be dredged from time to time to offset sedimentation".

P. Berbunut. Berbunut has a total land area of 112 ha and lies east of Bandar Seri Begawan. With a very small population, it has only one village (*kampong* or Kg.), Berbunut, situated at the southeastern side of the island. In 1929, the first charcoal kiln was started here, followed by several others. Berbunut is the leading producer of domestic charcoal and is the seat of the charcoal-making industry in the country (Lim 1975).

The northern coast is composed of swamps with isolated fringes of mangroves. The most dominant species, *Avicennia marina*, can be found growing along the north to northwest coast. Some *Sonneratia alba* can also be seen. The south coast of the island supports some thick stands of *Nypa fruticans*. The extensive intertidal mudflats to the north and northwest of Berbunut exposed during low tide are the second most important area for migratory birds in Brunei Darussalam. At least six species of shorebirds are known to forage for food on the mudflats; the most abundant is the whimbrel followed by the common redshank *(Tringa totanus)*. Berbunut also supports other fauna. The most popular is the endangered proboscis monkey.

P. Baru-Baru and P. Pepatan. Lying adjacent to Berbunut is Baru-Baru with a total land area of 86 ha. It also boasts of kilns which produce charcoal for domestic consumption. It is sparsely populated with approximately 60 people in only one *kampong*, Kg. Baru-Baru, situated in Sg. Brunei northwest of the island, fronting P. Berambang. Baru-Baru is almost entirely surrounded by swamps and mangroves dominated by *Avicennia* mixed with *Rhizophora* and some *nipa* except for the southern end where the highest point of the island, 107 m above sea level, is situated. The center of the island is mostly undisturbed primary forest with some areas previously cleared for agriculture.

North of Baru-Baru lies the uninhabited 39-ha Pepatan. Similar to its neighbor, the island is almost completely surrounded by swamps and mangroves of the same species. The center also consists mainly of undisturbed primary forest. During low tide, intertidal flats form a continuous band extending along the eastern edge of Baru-Baru to a promontory less than 1 km northeast of Pepatan (Mohd. Jaya and Howes 1986). Here some species of migratory shorebirds have been observed foraging for food; the most dominant is the Asian golden plover followed by the common redshank.

P. Kaingaran. Kaingaran is a long uninhabited island near the mouth of Sg. Brunei, northeast of Bandar Seri Begawan. Its 25-ha land area is mainly covered with primary forest with some fringes of mangroves of the *Avicennia* species. The channel between the island and the mainland was once the site of the first green mussel farm in Brunei Darussalam. No information is available on the fauna.

P. Chermin. Located at the mouth of Sg. Brunei, Chermin has a total land area of 5 ha. The island is historically important to Brunei Darussalam as the site of an ancient fortress held by Sultan Hassan in 1700 A.D. (Harisson 1970). Chermin does not support a very complex fauna and flora. Some *nipa* palms found at the east side are associated with a fringing mangrove composed of *Avicennia* mixed with *Rhizophora* and *Sonneratia*. The seagrass *Enhalus* has been recorded from this island by the Biology Department of UBD (1990). The rest of Chermin has primary forest growth. The beach is mainly muddy; very few places along its coastline have sandy beaches. Considerable erosion is observed on the west side of the island. At present, Chermin is uninhabited but serves as a recreational area for some avid sports fishermen.

Other Islands in Brunei Bay. Other islands found in Brunei Bay are Silipan, Silama, Salar, Pasir Tangah, Bedukang and Simangga Besar. These are uninhabited small islands with an average size of about 5 ha, except for 20-ha Bedukang. Situated at different parts of the bay, all are mainly mangrove islands dominated by *bakau* mixed with *Avicennia* and *pedada* (*Sonneratia* sp.) (Cabahug, pers. comm.). Information on these islands is scanty, and none is available on the fauna, except for Bedukang. Its flora and fauna are in good condition. The mudflats serve as nurseries for postlarval horseshoe crabs, edible mangrove crabs and penaeid shrimps.

Sg. Brunei Area

P. Berambang. Berambang is located in Sg. Brunei, east of the mainland. With a total land area of 1,939 ha, it has the largest population among the inhabited islands. It is surrounded by extensive mangroves which provide breeding grounds for fish and crustaceans, making it ecologically important to the fishing industry of Brunei Darussalam. The mangrove is fringed along the west coast with undifferentiated pure *nipa (Nypa fruticans)* or a *nipa-dungun (Nypa-Heritiera globosa)* mixture. Along the east coast of the island, *Rhizophora* dominates the mangrove fringe, while along Sg.

Manunggol near Kg. Manunggol, a wide area of pure stands of *Avicennia* can be found (Cabahug, pers. comm.). The higher regions are either covered by secondary forest composed of *Hibiscus* and *Xylocarpus* and other associated species, or are under cultivation.

Berambang is also particularly important as a natural habitat of the proboscis monkey and some other animals and birds. Moreover, the first commercial-scale fish cage farm in Brunei Darussalam which was started in early 1990 is located just off the island (R. Agbayani, pers. comm.).

P. Ranggu, P. Sibungor, P. Lumut Lunting and P. Luba. These other islands in Sg. Brunei are situated southwest of Bandar Seri Begawan. They have almost similar characteristics, are all uninhabited and serve as natural habitats for the endangered proboscis monkey.

Ranggu, the biggest of the four, has a total land area of 199 ha. Bordered by Sg. Damuan on the northwestern coast and Sg. Brunei on the southeastern coast, it is completely surrounded by swamps and mangroves. *Rhizophora apiculata* is the dominant mangrove species mixed at times with *Avicennia. Nyireh bunga (Xylocarpus granatum)* and *linggadai (Bruguiera gymnorrhiza)* are found in the inner reaches of the mangrove forest. The extensive mangrove forests provide valuable breeding and nursery areas for fish, shellfish and other aquatic organisms. The middle southwest portion of the island is mainly primary forest.

Sibungor and Lumut Lunting have almost identical characteristics, though the former is 8 ha while the latter is only about 1 ha. However, the Biology Department of UBD (1990) reports that Lumut Lunting is "biologically very disturbed". Both islands are surrounded by swamps with isolated fringes of mangrove, primarily *Rhizophora apiculata.* They lie adjacent to one another southeast of the capital.

About 50 ha, Luba lies west of Ranggu. Mangroves can be found on both ends of this small elongated island while sundry tree cultivation occupies the rest. Little else is available on the fauna and flora. The island has been used as sacred burial grounds of the royal family.

Offshore Islands

Pelong Rocks and P. Punyit. Of the 33 islands of Brunei Darussalam, only 2 can be found offshore in the South China Sea, namely, Pelong Rocks (or Pelong Pelongan as it is locally known) and Punyit (Fig. 1). Pelong Rocks is a 2-ha island located off the coast of Muara, northeast of Bandar Seri Begawan. Punyit is situated off the coast of Jerudong, northwest of Bandar Seri Begawan and has a total area of 8 ha.

Though these islands are not anywhere near each other, both have almost similar characteristics. Their fauna and flora are limited due to their rocky profiles. Both islands are surrounded by gradually sloping fringing coral reefs, the only ones in Brunei Darussalam. In reef surveys at Pelong Rocks, Punyit and Two Fathom Rocks, Chou et al. (1987) document 88 species of hard coral distributed among 52 genera from the three sites combined. The two islands also serve as nesting grounds to some seabirds. In 1958, a breeding colony of roseate tern *(Sterna dougalli)* was discovered on Pelong Rocks. Other birds found on the islands are the brown-winged tern *(Sterna anaetheta)*, the common tern *(Sterna hirundo)* and some egrets like the Pacific Reef egret *(Egretta sacra).*

Temburong District

Brunei Bay Area

P. Selirong (Selirong Forest Reserve). The 2,566-ha Selirong Forest Reserve (SFR) in Temburong is bordered on the east by Sg. Bangau[1], Aloh Besar on the south and Brunei Bay on both the west and north sides (DOTCP 1986). Completely surrounded by water, SFR is in itself an island. It is part of the proposed Labu Selirong Wildlife Sanctuary (LSWS).

The area is uninhabited and is comprised of swamps and mangroves. Out of the total land area of the island, 2,409 ha or 94% are mangrove forests (Zamora 1987). Most of the mangroves are almost pure stands of *bakau,* though some patches of *nyireh bunga* and *linggadai* can be found in the middle north part of the island. Under the supervision of the Forestry Department (FD), the mangrove forest is being exploited for charcoal, firewood and mangrove poles used for piling in construction work. De la Cruz et al. (1987) note that "although these forests are designated to become wildlife sanctuaries, it is envisaged that limited cutting of mangrove and other timber, particularly by those with customary rights, will be permitted".

P. Siarau. The 393-ha P. Siarau is also part of the proposed LSWS (DOTCP 1986). It lies in the Brunei Bay area southeast of Bandar Seri Begawan, and is bordered by Sg. Temburong on the east, Sg. Pandaruan on the south and Brunei Bay on the north and west. Totally uninhabited, Siarau is comprised of swamps

[1]Sg. Bangau also marks the boundary between Malaysia and Brunei Darussalam.

and mangroves. *Bakau*, the most dominant species of mangrove, can be found in the island, with scattered patches of *linggadai* and *nyireh bunga*. Large stands of *nipa* and *nipa* mixed with *dungun* grow along Sg. Pandaruan and Sg. Temburong.

A natural habitat of the proboscis monkey, the island is also the roosting site of an enormous population of fruit bats or flying foxes. Every 6-7 P.M., thousands of these bats fly out from the island to forage for food along the coasts of Brunei Darussalam and nearby Sarawak (Mittermeier 1980).

P. Kitang, P. Selanjak and P. Tarap. These three uninhabited islands are covered with swamps and mangroves dominated by *bakau* mixed with *nyireh bunga* and *linggadai*. Scattered patches of *nipa* are found along the riverbanks. Although the fauna of the islands are unknown, proboscis monkeys possibly live there.

Sg. Temburong Area

P. Kibi, P. Pituat, P. Batu Mas, P. Langsat and P. Amo. Of the ten islands found in Temburong District, these five are found in Sg. Temburong. Kibi has an area of 569 ha while Pituat is 369 ha. Both islands are predominantly swamps and mangroves and possible habitats of the proboscis monkey. Kibi's mangroves are principally *nipa* with small patches of *bakau*. Towards the middle portion of the island, *Heretiera* and *Cerbera* can be found (Cabahug, pers. comm.). Pituat's mangrove forest is primarily *bakau* mixed with *nyireh bunga*, *Bruguiera* spp. and some fringes of *nipa*. Aside from a few mangrove species, information about the flora and fauna of both islands is very limited.

Batu Mas, Langsat and Amo, found in the innermost reaches of Sg. Temburong, are relatively small compared with the majority of the islands in Temburong District. Batu Mas comprises about 4 ha, Langsat, 2 ha and Amo, 6 ha. The first two are areas of shifting cultivation. Batu Mas is situated near Kg. Sibut and Kg. Sumbiling Baru. It is also close to an old rubber plantation now overgrown with weeds and other vegetation and has since been reclaimed by the jungle. Not far off, down Sg. Temburong, near Kg. Sumbiling Lama is Langsat, which once must have had plenty of langsat fruit trees. Upriver, just after Batu Mas is P. Amo, near Kg. Amo A and B. It was once part of a large rubber plantation that, like all the others in Brunei Darussalam, is now overgrown with creepers and has since reverted to the jungle. Though near human habitation and disturbed by people, all three islands are unsettled. Information on the natural fauna and flora of the islands is unavailable.

Tutong District

Sg. Tutong Area

P. Salawat, P. Bakuku and P. Tanjong (or Tg., i.e., cape) *Maya*. Little is known about these three islands except that they are uninhabited and undisturbed, and covered with primary forests fringed by mangroves and *nipa*. Salawat is about 13 ha, Bakuku, 9 ha and Tg. Maya, 16 ha. Adjacent are two small unnamed islands; one is informally referred to as Tangah. When the waters surrounding this islet turn murky, crocodiles are reported to be seen in the area. During these periods, local residents stay clear of the area.

Management Strategy for the Islands

The majority of the islands of Brunei Darussalam are virtually untouched, in a world where pristine or near pristine ecosystems are fast becoming a rarity. A practical strategy balancing the needs of development and those of the islands and their unique floral and faunal communities would be necessary to ensure that these ecosystems do not unnecessarily fall prey to development. The country has been in a favorable position where the exploitation of natural resources other than oil and gas has not been absolutely necessary to sustain its economic stability. As such, it is among the few countries of the world in an enviable situation where practical plans could be incorporated into development plans to ensure the sustainable use of the relatively unexploited coastal ecosystems.

Classification of the Islands

Only three coastal islands (Berambang, Berbunut and Baru-Baru) in Brunei Darussalam have permanent human settlements. Although uninhabited, many of the remaining islands are subjected to human interference of varying degrees. Disturbed islands and those earmarked for specific development programs require a degree of environmental protection in keeping with existing or planned activities. Undisturbed islands that harbor endangered species and those known for their biodiversity and genepool contribution need maximum protection.

Based on these considerations and as a first step towards the development of a strategy for sustainable

management, the islands have been classified into three major groups: (1) general use, (2) conservation and (3) protection. Table 1 summarizes the important features and recommended status of the islands in the coastal zone of Brunei Darussalam.

Islands for general use

With the lowest protection status, these could be designated as multiple-use islands for recreational, educational and other purposes. Every effort should make use of the natural attributes of the islands for the planned activities. The islands should be zoned for compatible activities and need basic precautions against pollution and overexploitation.

Brunei-Muara District

P. Muara Besar. Based on ongoing research by the Biology Department of UBD, the island is a good habitat for benthic invertebrates and seagrasses and as a possible turtle nesting site. Because of the slightly offshore situation and relatively low sediment load, this area may be serving as a source of gene pool and parent stock for many of the benthic marine invertebrates found in nearshore areas. The mangroves should be protected. On the other hand, DOTCP (1988) recommends about 50 ha of the southeastern end of the island as an alternative site for sand extraction.

Ideally located near the main port town of Muara, Muara Besar could be developed into a recreational

Table 1. The islands of Brunei Darussalam and their recommended protection status.

District and location	Island (Pulau)	Area (ha)	Habitat type	Interesting fauna	Recommended protection status
Brunei-Muara					
Islands in Inner	Muara Besar	940	Primary forest, mangroves	Migratory water/shorebirds	General use
Brunei Bay	Pelompong	64	Primary forest	Probable turtle nesting site	Conservation
	Berbunut	112	Mangroves, swamps, mudflats	Proboscis monkeys, shorebirds	Conservation
	Baru-Baru	86	Mangroves, swamps. mudflats	Migratory water/shorebirds	General use
	Pepatan	39	Mangroves, swamps, mudflats	Migratory water/shorebirds	Protection
	Kaingaran	25	Primary forest, mangroves	Unknown	Protection
	Chermin	5	Sundry vegetation, fringing mangroves	Unknown	Conservation
	Silipan	6	Mangrove forest	Unknown	Protection
	Silama	6	Mangrove forest	Unknown	Protection
	Salar	5	Mangrove forest	Unknown	Protection
	Pasir Tangah	4	Mangrove forest	Unknown	Protection
	Bedukang	20	Mangrove forest	Unknown	Protection
	Simangga Besar	4	Mangrove forest	Unknown	Protection
Islands in	Berambang	1,939	Mangrove and secondary forests	Proboscis monkeys, birds, etc.	Conservation
Sg. Brunei	Ranggu	199	Mangrove forest, swamps	Proboscis monkeys	Protection
	Sibungor	8	Mangroves, swamps	Proboscis monkeys	Protection
	Lumut Lunting	1	Mangroves, swamps	Proboscis monkeys	Protection
	Luba	50	Sundry tree cultivation	Unknown	Conservation
Offshore islands	Pelong Rocks	2	Rocky, fringing coral reef	Birds, coral reef species	Conservation
	Punyit	8	Rocky, fringing coral reef	Birds, coral reef species	Protection
Temburong					
Islands in	Selirong	2,566	Mangrove forest, swamps	Proboscis monkeys	Conservation
Brunei Bay	Siarau	393	Mangrove forest, swamps	Flying foxes, proboscis monkeys	Protection
	Kitang	12	Mangrove forest, swamps	Unknown	Protection
	Selanjak	329	Mangrove forest, swamps	Unknown	Protection
	Tarap	128	Mangrove forest, swamps	Unknown	Protection
Islands in	Kibi	569	Mangrove forest, swamps	Unknown	Protection
Sg. Temburong	Pintat	369	Mangrove forest, swamps	Unknown	Protection
	Batu Mas	4	Shifting vegetation	Unknown	Conservation
	Langsat	2	Shifting vegetation	Unknown	Conservation
	Amo	6	Sundry vegetation	Unknown	Conservation
Tutong					
Islands in	Salawat	13	Mangroves, swamps	Unknown	Protection
Sg. Tutong	Bakuku	9	Mangroves, swamps	Unknown	Protection
	Tanjong Maya	16	Mangroves, swamps	Unknown	Protection

island similar to Sentosa Island in Singapore. Well-laid out parks with strategically planted trees that would enhance the natural forests, clean sandy beaches and educational/recreational facilities (e.g., oceanarium, marine museum, swimming pools, windsurfing and yatching areas, restaurants, holiday chalets) will make this island exceptionally attractive. A wildlife deer-and-bird park and aquaculture farms could also be easily accommodated, if properly planned.

For its part, the Brunei Muara Development Plan (DOTCP 1987a) notes that Muara Besar may be used in the future (post-2005) either for urban development or for expansion of marine facilities.

P. Baru-Baru. The Biology Department of UBD proposes protection of the mangroves for their filter/fisheries input. As this island has already been disturbed, it could be utilized for planned programs which require an island environment.

Islands for conservation

These islands could be used for ecotourism, education and research with emphasis on rationally managed exploitation of resources. Careful planning and zoning of the islands are necessary to ensure that the natural resources, particularly the fauna and flora, are managed on a sustainable basis. Inhabited and partly privately owned islands should possess buffer zones of adequate size to prevent disturbance of endangered wildlife such as proboscis monkeys and their habitats.

Brunei-Muara District

Pelong Rocks (Pelong Pelongan). The Biology Department of UBD has ongoing research on the island and maintains that it should be totally protected as a unique habitat with nesting birds, bat caves, snakes, and coral and coral outgrowths vulnerable to set and drift netting. No landing should be permitted on the main island. Pelong Rocks could be a nature reserve or, as the Museums Department (MuD) and DOTCP (1986) also recommend, a wildlife sanctuary. With its potential to be developed into a marine park, the island requires a specific management plan to zone activities and maintain sustainability.

P. Pelompong. Currently used for recreation such as fishing, Pelompong is recommended as a nature reserve by DOTCP (1986). Its beaches are used by turtles for nesting. This island could be a site for a turtle hatchery which could assist in the conservation and study of endangered turtles rarely seen in Brunei Darussalam.

P. Berbunut. The entire island has been proposed as a nature reserve (DOTCP 1986). Zoning for activities (such as charcoal making) should consider the island's mudflats which are important for migratory birds; and the mangroves which harbor a population of the endangered proboscis monkey.

P. Chermin. The Biology Department of UBD is conducting research on the island and has suggested that it be protected for its fine sediment, and fauna and flora. Moreover, with the reconstruction of the historically significant fortress that was once on the island, it can be developed as an interesting archaeological site for visitors. The MuD has proposed that Chermin be declared a historical site under Section 17(1) of the Antiquities and Treasure Trove Enactment of 1967 and has taken steps to protect the status quo.

P. Berambang. In 1982, MuD proposed that the 721 ha of mangroves in this island be a conservation area. With its current research on Berambang, the Biology Department of UBD likewise suggests that the mangroves be protected for their filter/fisheries input roles. The island should be zoned to provide for an undisturbed mangrove reserve with a sufficient buffer zone to serve as a habitat for the proboscis monkeys. Due to its proximity to Bandar Seri Begawan, the entire island would be an ideal nature reserve for use by schools, in ecotourism and for its "mangrove areas and [...] important higher regions mostly covered with mature secondary forest" (DOTCP 1986).

P. Luba. Like all uninhabited islands in Brunei Darussalam, it is proposed as a wildlife sanctuary in NBDMP. The Biology Department of UBD sees Luba's potential for ecotourism based on the good quality of its mangroves, the beauty of the surroundings and its proximity to town. The erection of plankwalls in mangroves should be considered to contain the damage being caused by illegal logging and clearing of mangroves.

Temburong District

P. Selirong. Situated near the border of the State of Sarawak in East Malaysia, this mangrove island could be utilized for recreational, educational and research purposes.

P. Batu Mas, P. Langsat and P. Amo. These islands are proposed wildlife sanctuaries in NBDMP. With proper management and the necessary technical assistance from either or both Forestry and Agriculture Departments, these islands may be utilized as sites for future fruit or vegetable farms.

Islands for protection

These islands need protection by virtue of their biodiversity, near pristine nature and the presence of rare

species. Only minimal disturbance for restricted scientific research and monitoring purposes may be approved.

Brunei-Muara District

P. Pepatan. Protection of this island's mangroves is recommended by the Biology Department of UBD for their filter/fisheries input functions.

P. Kaingaran. The island is being considered by the Department of Fisheries (DOF) as a potential site for fish cage culture. Furthermore, the Biology Department of UBD advocates the protection of the mangroves fringing P. Kaingaran for their filter/fisheries contribution and role as a greenbelt for developments at the industrial site in Mentiri. The DOTCP (1986) suggests that this island be designated as a wildlife sanctuary.

Silipan, Silama, Salar, Pasir Tangah, Bedukang and Simangga Besar. These islands are proposed as wildlife sanctuaries in NBDMP. The Biology Department of UBD recommends protection of the mangroves of Bedukang and Simangga Besar. The latter's mangroves also serve as a greenbelt for Mentiri and could help buffer the development-related disturbances on the immediate mainland.

P. Ranggu. The DOTCP (1987b) proposes the creation of the Damuan River Park by linking Ranggu to the ASEAN Sculpture Park adjacent to the Istana Nurul Iman (The Palace of His Majesty, the Sultan of Brunei Darussalam). The proposal includes provision of facilities for those interested in the island's wildlife. Similarly, the Biology Department of UBD says that Ranggu can be developed for ecotourism, like Luba, with the same protective measures for its mangroves.

P. Sibungor and P. Lumut Lunting. These uninhabited islands located upriver of Sg. Brunei are recommended in NBDMP as wildlife sanctuaries.

P. Punyit. This possesses features nearly identical to those of Pelong Rocks. As such, DOTCP (1986) and the Biology Department of UBD recommend its designation either as a nature reserve or a wildlife sanctuary for the same reasons as those cited for Pelong Rocks. In addition, fishing, gathering or landing should be prohibited on this unique island habitat which has nearshore corals and a wide range of marine flora and fauna.

Temburong District

P. Kitang. This is a very small, uninhabited, mangrove-filled island near Selirong. Although information on the fauna is lacking, it could possibly be a habitat of the proboscis monkey. For these reasons, it is advised in NBDMP that the island be made a part of LSWS.

P. Siarau. This island is designated by MuD as a conservation area and proposed as a wildlife sanctuary in NBDMP. Likewise, the Biology Department of UBD recommends it as a nature reserve or sanctuary. Its biologically rich community should be totally protected.

P. Kibi, P. Pituat, P. Selanjak and P. Tarap. All these islands are recommended as wildlife sanctuaries in NBDMP. The Biology Department of UBD urges general protection for the mangroves as biological filters, sediment stabilizers and substantial contributors to fisheries. While development for economic/social reasons of some of these places is inevitable, the department strongly advises that any such area should only be developed/disturbed after a detailed environmental impact assessment.

Tutong District

P. Bakuku, P. Salawat and P. Tanjong Maya. The NBDMP advocates that these islands be protected as wildlife sanctuaries. The Biology Department of UBD suggests that mangroves on Salawat and Bakuku (and those fringing Sg. Penyatang and Sg. Danau) be conserved to protect the White Sands Nature Reserve and Tutong Spit.

Establishment of a Working Group on Island Management

Until such time as a single authority responsible for the overall management of the islands and their resources is established, a Working Group on Island Management (WGIM) could be formed. This group could coordinate the efforts of the relevant departments until a better alternative would be available for island management. The personnel for WGIM could be drawn from MuD, Ministry of Culture, Youth and Sports; FD and DOF, Ministry of Industry and Primary Resources; DOTCP, Ministry of Development; and UBD, Ministry of Education.

Immediate steps need to be taken to set up WGIM, which would be tasked with the following responsibilities:

- compile information on present and planned activities on the islands;
- assess present and planned activities in relation to the proposed protection status of the islands;
- seek the cooperation of the relevant departments and institutions to promote scientific

research on the sustainable development of the islands and proper coordination to prevent unnecessary overlaps;

- seek the cooperation of the relevant departments to initiate the formulation of management plans for the islands for general use and for conservation;
- propose steps for better management of the islands; and
- propose an initial island monitoring system utilizing the available staff and facilities in FD, DOF, MuD and other relevant departments.

References

BD-UBD (Biology Department, Universiti Brunei Darussalam). 1990. Proposal for the protected areas in the coastal zones of Negara Brunei Darussalam (including offshore islands). (Unpublished).

Chou, L.M., M.W.R.N. De Silva and A.T. White. 1987. Coral reefs, algae and seagrasses, p. 43-60. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam and International Center for Living Aquatic Resources Management, Manila, Philippines.

De la Cruz, C., L.M. Chou and M.W.R.N. De Silva. 1987. Land use capability, p. 79-88. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam and International Center for Living Aquatic Resources Management, Manila, Philippines.

DOTCP (Department of Town and Country Planning). 1986. Negara Brunei Darussalam Master Plan: Special Report on Wildlife Conservation and Management. Department of Town and Country Planning, Brunei Darussalam.

DOTCP (Department of Town and Country Planning). 1987a. Negara Brunei Darussalam Master Plan: Brunei-Muara Development Plan. Draft Final Report. Department of Town and Country Planning, Brunei Darussalam.

DOTCP (Department of Town and Country Planning). 1987b. Negara Brunei Darussalam Master Plan: Main Volume. Draft Final Report. Department of Town and Country Planning, Brunei Darussalam.

DOTCP (Department of Town and Country Planning). 1988. Muara Local Plan and Ports Study. Vol. 1 and 2. Department of Town and Country Planning, Brunei Darussalam.

Harisson, D.T. 1970. The siege of Pulau Chermin. Brunei Mus. J. 2(1): 198-208.

Lim, J.S. 1975. Charcoal production in Brunei (Sharifuddin, Dato P.M.). Brunei Mus. J. 3(3): 201-220.

Mittermeier, R.A. 1980. Conservation in Brunei. Brunei Mus. J. 4(4): 251-261.

Mohd. Jaya and J. Howes. 1986. A study of the littoral ecosystem in Brunei Estuary, Brunei Darussalam. Data Draft Report. Brunei Museum and Interwader (East Asia/Pacific Shorebird Study Programme), Kuala Lumpur, Malaysia. (Unpublished).

Zamora, P.M. 1987. Mangroves, p. 28-48. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam and International Center for Living Aquatic Resources Management, Manila, Philippines.

Zonation of Industrial Activities to Minimize Environmental and Coastal Water Quality Degradation in Brunei Darussalam

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Abstract

The anticipated industrial diversification and development in Brunei Darussalam require sound planning and sufficient pollution control measures to minimize potential adverse consequences on coastal water quality and the environment. Industries should be initially screened for environmental impacts. The identification of 23 industrial development sites (IDS) will facilitate zoning of industrial activities, based on their pollutive capacity, into light (nonpollutive), pollutive and highly pollutive types. Industries must be located in appropriate and compatible sites. Effluent-producing activities should be away from highly vulnerable estuaries, particularly the Brunei Bay and the Brunei River estuarine system. Pollutive and highly pollutive industries have to undergo an environmental impact assessment (EIA) and a long-term cost-benefit evaluation, and be provided with adequate pollutant treatment facilities. Nonpollutive industries must be actively encouraged.

Introduction

Brunei Darussalam recently adopted a strategy to diversify its economy which has been primarily dependent on the exploitation of petroleum hydrocarbons for the past four to five decades. The strategy calls for rapid growth in the non-oil industrial sector with the support of financial, institutional and policy measures. The Ministry of Industry and Primary Resources (MIPR) is mainly responsible for this new government thrust. In support of its declared mission to "facilitate and promote productive industrial activities for the well-being of Brunei Darussalam," MIPR will offer physical facilities such as land and buildings; local primary and natural resources; commercial advantages and incentives; technical and productive services; and administrative services.

More than 85% of the country's population lives in the coastal belt, and almost all of its major economic activities are confined to this area. Potential adverse effects of planned industrialization on the environment need to be neutralized. In this connection, MIPR issued the following guidelines:

- Physical facilities will be developed and offered with full cognizance of the environmental needs of Brunei Darussalam.
- Development of natural resources will be based on sustainable development with full consideration of environmental impacts and optimal use.

The country has a limited coastline of approximately 130 km. Many of the identified IDS for the non-oil-based sector, as well as installations of the oil-based industry, are primarily located in the coastal zone. Evidence available at present indicates that coastal waters

in the vicinity of the Brunei Shell Petroleum Co. (BSP) oil refinery have been negatively affected by effluent discharges. This prompted the Public Works Department to commission a study (PWD 1987) on water quality which recommends, as a precautionary measure, that licenses be withheld for part-time and artisanal inshore fishing within 3 km of the existing major BSP discharge for a period to be determined by the Minister of Development. The BSP has since carried out a study to assess the impact of its refinery discharges on marine macrobenthos.

The desire of the government to have a clean and healthy environment and promote fisheries and ecotourism in the country makes it necessary to prevent/minimize any further deterioration in the quality of the marine environment. Industrial development programs should therefore incorporate adequate environmental safeguards.

A large number of industries discharge effluents that cause water pollution unless proper treatment methods are adopted (see Lim, this vol.). The extent to which treatment is required will not only depend on the type and scale of industry but also on the waters receiving the effluent. Estuaries have been singled out as highly vulnerable to pollution. Due to tidal effects, estuaries are unable to completely discharge water into the sea. Under normal conditions, most of the water discharged into the sea at low tide gets pushed back into the estuary at high tide. This effect, which concentrates nutrients in the estuary that create the base for high productivity, also concentrates pollutants.

Brunei Bay and the Brunei River estuarine system are very vulnerable to water pollution from industrial development, unless proper planning and pollution preventive measures are implemented. Productive fishery in the coastal waters is sustained by the relatively unpolluted water and associated ecosystems (e.g., mangroves) of the area. Degradation of water quality would have dire consequences on fisheries, aquaculture and other activities (see Lim, this vol.).

Maintaining the favorable water quality of Brunei Bay and the estuarine system should not be compromised. Effluent-producing industries need to be carefully assessed and, where possible, located away from Brunei Bay and the catchment basin of Sungai or Sg. (i.e., river) Brunei. Industrial planning should also consider the sensitivity of aquaculture/mariculture and water-based recreational sites.

Industrial Development and Appropriate Siting

The Industrial Unit (IU) of MIPR has identified 23 IDS in Brunei Darussalam with a total area of 489.5 ha (Fig. 1 and Table 1). Twelve are found in Brunei-Muara District, 5 in Belait District, 3 in Tutong District and 3 in Temburong District. The Muara (A, B and C), Beribi (Phase I), Lambak Kanan (West), Anggerek Desa and Kuala Belait (Phase I) sites have already advanced to infrastructure stage, while many others are not too far behind. Based on the proposed activities for each site, it may already have been planned to locate large-scale polluting industries in Sg. Liang (Belait District). The Negara Brunei Darussalam Master Plan (NBDMP) (DOTCP 1987) recommends:

> an assessment survey [...] of state and neighbouring land in Mukim Sungai Liang to determine its suitability for industrial development, taking into account the needs and possible pollution hazards of [...] different industries which might be located there including a plymill and medium-density fiberboard complex, glass factory, cement bagging plant, artificial coarse aggregate and precast concrete manufacture and other polluting industries requiring direct drainage to the open sea.

Planned industrialization, of which the initial steps have been taken, can prevent the costly environmental mistakes of other countries that plunged into rapid industrialization without sufficient forethought.

The identification of IDS prior to industrial expansion gives Brunei Darussalam the distinct advantage to zone its industries and prevent unnecessary environmental problems. Industries should be zoned on the basis of their pollutive capacity and allocated to compatible sites. Effluent treatment and other pollution control measures should be adopted and shared where necessary. Only nonpolluting industries should be located in the proximity of development projects and vulnerable environments. Such a zonation will prevent conflicts among development projects and allow for industrialization without compromising environmental quality and the health, social and cultural well-being of the people.

The Muara Industrial Development Site (MIDS) illustrates this point. Proximity to the major port facility in Muara makes MIDS desirable for industrial development. However, this site is also near residential areas; the Serasa Aquaculture Development Site of the Department of Fisheries (DOF); the productive fishing areas of the Brunei estuarine system; and the recreational beach areas of Muara and Serasa. Available information (de la Cruz et al. 1987) indicates that any pollutant discharged into the sea from MIDS will flow into Serasa Bay during incoming tides. Therefore, perpetuation of aquaculture and recreational activities in Muara would require the absence of harmful effluent discharge from MIDS into the sea.

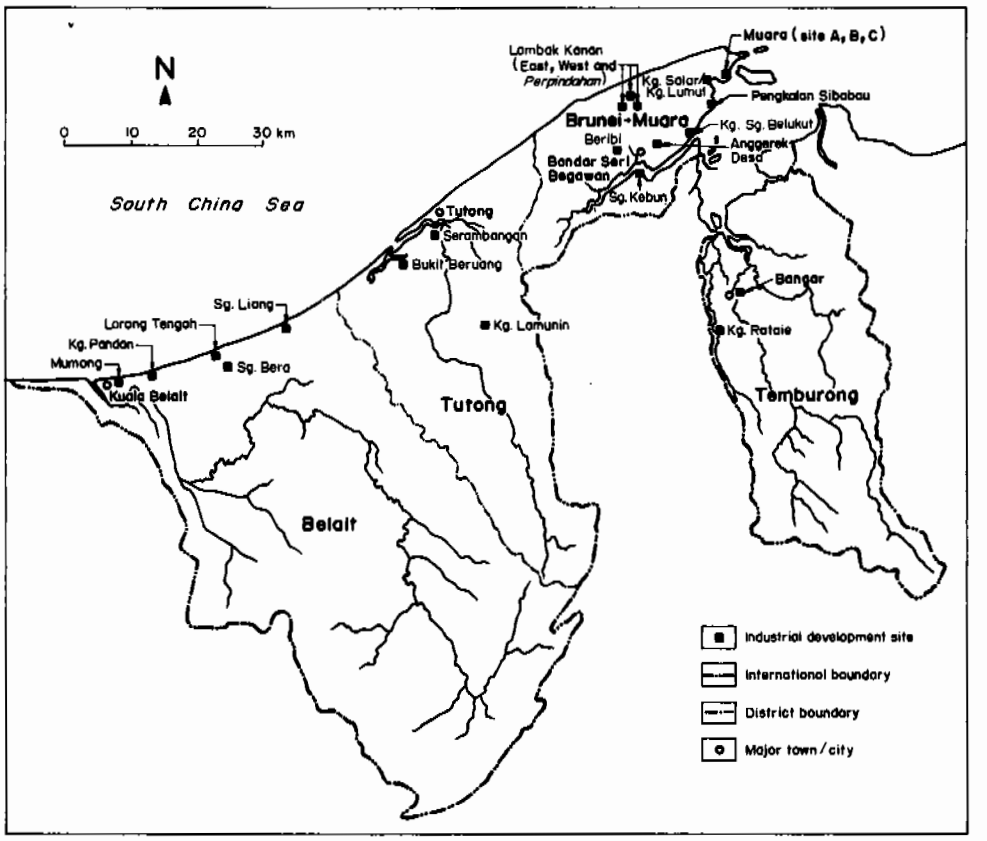

Fig. 1. IDS identified by MIPR, Brunei Darussalam.

Table 1. Industrial development sites identified by MIPR and their development status as of 30 July 1990.

District/industrial site	Proposed industry/activity	Area (ha)	Development status[a]
Brunei-Muara			
Muara			
Site A (filled area)	Exporting firms and those requiring close proximity to the port	20.6	1-5
Site B (existing area)	- do -	32.0	1-5
Site C (new area)	- do -	30.0	1-5
Beribi			
Phase I	New enterprises and some relocated from Jalan Gadong	13.4	1-5
Phase II	Multipurpose firms and manufacturing industries	37.9	1-4
Lambak Kanan			
East	-	72.0	1-3
Resettlement *(Perpindahan)*	Light industries such as services, general manufacturing and other uses to serve the resettled population	6.0	-
West	Food processing	44.5	1-5
Sg. Kebun	Motor workshop and other service industries for the Kg. Ayer vicinity	3.0	1-3
Anggerek Desa	Service industries and general manufacturing	3.7	1-5
Pengkalan Sibabau	Light industries such as boatmaking, repair, engine workshop and others	3.9	1-4

Continued

Table 1. (continued)

District/industrial site	Proposed industry/activity	Area (ha)	Development status[a]
Kampong or Kg. (village) Salar/ Kg. Lumut, Muara	Warehousing purposes	31.9	1-4
Kg. Sg. Belukut	Timber loading	2.5	1-4
Belait			
Kuala Belait/Mumong			
Phase I	Manufacturing, distribution and service industries	11.0	1-5
Phase II	- do -	20.4	1-4
Kg. Pandan	Service industries and other uses for the resettled population	6.0	1
Lorong Tengah	Repair works, furniture-making and other types of manufacturing industries	10.0	1
Sg. Liang	Large-scale (polluting) industries	50.0	1
Sg. Bera	General manufacturing, assembling, warehousing and distribution	50.0	1-3
Tutong			
Serambangan			
Phase I	General manufacturing, workshop and service industries	9.8	1-4
Phase II	- do -	8.2	1-3
Phase III	- do -	8.7	1-3
Bukit Beruang	Light industries and commercial uses to serve the resettled population	4.0	1-4
Kg. Lamunin	Service industries such as workshop	2.4	1-2
Temburong			
Kg. Rataie	Service industries and other uses for the resettled population	2.6	1-2
Bangar (Batu Apoi)	General manufacturing, workshop and service industries	4.9	1-4
Total		489.4	

[a]Work completed is as follows: 1 - topography; 2 - soil investigation; 3 - design; 4 - earthwork; and 5 - infrastructure.

The three industrial sites in Muara (Fig. 1 and Table 1) are expected to accommodate export firms and industries requiring close proximity to Muara port. Heavy industries initially proposed for this area prior to the formation of MIPR include: the manufacture of cement, fiberglass and glass; papermills; bleach and dye works; and aluminum, iron and steel works. The plans for the last group have been found nonviable and consequently withdrawn. Papermills, cement manufacture, bleach and dye works and similar industries are generally highly pollutive and should not be located at MIDS.

It may be argued that effluent and other treatment plants are able to clean up pollutants prior to discharge. However, many of the more efficient ones are expensive and require considerable maintenance. Even the best maintained treatment plants in highly industrialized countries where spare parts, skilled manpower and technology are available have had breakdowns of pollution control and safety devices. Further, regular monitoring by the government would be necessary to ensure that industries follow the standards and guidelines set for environmental quality management. Even if all these requirements were met, the risk of accidents

could not be ruled out. Thus, industries with pollutive effluents (particularly those containing hazardous chemicals) should be carefully evaluated and sited in appropriate, nonsensitive locations.

At present, industries approved to be sited at MIDS include: two paint factories, a chemical plant (Brunei Chemical Co.), a semi-knockdown vehicle assembly plant and a garment factory. Some of these were allocated to MIDS prior to the establishment of MIPR and several environmental concerns seem to have been overlooked (Appendix 1). The immediate environmental concerns of siting the paint factories at MIDS have been met by a proposed treatment of discharges. However, considering long-term consequences and to allow for future expansion of activities, it would have been better had they been allotted to a site away from the Brunei River estuarine system. The same can be said of the establishment of cement factories (Appendix 1). The possible environmental impacts of an industry have to be thoroughly investigated prior to its allocation to a particular site.

With stringent environmental and safety standards being enforced in most developed countries, many polluting industries are on the lookout for countries with slack or no environmental and safety laws. Even multinational industrial giants are known to have taken advantage of such legislative weaknesses to enhance profits. This can lead to disastrous environmental consequences in the host countries.

Industries and Associated Pollution

Countries undergoing industrial development constantly face the need to balance the benefits of reduced pollution and the high costs which control measures entail. Very stringent pollution control measures could discourage potential industrial investors, while very lenient ones could attract investors of highly polluting industries looking for places to operate at low costs. Decisions should be based on cost and benefit analysis over the long term, taking into account not only immediate monetary gains, but also the ultimate damage to the environment and the health, social and cultural well-being of the people.

Experience in industrialized countries has proven that anti-pollution technology is cost-effective in terms of health, property and environmental damage avoided. It has also made many industries more profitable by making them more resource-efficient. The economic stability of Brunei Darussalam puts it in a position to reject industries geared towards immediate economic gain at the unnecessary expense of the environment. This security also gives it the edge to strategically plan out industrial development for a long-term multisectoral advantage.

Based on the severity of pollution they are capable of causing (prior to any form of treatment or controls), their size and suitability to be in industrial sites near housing estates or built-up areas, industries can be broadly divided into: light (nonpollutive), pollutive and highly pollutive (Table 2) (Anon. 1985). Pollutants that could be expected from some of the more common industries are summarized in Table 3.

Light (nonpollutive) industries

These can be located in industrial sites or zones near built-up areas. The following guidelines are recommended:

- They must not have any fuel-burning equipment such as boilers, furnaces, ovens and kilns.
- They must not generate excessive impulsive or continuous noise from machinery, fans, compressors, motors, presses, generators, cooling towers, etc. The noise level at the factory boundary must generally not exceed 60 decibels during daytime (7 A.M.-10 P.M.) or 50 decibels during nighttime (10 P.M.-7 A.M.).
- They must not involve the use or production of large quantities of toxic and dangerous materials such as solvents, acids and other chemicals or generate large quantities of liquid effluents and solid wastes.
- They must not produce materials which may be discharged into a watercourse in concentrations that may adversely affect its present or potential use as a source of domestic water supply or other downstream beneficial uses.
- A sufficient buffer distance of at least 200-500 m must be provided between the factories and the nearest residential buildings.
- Raw materials utilized should not require primary or secondary treatment such as sashing, dyeing, electroplating or galvanizing; i.e., the raw materials should be prepared and obtained from elsewhere and made only into the final product at the factory.

Pollutive industries

These can be located in industrial sites or zones at a reasonable distance from built-up areas. Cleanup measures and EIAs would generally be necessary depending on the size and output of the factory. The following guidelines are recommended:

Table 2. Types of industries based on their pollutive capacity.

- Light (nonpollutive)
  - Manufacturing
    - Bakery products
    - Textile goods
    - Wearing apparel other than some types of footwear
    - Office computing and accounting machines
    - Radio, television and communications equipment
    - Photographic and optical goods (excluding films)
    - Watches and clocks
    - Jewelry and related articles of precious metal
    - Sporting and athletic goods except firearms, rubber and plastic products
    - Wooden and cane containers and cane ware
    - Wood and cork products
    - Furniture and fixtures
    - Containers
    - Printing, publishing and allied industries
    - Knitting mills
- Pollutive
  - Manufacturing
    - Paints, varnishes and lacquers
    - Tires and tubes
    - Animal feeds
    - Tobacco
    - Carpets and rugs
    - Chemical products
    - Glass and glass products
    - Cocoa, chocolate and sugar confectioneries
    - Drugs and medicines
  - Mills
    - Grain products
    - Spinning, weaving and finishing textiles
    - Sawmills, planing and other woodmills
  - Shipbuilding and repair
- Highly pollutive
  - Manufacturing
    - Petroleum and coal products
    - Synthetic resins, plastic materials and man-made fibers
    - Fertilizers and pesticides
    - Pulp, paperboard and paper
    - Soap and cleaning preparations
    - Perfumes and cosmetics
    - Cement, lime and plaster
    - Dairy products
    - Vegetable and animal oils and fats
    - Soft drinks
  - Petroleum refineries
  - Sugar factories and refineries
  - Tanneries and leather finishing
  - Iron and steel industries
  - Basic nonferrous metal industries
  - Slaughter, preparing and preserving meat
  - Canning and processing fruits, vegetables, fish, crustacea and similar foods

Source: Anon. (1985).

Table 3. Industries with wastewater liable to pollute receiving waters.

- I. Industries discharging dissolved organic pollutants
  - A. Toxic pollutants
    - Oil refineries (phenols, hydrocarbons)
    - Pesticide manufacture (benzene, toxic synthetic chemicals)
    - Gas works, coal tar processing, plastic manufacture and plywood factories (phenols)
    - Pulp mills (sulfur-containing compounds)
    - Paint manufacture (biocides)
  - B. High BOD
    - Pulp mills
    - Canneries
    - Dairies
    - Slaughterhouses
    - Breweries
    - Palm oil mills
    - Sugar refineries
    - Tanneries
    - Pharmaceutical manufacture
  - C. Nutrient-enriching wastewater
    - Canneries
    - Dairies
    - Slaughterhouses
    - Breweries
    - Sugar refineries
  - D. Foaming wastewater
    - Soap and nonbiodegradable detergent manufacture
    - Pulp mills
    - Slaughterhouses
    - Meat-packing plants
- II. Industries discharging dissolved inorganic pollutants
  - A. Inorganic pollutants
    - Pulp mills
    - Electroplating
    - Titanium dioxide manufacture
    - Chemicals manufacture
    - Plywood manufacture
  - B. pH-shifting pollutants
    - Chemical factories dealing with strong acids and alkalines
    - Metal-pickling industries
    - Fertilizer manufacture
    - Explosives manufacture
    - Dye manufacture
    - Petrochemical industries
    - Textile dyeing industry
    - Titanium dioxide manufacture
  - C. Nutrient-enriching wastewater
    - Fertilizer manufacture
    - Explosives manufacture
    - Potash works
- III. Industries discharging insoluble chemical pollutants
  - A. Immiscible liquids
    - Petroleum refineries
    - Dairies
    - Edible oil refineries
    - Soap manufacture
    - Fish, meat and poultry canneries
    - Fat and oil processing
  - B. Suspended solids
    - Used paper manufacture
    - Paper and pulp mills
    - Palm oil mills
    - Flour mills
    - Furnace and electrolytic operations

- A sufficient buffer distance of at least 1,000-1,500 m must be provided between the factories and the nearest residential buildings.
- The noise level at the boundary of the factories must not generally exceed 65 decibels during daytime or 55 decibels at nighttime.
- Sufficient space should be provided within the factory premises for installation of treatment facilities of liquid waste discharges. Solid waste should be brought to approved dumping grounds or incinerators.
- Toxic or dangerous materials should not be produced.

Industries in a particular site must be compatible, e.g., food and metal or chemical industries should not be side by side. Food and metal industry zones should be separated by at least 20- to 50-m wide greenbelts of planted trees.

Highly pollutive industries

These industries will give rise to solid waste and air, water and/or noise pollution. Extensive pollution control measures will be expected in most cases. The following guidelines are recommended:

- They should be sited in designated industrial estates at least 1,500-3,000 m away from residential buildings.
- Industries to be sited in a particular zone must be compatible and separated from other zones (e.g., food industrial zones from chemical industrial zones) by at least 50-m wide greenbelts of trees.
- Siting of these industries is very critical. The downstream uses of the watercourse into which effluent wastes are likely to be discharged should be considered.
- Compatible industries with liquid effluents may be grouped together to enable centralized treatment.

Screening Industries for Pollutants

Industries should be initially screened to determine whether they could cause environmental stresses or not. All prospective applicants must fill up a simple preliminary environmental questionnaire which seeks the following information:

- Solid waste production
  - the amount of solid waste that would be produced;
  - its chemical composition/formula(e); and
  - details of proposed disposal method, if any.
- Wastewater (effluent) production
  - the volume of wastewater produced;
  - its chemical and other constituents;
  - details of proposed treatment, if any; and
  - the proposed disposal method.
- Toxic materials
  - the amount of toxic material produced;
  - its type and chemical formula(e); and
  - a detailed description of the proposed disposal method.
- Emission/dust/fumes
  - the amount of emission/dust/fumes;
  - their chemical composition/formula(e); and
  - a detailed description of the proposed method of controlling emission/dust/fumes.
- Noise
  - the level expected and
  - techniques of noise reduction, if any.
- Future expansion
  - the company should detail expansion programs which must be evaluated for environmental impacts.

The One Stop Agency (OSA) of MIPR could carry out the initial screening of industries for environmental impacts. All nonpollutive industries could be cleared by OSA and located in any of the IDS without further investigation, provided that the recommendations given above are complied with.

Pollutive and highly pollutive industries and others not listed in Table 2 need to be carefully assessed. EIA procedures should be adopted where required. Locating these industries in any of the proposed IDS in Brunei-Muara, Temburong and Tutong Districts is not generally recommended. However, if absolutely necessary, food processing and other industries of a limited scale with only high BOD or minor pollution problems could be considered under special circumstances. This is provided that their effluents are subjected to adequate treatment prior to discharge into waterways.

A technical Environmental Impact Review Committee (EIRC) is proposed to evaluate all EIAs, where required, and to make recommendations to OSA. The existing MIPR Committee on Environment and Social Services could perform these tasks until EIRC is established. Until Brunei Darussalam develops its EIA procedures, those adopted by its Southeast Asian neighbors (such as Malaysia and the Philippines) could be used in the interim.

Conclusion

Although Brunei Darussalam has a very limited coastline, sound planning and sufficient pollution control measures could minimize adverse impacts of anticipated industrial development.

The following related issues should also be considered:

- Is it absolutely necessary to take environmental risks by having pollutive industries in highly vulnerable estuarine areas such as Muara/Serasa? Should the natural productivity and beneficial uses that depend on good water quality in such areas be sacrificed?
- Is it too late to reallocate approved but as yet unestablished pollutive industries from MIDS to the proposed IDS in Sg. Liang endorsed by IU?

Depending on the type of pollutant and size of industry, there might be a need to identify other sites for pollutive industries without compromising water quality and the environment. Nonpollutive industries should be actively encouraged.

References

Anon. 1985. Guidelines for the siting and zoning of industries. Bahagian Alam Sekitar, Kementerian Sains, Teknologi dan Alam Sekitar, Kuala Lumpur, Malaysia. (Unpublished).

De la Cruz, C., H.W. Khoo, B. Pudadera and V. Wong. 1987. Aquaculture, p. 109-130. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

DOTCP (Department of Town and Country Planning). 1987. Negara Brunei Darussalam Master Plan: Main Volume. Draft Final Report. Department of Town and Country Planning, Ministry of Development, Brunei Darussalam.

PWD (Public Works Department). 1987. National Water Quality Standards Study. Draft Final Report. Public Works Department, Ministry of Development, Brunei Darussalam.

Appendix 1

Environmental Problems Related to Paint and Cement Factories for Construction at MIDS

Paint factories

In an application to IU in 1987 to set up a paint factory, the applicant described the ecological and visual effects of their effluents as follows:

> Some water soluble material [which] will be present in the 500 or so liters of wastewaters are known to have effects [on] organisms like bacteria and enzymes. Depending on the degree of dilution [...], these agents will have a steadily decreasing effect. A [0.0078%] [...] halogenated acid amide with organic and inorganic activators will be present in the wash waters [...] and is designed for the destruction of bacteria-attacking cellulose thickeners. Significantly, our local authority allows this and similar materials into the local sewerage system because extreme dilution renders it harmless. The only other effluent effect will be its appearance at the point it discharges [...] as a dense milky whiteness caused by the chalk, silicas, titanium dioxide and is absolutely harmless.

The DOF's request for detailed information on the chemical and other characteristics of the factory discharges brought to light the following facts:

- The effluent that would be discharged from the factory's Water Based Products Section after settling would contain the following:
  - Biocide (Parametol A23), a halogenated acid amide with organic and inorganic activators. The wash water would contain 200 ppm of the biocide.
  - Chemical oxygen demand (COD) of "typically" 5,000 mg/l.
  - Biological oxygen demand (BOD) of usually significantly lower than COD.
  - Colloids - 700 ppm

- Chalk - 5,000 ppm
- Clay - 12,000 ppm
- Fine silica - 2,000 ppm
- Dispersed solid polymer particles - 12,000 ppm

- Waste from the Solvent Based Department would contain cleaning solvents as well as high pigment and resin contents. The solvent is a mixture of saturated and unsaturated aliphatic hydrocarbons and usually between 15% and 20% aromatic hydrocarbons.

There is no doubt that this factory could cause serious environmental damage to the Brunei River estuarine system unless the effluent is adequately treated prior to discharge into waterways because:

- The biocide Parametol A23 contains bioaccumulating organochlorides. This biocide is used normally at concentrations of 1,000-3,000 ppm as an antibacterial agent. The factory effluent would contain at least 5 to 15 times this concentration.
- The COD is at least 50 times more than the effluent standard set for COD for factory discharges in Singapore and several other countries.
- The discharge would be laden with suspended solids (SS) and will have a distinct milky color. The SS and the resultant turbidity will at least alter the light regime, causing adverse effects to photosynthetic organisms and on settling nonmotile benthos.

In 1988, the government approved the setting up of this paint factory in Serasa. Effluent from the factory was to be treated prior to discharge into the nearby Brunei River estuarine system. A second paint factory has been approved in MIDS but will primarily be a mixing and packaging factory and no effluent discharge to any waterway is expected during operations. Caution is needed to ensure that polluting effluents are not discharged either directly or indirectly into the Brunei River estuarine system due to expansion of this factory in the future.

Cement factories

Cement factories are classified in the Philippines and several other countries as highly pollutive and hazardous. The Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 1987 of Malaysia describes cement manufacture for clinker of 30 t/hour and above as a prescribed activity requiring full EIA. The guidelines for the siting and zoning of industries in Malaysia (Anon. 1985) states that for some of the "dirtier industries such as cement plants and steel mills, buffer distances greater than 3,000 meters may be necessary and should be considered on a case-to-case basis".

A cement factory causes severe air pollution by dust up to 6 km or more downwind of the factory. Dust from cement factories also brings about bronchial problems, particularly in children subjected regularly to even low-level exposure. The World Health Organization (Anon. 1985) estimates that production of 1 t of cement could produce 170 kg of dust. The dust content could be reduced to 34 kg/t using multicyclones, and brought down to 8.4 kg/t by electrostatic precipitators. A combination of the two could further diminish the dust level to 4.3 kg/t. Epiphytic plants (e.g., lichens) are generally used as indicators of air pollution due to cement manufacture.

Depending on the manufacturing process, effluent discharges which could affect aquatic life could also be expected.

Thus, siting of cement factories is not recommended near human settlements or near the coast.

Socioeconomic Contribution of Coastal Resources of Brunei Darussalam*

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Abstract

This paper discusses the current contribution of coastal resources to the economy and coastal communities of Brunei Darussalam using existing socioeconomic and demographic data. The potential socioeconomic significance of these resources is assessed based on the development trajectory the country is likely to take. Given its diminishing oil reserves, economic diversification is a sound development goal. However, this has resource-use implications. Direct dependence on primary resources may be reduced in relative terms, but indirect dependence is likely to increase as the resources are used as inputs into new industries. Well-intended efforts to develop and diversify the economy can inadvertently result in problems with existing economic activities.

Results of this study indicate that fisheries have the highest value among the non-oil coastal resource-based activities. Mangroves contribute a modest portion to use value, although they are significant for the nonmarketed goods and services they provide. The projected use values of oil and non-oil coastal resources justify intensified management efforts.

Introduction

This paper deals with the socioeconomic component of the Association of Southeast Asian Nations/United States Coastal Resources Management Project (ASEAN/US CRMP) in Brunei Darussalam. The component is intended to characterize and, where possible, quantify the socioeconomic importance of coastal resources and thus provide the rationale for investment in their management. It also aims to assess the socioeconomic aspects of management and policy issues associated with ongoing and potential economic activities in the coastal area. A two-part topology of the study is shown in Fig. 1:

1. quantification of the current socioeconomic contribution of coastal resources and
2. assessment of their potential economic significance.

Early in the study, it was determined that surveys to gather primary data were difficult to conduct from the available logistical support and manpower with appropriate language skills. Thus, the economic contribution of coastal resources was derived from existing socioeconomic and demographic data. This was characterized by the gross production value and the employment generated by these resources directly in the primary sector and as inputs into other sectors. Various ministries and departments were consulted to clarify and interpret the secondary data.

Part 2 of the study required projections of the likely trajectory of economic development and its implicit resource utilization. In addition to the Negara Brunei Darussalam Master Plan (NBDMP) (DOTCP 1987) and other sectoral and regional planning documents, the current (Fifth) and upcoming (Sixth) National Development Plans (NDPs) formed the basis of resource-use projections and derivation of resource

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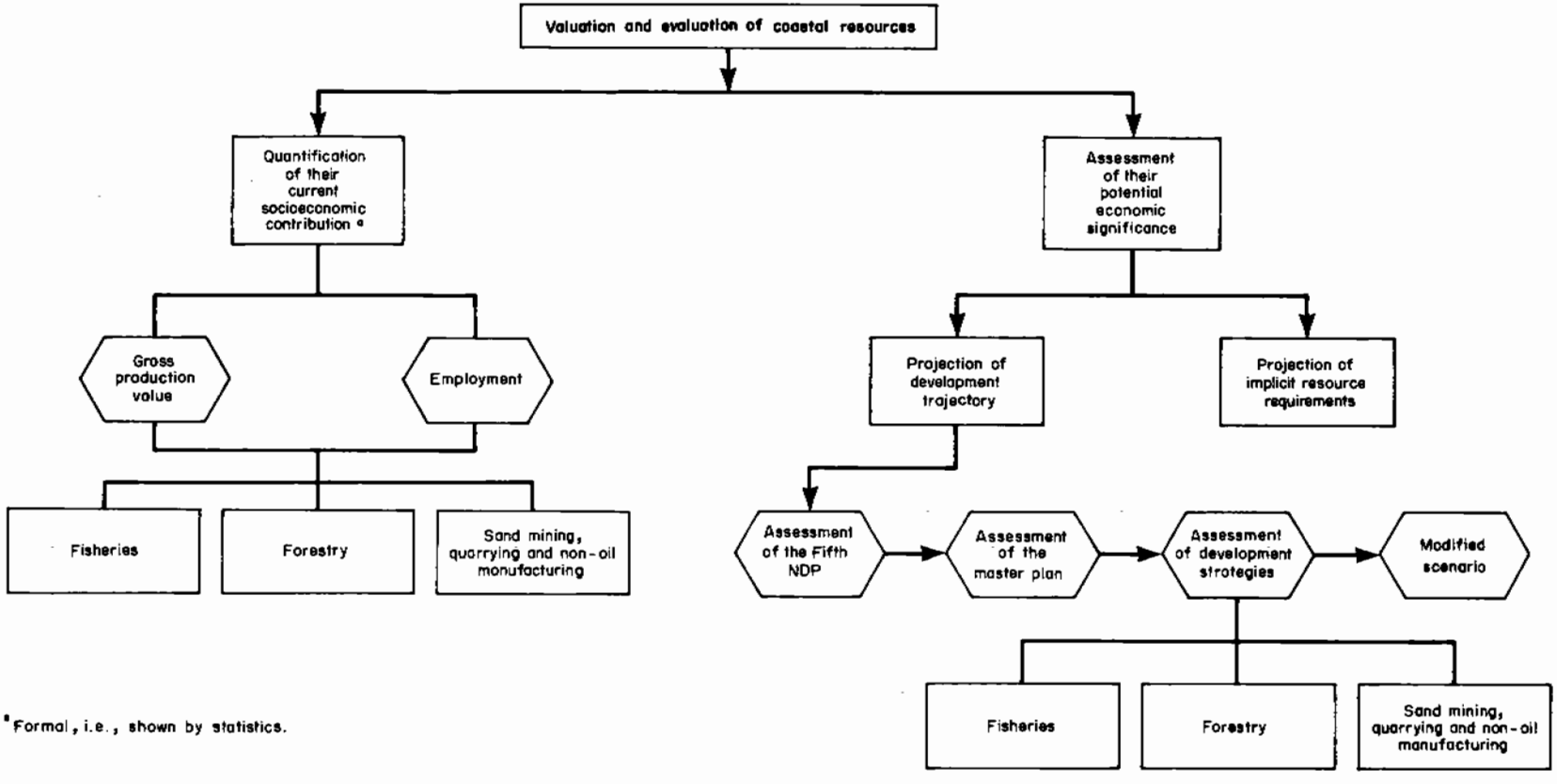

Fig. 1. Topology of the study to assess current and potential socioeconomic contribution of Brunei Darussalam's coastal resources.

values implicit in the projected level of use. Individuals knowledgeable about the five-year plans provided useful background information.

Modified scenarios of the trajectory of economic development were based on the extent to which targets of the previous plans were achieved, and changes in sectoral assumptions warranted by results of other reports in this volume. Projections of resource requirements implied in the development plans were also made. Implicit values were then placed on coastal resources relative to their potential roles in the future economic development of the country. Results of the study are presented below, preceded by a short background on the importance and valuation of coastal resources.

Importance and Valuation of Coastal Resources

The role of coastal resources in economic development

Coastal areas contribute to economic and social development to a greater or less extent, depending on a country's resource endowment. Within the ASEAN region, coastal resources play a key role in the Philippines, Malaysia, Thailand and Indonesia. This is evident in the concentration of population in coastal areas and strong linkages between the potential for economic advancement and activities dependent on coastal resources. Generally, coastal areas are focal points of productive human activities in tropical developing countries. Their economies are often undiversified and typically natural resource-dependent. The direct contribution of primary-producing sectors is quite significant in terms of gross domestic product (GDP), export earnings and employment. The livelihood of coastal residents is directly linked, and the social structure of coastal communities closely tied, to coastal resource use.

The case of Brunei Darussalam is unique in the sense that its economic development has been dependent primarily on oil and natural gas. The country's non-oil sector contributes moderately to domestic economic activities and employment; no great pressure has been exerted on coastal resources other than oil and gas. However, in about a quarter of a century, Brunei Darussalam's known oil reserves will be significantly reduced, and the government is making attempts to develop other sectors. As oil revenues decline, the role of non-oil coastal resources in restructuring the country's economy and their potential contribution to future economic activities will become increasingly essential.

The type, magnitude and success of economic diversification depend on available resources (in terms of natural resources, labor and capital) and socioeconomic conditions. In most cases, the starting point of economic development is heavy reliance on the primary sectors which are developed close to their full potential. It is likely that Brunei Darussalam will increase its dependence on primary activities over the short term, and then switch to other activities, such as value-added[1] processing and manufacturing, as they begin to grow. In general, natural resource-based sectors contribute a decreasing share to GDP as economies develop and mature. Diversification may reduce direct dependence on natural resources in relative terms but indirect dependence will likely increase. Instead of being used as primary commodities, coastal resources will become inputs into other economic activities, thus increasing the value derived from them. Moreover, as populations and pressures for economic and social development increase, a corresponding demand is placed on coastal resources, directly or indirectly. In terms of direct demand, the domestic investment required for structural transformation of developing economies must be financed through the continuing productivity of natural resource assets. This, coupled with maintenance of environmental quality, are thus crucial to long-term economic development.

In many countries, national income accounts such as GDP are used as the primary basis for macroeconomic policy decisions. In Brunei Darussalam, projections of economic diversification are based on such indicators. Changes and rates of change in these indicators are used as measures of economic performance. It is assumed that overall economic and social well-being will rise with an increase in GDP. As such, it is taken as an indicator of economic development (as distinguished from growth), including improved living standards and enhanced national wealth. However, GDP, the total value of goods and services produced by a nation in a given period, is a measure of income (as distinguished from wealth). In general, income is the maximum amount that can be consumed in a given period without reducing the amount of possible consumption in a future period. Income includes earnings, adjusted for changes in asset positions (i.e., capital gains or losses).

However, unlike man-made assets such as buildings and equipment, natural resource assets, particularly renewable resources, are generally not considered capital assets. Thus, their depletion is not reflected in national income accounts such as GDP. In natural

[1]Value added is the difference between the value of goods produced and the cost of inputs used in their production.

resource-dependent economies, this can result in indicators such as GDP giving misleading signals to policymakers regarding the potential contribution of natural resource sectors to future development. Therefore, when using indicators such as GDP as the basis for projections of economic growth and diversification, derived demand for coastal resources must be explicitly considered to avoid development plans which imply unsustainable resource use.

Well-intended efforts to develop and diversify the economies of coastal areas often inadvertently create problems for existing activities. For example, inappropriate land use and management can result in large-scale erosion and sedimentation-related problems in coastal waters. Similarly, improper siting of industrial or other types of development in coastal areas can cause loss of critical habitats, such as mangroves. Moreover, pollution from domestic, industrial, agricultural and aquaculture sources is a typical result of unmanaged development. All of these, individually and collectively, can adversely affect the productivity of estuarine and coastal fisheries.

Economic diversification increases the complexity and interconnections in economies, with significant implications for sustainability. As Myers (1989) observes:

> ...as developing economies become increasingly complex and integrated, we can expect [natural resource and environmental] conflicts to become more numerous, more complex and more acute. In response, we need to adopt a more integrative approach to natural resource issues. Our limited understanding of environmental interactions underscores the need for research to clarify the issues, and for monitoring of the depletive processes that undermine the very basis of sustainable development.

In the absence of proper management of coastal areas, these can become degraded, coastal resources overexploited, and conflicts among competing users can arise. The net effect is decline in productivity, and prospects for continued economic development are diminished.

In the case of Brunei Darussalam, sustainable development (which allows for improvements in societal welfare for the current generation without jeopardizing the possibilities for similar development for future generations) requires institutional and structural changes in the economy, and new economic activities to supplement and eventually replace old ones. Intersectoral relationships as well as the economic, social, biophysical and environmental aspects must be fully recognized and duly considered in the choice of activities to lead economic development and diversification and minimize coastal management problems or conflicts. This perspective requires a multifaceted, integrated approach that addresses the key factors which influence progress toward sustainable development. This paper addresses one such aspect--the socioeconomic value of coastal resources.

Approaches to valuation of resources

Estimating resource values requires the use of valuation techniques. The values society puts on resources, which are necessarily human values, are made for several reasons:

Use Values. People benefit from current or future uses of resources and the environment. Most valuation work centers on estimation of current and future use values. These uses could be either *in situ* or extractive. For example, people currently use mangrove areas in multiple ways: as nursery grounds for capture fisheries and source of wood for building materials and fuel; nonwood forest products including tannins and fruits; and food such as finfish, crustaceans and molluscs.

If the multiple uses are compatible and at sustainable levels, conversion of mangrove areas to other land uses (such as housing or industrial sites and aquaculture ponds) represents a loss of benefits now and in the future, which signifies a real social cost. If society potentially can be compensated for this loss through benefits associated with conversion, then it means a net benefit to society (i.e., total benefits exceed total cost). If not, conversion represents an inefficient allocation of resources and a loss from a social perspective.

Current use values are the easiest for economists to estimate. Some are accurately represented by market values for goods and services. However, some goods and services derived from natural resources and the environment are not directly traded and, therefore, no market values are available. In such cases, indirect estimates must be made. The values of future uses can be projected from the values of current uses, with appropriate adjustments.

Option Values. People also value resources for their potential use. Sometimes these uses are known, as in the extension of current uses into the future. Further, although people do not use a resource at present, they may place a value on the possibility of its future use.

Quasi-Option Values. In cases where potential uses of resources are not known, use values of resources are also uncertain, but people value the option of putting resources to good use in the future.

Existence Values. Totally separate from the values society derives from the use of resources and the environment, people place "existence values" on unique resources. Arguments for the preservation of biodiversity to a large extent center around option values, quasi-option values and existence values rather than current use values.

In this study, only current and future uses of marketed products were considered. Therefore, the value estimates represented the minimum of possible resource values. No attempt was made to formally adjust national income accounts along the line suggested by Repetto (1986). However, implicit demand for coastal resources in government projections for GDP growth in various sectors was estimated and compared with potential and suggested yields given in other contributions to this volume.

Current Role of Coastal Resources in the Brunei Economy

Brunei Darussalam has long depended on coastal resources for food, livelihood and shelter. Today, the role of coastal resources remains significant. Many productive economic activities, including oil and gas operations, are concentrated in the coastal zone. Before the oil and gas resources were developed, the majority of the population relied on agriculture and fisheries as means of livelihood and source of food. Today, fish and fish products still figure prominently in local diets. However, the contribution of the local fishery to fresh fish marketed in Brunei has declined from 96% (3,384 t) in 1965 to only 34% in 1989 (1,826 t).

The coastal area is home to 85% of the population, or some 218,000 persons in 1990. Houses are either propped up on stilts in water villages or situated on land within the coastal zone. Many Bruneians still use traditional rot-resistant mangrove poles as house posts, although some are beginning to show preference for concrete posts. Sand for landfill also comes from coastal areas.

In 1989, close to 20% of the working population were involved in coastal resource-dependent activities. Only 6% of these, however, were Bruneians. Although much of this employment was in the oil and gas sector, others worked as coastal farmers, fishermen, sand miners, bricklayers, loggers and food processors.

Due to its size, the oil and gas sector tends to obscure the performance and contribution of other parts of the economy. Thus, to properly evaluate the socio-economic contribution of coastal resources, this study segregated the oil and gas sector from the non-oil sector.

Oil and gas sector

Since its initial development in the 1920s, oil and gas has been the leading sector in the Brunei economy, contributing a large proportion to GDP (Table 1). However, its position has gradually slipped over the years from 88% of GDP in 1974 to 58% in 1990. The decline is primarily due to efforts to conserve oil reserves through regulation of the oil extraction rate, and to a lesser extent, to a drop in the real price of oil. Even so, the oil and gas sector still exercises great influence on other activities, particularly services which are stimulated during periods of brisk oil trading and dampened when oil revenues are low.

Despite the prominence of oil and gas in the country's economy, its contribution to world supply and holdings of total known reserves of oil and natural gas is small. Between 1987 and 1989, Brunei Darussalam produced 7 million t/year of oil (BPEU 1990) and a daily average of 880 million ft^3 or 24.9 million m^3 of natural gas, a mere 0.2% and less than 0.5% of world supply, respectively. The country's proven oil reserves as of 1989 were approximately 200 million t (1.4 billion barrels), or 0.1% of proven reserves worldwide. The ratio of Brunei oil reserves to annual production rate (R/P ratio) indicates that the reserves will be exhausted in about 27 years given current rates of extraction. Proven natural gas reserves in 1989 amounted to 11.4 trillion ft^3 or 320 billion m^3 (0.3% of total world gas reserves), with an R/P ratio of about 39 years.

It is difficult to ascertain the gross production value of the oil and gas sector. However, if value added in transportation is assumed minimal, export earnings may be used as an approximation. As shown in Table 2, the sector consistently contributes the bulk of export revenues, comprising 96% in 1989. However, only domestic production is included in this estimate. Offshore investments, excluded from the Brunei statistical yearbooks and not otherwise made available, are believed to have overtaken oil and gas in terms of contribution to gross national product (GNP).

Estimates of employment in the oil and gas sector vary. The Labour Department (LaD), which conducts annual surveys of private companies, estimated employment in the sector in 1989 to be 4,150. Of these, 57% were citizens, 27% immigrant workers and the rest permanent residents. The Petroleum Unit's (Prime Minister's Office) estimate of 3,717 workers in the sector in 1990 included only those directly employed by the Brunei Shell Petroleum Co. (BSP) and subsidiaries (i.e., Brunei Liquified Natural Gas, Brunei Shell Trading and Brunei Shell Marketing). Projects are sometimes awarded by BSP to private contractors who

Table 1. GDP (B$ x 10^6) by kind of economic activity for selected years.[a,b]

Economic activity	1974 (B$ M)	1974 (%)	1980 (B$ M)	1980 (%)	1985 (B$ M)	1985 (%)	1990 (B$ M)	1990 (%)
Oil sector	2,301.7	87.98	3,563.9	83.68	2,573.5	72.79	2,178.6	57.92
Non-oil sector	314.6	12.02	695.0	16.32	961.7	27.21	1,582.6	42.08
Government	115.8	4.43	264.4	6.21	524.6	14.84	975.4	25.93
Private	198.8	7.60	430.6	10.11	437.2	12.37	607.2	16.14
Productive industries	60.1	2.30	74.0	1.74	67.9	1.92	74.7	1.99
Agriculture and hunting	27.3	1.04	32.8	0.77	29.3	0.83	35.7	0.95
Forestry and logging	3.1	0.12	5.0	0.12	7.9	0.22	5.7	0.15
Fishing	4.8	0.18	4.2	0.10	5.9	0.17	4.6	0.12
Mining, quarrying and manufacturing	24.9	0.95	32.0	0.75	24.8	0.70	28.7	0.76
Service industries	267.8	10.24	676.8	15.89	966.4	27.34	1,587.5	42.21
Electrical	7.0	0.27	(3.9)	0.09	17.4	0.49	15.5	0.41
Construction	35.1	1.34	98.3	2.31	72.9	2.06	77.2	2.05
Wholesale trade	11.5	0.44	29.0	0.68	32.0	0.91	44.3	1.18
Retail trade	41.0	1.57	81.6	1.92	70.8	2.00	90.0	2.39
Restaurants and hotels	6.5	0.25	13.6	0.32	16.7	0.47	18.6	0.49
Transport, storage and communication	14.1	0.54	37.2	0.87	73.7	2.08	169.4	4.50
Banking and finance	12.8	0.49	69.0	1.62	85.9	2.43	101.1	2.69
Insurance	0.9	0.03	3.9	0.09	7.7	0.22	52.4	1.39
Real estate and business services	12.3	0.47	58.2	1.37	60.9	1.72	79.2	2.11
Ownership of dwellings	12.0	0.46	14.8	0.25	17.7	0.50	20.4	0.54
Community, social and personal services	114.6	4.38	275.1	6.46	510.7	14.45	919.4	24.44
Less bank charges[c]	(13.3)	-0.51	(55.8)	-1.31	(72.6)	-2.05	(79.6)	-2.12
GDP	2,616.3	100.00	4,258.9	100.00	3,535.2	100.00	3,761.2	100.00

[a]September 1991: B$1.70 = US$1.00.
[b]Minor discrepancies in figures are due to rounding off.
[c]Bank charges arise from loans extended to firms in individual industries. Generally, bank charges are built in or deducted from the GVA of each sector. In Brunei Darussalam, however, they are represented as a separate account to be deducted from the final computation of overall GDP.
Source: EPU (various years).

employ their own workers whose numbers are not reflected in the above estimate.

Not labor-intensive, the oil and gas sector was forecast to employ only 5% of the work force in 1990, while it accounted for 58% of GDP (Table 3). Thus, it had the highest value added per worker.[2] Labor productivity in the sector dropped from B$746,000 in 1981 to B$436,000 in 1990, attributed to a considerable decline in oil extraction. Nevertheless, labor productivity in oil and gas remains highest among all sectors, and its workers among the highest paid in the country.

[2]Value added per worker, or labor productivity, is the ratio of gross value added (GVA, another term for GDP, is the sum of the values added at each stage of production by industries and productive enterprises in the country.) to labor force in the sector. It is an indicator of the contribution of labor to the total output of a sector and more importantly, a measure of labor intensity.

Non-oil sector

The scale-down in volume of oil produced calls for development of new sources of revenue. The non-oil sector is expected to take a more active role in the economy and form the base for economic diversification. This sector is composed of the productive and the service industries (Table 3). In this paper, only coastal resource-dependent activities under these categories are discussed.

From 12% of GDP in 1974, the non-oil sector increased its share to 42% in 1990, or about B$1.58 billion (Table 1). Employment projection in this sector for 1989 was 95% of the work force with an average productivity of B$16,900 per worker, a mere 4% of that of the oil sector (Table 3). Thus, per dollar of GDP generated, the non-oil sector is considerably more labor-intensive than the oil sector. Economic diversifi-

Table 2. Exports of crude oil, natural gas and petroleum products (B$ x 10^3) for the period 1965-1989.

Year	Crude oil	Petroleum products	Natural gas	Total exports	Oil and gas % of total exports
1965	190,585	1,463	555	199,750	96.42
1966	213,028	2,624	741	225,540	95.94
1967	235,511	2,313	1,121	248,260	96.25
1968	268,356	2,848	1,095	281,420	96.76
1969	254,792	2,573	832	270,140	95.58
1970	276,538	2,515	840	292,060	95.83
1971	304,815	2,520	537	323,640	95.13
1972	462,054	3,141	1,952	497,380	93.92
1973	762,376	18,627	46,511	852,060	97.12
1974	1,970,248	86,579	291,094	2,388,310	98.31
1975	1,939,913	97,857	424,969	2,494,810	98.71
1976	2,428,442	146,368	685,215	3,293,150	98.99
1977	2,704,684	126,812	1,121,284	3,999,980	98.82
1978	2,618,654	165,185	1,320,809	4,195,210	97.84
1979	3,936,427	285,635	1,480,439	5,796,490	98.38
1980	6,090,173	577,113	3,045,410	9,852,940	98.58
1981	4,777,823	322,869	3,397,243	8,591,730	98.91
1982	4,572,515	226,269	3,274,997	8,153,260	99.02
1983	4,000,206	199,959	2,891,413	7,170,680	98.90
1984	3,840,137	35,714	2,852,385	6,813,940	98.74
1985	3,552,295	99,259	2,782,699	6,532,890	98.49
1986	1,619,934	146,656	2,110,701	3,990,100	97.17
1987	1,953,986	177,198	1,772,130	4,005,600	97.45
1988	1,460,326	181,357	1,717,792	3,463,400	97.00
1989	1,732,900	1,645,900	179,500	3,693,500	96.34

Source: Brunei statistical yearbook (various years).

cation would therefore require a significant inflow of skilled labor.

During the Fourth National Development Plan (NDP) (1980-1984), diversification efforts through growth in agriculture and non-oil related industries were not very successful. The economy posted an average annual growth rate of -4.4% over that period. The growth rate of 13.2% in the non-oil sector failed to offset the shrinking value added of the oil and gas sector, which slowed to an average growth rate of -7.8%. Agriculture, which was to be a catalyst of accelerated growth, showed a disappointing 1.7% rate. An average growth of 14.8% was experienced in the service industries, compared with the much lower rate of 3.2% in the productive industries during the same period.

During 1986-1989, part of the Fifth NDP implementation period, the economy posted an annual growth rate of 0.8%, despite oil production quotas and depressed oil prices. Services continued to dominate the non-oil economy, accounting for 35% of GDP on the average, in contrast to the productive industries which averaged 2.1% of GDP.

Productive Industries. Agriculture. Too small in volume and value to be significant, coastal agriculture consists mainly of narrow strips of land farmed with coconut, watermelon, cashew, banana, pineapple, homeyard vegetables and fruit trees (Zamora 1987). A cattle fattening station in Jerudong, cattle breeding stations in Luahan and Mukim Gadong and about 1,400 ha (between Padang Terbang Anduki and Lilas Village) of small farms and poultry units are the only significant livestock farms in the coastal area. Other areas in Temburong and Tutong have been identified as suitable for small-scale farming, but these are mostly inland from the coastal zone. Information from the Ministry of Industry and Primary Resources (MIPR) attests to the limited scope of large-scale farms, which are found in Temburong, Pangkalan Batu and Gadong, away from the coastal area.

In general, agriculture is small relative to other industries in Brunei Darussalam. Its share of GDP has not risen above 1% since 1974 (Table 1). However, among the productive industries, agriculture's GVA is significant. For instance, in 1990, agriculture contributed 0.95% to total GDP, while the shares of forestry; fishing; and mining, quarrying and non-oil manufacturing were only 0.15, 0.12 and 0.76%, respectively.

In addition to lack of suitable sites, several constraints to development of agriculture are: poor soil;

Table 3. GDP (B$ x 10^6), working population (x10^3) and labor productivity (B$ x 10^3/worker) for selected years. Monetary unit at 1974 constant prices.

Sector/industry	1981 GDP	1981 Working population[a]	1981 Value added per worker[d]	1985 GDP	1985 Working population[b]	1985 Value added per worker[d]	1990 GDP	1990 Working population[c]	1990 Value added per worker[d]
Oil and gas	2,686.2	3.6	746.0	2,573.5	5.3	485.6	2,178.6	5.0	435.7
Non-oil	728.3	64.5	11.3	961.7	76.3	12.6	1,582.6	93.6	16.9
Productive industries									
Agriculture, fishery and forestry	35.9	3.4	10.5	43.1	3.8	11.3	46.0	4.3	10.7
Mining, quarrying and manufacturing	39.5	3.0	13.0	24.8	3.5	7.1	28.7	5.4	5.3
Service industries									
Construction (including utilities--electricity and water)	119.0	14.6	8.1	90.3	16.9	5.3	92.7	17.8	5.2
Trade, hotels and restaurants	133.0	7.4	18.1	119.5	8.3	14.4	152.9	10.2	15.0
Transport and communication	36.8	4.5	8.1	73.7	5.0	14.7	169.4	6.4	26.5
Finance, banking, insurance, real estate and business services	134.0	2.0	66.7	154.5	2.4	64.4	232.7	3.0	77.6
Community, social and personal services and ownership of dwellings	307.5	29.3	10.5	528.4	36.4	14.5	939.8	46.5	20.2
Unclassified		0.3							
Less bank charges	(77.4)			(72.6)			(79.6)		
Total	3,414.5	68.1	50.1	3,535.2	81.6	43.3	3,761.2	98.6	38.1

Sources:

[a]EPU (1981).

[b]DOTCP (1986a).

[c]DOTCP (1986a).

[d]Minor discrepancies in figures are due to rounding off.

stiff competition from foreign producers in domestic and international markets; insecurity of land tenure; low labor returns; and more attractive opportunities for labor in other activities (DOTCP 1986a). The last two have led to structural changes in agriculture: full-time farmers were bid out of farming by better-paying jobs in government service and large-scale, mechanized and capital-intensive enterprises emerged to fill the gap. This has moved the country towards self-sufficiency in selected commodities, namely, poultry, beef and eggs and, to a less extent, fruits and vegetables. However, local contribution to domestic food supply is estimated to be only 20%.

Fisheries. Despite increases in supply and consumption of livestock, fish remains the main source of animal protein for Bruneians. One of the highest worldwide, per capita consumption of fish in 1989 was estimated at 40 kg/year, higher than that of chicken (29.4 kg/year) and beef (10.5 kg/year). Aggregate supply of fresh fish from domestic sources averaged 3,400 t/year in the 1970s and 4,400 t/year in the 1980s. Gaps between supply and demand have been made up by imports. Annual supply of fish for human consumption is 9,000-10,000 t, composed of local and imported fresh fish and shrimps; imported frozen, canned and dried products with live weight equivalent of 5,500 t in 1985, and a conservative allowance for subsistence consumption of about 500 t (NC 1989b). Besides direct human consumption of fish, local animal feed manufacturers import about 150 t of fish meal or a live weight equivalent of 9,000 t annually from Thailand and Singapore, valued at B$2 million (NC 1989c).

Much of current diversification efforts hinge on fisheries, believed to have a potential yield of 25,700 t/year (Silvestre and Matdanan, this vol). To meet diversification targets, fisheries is projected to make a greater contribution to GDP, which has suffered a decline since 1985 (Table 1). This is due to a reduction in fishing effort rather than a drop in production potential.

Increased production is intended not only to partially replace imports (which reached 65% of supply in 1989), but also to tap the industry's export potential. However, this will require increased employment in fisheries, which currently consists primarily of part-timers. The number of full-time fishermen has remained between 500 and 600 in the past ten years. (Full-time fishermen solely depend on fishing for their livelihood, in contrast to part-time fishermen whose incomes stem chiefly from other occupations, but who fish during weekends, holidays or times of peak fish abundance). Of the 1,876 fishermen in 1989 (about 2% of Brunei's working population), 572 worked full-time and 1,304 part-time; 1,790 and 86 were in artisanal and industrial fisheries, respectively. Temporary residents, citizens and permanent residents comprised 59, 34 and 7%, respectively, of those employed in industrial fisheries. Similar statistics for artisanal fisheries are not available, but citizens are thought to dominate those employed full-time.

Development of fisheries would create a derived demand for labor and would encounter impediments (such as low returns to labor) associated with recruiting full-time workers. There are also better job opportunities in other industries, particularly in government service, so the opportunity cost of labor is high. The low social and economic status of fishing (NC 1989a) and its physical demands (Lim 1986) have led Bruneians, especially the younger generation, to prefer work in other industries.

A survey by ULG Consultants (1983) reveals that the majority of part-time fishermen (who outnumber full-time fishermen) are otherwise employed, and fish outside working hours mainly for family consumption. A study by Idris (1988) shows that the majority of full-time fishermen are relatively uneducated. Approximately 56% of those surveyed were 36-50 years old, while 38% were over 50 years.

Forestry. As a result of a four-decade old conservation policy and a more recent, almost complete prohibition of forestry exports, about 80% (461,200 ha) of Brunei Darussalam's land area is still covered with forest. Only a small portion of forest cover, and five out of nine principal forest types, namely, beach, mangrove, peat swamp, heath and secondary, are found within the coastal zone (Zamora 1987). Of these, only the mangrove forest is significant for this study.

Mangrove areas were once considered of little or no value in their natural state. Often, concessionary leases were granted for conversion of these areas to housing, industrial and brackishwater pond sites. However, the ecological functions of specific natural ecosystems within these areas have begun to be better appreciated. Ecological studies have documented that large quantities of nutrients exported from mangrove swamps fuel the natural productivity of coastal waters. Further, mangrove areas are breeding grounds and nursery areas for many commercially important species of finfish, crustacea and molluscs, and support low-volume small-scale fisheries. Mangroves also serve as habitats for many unique species of birds and other fauna. Wood and wood products such as poles, timber, firewood, woodchips and charcoal, and derivatives such as resins, dyes and tanning agents are collected from mangrove areas. Currently, mangroves are used as piles for building foundations and posts for houses along coastal areas. On a smaller scale, mangroves are a source of firewood and charcoal for cooking and traditional post-natal treatment (Zamora 1987).

	Location of goods and services	
	On-site	Off-site
Marketed	1 Usually included in an economic analysis (e.g., poles, charcoal, woodchips, mangrove crabs)	2 May be included (e.g., fish or shellfish caught in adjacent waters)
Nonmarketed	3 Seldom included (e.g., medicinal uses of mangrove, domestic fuelwood, food in times of famine, nursery area for juvenile fish, feeding ground for estuarine fish and shrimp, viewing and studying wildlife)	4 Usually ignored (e.g., nutrient flows to estuaries, buffer to storm damage)

Fig. 2. Relation between location and type of mangrove goods and services and traditional economic analysis (Hamilton and Snedaker 1984).

The distinction between on- and off-site, and marketed and nonmarketed goods and services derived from mangroves is given in Fig. 2. Only values in Quadrant 1 were included in this study. In Brunei Darussalam, the principal products in this category are poles, charcoal and firewood. Data were not available to properly assess contributions in Quadrants 2, 3 and 4. Nevertheless, these nonmarket and/or off-site contributions would add to the total benefit. Therefore, the values given here should be viewed as the minimum of possible mangrove values.

Of the current 18,418-ha areal extent of mangroves in the country, 66% and 21% are located in Temburong and Brunei-Muara Districts, respectively. The remaining 13% is divided between Tutong and Belait Districts. Legal mangrove exploitation is currently limited to permits to extract timber from forest reserves. In 1990, 14 license holders were authorized to cut mangroves for commercial production of poles and charcoal. License holders subcontract to individuals who actually do the cutting. There are no cut quotas for mangroves, nor a silvicultural management scheme employed. Illegal cutting of mangroves for fuelwood and poles is done actively, especially in accessible areas along embankments of major waterways. The extent of this illegal practice is not known, but is significant enough to warrant the effort to control it.

Production of mangrove poles has increased since the earliest record of 34,400 pieces in 1965. Between 1979 and 1982, production averaged 98,000 pieces/year (Table 4), largely due to a construction boom during that period. However, despite a general slowdown in construction activity between 1983 and 1987, pole production averaged 171,160 pieces/year. In 1989, pole production was estimated at 362,500 pieces worth B$1.64 million, at an average production value of B$4.50/pole.

Next to poles, charcoal is the second most important mangrove product. Charcoal production has been decreasing in recent years, and by 1989 was down to 97.4 t, worth B$126,620, at a market value of B$1,300/t. No estimates are available on the volume or value of firewood production from mangroves.

It is unclear how royalty rates on mangroves are calculated, except that they are based on girth. Royalties collected are not significant. In 1983, revenue attributed to royalty from mangroves was estimated to be B$11,000 (DOTCP 1986b).

The Forestry Department (FD) (1989a; 1989b) estimated employment in the sector in 1989 at 671 persons, 77% of whom were immigrant workers. The number of full-time workers in mangrove-related activities (extraction for firewood, pole-making and charcoal production) has not been officially monitored, although estimates in 1986 were 92-120 (DOTCP 1986b). Based on this, productivity per worker is calculated to be B$4,382 to B$5,716/year, or 10.4 to 13.6% of the national average of B$41,900 across all industries.

Mining, quarrying and non-oil manufacturing. Mining, quarrying and non-oil manufacturing has consistently ranked second to agriculture among productive industries in terms of contribution to GDP (Table 1). Value added per worker in this sector has noticeably declined from B$13,000 in 1981 to B$5,300 in 1990, mainly due to the relative decline of non-oil manufacturing (Table 3).

Sand and gravel extraction and brickmaking, in support of the construction industry, have become impor-

Table 4. Estimated gross production value (B$) for mangrove products.

Year	Production (pcs.)	Pole: Average log cost (B$/pc.) (16 ft)	(20 ft)	(30 ft)	All types	Gross production value (B$)	Charcoal: Production (t)	Average cost (B$/pc.)	Gross production value (B$)	Total gross production value of poles and charcoal (B$)
1977	61,200						303.5	•	394,550	
1978	55,200						270.5	•	351,650	
1979	100,400						291.1	•	378,430	
1980	107,600						255.8	•	332,540	
1981	91,100						265.1	*	344,630	
1982	92,900						195.8	*	254,540	
1983	154,200						223.8	•	290,940	
1984	176,900				1.30	229,970	230.6	*	299,780	529,750
1985	168,100				1.30	218,530	275.8	*	358,540	577,070
1986	192,200				1.30	249,860	212.3	*	275,990	525,850
1987	164,400	1.90	3.90	7.75		742,540	145.2	*	188,760	931,300
1988	292,700	1.90	3.90	7.75		1,322,028	55.9	*	72,670	1,394,698
1989	362,500	1.90	3.90	7.75		1,637,292	97.4	•	126,620	1,763,912

*Constant at 1,300.
Sources: DOTCP (1986b); FD (1989a; 1989b); and Brunei statistical yearbook (various years).

tant activities. The LaD survey of registered companies in 1989 shows that 322 workers, 96% of them immigrant, were employed by 14 commercial operators engaged in quarrying activities. Of these, only sand mining and gravel extraction have considerable implications for the coastal zone.

Beach sand in Brunei Darussalam is primarily used as landfill. Land Department statistics indicate a yield of 162,648 m^3 in 1988. About 300 million m^3 of sand is potentially exploitable. However, overexploitation in some areas has resulted in flooding (White 1987). If the proposal to preclude extraction from below the level of the water table is implemented, the amount of sand available for exploitation would be reduced to about 12 million m^3 (DOTCP 1986b). Supply is estimated to last only until 1996. Set at B$0.50/$yd^3$ (about B$0.38/$m^3$), royalties amount to approximately B$105,000/year. Gross production value is B$2.30/t.

Alluvial gravel deposits found mainly in Temburong Valley are the only source of coarse aggregates in the country (ULG Consultants 1984a-b). In 1982, yield was 54,000-77,000 m^3/month. Of the 7.7 million m^3 supply estimated in 1981, only 5.3 million m^3 remained in 1985 (DOTCP 1986c). At current levels of consumption, existing supplies are expected to last until 1995. A royalty of B$28/t is charged.

Although projected to be one of the growth sources in the Fifth NDP, non-oil manufacturing grew slowly between 1986 and 1989. In fact, its performance has not improved significantly since 1974. Its GVA peaked at B$34.2 million in 1982 (at 1974 prices), but declined substantially to B$21.7 million in 1989. Its share of the non-oil sector's GVA went down from 6.3% in 1974 to 1.5% in 1989. Its contribution to overall GDP has likewise decreased, despite the entry of more firms. A total of 533 companies was engaged in non-oil manufacturing in 1989, about 46% higher than in 1984, and which employed approximately 4,330 workers.

Among the industries being targeted for development are the manufacturers of processed food and animal feed, garments, footwear, furniture, beverages and ice. Of these, only the food processing industry has notable coastal resource implications. There were 41 private companies with 330 workers engaged in food, drink and tobacco processing in 1989, comprising 7.7% of all firms and 7.6% of total employment in non-oil manufacturing, respectively. Current focus is on products such as milled rice, bakery goods, ice cream, coffee, sauces, spices, noodles and animal feed. Fisheries-based food processing is being eyed for its good potential. In addition, animal feed processing currently uses fish products as inputs. Both of these would create an increased domestic market for fisheries products.

Service Industries. The government predominates the service industries, accounting for as much as 92% of community, social and personal services, which contribute most of the GDP from services. In 1990, the service industries contributed 42% to total GDP (Table 1). Among the private service industries, only construction has a substantial impact on coastal resources, because it uses them as inputs. Among these are sand for landfill and fine aggregates, gravel for coarse aggregates, clay for brickmaking and mangrove poles for building foundations. It also occasionally requires clearing of the forest area to give way to sites for buildings and facilities.

The bulk of construction activities in Brunei Darussalam in the 1970s and early 1980s was mainly spurred by developments in the oil and gas sector. Thus, a slowdown in the latter has led to a slackening of construction. The construction industry was responsible for 14.1% of non-oil GVA and 2.3% of overall GDP in 1980, but its share decreased to 4.9% of non-oil GVA and 2.0% of GDP in 1990 (Table 1). Construction is second only to the government in the size of its work force. In 1986, it employed 11.6% of the working population or about 9,424 individuals (EPU 1986b). A 1989 survey by LaD indicated an increase to 19,940 workers, over 92% foreigners.

Potential Role of Coastal Resources in Economic Development

Past economic performance

The NDP has traditionally set the direction and pace of the country's growth. The three most recent plans have all emphasized economic diversification. Although job generation was the primary concern in the Third NDP (1975-1979), the thrust towards diversification began to surface then. The diversification focus sharpened in the Fourth NDP. It was strengthened by the continued development of industrial estates, a move begun in the Third NDP to implement the government's industrial program.

Past diversification efforts, however, were not very successful, and diminishing known oil reserves underscored the need to reduce the economy's oil dependency. Thus, the Fifth NDP was designed to correct the limitations of previous development plans by being more definite about industrial development strategies and policies. The goal was "to develop new export-oriented and import-substituting industries". The plan also put in place and strengthened institutional mechanisms by which constraints may be removed. Moreover, it gave financial support to the strategies through the Fund for Industrial Promotion worth B$187 million (EPU 1985).

To fully diversify the economy and strengthen the country's productive base, the Fifth NDP envisioned a huge 20% growth in fishing, non-oil manufacturing and insurance for 1986-1990. High growth rates were also expected in the following industries: restaurants and hotels (12%); banking and finance (13%); real estate and business services (15%); and community, social and personal services (12%). At the end of 1989, some sectors managed to reach their targets. Insurance, transport, storage and communications performed satisfactorily by growing over twice their targets. Other gainers were agriculture and forestry which slightly exceeded their goals. Community, social and personal services missed their mark by about 1%. Fishing and non-oil manufacturing had posted negative growth rates since 1986.

While making ambitious targets in the Fifth NDP, the government recognized several difficulties and stipulated the need to lay down the "fundamental foundations" on which the private sector will thrive. Evidence of these are development of industrial sites and implementation of projects to improve public utilities, roads and buildings. In promoting socioeconomic development, the government planned to "provide more flexibility in the implementation of the plan to accommodate various changes in the socioeconomic situation during the Plan period". While the government hoped to intensify the effectiveness and efficiency of implementing agencies, it recognized that movement towards industrialization and diversification is a "continuous process" that will take years to achieve (EPU 1985).

Projection of development trajectory

Two perspectives of the expectations for the country's economic development can be discerned from available government documents. One perspective is found in the scenarios presented in NBDMP (DOTCP 1986a;1987). The second one can be gleaned from development strategies proposed by various government departments and agencies, which are likely to be incorporated in the Sixth NDP.

NBDMP Scenarios. Assuming no financial constraint on the projected 5-6% annual growth of public expenditure, and taking the government's intentions in the Fifth NDP and existing socioeconomic limitations as given, three alternative development scenarios (Scenarios A-C) for the period 1986-2005 are included in the master plan. For all three scenarios, the oil and gas sector is forecast to stagnate.

In brief, Scenario A projects continuation of rapid economic and population growth as experienced during the Fourth NDP period. It also assumes that the latter's policies and strategies will be implemented. The Fourth NDP aimed for a 6% and 4% growth in GDP and per capita income, respectively; a high rate of employment; diversification through rapid development of agriculture and other non-oil industries; low inflation; and narrowed disparity in income distribution. These were to be realized through channeling of more resources into productive industries and active government participation. Scenario A relies heavily on immigrant labor to fill the gap between labor supply and demand.

Scenario B assumes parameters similar to Scenario A's, but incorporates higher labor productivity through capital-intensive investment in the private sector and staff training in the government sector. Its strategy is geared towards tighter control of the entry of immigrant labor.

The most favored by the government, Scenario C follows a strategy put forth in the Fifth NDP to stimulate industrial development. The strategy involves removal of demand, supply and labor constraints through various procedural and institutional policies, as well as financial support. Under this scenario, agriculture and forestry are predicted to grow slightly, but emphasis will be on non-oil manufacturing industry. Assumptions on labor productivity increases are the same as in Scenario B, except that they are not expected to take place until the late 1980s and beyond.

Annual growth rates up to 1990 relative to the three scenarios are shown in Table 5. Comparison of actual annual growth for 1985-1989 with projections under Scenarios A, B and C indicates that most projections were off-tangent. Of the 15 industries, Scenarios A and B closely predicted the annual growth rates of only two--agriculture and forestry. Although both scenarios had less ambitious expectations from fisheries (7%); mining, quarrying and non-oil manufacturing (8%); restaurants and hotels (6.5-7.2%); and banking and finance (5.4-6%), even these were not met as growth rates posted were negative or way below the target.

Thus, for 1991-1995, only the most conservative projection--that of Scenario B--is considered. From this, agriculture is foreseen to grow at the same rate as population, i.e., 3.5% yearly. Some growth is anticipated for forestry because of planned operation of a plymill but this will slow down in the late 1990s due to lower per capita timber consumption and more efficient sawmills. As a result of the capital-intensive and rapid development of fisheries during 1980-1984, a yearly

Table 5. Comparison of target versus actual annual growth rates by economic activity for the late 1980s and projections for the early 1990s.

Economic activity	Mean annual growth rates								
	Fifth NDP target (1986-1990)	Master plan scenario (1986-1990)			Actual (1985-1989)	Master plan scenario (1991-1995)	Modified scenario (1991-1995)		
		A	B	C		B	1	2	3
Oil sector	-	-	-	-	-3.25	-	0.49	0.49	0.49
Non-oil sector	-	-	-	-	8.15	-	1.44	4.56	2.47
Government	-	-	-	-	11.70	-	1.00	3.72	1.64
Private	10.00	-	-	-	3.79	-	2.21	5.91	3.80
Productive industries	-	-	-	-	0.54	-	3.23	5.70	3.39
Agriculture and hunting	3.00	3.50	3.50	5.00	3.42	3.50	3.31	2.28	2.28
Forestry and logging	1.00	3.00	3.00	4.00	2.63	3.50	0.00	0.00	0.00
Fishing	20.00	7.00	7.00	7.00	-2.17	7.00	6.92	5.39	5.39
Mining, quarrying and manufacturing	20.00	8.00	8.00	12.00	-1.67	8.00	3.22	11.03	5.15
Service industries	-	-	-	-	8.68	-	1.44	4.50	2.52
Electrical	-	4.80	4.30	5.30	18.21	4.30	4.68	0.69	0.69
Construction	2.00	2.40	2.20	2.70	-4.62	4.30	2.76	-1.42	-1.42
Wholesale trade	6.00	-	-	-	-3.57	-	2.59	2.16	2.16
Retail trade	3.00	-	-	-	1.46	-	2.63	2.13	2.13
Restaurants and hotels	12.50	7.20	6.50	8.00	1.39	5.40	3.85	2.11	7.08
Transport, storage and communication	6.00	7.20	6.50	8.00	17.09	6.50	0.28	1.38	1.38
Banking and finance	13.00	6.00	5.40	6.60	2.23	5.40	3.56	2.86	2.86
Insurance	20.00	-	-	-	46.37	-	-1.81	3.93	3.93
Real estate and business services	15.00	-	-	-	0.53	-	2.51	1.14	1.14
Ownership of dwellings	-	4.80	4.30	5.30	2.74	4.30	3.73	1.00	1.00
Community, social and personal services	12.00	6.00	5.30	6.00	11.01	4.90	1.23	6.46	3.11
Less bank charges	-	4.80	4.30	5.30	-4.87	4.30	3.02	4.30	4.30
GDP	-	-	-	-	0.32	-	0.89	2.27	1.34

Sources: EPU (1985); DOTCP (1986a); and Brunei statistical yearbook (various years).

growth rate of 7% is projected. For mining, quarrying and non-oil manufacturing, greater growth is expected--8% yearly at a higher level of labor productivity.

While the government has made services robust, particularly community, social and personal services, it has inhibited growth in the productive industries. Thus, its objective in the Fifth NDP is to hasten the growth of the non-oil private sector and thereby reallocate employment opportunities from the public to the private sector. Consequently, under Scenario B, the growth of community, social and personal services is being restrained by hinging it on the growth of the Bruneian labor force and the 1% per annum productivity growth. Construction is expected to become leaner as the offshoot of the 1981-1983 construction boom dissipates. Growth of other activities envisioned in Scenario B does not have significant implications for coastal resources. Nonetheless, for purposes of comparison, they are presented in Table 5.

Development Proposed by Selected Departments. In the Sixth NDP, policies and strategies will continue to be geared towards diversification with emphasis on small- and medium-scale industries which enjoy competitive advantage. The government acknowledges that at the level of industrialization so far achieved, only these types of industries can thrive. Likewise, the entry of mechanized or technology-based enterprises is encouraged in recognition of labor supply shortage.

Fisheries. The Department of Fisheries (1990) estimates maximum economic yield at about 21,000 t valued at B$200 million annually. This closely coincides with the recommended harvest level of 20,000 t/year consisting of: 500 t of shrimps under average rainfall conditions; 11,900 t of demersals from accessible grounds; and 7,600 t of small and large pelagics (Silvestre and Matdanan, this vol.).

The government will launch an integrated development of the country's fisheries resources in the Sixth NDP, and attempt to raise production to the recommended harvest level by 1995. In support of this, zonation of fishing grounds will be implemented and potential sites for aquaculture identified. For intensive commercial shrimp culture, 200 ha in Telisay have been allocated and 50 ha in Pangkalan Sibabau earmarked for use by local entrepreneurs. Another 1,000 ha in Temburong are deemed suitable for semi-intensive shrimp culture while 6 ha in Serasa have been allotted for shrimp cage culture. Appropriate incentives in all stages of operation and a steady supply of inputs (i.e., fry, feeds, etc.) will be provided to new entrants. Meanwhile, 30 ha in Ulu Senukoh have been identified as technically suitable for freshwater fish culture. Potential areas for floating cage culture of seabass, groupers, carangids and red snappers are: Serasa (2 ha), Kaingaran (2 ha), Buang Tawar (4 ha) and Pelompong (4 ha).

Fish processing will likewise be developed to reduce dependence on imports and raise local contribution to processed products from 3% to 43% by 1992. Processing will focus on utilization of unmarketable fish for value-added goods such as fish balls, crackers and cakes and more sophisticated products such as prepared meals (NC 1989a). Exposure of consumers to imports has spurred a growing preference for convenience food items.

Agriculture. In the Sixth NDP, the Agriculture Department's proposed development strategy consists of four interrelated components, namely: (1) improvement and expansion of domestic productive capabilities; (2) continuity of food supply; (3) development of storage and processing capabilities; and (4) establishment and maintenance of food quality and safety. Priority will be given to industries proven to be viable and promising--livestock, poultry, vegetables, tropical fruits, ornamental plants and rice.

Most development thrusts are geared toward import substitution rather than increasing exports. For example, production of broilers is projected to double from 3 to 6 million yearly through development of a new poultry processing plant in Kuala Belait. Current demand for chicken is met through importation of 2 million birds yearly at about B$16 million. Egg production will be raised by about 30% from 59 to 77 million pieces yearly. The country currently imports 1.2 million eggs yearly at B$0.4 million.

Production of vegetables will be increased by 6,200 t to bring total production to 17,000 t/year and thereby raise the level of self-sufficiency to 80% from the present 60%. The ultimate goal is to achieve full self-sufficiency and eventually export vegetables (BID 1989). The contribution of domestic fruit production to the local market will likewise be improved from the current 14.8% to at least 34% by the end of the Sixth NDP. Crops grown in coastal areas are not specifically targeted for growth but would fall under the increased tropical fruit production initiatives. Rice, livestock and ornamental plant production will be raised to decrease dependence on imports.

Forestry. Contrary to NBDMP's Scenario B forecast for forestry of 3.5% growth yearly from 1991-1995, FD expects zero or negative growth as a result of the drastic 50% cut in local production from all forest types to only 100,000 m^3/year. Mangrove exploitation for poles, charcoal and fuelwood is not expected to increase considerably above current levels.

Mining, quarrying and non-oil manufacturing. To counteract the sluggish performance during 1985-1989, MIPR created the Industrial Unit (IU) to facilitate and

promote productive industrial activities by offering facilities (e.g., land and buildings), advantages and services to entrants at subsidized rates. So far, aside from the development of industrial estates, IU has identified preferred products and industries. Conscious of the limitations (e.g., small market, shortage of labor, no back-up industries), it is pushing for capital-intensive business ventures which employ advanced technology and provide human resource development.

To ensure self-reliance in basic necessities, integrated production and processing of food products are given priority. Preference for food-related over non-food-related manufacturing activities has strong implications on the demand for coastal resources, particularly fisheries and tropical fruits in coastal areas.

In the Sixth NDP, mining, quarrying and non-oil manufacturing is projected to contribute B$4-5 billion annually at current prices or 57-72% of the Economic Planning Unit's (EPU) estimated B$6.98 billion GDP for 1990. This seems too high considering this group's recent performance.

Modified projections of development

Given the above perspectives on development trajectory and the actual performance of the Brunei economy in 1985-1989, modified projections of economic development for 1991-1995 are made. However, due to confidentiality of and limited access to the data required, an input-output table cannot be done; a simple forecasting approach which employed multivariate regression is adopted (Table 5).

Methodology. Three alternative scenarios, referred to as Scenarios 1, 2 and 3, are presented. The GVA of the oil sector is assumed to be a function of oil prices and oil and gas production. Forecasts of economic performance require different treatments for the non-oil sector.

In Scenario 1, the non-oil sector's GVA is regressed against its lagged values; the deflator for the sector; per capita income in the sector; and GVA of the community, social and personal services industry. The average percentage share of each industry to the non-oil sector's GVA in 1986-1990 is then applied to the future values to get each industry's GVA.

Scenario 2 forecasts the GVA of each industry based on how it would likely be affected by various explanatory variables. The results are then summed up to get the non-oil sector's overall GVA. The same method is used for Scenario 3 except for mining, quarrying and non-oil manufacturing; restaurants and hotels; and community, social and personal services. Their average share of the non-oil sector's GVA is used to predict their future values.

Details of the projections for the three scenarios are given in the Appendix. The forecast GVAs and growth rates for the economy in the modified scenarios are much more conservative than the ones shown in the master plan for the same period (Table 5) because actual performance is taken into account in projecting future performance. Since diversification was not yet achieved during the Fifth NDP and the oil and gas sector continued to dominate, it is important that these factors be adequately considered in forecasting a realistic development trajectory.

Scenario 1. It is assumed that the direction of the non-oil part of the economy in 1986-1990 will continue. All industries will maintain their average percentage share of the non-oil sector's GVA, with services remaining dominant. Consequently, this scenario shows the lowest pace of growth for the non-oil sector at a mere 1.44% yearly (Table 5). Forestry's GVA is pegged at its 1990 level to reflect the proposed reduction in forest production. The oil sector, forecast to stagnate as a result of the limit imposed on oil production at 150,000 barrels a day, will grow at only 0.49% yearly.

Scenario 2. The oil and gas sector is likewise expected to stagnate. However, among the three scenarios, this one depicts the fastest growth for the non-oil sector at 4.56% yearly, assuming that the targeted growth in the productive industries in the proposed development strategies will actually take place.

Agriculture will grow at 2.28% yearly as a result of expanded domestic production of chicken, eggs, rice and vegetables to ensure food availability and reduce import dependence. Zero growth is expected for forestry for the same reason as in Scenario 1. Fishing is anticipated to grow at 5.39% yearly, assuming that the current production trend would continue over the forecast period. The shortfall will still be covered by imports.

Mining, quarrying and non-oil manufacturing is foreseen to grow fastest in Scenario 2 based on the projected growth in agriculture and fish production. This is because manufacturing activities in the primary sector appear to be a top priority (from MIPR's preliminary list of preferred products and associated industries). This is understandable since the primary sector is expected to provide a platform for industrial development. In the country's diversification efforts, it is hoped that industry, through small- and medium-scale enterprises, will eventually contribute more significantly to the economy, to sustain or even improve the current standard of living when the oil and gas sector takes a less dominant position.

Services as a whole will grow at 4.5% annually, not too far behind the productive industries' 5.7%. It will,

however, continue to dominate the non-oil sector, contributing over 60% of GVA. Electricity, gas and water is regressed against the lagged values of this industry's price deflator and the number of manufacturing companies that will operate. This assumes that its biggest client will be the manufacturing industry. Given these, it is forecast to grow at only 0.69%.

As in the master plan, construction is expected to diminish with the decreased demand for it in the oil and gas sector. Wholesale and retail trade will grow at the rate of 2.16% and 2.13%, respectively, in response to the favorable performance of the productive industries. Meanwhile, restaurants and hotels will grow at 2.11%, assuming that the workers in construction and the community, social and personal services will continue to be their biggest clients and the industry will still operate at a surplus.

In contrast to its growth in previous years, transport and communications will move at a much slower pace of 1.38%, based on expected tourist arrivals and the price deflator and lagged values for this industry. Banking and finance is foreseen to grow at a slower rate of 2.86% and reflect the effect of a stagnating oil and gas sector. Growth in insurance will likewise dwindle to 3.93% while real estate and ownership of dwellings will increase at 1.14% and 1%, respectively. Community, social and personal services is projected to grow fastest in the services sector at the rate of 6.46%. This is because the government, which is expected to finance its industrial and financial strategies in the next development plan, will inevitably stimulate growth in this industry.

Scenario 3. Projections for this scenario are basically similar to those in Scenario 2 except for mining, quarrying and non-oil manufacturing; restaurants and hotels; and community, social and personal services. These industries have been projected on the assumption that they will maintain their estimated average share of non-oil GVA over the Fifth NDP period. On this basis, the productive sector is anticipated to grow at 3.39%, the service sector at 2.52% and the non-oil sector as a whole at 2.47%. These rates are lower compared to projections in Scenario 2. The oil and gas sector is expected to stagnate as in Scenarios 1 and 2.

Projection of requirements

Fisheries. The total apparent consumption of fish in Brunei Darussalam for all purposes is 18,000-19,000 t/year (live weight equivalent), of which 14,500 t are imported. The country could move substantively toward import substitution and self-sufficiency, with room for limited export of fisheries products, without exceeding the recommended harvest level of 20,000 t/year. Since much of the imports is in processed form, import substitution would require the integrated development of harvesting and processing activities. Value-added processing of export items would also be beneficial to increase potential contribution to GDP of limited fisheries resources.

Agriculture. The contribution of fruit production to the local market is expected to double within five years. Fruits grown in coastal areas are implicitly targeted for growth under the Sixth NDP. This would create a significant demand for resource inputs, particularly land. For poultry and egg production, the projected doubling and 30% increase, respectively, would need expansion of existing poultry operations and setting up of new ones in the coastal zone.

Forestry. Mangrove exploitation for poles, charcoal and firewood is not foreseen to increase significantly above current levels. Even if production increases at rates similar to those of the Fifth NDP period, potential supply within allowable cut limits will outstrip demand by a considerable amount (see Zamora, this vol.).

Mining, Quarrying and Non-Oil Manufacturing. Future pressure on coastal resources by mining, quarrying and non-oil manufacturing will not be substantial despite the country's industrialization efforts. Extractive activities would be related only to construction of the necessary infrastructure to attract investors and support business ventures. The building of industrial estates would necessitate land clearing. Other construction activities would require sand mining for landfill and gravel extraction as a source of coarse aggregates for concrete. However, existing supply is limited and expected to be exhausted by the end of the period considered here.

Most non-oil manufacturing industries targeted for development (i.e., garments, footwear and furniture) do not have major implications for coastal resources. The exception is food processing such as value-added fish processing and animal feed production which would create a derived demand for fish. This could easily be accommodated since the current harvest level is way below the estimated resource potential (see Silvestre and Matdanan, this vol.).

Services. Future construction activities will concentrate on infrastructure for industrial estates, private-sector industrial facilities and government housing program. While the development of industrial estates is ongoing, it is too early to predict the construction that will be stimulated by new business ventures. Nevertheless, current construction activities create a demand for resources such as sand and gravel. Since domestic supplies are scarce and imports are very expensive, the limited availability of these inputs will likely take its toll on the growth of construction.

Table 6. Projected GDP contribution (B$ x 10^6) from non-oil coastal resources for 1991-1995.

Economic activity	GDP contribution		Projected GDP contribution							
			Lower bound				Upper bound			
	(1989)		(1991)		(1995)		(1991)		(1995)	
	GDP	GDP coastal	GDP	GDP coastal	GDP	GDP coastal	GDP	GDP coastal	GDP	GDP coastal
Agriculture	34.35	1.58[a]	35.00	1.61	39.90	1.84	36.95	1.70	42.40	1.95
Forestry	7.10	0.80[b]	5.70	0.70	5.70	0.70	5.90	0.72	6.77	0.83
Fisheries	4.90	4.90[c]	5.50	5.50	5.90	5.90	4.92	4.92	6.45	6.45
Mining, quarrying and non-oil manufacturing	27.30	0.25[d]	24.70	0.25[d]	46.20	0.25[d]	30.99	0.25[d]	42.17	0.25[d]
Total	73.65	7.53	70.90	8.06	97.70	8.69	78.76	7.59	97.79	9.48

[a]Coastal portion of fruit, cattle and egg production estimated to be 4.6% of agriculture sector GDP.
[b]Estimate of mangrove product values deflated to 1974 constant prices, contributing 11.3% of forestry sector GDP.
[c]Fisheries values assumed to be 100% coastal.
[d]Sand mining values only. Based on assumption that current production levels can be maintained until 1995, when supplies will be exhausted.

Projected values

Based on the foregoing projections, lower and upper bound limits for use values of non-oil coastal resources were obtained (Table 6). The lower bound estimates reflect the use values derived if the historical and current development path is projected to continue, based on modified development Scenario 2. The upper bound estimates reflect the use values of resources which would accrue if diversification plans envisioned under NBDMP Scenario B are realized. This is where individual industries are developed to their full potential.

The results show that fisheries have the highest use values among non-oil coastal resource-based activities. Mangroves contribute only a small portion although their *in situ* share in coastal protection and continuing fisheries production (which is not included here) must not be forgotten. Likewise, the GDP contribution of some highly resource-dependent activities such as food processing are also not listed in Table 6. These added values would not be realized or would be greatly diminished if the coastal resources on which they depend as inputs were depleted or degraded.

The values given should be treated as minimum estimates of future contribution from non-oil coastal resources. Adding the projected GDP contribution from the oil sector of about B$2.2 billion annually for 1991-1995 (see Appendix) emphasizes the significance of the coastal zone.

Conclusion

The main feature of Brunei's economic development is the undiversified nature of productive activities, dominated by the oil and gas sector in terms of GDP, export earnings and employment. The government has exerted concerted efforts to promote economic diversification within the following constraints: limited resource base; small size of the domestic market; concentration of employment of Brunei citizens in the government sector; and high dependence on expatriate workers.

Prospects for economic diversification are primarily dependent on the extent and status of the resource base. Except for capital, the modest resource endowment of the country offers few opportunities for comparative advantage in export-oriented activities and makes diversification difficult. Brunei's small population, estimated at 249,000 in 1989, translates to a very limited domestic market for goods and services. Diversification to activities geared toward import substitution is at best, only a short-term solution. The implication is that there are no economic panaceas, no single economic activity, which could replace the oil and gas sector's contribution to the country's domestic- or export-oriented activities. Rather, many small activities geared to both import substitution and export will need to collectively contribute to GDP. Diversification along these lines pushes the economy to become increasingly complex and interconnected, and has significant repercussions for management.

National development policies are typically aimed at increasing food availability, employment, export earnings and GDP. Unfortunately, such policies seldom explicitly or substantively consider sustainability. As a result, well-intended policies sometimes have negative side effects on long-term productivity due to resource extraction or utilization rates which exceed sustainable levels, or externalities, such as pollution from other activities. These can be perpetuated and further aggravated by the failure to abandon sectoral development initiatives and adopt a more integrated approach.

Unlike many ASEAN members with high rates of population growth, unemployment and underemployment are not problems in Brunei Darussalam. In fact, the country's small domestic labor force requires a strong dependence on expatriate labor, especially in the professions and trades. Permanent residents dominate the nongovernmental service sectors, whereas most Bruneian citizens are employed by the government. Dependence on immigrant labor has grown with increased diversification efforts. As of 1989, foreign workers made up 73% of the work force compared to only 66% in 1985. Of the total working population, only 13.2% are in the productive sector, over 77% of whom are foreign workers. Labor productivity in natural resource-based activities is low. Therefore, the relative roles of these activities in economic diversification and structural adjustment of the economy, and thus the economic (use) value of these resources, are likely to be limited by labor availability.

The limited supply of labor will be a major constraint to government plans to reduce dependence on the oil and gas sector. The latter realizes an extremely high value added per unit of labor; the non-oil sector can match only a fraction of this. Therefore, to replace a dollar of GDP from the oil and gas sector with a dollar of GDP from the non-oil sector would require substantially more labor. The significant social implications of augmenting the pool of immigrant labor must be weighed against the benefits associated with increased growth of the economy. Recognizing the importance of these social costs as well as the labor shortage, current government policies and strategies encourage mechanized or technology-based rather than labor-intensive enterprises.

Labor productivity will therefore necessarily influence the types of targeted industries to lead diversification efforts, and the activities promoted within specific industries. For example, there is a significant difference in labor productivity and gear selectivity between industrial and artisanal fisheries. The implications for management of labor peculiarities and gear selectivity are twofold. First, while it would require considerably less labor to develop industrial fishery, the per ton value of an increment in this sector would be less than that of a similar increase in the more selective artisanal sector. An in-depth analysis of tradeoffs in this regard is needed to identify relative levels of development which would allow for a maximum value added per new worker. Second, industrial fishing is dominated by immigrant labor, while artisanal fishing employs mostly Bruneians. Thus, differential development will substantially affect the distribution of benefits derived from the fisheries resources.

The interaction of these factors makes the socioeconomic implications of various fisheries development scenarios less than straightforward. Nevertheless, some general conclusions and recommendations can be drawn. To maximize social benefits from fisheries, the government must not only control the magnitude, but also the types of fishing effort. To the extent possible given labor constraints, preference should be given to artisanal fisheries. A balance must be struck between the desirability of high labor productivity on the one hand, and a broader distribution of benefits among Bruneian citizens. This can be achieved by encouraging Bruneians' participation in industrial fishing, and by promoting cost-effective expansion of artisanal fishing.

For the manufacturing sector, other constraints are relevant. Because the country's productive base is underdeveloped, there is a lack of basic industries which manufacture raw materials and inputs and provide back-up services. Entrepreneurs in mechanized or technology-based enterprises are thus faced with high unit costs because most or all of their inputs must be imported and large stocks maintained to ensure continuity of operations. To date, the only successful diversification efforts in non-oil manufacturing have been in simple processing of primary resources. This implies that the economy has not graduated beyond the early stages of industrial development. Government development plans continue to be geared toward diversification with emphasis on the promotion of small- and medium-scale industries which enjoy some competitive advantage. At the level of industrialization achieved so far, only these types of industries can thrive. These industries will necessarily have to build on existing primary (extractive) activities such as fisheries and agriculture. The derived demand for primary coastal resources in current plans for economic diversification justifies resource management.

Well-intended efforts to develop and diversify the economies of coastal areas can inadvertently create problems for coastal resources, ecological systems and existing activities. For example, diversification needs to be supported by infrastructure development which creates a derived demand for construction services and materials. Overexploitation of nonrenewable coastal resources, such as sand and gravel, will result in increased flooding, erosion and sedimentation. The tradeoffs must be evaluated between increased costs to acquire these materials from alternative sources (import), and the environmental and other costs associated with overexploitation. Management should place limits on acceptable levels of exploitation of these coastal resources.

Diversification also creates a derived demand for land for agricultural and industrial development. Inap-

propriate land use and management can result in large-scale erosion and sedimentation-related problems in coastal waters. Similarly, improper siting of industrial or other types of development in coastal areas can cause loss of critical habitats, such as mangroves. In addition, pollution from domestic, industrial and agricultural sources is a typical result of unmanaged development. All of these, individually and collectively, can adversely affect the ecology and productivity of estuarine and coastal habitats. Given the socioeconomic contribution of non-oil and oil-based coastal resources considered here, then management efforts for the coastal zone appear well warranted.

References

BID (Broadcast and Information Department). 1989. Brunei Darussalam Newsl. No. 41 (February, National Day issue). Broadcast and Information Department, Prime Minister's Office, Brunei Darussalam.

BPEU (British Petroleum Co., Economics Unit). 1990. BP statistical review of world energy. Corporate Communications Services, British Petroleum Co., London.

DOF (Department of Fisheries). 1990. Five-point Plan Uplifting the Fishing Industry. Department of Fisheries, Ministry of Industry and Primary Resources, Brunei Darussalam.

DOTCP (Department of Town and Country Planning). 1986a. Negara Brunei Darussalam Master Plan Background Paper No. 6: Macroeconomic Framework. Department of Town and Country Planning, Ministry of Development, Brunei Darussalam.

DOTCP (Department of Town and Country Planning). 1986b. Negara Brunei Darussalam Master Plan Background Paper No. 8: Forestry. Department of Town and Country Planning, Ministry of Development, Brunei Darussalam.

DOTCP (Department of Town and Country Planning). 1986c. Negara Brunei Darussalam Master Plan Background Paper No. 9: Geology and Mineral Resources. Department of Town and Country Planning, Ministry of Development, Brunei Darussalam.

DOTCP (Department of Town and Country Planning). 1987. Negara Brunei Darussalam Master Plan. Main Volume. Department of Town and Country Planning, Ministry of Development, Brunei Darussalam.

EPU (Economic Planning Unit). 1977. Brunei statistical yearbook - 1976. Statistics Division, Economic Planning Unit, Ministry of Finance, Brunei Darussalam.

EPU (Economic Planning Unit). 1981. Summary tables of the Brunei population census - 1981. Statistics Division, Economic Planning Unit, Ministry of Finance, Brunei Darussalam.

EPU (Economic Planning Unit). 1984. Brunei statistical yearbook - 1982-1983. Statistics Division, Economic Planning Unit, Ministry of Finance, Brunei Darussalam.

EPU (Economic Planning Unit). 1985. Fifth National Development Plan, 1986-1990. Economic Planning Unit, Ministry of Finance, Brunei Darussalam.

EPU (Economic Planning Unit). 1986a. Brunei statistical yearbook - 1984-1985. Statistics Division, Economic Planning Unit, Ministry of Finance, Brunei Darussalam.

EPU (Economic Planning Unit). 1986b. Brunei Darussalam population survey-1986. Demographic and Social Section, Statistics Division, Economic Planning Unit, Ministry of Finance, Brunei Darussalam.

EPU (Economic Planning Unit). 1989. Brunei statistical yearbook - 1988. Statistics Division, Economic Planning Unit, Ministry of Finance, Brunei Darussalam.

EPU (Economic Planning Unit). 1990. Brunei Darussalam key indicators - 1989. Statistics Division, Economic Planning Unit, Ministry of Finance, Brunei Darussalam.

FD (Forestry Department). 1989a. Forestry Strategic Plan. Forestry Department, Ministry of Industry and Primary Resources, Brunei Darussalam.

FD (Forestry Department) 1989b. Wood industry and plantation development study, Vol. 1. Forestry Department, Ministry of Industry and Primary Resources, Brunei Darussalam.

Hamilton, L.S. and S.C. Snedaker, editors. 1984. Handbook for mangrove area management. United Nations Environment Programme, and Environment and Policy Institute, East-West Center, Honolulu, Hawaii.

Idris, H.A.H. 1988. A preliminary report on the sociodemographic profile, fishing intensity and income level of small-scale fishermen in the Belait District of Negara Brunei Darussalam. Department of Fisheries, Ministry of Development, Negara Brunei Darussalam. (Unpublished).

Lim, J. S. 1986. The inter-relationship of technology, economy and social organization in a fishing village in Brunei. Brunei Mus. J. Monogr. No. 6, 123 p.

Myers, N. 1989. The environmental basis of sustainable development. *In* G. Schramm and J. Warford (eds.) Environmental management and economic development. The Johns Hopkins University Press for the World Bank, Baltimore, Maryland.

NC (Nautilus Consultants). 1989a. Brunei Darussalam fish utilization study. Commonwealth Fund for Technical Cooperation, Commonwealth Secretariat, London. (Unpublished).

NC (Nautilus Consultants). 1989b. Working Paper 1: Current fish utilization practices. Commonwealth Fund for Technical Cooperation, Commonwealth Secretariat, London. (Unpublished).

NC (Nautilus Consultants). 1989c. Working Paper 3: Industrial and commercial fisheries development. Commonwealth Fund for Technical Cooperation, Commonwealth Secretariat, London. (Unpublished).

Repetto, R. 1986. Natural resource accounting in a resource based economy: an Indonesian case study. World Resources Institute, Washington, D.C.

ULG Consultants. 1983. Agriculture and forestry development study: supporting annexes. Vol. 5. (Unpublished).

ULG Consultants. 1984a. The Temburong renewable resources study: agricultural development plan. Vol. 2. (Unpublished).

ULG Consultants. 1984b. The Temburong renewable resources study: fisheries report. Vol. 4. (Unpublished).

White, A.T. 1987. Mineral resources, p. 63-66. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Zamora, P. 1987. Coastal agriculture, p. 131-134. *In* T.-E. Chua, L.M. Chou and M.S.M. Sadorra (eds.) The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p. Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

Appendix: GDP Projections for the Modified Scenarios

This appendix presents in tabular form the detailed projections for the economy of Brunei under modified development Scenarios 1, 2 and 3. Results of the regression done on the various components of the economy using the MICRO TSP Version 5.1 package follow the assumptions outlined in the text for each scenario.

Table A-1. Estimates of GDP (B$x10^6) by kind of economic activity at 1974 constant prices for Scenario 1, 1974-1995.[a]

Economic activity	1974	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Oil sector	2,301.7	3,563.9	2,686.2	2,686.1	2,707.3	2,627.7	2,573.5	2,386.3	2,321.6	2,277.7	2,225.3	2,178.6	2,210.4	2,231.5	2,237.4	2,226.4	2,231.8
Non-oil sector[b]	314.6	695.0	728.3	863.4	860.1	961.1	961.8	1,047.4	1,143.2	1,269.7	1,416.4	1,582.6	1,555.0	1,599.3	1,646.0	1,663.5	1,698.7
Government	115.8	264.4	285.5	306.1	330.9	493.6	524.6	585.5	662.4	755.0	857.4	975.4	918.8	955.3	989.1	1,001.8	1,021.8
Private	198.8	430.6	442.8	557.3	529.2	467.3	437.2	461.9	480.8	514.7	559.0	607.2	636.2	644.0	656.9	661.8	677.0
Productive industries	60.1	74.0	75.4	91.7	77.4	71.9	67.9	72.2	73.0	72.7	73.6	74.7	84.5	84.5	85.2	85.2	87.1
Agriculture and hunting	27.3	32.8	24.2	26.9	27.4	29.0	29.3	30.5	31.7	33.0	34.3	35.7	40.3	40.5	40.8	40.9	41.8
Forestry and logging	3.1	5.0	7.4	8.6	6.7	7.1	7.9	11.5	10.8	8.3	7.1	5.7	5.7	5.7	5.7	5.7	5.7
Fishing	4.8	4.2	4.3	4.4	6.5	5.5	5.9	5.6	5.4	5.1	4.9	4.6	6.4	6.1	6.1	6.0	6.1
Mining, quarrying and manufacturing	24.9	32.0	39.5	51.8	36.8	30.3	24.8	24.6	25.1	26.3	27.3	28.7	32.2	32.3	32.6	32.6	33.5
Service industries	267.8	676.8	730.3	883.1	877.7	995.6	966.4	1,049.1	1,145.5	1,273.7	1,420.9	1,587.5	1,559.2	1,603.8	1,650.8	1,668.5	1,703.7
Electrical	7.0	(3.9)	6.8	9.8	9.3	8.8	17.4	13.6	13.8	18.9	14.5	15.5	18.7	18.9	19.3	18.5	19.2
Construction	35.1	98.3	112.2	133.5	123.0	94.8	72.9	67.8	63.1	67.5	72.2	77.2	84.9	84.0	85.6	86.2	86.2
Wholesale trade	11.5	29.0	32.7	67.6	41.3	57.9	32.0	34.2	36.5	38.9	41.5	44.3	47.4	48.1	48.9	49.1	50.3
Retail trade	41.0	81.6	84.7	124.5	93.5	82.2	70.8	74.1	74.7	75.3	86.5	90.0	97.5	97.7	99.1	100.5	102.3
Restaurants and hotels	6.5	13.6	15.6	18.3	20.6	17.0	16.7	17.1	17.4	17.8	18.2	18.6	21.8	21.8	21.7	21.8	22.3
Transport, storage and communication	14.1	37.2	36.8	58.4	80.7	65.2	73.7	87.0	102.8	121.4	143.4	169.4	148.3	156.4	163.6	166.7	169.9
Banking and finance	12.8	69.0	73.3	76.7	79.9	87.8	85.9	88.7	91.6	94.7	97.9	101.1	115.8	115.8	116.7	116.8	119.6
Insurance	0.9	3.9	5.6	3.4	7.4	5.3	7.7	11.3	16.5	24.3	35.6	52.4	31.9	36.0	39.7	41.8	42.5
Real estate and business services	12.3	58.2	55.1	62.1	71.7	73.6	60.9	62.6	64.2	68.9	73.9	79.2	84.7	85.4	87.1	87.5	89.5
Ownership of dwellings	12.0	14.8	15.4	16.0	16.6	17.3	17.7	18.3	18.8	19.3	19.8	20.4	23.6	23.5	23.7	23.6	24.3
Community, social and personal services	114.6	275.1	292.1	312.8	333.7	485.7	510.7	574.4	646.1	726.7	817.4	919.4	884.5	916.2	945.4	956.2	975.8
Less bank charges	(13.3)	(55.8)	(77.4)	(111.4)	(95.1)	(106.3)	(72.6)	(73.9)	(75.3)	(76.7)	(78.1)	(79.6)	(88.7)	(89.0)	(90.0)	(90.2)	(92.0)
GDP	2,616.3	4,258.9	3,414.5	3,549.5	3,567.4	3,588.8	3,535.3	3,433.7	3,464.8	3,547.4	3,641.7	3,761.2	3,765.4	3,830.8	3,883.4	3,889.9	3,930.5

[a]Values from 1974 to 1989 are actual; 1990 are estimates by EPU; and 1991 to 1995 are projections. Minor discrepancies in figures are due to rounding off.

[b]The predicted values for this sector were derived by using multiple regression analysis. The non-oil sector was regressed against its own lagged values, the deflator for the non-oil sector, the per capita income in the non-oil sector, and the GVA of the community, social and personal services industry. The GVA per industry in a given year was estimated using its average percentage contribution to the non-oil sector over the preceding 5 years.

Sources: EPU (1985); Brunei statistical yearbook (various years).

Table A-2. Percentage growth rates of GDP at 1974 constant prices for Scenario 1, 1974-1995.

Economic activity	1974-1975	1985-1986	1986-1987	1987-1988	1988-1989	1989-1990	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1975-1979	1980-1985	1986-1990	1991-1995
Oil sector	-1.89	-7.27	-2.71	-1.89	-2.30	-2.10	1.46	0.95	0.26	-0.49	0.24	12.43	(7.76)	-3.26	0.49
Non-oil sector	16.75	8.90	9.15	11.07	11.55	11.73	-1.74	2.85	2.92	1.07	2.12	11.28	13.24	10.48	1.44
Government	5.09	11.61	13.13	13.98	13.56	13.76	-5.80	3.96	3.54	1.29	2.00	10.55	22.57	13.21	1.00
Private	23.54	5.65	4.09	7.05	8.61	8.62	4.77	1.24	2.00	0.74	2.30	11.82	7.70	6.80	2.21
Productive industries	10.65	6.33	1.11	-0.41	1.24	1.49	13.17	0.01	0.78	0.02	2.17	1.66	3.18	1.95	3.23
Agriculture and hunting	-5.13	4.10	3.93	4.10	3.94	4.08	12.61	0.47	0.89	0.25	2.12	1.02	1.71	4.03	3.31
Forestry and logging	38.71	45.57	-6.09	-23.15	-14.46	-19.72	0.00	0.00	0.00	0.00	0.00	13.66	7.80	-3.57	0.00
Fishing	6.25	-5.08	-3.57	-5.56	-3.92	-6.12	38.60	-4.68	0.21	-1.66	2.12	4.36	2.97	-4.85	6.92
Mining, quarrying and manufacturing	25.30	-0.81	2.03	4.78	3.80	5.13	12.16	0.36	0.88	0.05	2.64	2.33	7.09	2.99	3.22
Service industries	20.72	8.56	9.19	11.19	11.56	11.72	-1.78	2.86	2.93	1.08	2.11	14.13	14.82	10.44	1.44
Electrical	8.57	-21.84	1.47	36.96	-23.28	6.90	20.39	1.13	2.05	-4.12	3.96	-32.16	(848.14)	0.04	4.68
Construction	45.87	-7.00	-6.93	6.97	6.96	6.93	9.98	-1.11	1.94	0.68	2.31	15.03	10.25	1.39	2.76
Wholesale trade	20.00	6.88	6.73	6.58	6.68	6.75	7.06	1.50	1.55	0.39	2.46	15.11	29.15	6.72	2.59
Retail trade	11.71	4.66	0.81	0.80	14.87	4.05	8.33	0.22	1.40	1.40	1.78	12.61	5.78	5.04	2.63
Restaurants and hotels	50.77	2.40	1.75	2.30	2.25	2.20	17.04	-0.09	-0.11	0.30	2.12	14.58	7.90	2.18	3.85
Transport, storage and communication	51.06	-18.05	18.16	18.09	18.12	18.13	-12.43	5.44	4.60	1.88	1.91	23.07	14.95	18.11	0.28
Banking and finance	67.97	3.26	3.27	3.38	3.38	3.27	14.59	-0.05	0.79	0.07	2.41	36.10	10.54	3.31	3.56
Insurance	-22.22	46.75	46.02	47.27	46.50	47.19	-39.16	12.88	10.24	5.26	1.71	33.81	39.77	46.75	-1.81
Real estate and business services	40.65	2.79	2.56	7.32	7.26	7.17	7.00	0.77	1.96	0.49	2.31	24.14	20.48	5.42	2.51
Ownership of dwellings	8.33	3.39	2.73	2.66	2.59	3.03	15.86	-0.54	0.82	-0.34	2.84	7.22	0.60	2.88	3.73
Community, social and personal services	5.85	12.47	12.48	12.47	12.48	12.48	-3.80	3.59	3.19	1.14	2.05	11.66	21.33	12.48	1.23
Less bank charges	69.17	1.79	1.89	1.86	1.83	1.92	11.48	0.32	1.07	0.26	1.98	29.84	19.90	1.86	3.02
GDP	0.36	-2.87	0.91	2.38	2.66	3.28	0.11	1.74	1.37	0.17	1.04	12.15	(4.35)	1.27	0.89

Table A-3. Estimates of GDP (B$x10^6) by kind of economic activity at 1974 constant prices for Scenario 2, 1974-1995.[a]

Economic activity	1991	1992	1993	1994	1995
Oil sector	2,210.4	2,231.5	2,237.4	2,226.4	2,231.8
Non-oil sector[b]	1,609.5	1,701.9	1,797.8	1,875.2	1,976.8
Government	951.1	1,005.7	1,062.3	1,108.1	1,168.1
Private	658.5	696.3	735.5	767.2	808.7
Productive industries	70.9	73.6	78.8	88.9	97.7
Agriculture and hunting	35.0	36.3	37.6	38.8	39.9
Forestry and logging	5.7	5.7	5.7	5.7	5.7
Fishing	5.5	5.7	5.8	5.8	5.9
Mining, quarrying and manufacturing	24.7	26.0	29.7	38.6	46.2
Service industries	1,621.7	1,714.9	1,809.3	1,880.5	1,977.3
Electrical	15.9	16.2	15.9	16.0	16.0
Construction	70.7	71.5	71.9	71.4	71.6
Wholesale trade	42.6	44.5	41.3	44.6	48.8
Retail trade	101.9	93.4	95.2	98.0	98.9
Restaurants and hotels	20.1	21.3	19.9	20.4	20.5
Transport, storage and communication	173.9	175.0	181.1	181.1	181.4
Banking and finance	104.2	107.6	110.9	113.7	116.4
Insurance	56.2	60.4	60.7	62.2	63.4
Real estate and business services	78.8	82.5	86.2	82.0	83.6
Ownership of dwellings	21.1	21.9	21.0	21.3	21.4
Community, social and personal services	936.3	1,020.5	1,105.2	1,169.7	1,255.3
Less bank charges	(83.0)	(86.6)	(90.3)	(94.2)	(98.2)
GDP	3,819.9	3,933.4	4,035.2	4,101.6	4,208.6

[a]Please refer to Table A-1 for 1974-1990 values; 1991-1995 figures are projections. Minor discrepancies in figures are due to rounding off.
[b]The predicted values for this sector were arrived at through multiple regression analysis. Explanatory variables relevant to each industry were used.
Sources: EPU (1985); Brunei statistical yearbook (various years).

Table A-4. Percentage growth rates of GDP at 1974 constant prices for Scenario 2, 1974-1995.[a]

Economic activity	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1975-1979	1980-1985	1986-1990	1991-1995
Oil sector	1.46	0.95	0.26	-0.49	0.24	12.43	(7.76)	-3.26	0.49
Non-oil sector	1.70	5.74	5.63	4.31	5.42	11.28	13.24	10.48	4.56
Government	-2.49	5.74	5.63	4.31	5.42	10.55	22.57	13.21	3.72
Private	8.44	5.74	5.63	4.31	5.42	11.82	7.70	6.80	5.91
Productive industries	-5.12	3.90	7.00	12.85	9.88	1.66	3.18	1.95	5.70
Agriculture and hunting	-2.00	3.80	3.43	3.39	2.77	1.02	1.71	4.03	2.28
Forestry and logging	0.00	0.00	0.00	0.00	0.00	13.66	7.80	-3.57	0.00
Fishing	20.34	2.17	2.30	0.51	1.63	4.36	2.97	-4.85	5.39
Mining, quarrying and manufacturing	-14.11	5.33	14.54	29.66	19.74	2.33	7.09	2.99	11.03
Service industries	2.15	5.75	5.51	3.93	5.15	14.13	14.82	10.44	4.50
Electrical	2.49	1.93	-1.61	0.41	0.23	-32.16	(848.14)	0.04	0.69
Construction	-8.37	1.14	0.54	-0.75	0.35	15.03	10.25	1.39	-1.42
Wholesale trade	-3.93	4.56	-7.13	8.03	9.28	15.11	29.15	6.72	2.16
Retail trade	13.19	-8.29	1.87	2.96	0.90	12.61	5.78	5.04	2.13
Restaurants and hotels	8.11	5.80	-6.64	2.79	0.50	14.58	7.90	2.18	2.11
Transport, storage and communication	2.66	0.65	3.48	-0.03	0.17	23.07	14.95	18.11	1.38
Banking and finance	3.11	3.24	3.08	2.50	2.36	36.10	10.54	3.31	2.86
Insurance	7.23	7.53	0.41	2.57	1.93	33.81	39.77	46.75	3.93
Real estate and business services	-0.50	4.68	4.51	-4.86	1.90	24.14	20.48	5.42	1.14
Ownership of dwellings	3.19	4.02	-4.14	1.54	0.41	7.22	0.60	2.88	1.00
Community, social and personal services	1.84	8.99	8.30	5.84	7.32	11.66	21.33	12.48	6.46
Less bank charges	4.30	4.30	4.30	4.30	4.30	29.84	19.90	1.86	4.30
GDP	1.56	2.97	2.59	1.65	2.61	12.15	(4.35)	1.27	2.27

[a]Please refer to Table A-2 for 1974-1975 to 1989-1990 values.

Table A-5. Estimates of GDP (B$X10^6) by kind of economic activity at 1974 constant prices for Scenario 3, 1974-1995.[a]

Economic activity	1991	1992	1993	1994	1995
Oil sector	2,210.4	2,231.5	2,237.4	2,226.4	2,231.8
Non-oil sector[b]	1,589.4	1,641.2	1,694.6	1,734.0	1,787.5
Government	939.2	969.8	1,001.3	1,024.6	1,056.2
Private	650.2	671.4	693.2	709.4	731.3
Productive industries	79.2	81.2	83.3	85.4	88.2
Agriculture and hunting	36.0	36.3	37.6	38.8	39.9
Forestry and logging	5.7	5.7	5.7	5.7	5.7
Fishing	5.5	5.7	5.8	5.8	5.9
Mining, quarrying and manufacturing	33.0	33.5	34.2	35.0	36.7
Service industries	1,593.3	1,646.6	1,701.6	1,742.8	1,797.5
Electrical	15.9	16.2	15.9	16.0	16.0
Construction	70.7	71.5	71.9	71.4	71.6
Wholesale trade	42.6	44.5	41.3	44.6	48.8
Retail trade	101.9	93.4	95.2	98.0	98.9
Restaurants and hotels	22.6	23.2	23.7	24.6	25.9
Transport, storage and communication	173.9	175.0	181.1	181.1	181.4
Banking and finance	104.2 [6]	107.6	110.9	113.7	116.4
Insurance	56.2	60.4	60.7	62.2	63.4
Real estate and business services	78.8	82.5	86.2	82.0	83.6
Ownership of dwellings	21.1	21.9	21.0	21.3	21.4
Community, social and personal services	905.5	950.3	993.6	1,027.8	1,070.1
Less bank charges	(83.0)	(86.6)	(90.3)	(94.2)	(98.3)
GDP	3,799.8	3,872.7	3,932.0	3,960.4	4,019.3

[a]Please refer to Table A-1 for 1974-1990 values; 1991-1995 figures are projections. Minor discrepancies in figures are due to rounding off.
[b]The predicted values for this sector were derived using their average market share to total GDP five years back.
Sources: EPU (1985); Brunei statistical yearbook (various years).

Table A-6. Percentage growth rates of GDP at 1974 constant prices for Scenario 3, 1974-1995.[a]

Economic activity	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1975-1979	1980-1985	1986-1990	1991-1995
Oil sector	1.46	0.95	0.26	-0.49	0.24	12.43	(7.76)	-3.26	0.49
Non-oil sector	0.43	3.26	3.25	2.32	3.09	11.28	13.24	10.48	2.47
Government	-3.71	3.26	3.25	2.32	3.09	10.55	22.57	13.21	1.64
Private	7.09	3.26	3.25	2.32	3.09	11.82	7.70	6.80	3.80
Productive industries	5.99	2.53	2.61	2.53	3.30	1.66	3.18	1.95	3.39
Agriculture and hunting	-2.00	3.80	3.43	3.39	2.77	1.02	1.71	4.03	2.28
Forestry and logging	0.00	0.00	0.00	0.00	0.00	13.66	7.80	-3.57	0.00
Fishing	20.34	2.17	2.30	0.51	1.63	4.36	2.97	-4.85	5.39
Mining, quarrying and manufacturing	14.82	1.68	2.21	2.33	4.72	2.33	7.09	2.99	5.15
Service industries	0.36	3.35	3.34	2.42	3.14	14.13	14.82	10.44	2.52
Electrical	2.49	1.93	-1.61	0.41	0.23	-32.16	(848.14)	0.04	0.69
Construction	-8.37	1.14	0.54	-0.75	0.35	15.03	10.25	1.39	-1.42
Wholesale trade	-3.93	4.56	-7.13	8.03	9.28	15.11	29.15	6.72	2.16
Retail trade	13.19	-8.29	1.87	2.96	0.90	12.61	5.78	5.04	2.13
Restaurants and hotels	21.25	2.68	2.54	3.52	5.41	14.58	7.90	2.18	7.08
Transport, storage and communication	2.66	0.65	3.48	-0.03	0.17	23.07	14.95	18.11	1.38
Banking and finance	3.11	3.24	3.08	2.50	2.36	36.10	10.54	3.31	2.86
Insurance	7.23	7.53	0.41	2.57	1.93	33.81	39.77	46.75	3.93
Real estate and business services	-0.50	4.68	4.51	-4.86	1.90	24.14	20.48	5.42	1.14
Ownership of dwellings	3.19	4.02	-4.14	1.54	0.41	7.22	0.60	2.88	1.00
Community, social and personal services	-1.51	4.95	4.55	3.45	4.11	11.66	21.33	12.48	3.11
Less bank charges	4.30	4.30	4.30	4.30	4.30	29.84	19.90	1.86	4.30
GDP	1.03	1.92	1.53	0.72	1.49	12.15	(4.35)	1.27	1.34

[a]Please refer to Table A-2 for 1974-1975 to 1989-1990 values.

Legal and Institutional Environment for the Management of Coastal Resources in Brunei Darussalam

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Abstract

This paper reviews the legal and institutional structure for coastal resources management (CRM) and environmental protection in Brunei Darussalam. Assessment of the coverage of existing laws focuses on those that affect: (1) the landward portion of the coastal zone, (2) sand mining, (3) water quality and (4) pesticide use. Results indicate that these laws are adequate to meet acceptable levels of environmental quality. Administrative agencies, however, have yet to use the full authority that the laws provide through their proper translation into relevant rules and regulations. Currently, no single ministry or department has responsibility for overall CRM. Considerable opportunity exists for enhanced coordination among agencies. Changes in existing procedures and institutional arrangements are proposed, mindful of the need to minimize disruption in government when reorganization is attempted. The most significant recommendations call for a national policy for environmental protection and the immediate designation of a lead agency responsible for various aspects of environmental management until a new high-profile unit or department is created.

Introduction

The development of any CRM plan requires an understanding of existing legal and institutional arrangements. What laws affect the use of coastal resources? Do these laws offer adequate protection against abuse or degradation of coastal resources? Similarly, are existing institutions organized to assess and respond to threats to these resources effectively? The goal of this study is to address these questions and provide a profile of governmental arrangements for the management of Brunei Darussalam's coastal resources. To achieve this goal, the study:

- analyzes existing legal and institutional arrangements and their suitability for environmental management;
- identifies legal and institutional constraints to a more effective CRM; and
- recommends improvements in laws and organizational structure.

For most nations, including Brunei Darussalam, the conscious management of coastal resources is a relatively new concern. Few nations have long-term experience in this area, which is not always transferable, particularly in the legal and institutional realm. A country's laws and institutions are a product of its history, religious and cultural heritage, relations with other nations and even its geographic location. Furthermore, governments and their legal systems have many diverse purposes; protection of the environment and concern for sustainable development may not be among these. The point is that legal and institutional arrangements in most countries predate concern for judicious CRM. Amendments in laws and institutions are frequently a desirable remedy, often preceded by a shift in perspective and a growing realization of the need for change.

Brunei Darussalam's recent national development plans indicate such a changing perspective. The Third

National Development Plan (NDP), covering 1975-1979, had 14 major objectives, none of which specifically included environmental considerations. The Fourth NDP (1980-1984) was similarly silent about the environment; emphasis was on rapid development of agriculture and industry. With the Fifth NDP (1986-1990), however, much has changed. Emphasis continues to be on economic development and "maximizing the economic utilization of the country's natural resources," but one of the long-term goals is to have a "clean and healthy environment." To achieve the latter, the plan calls for the formulation of a national policy to control environmental pollution (EPU 1986). This policy has not yet been developed, but there are indications that concern for environmental protection is growing.

As in many countries, such an interest has heightened the government's awareness of environmental issues. Within the last several years, for instance, there has been increasing concern about high levels of pesticide residues on vegetables; solid waste disposal in Kampong (or Kg., i.e., village) Ayer; and the need to dispose of asbestos from the operations of Brunei Shell Petroleum Co. (BSP). Nonetheless, many people remain unconvinced of the need to give greater attention to environmental protection. In a government-sponsored survey of public attitudes in 1988, over three-quarters of respondents indicated that they did not worry much about environmental pollution (Anon. 1988a). This seeming apathy is a cause for concern among government officials. The Minister of Development noted that lack of public concern and knowledge are contributing factors to environmental problems (Anon. 1988b). Other causes cited are indiscriminate exploitation of natural resources; development without regard for its effects on ecosystems; and limited financial resources for environmental protection. There has not been a ground swell of public demand for change. The government itself will have to initiate change to be more responsive to the mandates of CRM.

Institutional Framework

It is easy to describe Brunei Darussalam's governmental structure. His Majesty, the Sultan, serves as prime minister (and defense minister) and appoints and heads a cabinet of ten ministers. The ministers have responsibility for such traditional functions as health, finance, education and foreign affairs. Several ministries contain specialized departments, such as agriculture and fisheries. Table 1 lists the ministries and departments potentially relevant to the management of natural resources.

Table 1. Ministries and departments with potential responsibility for natural resources management in Brunei Darussalam.

Prime Minister's Office (PMO)
Petroleum Unit (PU)[a]
Ministry of Home Affairs
District Offices (DOs)[a]
Municipal Boards (MBs)[a]
Ministry of Communications
Marine Department (MD)[a]
Ports Department (PD)[a]
Ministry of Industry and Primary Resources (MIPR)
Department of Fisheries (DOF)[a]
Agriculture Department (AD)[a]
Forestry Department (FD)[a]
Ministry of Development (MOD)
Public Works Department (PWD)[a]
Department of Town and Country Planning (DOTCP)[a]
Land Department (LD)[a]
Ministry of Finance (MOF)
Economic Planning Unit (EPU)[a]
Economic Development Board (EDB)[a]
Ministry of Culture, Youth and Sports
Museums Department (MuD)
Ministry of Health (MOH)[a]
Ministry of Law (MOL)[a]

[a]One or more respondents were interviewed for this study during site visits from 27 June to 20 July 1989. Discussions were also held with representatives of a private consulting firm and BSP.

As in other governments, some agencies have line authority over specific sectoral or regulatory functions (e.g., land or fisheries) while other units are primarily involved with planning or administrative functions (e.g., EPU). Although these differences in function and scope of responsibilities make comparison difficult, some indicators can assess an agency's relative standing or significance within a government. Governments are free to distribute their budgetary resources among constituent units, but the process of distribution is never at random. Departments given huge budgets and larger than normal annual increases in allotments have significant influence in the councils of government. The figures in Table 2 suggest not only the enormous size of PWD relative to other departments but also its growing prominence as measured by the percentage increase in its budget from 1986 to 1989. Other departments that experienced large increases were Fisheries and Agriculture. In contrast, Ports and Marine suffered sharp reductions. These budgetary cuts have affected staffing and managerial skills, and possibly coastal-related responsibilities, too. One such responsibility is that for oil spill response under MD.

The most notable feature of Brunei Darussalam's government is that no single agency is responsible for environmental issues. Such responsibility is widely

Table 2. Consolidated fund appropriations for selected agencies in 1986 and 1989.

Department	Consolidated fund appropriation (B$ x 10^6)[a] 1986	1989	% change (1986-1989)
PWD	317.19	496.78	+56.6
AD	27.10	39.08	+44.2
MD	11.23	7.34	-34.6
PD	9.99	5.16	-48.3
LD	4.78	5.42	+13.4
FD	3.36	4.25	+26.5
DOF	3.30	4.88	+47.9
DOTCP	1.55	2.06	+32.9
Total budget[b]	2,206.20	2,748.83	+24.6

[a]September 1991: B$1.70 = US$1.00.
[b]Excludes appropriations to the development fund which comprise an independent budget for projects identified specifically in the Fifth NDP (1986-1990).
Sources: MOL (1986) and GBD (1989).

scattered among different ministries, departments and units, as is evident in Table 3, which is instructive in several ways.

First, although not all possible areas of coastal or environmental concern are included, several departments share responsibility for the same function, such as water pollution control. Overlaps indicate a need for improved coordination of efforts, not only to maximize manpower, but also to implement management measures effectively.

Second, some tasks are without masters--no department has responsibility for EIAs (which no law now requires), or for the collection and disposal of hazardous wastes. Consequently, some important functions may be neglected, to the detriment of environmental quality.

Third, some departments have statutory responsibility for a function but do not actually perform it. For example, PWD currently handles the construction and operation of sewage treatment works, though MBs are responsible for this function, and retain the authority to promulgate by-laws affecting sewage treatment and water quality. In other instances, departments may not have given priority to their statutory responsibilities or opportunities to influence environmental decisionmaking. Granting of licenses to mine sand, for example, may be viewed as a routine administrative function bereft of environmental responsibilities or one with important consequences for coastal erosion and aesthetics.

Fourth, some departments exercise influence or authority not because of an explicit statutory mandate but rather through default or because they have gradually accumulated the relevant skills. Several departments have adjusted their missions or organizational structure to be more responsive to environmental concerns. According to its 1988 annual report, DOTCP's mission is to "plan and coordinate physical development on [the] basis of sustainable and environmentally sound socioeconomic development." The department created a Landscape and Environment Section in early 1989 to initiate and coordinate environmental activities; assess the suitability of erosion control measures; and promote environmental awareness. The AD also reorganized itself in early 1989 to create five divisions, one of which is the Environment Division.

When MIPR was created in January 1989, its minister established a Committee on Environmental Management and Related Social Services, with representatives from the minister's office, the Industrial Unit and DOF, FD and AD. The committee recommended that the ministry "protect, monitor, restore, enhance and sustain the quality of the terrestrial, aquatic and atmospheric regimes for environmental stability and optimum social benefits for people" (MIPR 1989). To its credit, the committee developed a detailed action plan (Table 4) that identifies eight environmental problems in Brunei Darussalam, indicating the areas of concern and the appropriate remedial actions. A much broader effort has also been initiated. With His Majesty's approval, a Committee on Tourism and Recreation was established in 1988, with representatives from different ministries and departments. The EDB under MOF serves as the committee's secretariat. After several meetings, the committee broadened its mandate and renamed itself the Tourism and Environment Body because of linkages between the two issues. This body considered a proposal to direct its resources to four areas of activity: (1) pollution control; (2) wildlife conservation; (3) landscape protection and rehabilitation; and (4) recreational resort development (MOD 1988).

From the perspective of improved CRM, all these organizational activities are beneficial. At the same time, one must acknowledge that Brunei Darussalam's response to environmental management remains fragmented. A report from MOD (1988) summarized the situation:

> Matters concerning the environment have received a relatively low priority in the national development effort...because of a lack of strong focus and a consequent fragmentation of responsibility. While there is widespread concern about the degradation of the environment within the government, it has not been possible to organize effective, coordinated action.

Table 3. Legal and institutional responsibilities in Brunei Darussalam for selected environmental issues.

Environmental issue/concern	Ministry/Department												
	PWD	AD	DOTCP	MB	DO	FD	MuD	MOH	DOF	HDB[a]	PD/MD	PU	LD
General environmental protection													
• Preparation of necessary legislation for environmental protection and environmental quality			x										
• Coordination at design and planning stage to reduce environmental damage			x										
• Coordination of national efforts concerned with environmental protection													
Environmental impact assessment (EIA)													
• Preparation of guidelines													
• EIA of major projects - industrial and private projects, sand and gravel mining, roads, etc.													
Public awareness/education													
• Response to public inquiries concerning environmental activities	x	x	x	x		x	x	x	x				
• Public awareness programs/activities													
Water and sewerage													
• Planning for future water consumption	x												
• Establishment and monitoring of water quality standards	x			x		x		x	x		x	x	x
• Provision, maintenance and operation of water supply, sewerage and drainage services	x			x									
• Sampling and analysis of estuarial and wastewaters								x		x			
• Sampling and analysis of distributed water and drinking water sources	x						x						
• Cleaning of rivers or ports	x			x			x	x		x			
Waste disposal (domestic, toxic and hazardous)													
• Preparation of guidelines, legislation and policies	x		x	x	x			x					
• Planning and development of refuse disposal facilities	x			x	x								
• Collection and disposal of domestic waste	x			x	x								

Continued

Table 3. (continued)

Environmental issue/concern	Ministry/Department PWD	AD	DOTCP	MB	DO	FD	MuD	MOH	DOF	HDB[a]	PD/MD	PU	LD
• Operation of refuse disposal facilities				x	x								
• Enforcement of waste disposal in public, recreational, residential, commercial and industrial areas				x	x						x		
• Enforcement of waste disposal in Kg. Ayer					x								
• Enforcement of collection of scrapped cars													
Coastal erosion													
• Identification of areas requiring immediate erosion control measures	x		x			x							
• Planning and development of erosion control and land rehabilitation	x		x										
• Studies/trials on erosion control measures	x	x	x			x							
• Coordination of erosion control activities													
• Mining of sand	x					x					x		x
Landscape													
• Preparation of landscape plans for new government buildings	x					x							
• Identification, planning and design of recreational areas, including parks and gardens	x		x	x	x	x							
• Supervision of project implementation	x	x	x							x			
• Preparation of landscape guidelines and standards	x	x	x			x							
• Preparation of specifications, maintenance schedules, tenders	x	x	x	x						x			
• Comments on development control matters			x										
• Implementation of projects	x	x		x	x	x				x			
• Maintenance of landscaped areas	x	x		x	x	x				x			

Continued

Table 3. (continued)

Environmental issue/concern	Ministry/Department PWD	AD	DOTCP	MB	DO	FD	MuD	MOH	DOF	HDB[a]	PD/MD	PU	LD
Nature conservation													
• Preparation of a national conservation strategy			x										
• Preparation of a national conservation development plan		x											
• Preparation of Wildlife Conservation Enactment			x				x						
• Preparation of proposals for totally protected areas (TPAs)			x			x	x						
• Development and implementation of detailed management plans for TPAs													
• Maintenance of TPAs							x						
• Enforcement of the protection of species							x						
• Administration of wildlife protection and management							x						
• Protection of mangroves						x						x	
• Marine parks							x						

Note: x marks represent involvement of respective departments in the various activities listed.
[a]Housing Development Board.
Source: Adapted from MOD (1988).

Table 4. Action plan of the Committee on Environmental Management and Related Social Services, MIPR.

Resource area	Priority	Problem	Area of concern	Remedial action
Land	1	Land degradation	Reforestation Shifting cultivation Topsoil excavation Mining/quarrying Fire Roadwork Hillslope farming Waste/garbage disposal Denudation of coastal areas Defective design and construction Indiscriminate/improper use of chemicals Wrong cultural practices	Prevent further land degradation Revegetate degraded/eroded lands Stabilize coastlines Rationalize and sustain land use Recommend appropriate legal and institutional measures Coordinate/cooperate among agencies Effectively enforce laws and monitor compliance Conserve terrestrial ecosystem
	1	Endangerment of flora and fauna	Overexploitation Diminishing biota and natural habitats Poaching Introduction of exotic plants and animals	Prevent further degradation or loss of living resources Stabilize plant and animal population Protect their natural habitats

Continued

Table 4. (continued)

Resource area	Priority	Problem	Area of concern	Remedial action
				As necessary, establish wildlife sanctuaries/refuges Recommend appropriate legal and institutional measures Educate the public Effectively enforce relevant laws and rules
	2	Inadequate facilities and services for social amenities	Lack of facilities Improper/inadequate maintenance Deteriorating facilities and services Vandalism Nonstrategic location Lack of management plan Conflict in management Lack of promotion and education Lack of institutional framework Untapped business opportunities	Improve the maintenance and protection of existing facilities and services Develop and upgrade necessary facilities and services for social amenities Prepare and implement management and development plan Recommend appropriate legal and institutional measures Consider feasible opportunities, e.g., tourism, research, education, etc.
Water	1	Deterioration of water quality	Kg. Ayer water pollution Effluents and solid wastes Sedimentation Soil erosion	Prevent further water quality deterioration Attain minimum water quality standard Improve water quality Educate the public and conduct vigorous promotional campaign Effectively enforce laws and monitor compliance
	1	Inadequate water for domestic, agricultural, industrial, recreational, transport, trade and other purposes	Erratic supply for irrigation Water rationing Chemical pollution Waterway hazards Possible opportunities	Same steps as above Sustain water quality Consider feasible opportunities, e.g., water recreation, education, research, tourism, etc.
	1	Threatened watersheds	Flood Drought Erosion Sedimentation/siltation	Same steps as above Initiate reforestation/afforestation
	2	Degradation of aquatic ecosystems and resources	Indiscriminate fishing Indiscriminate use of chemicals Overexploitation Pollution (oil, industrial/chemical wastes) Blast fishing "Red tide" phenomenon	Prevent further degradation Rationalize resource use Recommend appropriate legal and institutional measures Conduct necessary studies/develop appropriate technologies Educate the public
Air	2	Deterioration of air quality	Industrial/vehicular emissions Noise and chemical pollution "Greenhouse effect"	Control air pollution Monitor relevant phenomena and processes in the atmosphere Recommend appropriate legal and institutional measures

Source: MIPR (1989).

In the context of organizational structures, it is interesting to note the conclusions of a report submitted to PWD (1987a) that the present solid waste administration system in Brunei Darussalam "is fragmented, which has created inefficiencies and inadequacies in the management of solid waste collection and disposal...there is no formal coordination function" (see also PWD 1986b). The same can be said about other areas of environmental concern, such as the disposal of toxic wastes, monitoring of environmental pollutants and management of the coastal zone.

Legal Framework

Brunei Darussalam's long association with Great Britain explains much of the former's legal system, which is based on English common law. Like the laws of England, Brunei Darussalam's laws tend to be brief and general. They provide broad grants of relatively unconstrained authority to ministries and departments, reflecting a trust in the administrators' exercise of discretion. The Land Code offers a pertinent example. After listing areas in which His Majesty in Council (HMIC) may issue rules governing the use of state land, the code further provides for the issuance of rules for "all other purposes whether similar or not" to the ones already specified (Land Code, section 31[2] [x]). The Water Supply Act likewise provides for the promulgation of regulations for "all such matters not herein before specifically mentioned as may conclude to the better and more effective carrying out of this Act" (section 48[1] [y]). Used creatively and effectively, such open-ended grants of authority can be used to respond to problems not anticipated at the time the law was adopted, as long as an applicable law is available. Nearly all of Brunei Darussalam's laws are a vestige of the era when the country was a British protectorate. Few laws have been revised substantively since its independence in 1984; most are at least 20 to 30 years old. Consequently, much of the legal code predates current interest in environmental protection, and some areas of concern are without applicable laws or legally authorized rules or regulations.

Ideally, a single law would provide authority to manage coastal resources in a comprehensive manner. No such law exists, so it is necessary to consider many laws that potentially affect the management of Brunei Darussalam's coastal resources. The discussion below examines several areas of environmental law, ranging from land use and sand mining to water quality and pesticide control. Specifically, the following questions are addressed: Do existing laws provide adequate legal authority to achieve the goals likely to be included in Brunei Darussalam's CRM plan? Is existing legal authority exercised to the extent necessary to protect coastal resources? To the extent determinable, does enforcement of these laws and their associated regulations provide an acceptable level of environmental quality and CRM?

Laws affecting the landward portion of the coastal zone

Several significant laws are related to land control. The most noteworthy is the Land Code, which is important in understanding land use in the country. The code declares, with a few minor exceptions, that all "forest, waste, unoccupied or uncultivated land shall be presumed...to be state land and all cultivated lands...abandoned or suffered to lie waste shall be deemed to be forest or wasteland...."(section 4). The code authorizes land alienation for any purpose consistent with the Land Code. For land that has been alienated or turned over to private use, the code authorizes the government to exercise eminent domain for public purposes. The code also provides authority to establish reserves. In short, it provides sufficient legal authority to accomplish all but the most unusual facets of land use in the landward portion of the coastal zone.

Although the Land Code is the most relevant statute, its use has focused on ownership, registration and alienation of land rather than on how land is used or managed. Pertinent to the coastal zone, the code specifically reserves to the government a belt of land 50 yd (45.7 m) wide "along the banks of all navigable rivers, streams and creeks and along the seashore above high water marks" (section 12). The presumption is that this land is of such importance that government ownership is vital to ensure proper protection or use in the public's interest. Despite the opportunities this provision provides, LD does not rely on or use the provision in any substantive way. The 50-yd belt is no longer applicable because portions of it are already highly developed, with Kg. Ayer providing the best example. It is also difficult to determine where the belt begins. Does one measure from the edge or middle of a river, and if from the former, during high or low tide?

In contrast to the Land Code, the purpose of the Town and Country Planning (Development Control) Act (TCPA) is to plan for and control development. This control is effected through the designation of development control areas (DCAs), the (discretionary) preparation of development planning schemes, and their enforcement and oversight by competent authorities that the Minister of Development appoints. Once a

Table 5. Current DCAs in Brunei Darussalam.

Area	Date of designation
Jalan Gadong (Main Road DCA 1)	26 October 1974
Jalan Berakas (Main Road DCA 2)	-do-
Jalan Kota Batu (Main Road DCA 3)	-do-
Jalan Seria (Main Road DCA 4)	-do-
Jalan Tutong (Main Road DCA 5)	-do-
Jalan Tutong (Main Road DCA 6)	22 July 1976
Jalan Gadong (Main Road DCA 7)	-do-
Jalan Muara (Main Road DCA 8)	18 April 1987
Muara DCA	12 April 1975
Subok DCA	7 June 1975
Jerudong DCA	December 1978

DCA is established, nearly all development, construction or demolition within the land area is subject to prior written consent of the appropriate competent authority. The Minister is also authorized to make regulations necessary for the act's implementation. These regulations can be used to preserve trees, forests and woodlands (First Schedule, section 6) or to maintain land and gardens (First Schedule, section 8). Most DCAs (Table 5) involve main roads. No development occurs on the roads themselves, so DOTCP has extended these DCAs to include 500 yd (457 m) on either side of the road's center lines. As shown in Fig. 1, this areal definition includes much of the coastal zone, including the shoreline. The act seems to anticipate the need to regulate development adjacent to the seashore because it defines land to include "land covered by water" (section 2). At present, however, DOTCP restricts its jurisdiction over DCAs to dry land only, thus excluding beaches and riverbeds.

In the mid-1980s, DOTCP hired a consulting firm to prepare a comprehensive master plan for the entire country. This effort led to the publication of nearly 20 volumes on Brunei Darussalam's development, including a four-volume report on wildlife conservation and management (DOTCP 1986), and shorter reports on related topics, such as fisheries and aquaculture. The master plan, completed in late 1987, contains specific recommendations for several existing DCAs, including those of Muara and Jerudong (DOTCP 1987).

The plan suffers from at least two problems. The first is administrative. Although published several years ago, its recommendations had to be held in abeyance pending formal approval from MOD authorities. The plan was not initially available to the public, but it was to all government departments for reference purposes. The second problem is substantive. The plan gives some attention to mangroves, fishing and aquaculture, but has a land-based focus. Little detail or explicit attention is given to coastal resources.

The fact that TCPA does not apply to the government is another cause for concern (as expressed in the master plan) because the government plays a significant role in the country's development. (Moreover, the act exempts from development controls "the use of any land and associated buildings for the purpose of agriculture or forestry" [Second Schedule, section (e)]). Under the Fifth NDP, the government authorized expenditures of over B$4.1 billion between January 1986 and December 1989. The size of many government projects suggests that their environmental effects will be far more significant than those associated with typical privately financed development. Orderly development is always a desirable goal, so there may be no reason to grant a blanket exemption to all government projects even before one knows what they are, their location or possible environmental effects. As the master plan concludes (DOTCP 1987), to "ensure consistency of approach and the appropriate direction of resources, such development by Government should be subject to control."

The plan further recommends that the entire country be designated as a DCA. This would mean a unified system to ensure coordinated control of private development throughout the country rather than in the few existing DCAs. For much of the country, such a designation would have few noteworthy consequences. Elsewhere, the impacts could be significant, such as in Bandar Seri Begawan where development is not subject to the jurisdiction of DOTCP but under that of its MB and related statute, the Municipal Boards Act, gazetted in 1920. The act authorizes MBs to pass by-laws "not inconsistent with the provisions of the Act" (section 5) and to take all lawful measures "connected with the conservancy and the improvement of the area subject to its control" (section 4 [q]). Bandar's MB is reviewing its outdated by-laws approved in 1921. This can provide an opportunity to incorporate concern for the coastal zone. Changing the Municipal Boards Act to impose some form of control over government projects in municipal areas might also be considered.

Another area of potential duplication involves the Ports Act, which states that any area of Brunei Darussalam can be declared a port (section 2[1]). The act grants to the controller of ports "control and management of all land and buildings of the government situated in the land area of the port" (section 10[1]) unless such land and buildings are exempted from this control and management (section 10[2]). He is also authorized "to promote the use, improvement and development" of the port (section 7[b]) and to "carry on such activities" as are "advantageous, necessary or convenient for him ...[in] the discharge of his duties" (section 8). A potential conflict exists because part of the Muara DCA

occupies the port of Muara (see Fig. 1). Consequently, separate laws and departments simultaneously govern development in the coastal area around Muara. Fortunately, anticipated conflicts are minimized because the controller of ports is a member of the competent authority for the Muara DCA.

Brief mention should be made about enforcement of development controls in DCAs. According to DOTCP (1987), the real or perceived shortage of a free property market and the cumbersome approval process for construction activities encourage illegal development. Whatever the cause, DOTCP believes that there is a large number of commercial and industrial violations, albeit minor, particularly in the Muara and Jalan Tutong DCAs. The department notifies the violator with the expectation that the violation will be corrected. Otherwise, after several notifications, water and electricity services are disconnected. This usually results in compliance. In some instances, more severe penalties are desirable, and legal sanctions are sought through MOL.

Illegal activities within reserved forests are much less of a problem. These forests constitute a fair portion of the country's coastal zone, and any land in Brunei Darussalam can be designated as a reserved forest (Forest Act, section 4). Except as approved by HMIC, the Forest Act prohibits: (1) granting rights "of any description in or over a reserved forest or any part thereof (section 16) and (2) any person, unless specifically permitted, to "fell, cut, ring, mark, lop or tap any tree or injure by fire or otherwise or remove any tree or timber" in a reserved forest (section 19[b]) and "clear or break up any land for cultivation or any other purpose" in a reserved forest (section 19[e]).

The act and FD's implementation of it appear to be quite successful in protecting timber resources, including the 212,000-ha mangroves within reserved forests.

Some cutting of full-sized mangroves for pilings and production of charcoal is allowed, but overall environmental impact is slight, at least when compared to that in Brunei Darussalam's neighbors in Southeast Asia. The present cutting rate of other timber in reserved areas is about 140,000-180,000 m^3/year, but FD believes that such levels are no longer sustainable. Consequently, the department intends to reduce logging in the reserves by 50% within the next year and eliminate it entirely within the next five to ten years. Moreover, the department plans to replant many areas adjacent to the coast where excess cutting has occurred.

Laws related to sand mining

Sand, a vital component of concrete, is often necessary for drainage projects. Despite sand's utility, its mining in Brunei Darussalam is a cause of significant coastal erosion (DOTCP 1986; PWD 1986a; Chua et al. 1987). Depending upon the miner and the location of the sand, its removal is under the control of: LD (through the Land Code), for private contractors on alienated, state-owned or leased land; MD (through the Ports Act), for offshore mining and port areas; FD (through the Forest Act), for forest reserves; PWD, for

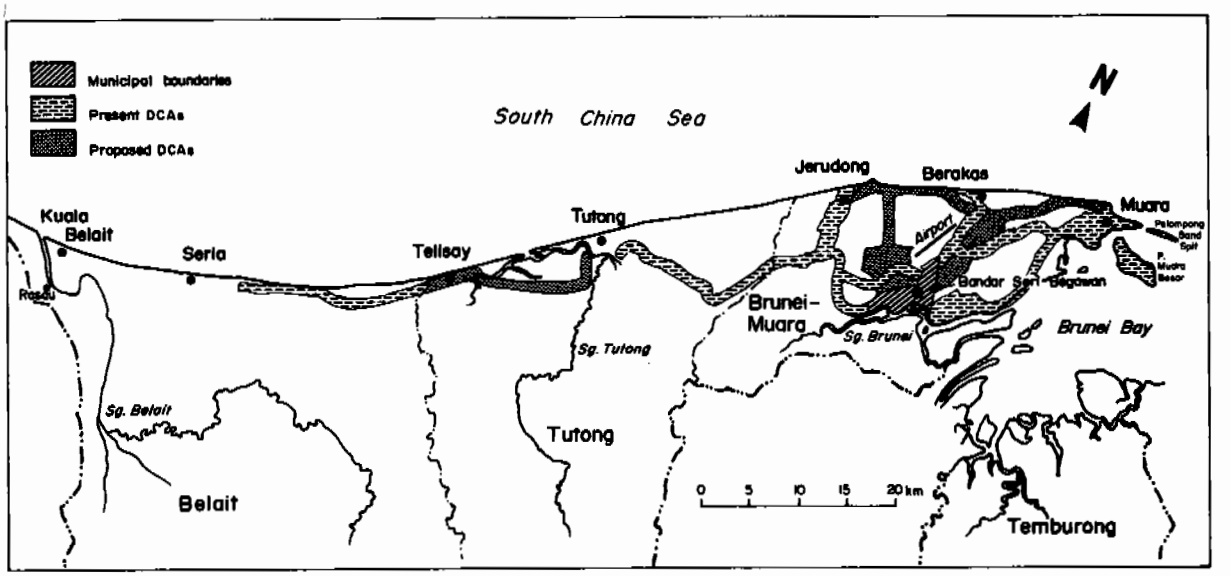

Fig. 1. DCAs designated under TCPA (DOTCP 1987).

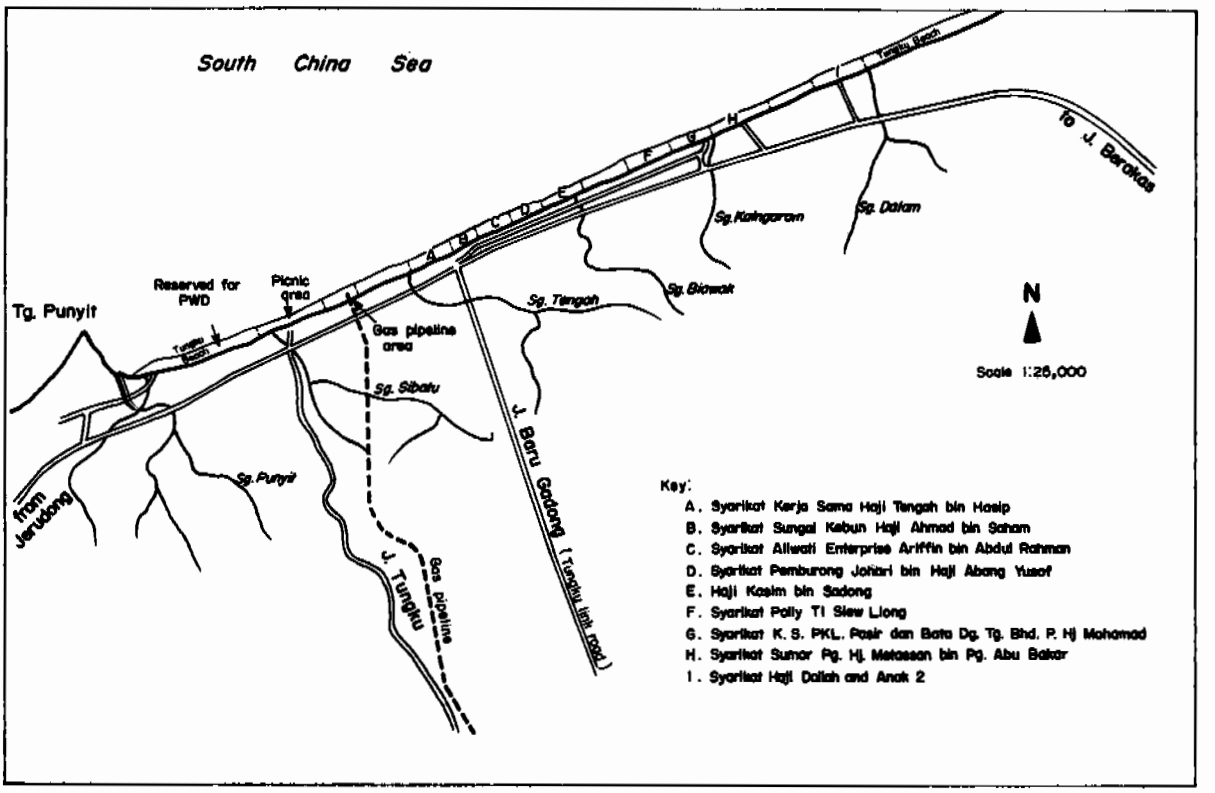

Fig. 2. Sand mining concessions, Tungku Beach. The letters A to I denote companies with permits to mine beach sand as of July 1989 (Unpublished records).

government projects in which the government is actually doing the work; and PU, which allows BSP to remove sand from the latter's scheduled lands. (Appendix 1 summarizes the applicable statutory provisions covering sand mining.)

Among these government agencies, LD is the most active. Through MOD, LD leases portions of Tungku Beach, northeast of Tanjong (or Tg., i.e., cape) Punyit, to nine private companies (Fig. 2). These companies are allowed to mine sand within a specified area and sell it to building contractors or others who need sand, including PWD.

To acquire sand from one of these nine companies, a contractor must first reach an agreement with the company regarding the cost and amount of sand needed. With this information, the contractor submits an application to LD to ensure that the appropriate royalty is paid (B$0.50/yd^3 or B$0.65/m^3). A total of 71,795 m^3 of sand or about 3,989 m^3 per month was mined from Tungku Beach between 1 January 1988 and 30 June 1989.

The PWD is responsible for some government construction or rehabilitation projects (not involving private contractors). A government body, PWD also has a specified area (east of Tg. Punyit) where sand can be mined with no need for prior approval from any agency. Even with this authority, however, the department depends on private contractors to provide most of the sand it uses.

The MD is authorized to grant permission for the commercial removal of sand from "the marine area of a port." However, no sand is currently removed (at least legally) for commercial reasons from any port area. The department issues relatively few permits for offshore mining of sand, usually only 500-1,000 m^3 per permit, most of which occurs near Muara, east of Pelompong Spit, about 1.6-3.2 km offshore (see Fig. 1). The application process is similar to that in LD.

Though FD has authority to grant licenses to remove sea, river and shell sand from reserved forests, no licenses are at present issued. Finally, in the current "Onshore Agreement" with BSP, the government allows BSP to remove sand, free of charge, from the scheduled lands (i.e., the land to which BSP has a concession to search or drill for oil).

No sand should be mined without consideration of environmental consequences. The Land Code provides authority to "make and publish rules" regarding sand mining, but current procedures do not require any assessment of its impacts on the coastal environment. Moreover, LD does not appear to have any policy governing environmental effects of sand mining, and no

unit or officer within the department has responsibility for environmental management. The present practice of depending on sand mining companies to minimize the adverse environmental impacts of their activities should be revised. It is doubtful that the nine companies mining sand at Tungku Beach are aware of this expectation or even capable of assessing the environmental consequences of their activities; even if they are, the incentives are not compelling. The LD has indicated that requests for alternative sites are not likely to be granted to the companies. Thus, a company that wants to maximize its profits must mine regardless of the environmental consequences. Severe erosion is quite evident along much of Tungku Beach, thus diminishing the utility and attractiveness of the picnic area at Pantai Tungku.

The opportunities for illegal sand mining along the coast are high. Unless full-time inspectors are available, LD cannot guarantee that royalties are paid on sand that is removed or even that the companies are mining in their designated locations. During the site visit for this study, for example, a private contractor at Tungku Beach was operating illegally in the area reserved for PWD.

In contrast to LD, MD gives some attention to the effects of offshore mining, but again, not through formal rules, regulations or requirements that contractors operate in an environmentally safe manner. When an applicant requests a permit, MD attempts to assess the suitability of the proposed site. It is relatively easy for the department to detect illegal sand mining in the area under its jurisdiction. As a result, illegal mining in offshore areas does not seem to be a problem.

Should Brunei Darussalam wish to consider development and implementation of regulations covering sand mining, it could benefit from recent research and recommendations associated with Malaysia's Coastal Resources Management Program for South Johore. The purposes for which sand will be used might also be taken into account. Beach sand is now used for both concreting and drainage. The lower quality offshore sand, which contains many shells, might meet the latter need just as effectively with far fewer detrimental effects on coastal erosion. Finally, LD may wish to end all mining of sand within the littoral drift zone, recommended several years ago (PWD 1986a). A suitable alternative site for concreting sand is available in the Tunggulian/Sungai Paku area, west of Telisay at the boundary of Tutong and Belait Districts (see Fig. 1). Although present coastal resources may be readily available for exploitation, long-term costs for remedial measures will be far greater than the present short-term benefits.

The need for action is evident, especially in view of anticipated private and public construction projects, which will impose a considerable, long-term need for sand. It was estimated that approximately 3.8-11.5 million m^3 of sand would be needed between 1978 and 2001 just in the Belait District (Townson and de Nes 1978). In a drainage project now underway at Brunei Darussalam's international airport, demand for sand is anticipated to be about 876,000 m^3.

Laws related to water quality

Several studies have recommended the adoption of new water quality legislation (PWD 1987a; 1987b). Although some specialized laws might be necessary, Brunei Darussalam already has at least ten separate laws that relate to water quality and pollution, namely, Water Supply Act, Land Code, Ports Act, Municipal Boards Act, Minor Offences Act, Fisheries Act, Forest Act, Mining Act, Petroleum Mining Act and Penal Code. (Appendix 2 summarizes relevant portions of these laws.)

Among the ten laws, all but the Penal Code and the Minor Offences Act provide administrators with authority to issue rules or regulations governing water quality. The Fisheries Act, for example, authorizes the minister "to regulate or prohibit the deposit or discharge of any solid or liquid substance into the water" (section 5[1]). Likewise, the Land Code reserves to the government "the right to control all watercourses for irrigation, navigation and mining or industrial purposes and for all purposes of general utility" (section 9[2][d]). To achieve this control, HMIC is permitted "to make...rules not inconsistent with the general purposes of this Code" (section 31[1]). These and similar authorizations in the other laws offer the legal tools necessary to combat most forms of water pollution in Brunei Darussalam.

However numerous the opportunities are, these laws have yet to be used effectively. Table 6 summarizes the rule-making authority granted in eight separate acts and reveals that under only one (the Municipal Boards Act) has this authority been used. The MB for Bandar Seri Begawan issued by-laws in 1921. The relevant sections prohibit the: (1) construction of cesspools within the municipal area (section 55); (2) deposit of "any earth or materials of any description or any offensive matter of any kind into or upon any street, sewer, or drain" (section 146); and (3) discharge "into or along any drain, sewer, river or stream any night soil or excrementitious matter" (section 152). These three dated sections apply only to Bandar's 13 km^2 as opposed to the country's 5,699-km^2 land area and 48,000 km^2 of

Table 6. Rulemaking authority for control of water pollution in Brunei Darussalam.

Act	Authority given to:	Section	Instrument	Authority used?
Land Code	HMIC[a]	31	Rules	No
Forest	-do-	52	Rules	No
Mining	-do-	23	Rules	No
Ports	-do-	22	Regulations	No
Water Supply	-do-	48	Regulations	No
Municipal Boards	MB	5	By-laws	Yes
Fisheries	Minister	5	Regulations	No
Petroleum Mining	Minister	*	Instructions	No

[a]Sections 47(3) and 49 of the Second Schedule (for Onshore State Lands) and sections 32(3) and 34 of the Third Schedule (for Offshore Lands) provide authorization to issue instructions applicable to water pollution.

offshore waters lacking administrative rules or regulations for water quality. Thus, most of Brunei Darussalam does not have any legally enforceable effluent or water quality standards.

The absence of such standards does not mean that a person or company can pollute without legal sanction, but the many laws (and their lack of administrative rules) can create legal and administrative uncertainty. Consider the possible legal ramifications of an accidental oil spill in an offshore area. If prosecution was deemed appropriate, MOL would potentially have to choose among the Petroleum Mining Act, Ports Act, Mining Act, Fisheries Act, Penal Code and Minor Offences Act. If the spill involved a pipeline, the Petroleum (Pipelines) Act would also be relevant.

In another situation, a fisherman who dumped a small amount of poison in a river passing through a reserved forest could be charged under the Land Code, Fisheries Act, Forest Act, Penal Code, Minor Offences Act or Water Supply Act (if the river is also a catchment area). Depending on the act used to prosecute, the polluter could be fined as little as B$1,000 or as much as B$3,000 upon conviction. If the Penal Code was the basis of prosecution, the person could also be subjected to six months' imprisonment with hard labor.

Under the current legal regime that operates without administrative rules or regulations, the government would find it difficult to prosecute someone disposing of toxic or hazardous wastes on alienated land, and nonpoint as opposed to point sources of water pollution. Moreover, having so many laws produces doubts about which ministry or department can or should take the lead in protecting Brunei Darussalam's waters. There may be reluctance to propose water quality regulations because they might conflict with informal standards that other departments apply, or encroach upon another's area of responsibility.

Some departments, such as Fisheries, informally impose water quality standards on new businesses or industrial sources that cannot be enforced (and almost no monitoring of effluents occurs). In contrast, existing industrial sources of water pollution, although few, can operate without regard for the pollution they create. Moreover, as is the case with the landward portion of the coastal zone, governmental activities that cause or contribute to water pollution are exempted from compliance. Privately owned vessels are prohibited from discharging "any oil, oily substance or oily liquid into the waters of Brunei" without written permission (Ports Act, section 25). This prohibition does not apply to "any vessel in the service of His Majesty" (Ports Act, section 72), and consequently, some of these vessels may be the most egregious sources of water pollution. Respondents cited many instances in which government departments negligently contribute to water pollution at onshore sites.

All these examples reveal important gaps in many areas of water pollution control in Brunei Darussalam. As an illustration, BSP is not required to inform the government of oil spills, and it occasionally disposes of chemicals at sea. No government department monitors this disposal process or is aware of the location of the dumping. Also, the Electrical Services Department is trying to sell 10-20 defective electric transformers as scrap metal, but they contain toxic polychlorinated biphenyls (PCBs) which should be disposed of properly. Scrap metal dealers are unlikely to know about the dangers of PCBs. Without disposal rules, these chemicals could enter Brunei Darussalam's waters or sewage treatment system.

In the absence of any recovery program or regulations governing disposal, most waste oil from motor vehicles is probably dumped into sewers or storm drains. This problem could be easily addressed if

existing oil-related expertise and facilities are tapped. The BSP could be approached to organize and implement a public service program on the collection and disposal of waste oil.

The Petroleum Mining Act requires oil companies to comply with government instructions to prevent water pollution of the shoreline and coastal areas (section 32[3]). To date, however, no government guideline on environmental management has been provided. In the event of an offshore oil spill, the decision to use chemical dispersants rests solely with BSP. Such dispersants can affect aquatic resources, so it is desirable to have government guidelines indicating the circumstances and locations in which dispersants could be used. The BSP has an oil spill contingency plan, but no government agency has formally appraised its suitability or responsiveness to environmentally sensitive areas, such as fishing grounds or mangrove swamps.

No contingency plan can foresee all the problems associated with a spill, and each incident provides lessons to be incorporated into revised plans. The 1989 blowout at Rasau in western Brunei Darussalam (see Fig. 1) indicates the need to amend the existing plan, last revised in January 1988. Some government officers seemingly assume that BSP can and will handle all oil spills, even those not of its own making, without difficulty and assistance from the government. This is an unreasonable expectation, but it underscores the need for the government to develop its own oil spill contingency plans.

An opportunity for improved communication between BSP and the government now exists. All BSP's contacts with government officials, and vice versa, including those involving environmental matters, are required to go through PU. This arrangement may have some administrative appeal, but it can also frustrate effective protection of the environment. No one at PU has responsibility for environmental oversight of the country's petroleum operations, nor has it issued any environmental guidelines.

The lack of environmental expertise in PU is a cause of potential concern not only for BSP but also for other government units. The BSP prefers much greater contact with government officials and departments not only in planning responses to possible oil spills but in other areas of environmental concern as well. Meanwhile, some government officers commented on the difficulty in getting environmentally related information from the company. To develop a more efficient way of communication, BSP and government departments could be allowed to contact each other directly, with copies of all correspondence provided to PU. Should major decisions be required, representatives from PU could be involved at appropriate stages.

Laws related to pesticide use

Agriculture's contribution to the economy is relatively small, and the country imports much of its food. The latter may be disadvantageous from an economic perspective, but as a result, Brunei Darussalam is far less dependent on agrochemicals than it otherwise might be. However, it does not mean that concern about the use of agrochemicals is unwarranted, especially because these include rodenticides, insecticides and other substances unrelated to agricultural production. All these chemicals can affect water quality, and marine and aquatic organisms.

The Poisons Act governs the use of pesticides and serves to prevent the misuse of poisons by regulating their import and sale. The MOH's director of medical services has legal responsibility for implementing the act. It contains a two-part "Poisons List," the first covering pharmaceutical drugs and the second, pesticides, herbicides and other agrochemicals. The Poisons List can be revised any time and published in the Gazette.

In order to import or sell any substance on the Poisons List, it is necessary (with exceptions noted below) to apply for a license from the Office of Medical Services (OMS). The act lists some conditions under which poisons can be sold (Appendix 3). A license can also include "such special conditions and limitations as the Licensing Officer may think fit" (section 10[21]). The act also provides authority to make rules governing "the importation, use and control of poisons, and any precautionary measures relating thereto" (section 21[a]). Though such rules have been issued, typical licensing conditions for importation and sale of pesticides include requirements that: (1) the chemicals not be stored with food items; (2) any prepacked chemicals be labeled clearly to avoid mistaking their contents for another item; (3) users be informed of correct usage, application, dilution and disposal of chemicals; and (4) approval prior to importation be given by AD.

The Poisons Act is comprehensive and appears to provide sufficient authority to ensure proper use of agrochemicals. Nonetheless, the act's implementation may not be as effective as its authors had hoped or expected. First, Part II of the Poisons List has not been updated in several years, and some pesticides should be included. The World Health Organization (WHO) classifies coumaphos, disulfoton, flocoumafen, brodifacoum, chlorfenvinphos and phosphamidon as "extremely hazardous." Despite this classification, none of these pesticides is included on the Poisons List, but all were in use or available in Brunei Darussalam in May 1989, according to records of AD. Other pesticides that WHO classifies as "highly hazardous" or "moderately hazardous" are likewise absent from the Poisons List. From a legal perspective, these unlisted

pesticides can be imported, sold and used without restriction. From a practical perspective, OMS is able to exercise informal controls over the sale of these hazardous pesticides because most importers are willing to request a license for all their imports, regardless of whether these are on the Poisons List. Nevertheless, illegal imports of pesticides are of potential concern.

Second, appearance on the Poisons List seems to justify granting licenses to import and sell certain pesticides. Some chemicals are highly efficacious--they eradicate the unwanted pests, ants or termites--but they have far more undesirable side effects in terms of their persistence, acute toxicity or carcinogenic potential. Because some pesticides used in Brunei Darussalam are potentially dangerous to humans, PWD (1987c) recommends that their import or use under any circumstances be made illegal. The report further proposes a "black list" of at least seven pesticides not approved for use in many countries (Table 7). Among the seven pesticides, the two most frequently imported are paraquat and dieldrin, which amounted to approximately 35,000 and 700 l, respectively, in 1988. Although relatively small amounts of dieldrin are in use, its potential impacts should not be underestimated. When the European Economic Community (EEC) considered which of nearly 100 dangerous substances discharged into the aquatic environment should be on ECC's black list, the Community's Environment Group recommended that priority attention be given to dieldrin, aldrin and endrin. Concluding that the use of aldrin and dieldrin poses "unreasonable human health risks," the United States Environmental Protection Agency (USEPA) banned their production in 1974. The continued use of the pesticides may reflect commercial rather than practical justification. Except for 2, 4, 5-T, alternative and less hazardous pesticides are available as substitutes.

Third, the present Poisons Act is not all inclusive in its coverage of pesticide users. It grants exemptions to any rules made under the act to: "the sale of poisons for use by or on behalf of a Government Department...for the purpose of public service" (section 8[e]); and "the sale of poisons to a person or institution concerned with scientific research...for the purpose of education or research" (section 8[f]). The effect of these subsections is to allow government departments to import and use pesticides without licenses and prior approval or knowledge of AD or the director of medical services. Some government departments bypass licensed importers, choosing to deal directly with foreign wholesalers or manufacturers. As one respondent noted, the government's use of pesticides is "the most difficult to control." Other departments lack the expertise of, for example, the departments of Forestry and Agriculture, and may use inappropriate pesticides or proper ones incorrectly. There is no compelling reason to exempt sellers or pesticide applicators, including government departments, from regulations designed to protect the environment or the public's health.

Table 7. Status of pesticides recommended for blacklisting.[a]

Pesticide	On Poisons List?	Available in Brunei Darussalam?	Substitute available?
Aldrin	Yes	Yes	Yes
Dieldrin	Yes	Yes	Yes
Endrin	Yes	No	Yes
Lindane (gamma BHC)	Yes	Yes	Yes
Parathion	No	No	Yes
Paraquat	Yes	Yes	Yes
2,4,5-T	Yes	Yes(?)	No

[a]The recommendation that the seven pesticides be banned from use and importation is included in PWD (1987c).

How well the environment and its coastal resources are now protected from misuse of pesticides is problematic. The AD tests for pesticide residues only in vegetables. Tests conducted in early 1988 found excessive residues, but such are now more frequently within acceptable limits, at least for those which AD is capable of measuring, such as methomyl, carbofuran, carbaryl and dithiocarbonates. In contrast, the department does not have the capability to test for chlorinated hydrocarbons like dichloro-diphenyl-trichloro-ethane (DDT), dieldrin, chlordane or endosulfin. This is unfortunate because hydrocarbons decompose slowly and can remain in the environment for a long time. There is also a need to test for pesticide residues in water, fish and other marine organisms. The PWD plans to begin testing for residues in water samples after it has developed its capability to monitor heavy metals.

At least some of the problems noted are being addressed. The AD established a Pesticide Assessment Committee (PAC) in early 1989 to screen applications for licenses to import agrochemicals (forwarded for review by the director of medical services) and to assess the competence of sellers. The committee has recommended that some sellers not be allowed to import certain pesticides, so licenses are unlikely to be issued to these sellers. To date, no applications to import pesticides have ever been denied, revoked, nor requests for renewal of these annual licenses rejected.

In an effort to rationalize the use of pesticides, PAC has also compiled an informal list acceptable for specified uses within Brunei Darussalam, which includes: 2,4-D, benomyl, captan, carbaryl, carbendazim, carbofuran, copper oxychloride, edifenphos, glyphosate, lindane, malathion, metaldehyde, methamidophos, methomyl, paraquat and phosphamidon. These 16 pesticides represent only 15% of all pesticides available in

the country in 1989. Note that two of these, lindane and paraquat, are among the seven pesticides recommended to be completely banned by PWD (1987c). Another, phosphamidon, is one of the pesticides that WHO classifies as "extremely hazardous."

Even with the formation of PAC, no government agency or department now has legal authority to ban the import or sale of pesticides not on the Poisons List. The ability to restrict pesticides already on the list is likewise limited. Two listed substances, DDT and 2,4,5-T, are no longer officially available to the public, only because AD was able to convince sellers to halt further imports. The AD collected the remaining supplies of 2,4,5-T (which contains dioxin and is one of the deadliest substances known) and is considering ways of disposal. Despite this effort, several respondents outside the department believe that both DDT and 2,4,5-T are still in use.

Pesticide vendors are supposed to inform users about correct usage, application and disposal, but often, these requirements are not enforced. There are no formal or required training programs for pesticide applicators. Exterminators need not be certified, nor demonstrate competence or familiarity with the chemicals they apply. No rules or guidelines cover the disposal of excess pesticides or their containers.

Ready availability of pesticides and lack of required training for exterminators may mean that some pesticides are used inappropriately or applied excessively. Further, exterminators and others can be exposed to hazardous fumes, and agricultural runoff can contaminate water supplies or fisheries resources. Indeed, AD has received reports that one pesticide, permethrin, is intentionally dumped in rivers to kill fish, and that methomyl is used to kill monkeys illegally.

The AD and the director of medical services asked WHO for assistance in drafting a comprehensive law covering both agro- and industrial chemicals. The PWD's (1987c) proposed draft legislation covering pesticides may overlap WHO's recommendations, but it is unclear whether those responsible for monitoring pesticide use have had access to the former. Appropriate representatives from MOH, AD and MOL cannot recall having seen the report or being informed of its recommendations. This provides another example of the fragmented decisionmaking that characterizes environmental management in Brunei Darussalam.

Recommendations

One should always be hesitant about recommending changes in long-standing legal and institutional arrangements. Regardless of what it is, a reason exists for the current structure. Moreover, calls for reorganization often encounter either polite neglect or stiff resistance. These concerns have not deterred others from making recommendations about how Brunei Darussalam ought to change its laws or organizational structure affecting environmental quality, though many of these recommendations are yet to be implemented.

In some respects, the lack of legal change may be fortuitous. As this report has suggested, the existing legal framework may already be adequate to manage most current and potential environmental problems. The drafting and approval of new laws can be a cumbersome process, and, with a shortage of legal expertise, unnecessarily burdensome and time-consuming. New laws may be necessary in selected areas, but more effective use of existing laws and of the discretionary authority these laws provide to various departments is far more desirable.

There is a growing recognition that current practices in dealing with environmental matters are not as effective as they could be and, at times, frustrate the quest for both acceptable levels of environmental quality and sustainable development. This recognition is likely to increase as Brunei Darussalam diversifies its economy. The country is already facing environmental problems with which it has little experience, like the disposal of asbestos and hazardous wastes. How well the government is organized to deal with these environmental issues depends on its capacity to respond to them. Improved coordination among government departments is essential: its absence is a factor that diminishes the efficient use of human and natural resources.

Possible solutions towards effective coordination are legion, but one frequently mentioned involves the creation of a new unit or department to coordinate major environmental issues in Brunei Darussalam. Considerable thought has already been given to this idea. In early 1989, EPU, which has lead responsibility for developing each NDP, submitted a report on "Environmental Protection and Development Planning" to the National Development Committee. The report summarizes the state of Brunei Darussalam's environmental quality and recommends the creation of a comprehensive environmental agency with effective regulatory authority and legal powers beyond those currently available. Most government officers are highly supportive of the idea, acknowledging its necessity.

Such an environmental body would cure many ills, but creating it would mean significant change, to which many organizations are adverse. Rather than instituting the change immediately (and in view of personnel shortages that typify government service), it may be useful to work in graduated steps, which could include the following:

1. The preparation of a national policy for environmental protection for His Majesty's approval - this need not be a lengthy document, but should place Brunei Darussalam's goals for economic diversification in the context of acceptable levels of environmental quality.
2. An assessment of each department's capacity to monitor different environmental pollutants and a division of responsibility among these departments - the monitoring capacity of appropriate units should then be strengthened to address areas not receiving adequate attention.
3. A survey of existing environmental expertise within the government and identification of skills to be developed - these skills should be related to the kinds of coastal or environmental problems that can reasonably be foreseen, such as oil spills and the disposal of hazardous wastes.
4. The creation of a clearinghouse through which all ministries, departments and committees would be informed of pertinent, ongoing and completed investigations by consultants or other departments.
5. The convening by PMO of relevant ministries and departments to discuss jurisdictional responsibilities for water quality, disposal of hazardous wastes and CRM, and the designation of a lead agency for each area - the experience of DOF suggests its appropriateness as a lead agency for CRM while DOTCP may be well suited to develop and implement policies for the management and disposal of hazardous wastes.
6. The determination of a mechanism to ensure that government departments assume leadership in environmental protection.
7. The immediate designation of a single existing department or ministry to coordinate and monitor environmental activities and problems until a new agency is created.
8. Improved coordination and communication between government units and BSP regarding environmental issues - this presents another important opportunity for PMO (or PU) to foster better, mutually beneficial relations between the government and BSP, which has considerable experience and access to environmental experts worldwide.
9. The consideration of how multisectoral environmental projects can be incorporated into NDPs - the unisectoral approach to development is unsuitable for integrated CRM or environmental management.
10. The consideration of EIAs for major projects - in the past, such assessments would have been beneficial to sand mining, construction of the coastal highway and private developments that have generated increased vehicular traffic. Use of EIAs is widespread, and many countries find that both its economic and environmental benefits far exceed the associated costs.

The creation of a single environmental authority also raises questions about its institutional location. Environmental agencies that find themselves in a position where they must control or regulate the actions of other agencies or private firms need both effective political support and an independent base of authority to succeed. Buried deep in an existing department, a new environmental unit is likely to have only minimal influence, subject to superiors whose primary goals may not mesh well with concerns for environmental quality. In many governments, institutional location itself is a measure of power and influence. If the new agency is placed in a desirable location, perhaps within PMO, it will boost its chances for success and help ensure sustainable environmental development.

Brunei Darussalam prides itself of the quality of its environment. With a few exceptions, this pride is justified. It would be unfortunate, therefore, to allow this environment to deteriorate not because skills, resources or desire are wanting, but rather for lack of adequately utilized or effectively coordinated institutions.

References

Anon. 1988a. Brunei moves to end pollution. Borneo Bull. (November 5 issue).

Anon. 1988b. Water village to get clean-up. Borneo Bull. (October 7 issue).

Chua, T.-E., L.M. Chou and M.S.M. Sadorra, editors. 1987. The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. ICLARM Technical Reports 18, 193 p., Fisheries Department, Ministry of Development, Brunei Darussalam, and International Center for Living Aquatic Resources Management, Manila, Philippines.

DOTCP (Department of Town and Country Planning). 1986. Negara Brunei Darussalam Master Plan Special Report: Wildlife Conservation and Management. Department of Town and Country Planning, Brunei Darussalam.

DOTCP (Department of Town and Country Planning). 1987. Negara Brunei Darussalam Master Plan. Main Volume. Department of Town and Country Planning, Brunei Darussalam.

EPU (Economic Planning Unit). 1986. Fifth National Development Plan, 1986-1990. Economic Planning Unit, Ministry of Finance, Brunei Darussalam.

GBD (Government of Brunei Darussalam). 1989. Brunei Darussalam in profile. 2d ed. Shandwick, London.

MIPR (Ministry of Industry and Primary Resources). 1989. Policy guidelines on environmental management and related social services. Ministry of Industry and Primary Resources, Brunei Darussalam.

MOD (Ministry of Development). 1988. Committee on Tourism and Recreation: Draft Discussion Paper on Role Development. Ministry of Development, Brunei Darussalam.

MOL (Ministry of Law). 1986. The Emergency (Supply) (1986) Order, 1985. *In* Brunei Darussalam subsidiary legislation. Government Gazette. (January 25 issue).

PWD (Public Works Department). 1986a. Control of Beach Erosion Feasibility Study. Prepared by SPECS Sdn. Bhd. Public Works Department, Brunei Darussalam.

PWD (Public Works Department). 1986b. Kampong Ayer Waste Management Study. Final Report. Prepared by Scott and Furphy Consulting Group. Public Works Department, Brunei Darussalam.

PWD (Public Works Department). 1987a. Solid Waste Management Master Plan. Final Report. Prepared by Jurutera Tempatan in association with Engineering Science and Langdon Every and Seah. Public Works Department, Brunei Darussalam.

PWD (Public Works Department). 1987b. Sungai Brunei Water Quality and Pollution Study. Final Report. Public Works Department, Brunei Darussalam.

PWD (Public Works Department). 1987c. The prevention and control of water pollution in Negara Brunei Darussalam. Final Report. Prepared by Watson Hawksley Asia. Public Works Department, Brunei Darussalam.

Townson, W.G. and S.J.S. de Nes. 1978. A review of sand resources in the area between Kuala Belait and Lumut (Belait District), Brunei. A report prepared for Brunei Shell Petroleum Co., Seria, Brunei Darussalam. (Unpublished).

Appendix 1

Selected Legal Provisions Related to Sand Mining

Land Code (ch. 40):

- reserves to the Government "the right to remove earth, clay, sand, stone or any other material which may at any time be required for the roads, public buildings or other public purposes of Brunei without compensation save for actual damages to growing crops, fruit trees or buildings" (section 9[2][c]);
- authorizes HMIC to "make and publish rules" that may provide for: "licensing of persons to remove gravel, stone, coral, shell, rock, guano, sand or loam and of prescribing the payments to be made in respect thereof" (section 31[2][iv]);
- declares that "in the absence of any express provision to the contrary" the person who holds title to any [alienated] land "shall have no right to remove beyond the boundaries of the land specified [in the title] any of the articles enumerated" in the previous paragraph (section 9[3]);
- provides for "the fixing of penalties for breaches of any rules made" pursuant to section 31(2) (section 31[2][vii]).

Forest Act (ch. 46):

- defines forest produce to include "guano, peat, rock, sea sand, river sand, seashells, shell sand and surface soils" found in a reserved forest or State land (section 2[1][a]);
- authorizes HMIC to make rules to "regulate by licensing or otherwise the sale, purchase or storage of forest produce" (section 52[2][e]); "prohibit any dealings in specified kinds of forest produce and make it an offence to be found in possession thereof" (section 52[2][f]);
- states that no person shall, in a reserved forest, "search for, collect, subject to any manufacturing process or remove any forest produce or minerals" (section 19[d]) unless permitted to do so by a properly authorized forest officer (section 51[1][b]);
- states that "whoever commits an offence against the provisions" of section 19(d) "shall be guilty of an offence: penalty, a fine of $1,000 and imprisonment for 6 months" (section 26[1]);
- declares that "Any person found in possession of any forest produce for which royalty or other payment to the Government...has not been paid or made shall be guilty of an offence: penalty, a fine of $10,000 and imprisonment for 2 years" (section 27[1]).

Ports Act (ch. 144):

- "No person shall, without the permission of His Majesty in Council or a public officer authorized by His Majesty in Council...deposit in the marine area of a port, or remove or carry away therefore, any rock,

stone, shingle, gravel, sand, soil or other materials whatsoever" (section 31[1][b]);
- with the exception noted below, declares that violators of section 31(1) "shall be guilty of an offence: penalty, a fine of $5,000 and imprisonment for 6 months and liability to pay all reasonable expenses which may be incurred in repairing any injury caused by that person to any part of the marine area of a port" (section 31[4]);
- exempts from section 31(1) "any dredging operations or other works carried out by or on behalf of the Government (section 31[2]).

Appendix 2

Selected Legal Provisions Related to the Control of Water Pollution

Water Supply Act (ch. 121):
- defines "waterworks" to include all catchment areas, reservoirs and dams (section 2);
- declares that:
  1. "Any person who deposits or allows to be deposited any earth, material or liquid in such manner or place that it may be washed, fall or be carried into the waterworks, shall be guilty of an offence and shall, on conviction, be liable to a fine of $1,500" (section 30[1]);
  2. "If any earth, material or liquid is allowed to remain so deposited after the Water Authority has given notice in writing to such person...requiring such earth, material or liquid to be removed, or the continuing deposit of any such earth, material or liquid to cease, such person shall be liable to a further penalty of $300 for each day during which the offence continues" (section 30[2]);
  3. "Any person who washes or bathes in, or throws into any water, river, or stream forming part of the waterworks, or washes, throws or causes to enter therein any creature, dead or alive, or anything whatsoever, shall be guilty of an offence and shall, on conviction, be liable to a fine of $1,500" (section 30[3]); and
  4. neither (a)"any method of cultivation of lands which is in accordance with the principles of good husbandry" nor (b)"the reasonable use of oil or tar on any highway maintenance at public expense" shall be prohibited or restricted "so long as all reasonable steps are taken for preventing the pollution of any part or any water of the waterworks" (sections 30[4] and [b]);
- authorizes HMIC to make regulations for "preventing the misuse, waste, resale or contamination of water from the waterworks, including any river intakes connected therewith" (section 48[1][c]); and "the regulation, protection and control of the waterworks, including any river intakes connected therewith" (section 48[1][u]).

Land Code (ch. 40):
- states that every title to land "shall vest in the person named therein a surface right only to the land specified therein" (section 9[1]);
- reserves to the government "the right to control all watercourses for irrigation, navigation and mining or industrial purposes and for all purposes of general utility" (section 9[2][d]);
- authorizes HMIC "to make...rules not inconsistent with the general purposes of this Code" (section 31[1]).

Fisheries Act (ch. 61):
- defines Brunei's waters to include "all waters whether navigable or not within Brunei and that part of the seas adjacent to Brunei both within and outside territorial waters, within which citizens of Brunei have by international law the exclusive right of fishing" (section 2);
- authorizes the minister to make regulations "to regulate or prohibit the deposit or discharge of any solid or liquid substance into the water" (section 5[1]);
- declares that:
  1. "Any person who does or attempts to do an act contrary to, or fails to comply with, the provisions of this Act or any regulations made thereunder shall be guilty of an offence, if no special penalty is provided,

be liable to a fine of $2,500 and imprisonment for 1 year" (section 11[1]);

2. "Where an offence is continued after conviction or where an order made under this Act is not obeyed within the time required, there shall be payable by the offender for each day of the offence or failure to obey is continued, a fine of $50; and where such offence is continued for a period exceeding 10 days after conviction, the offender shall be liable to imprisonment for 6 months" (section 11[2]).

Forest Act (ch. 46):

- prohibits any person, unless specifically permitted, from poisoning water in a reserved forest (section 19[f]); for violations of this prohibition, imposes "a fine of $1,000 or in default of payment of such fine...imprisonment for 1 month" (section 26[iii]);
- authorizes HMIC to "make rules to carry out the objects and purposes of this Act" (section 52[1]); provides that for any breach of such rules the penalty shall be "a fine of $10,000 and imprisonment for 2 years" unless another penalty is expressly provided by the rule (section 28).

Ports Act (ch. 144):

- authorizes HMIC to "declare any area in Brunei and any navigable river or channel leading into such areas to be a port" (section 3[1]);
- authorizes HMIC to make "regulations for the maintenance, control and management of any port or approaches thereto "in respect to" keeping clean the basins; works and premises in a port and the water of the port and the approaches thereto and preventing oil, filth, rubbish or other things being thrown or entering therein or thereon" (section 22[1][u]);
- declares that "No person shall discharge any oil, oily substance or oily liquid into the waters of Brunei without the written permission of the Director [of MD] or such other person as may be authorized by His Majesty or without lawful excuse, and any person who so discharges the same or causes the same to be discharged and the owner and master of any vessel from which the same is discharged shall be guilty of an offence: penalty, a fine of $50,000 in addition to any expenses which are incurred by the Director in removing or procuring the removal of the same" (section 25);
- exempts from the provisions of the act any vessel in the service of His Majesty (section 72).

Mining Act (ch. 42):

- covers crude oil, petroleum, natural gas and minerals (e.g., coal, gold metals, ores, precious stones);
- authorizes HMIC to make rules "not inconsistent with the general purposes of this Act" to provide for:
  - "the due control of watercourses and the prevention of pollution thereto" (section 23[2][iv]);
  - "the precautions to be observed for the health, safety or convenience of the public...." (section 23[2][vi]);
  - "prescribing the fine with which the contravention of any rule made under this Act shall be punishable, but...shall not exceed $2,000" (section 23[2][xv]);
  - "any other matters whether similar or not to the above as to which rules may be necessary or desirable for enforcing the provisions of this Act" (section 23[2][xvi]).

Petroleum Mining Act (ch. 44):

- Second Schedule (Onshore State Lands) and Third Schedule (Offshore State Lands);
- requires petroleum mining companies to "take all steps practicable" in order:
  - "to control the flow and prevent the escape or waste of petroleum discovered in the Scheduled Lands" (Second Schedule, section 47[2][a]); (Third Schedule, section 32[2]);
  - "to prevent the pollution of any water-well, spring, stream, river, lake, reservoir, estuary or harbour and...the coastal waters and shoreline" (Second Schedule, section 47[2][d]); (Third Schedule, section 32[2][d]);
  - "to cause as little damage as possible to the surface of the Scheduled Lands and to the trees, crops, buildings, structures and other property thereon" (Second Schedule, section 47[2][e]);
- requires such companies to "use generally accepted standards of good petroleum-field operations for confining the petroleum obtained from the Scheduled Lands in tanks, gasholders, pipes, pipelines or other receptacles constructed for the purpose. No petroleum shall be put or enclosed in an earthen reser-

voir, except as a temporary measure during any emergency" (Second Schedule, section 48); (Third Schedule, section 33);
- requires such companies to "drain all waste oil, salt water and refuse from tanks, gasholders, boreholes and wells with proper receptacles....The company shall dispense of such waste oil, salt water and refuse in a manner from time to time approved by the Minister" (Second Schedule, section 49); (Third Schedule, section 34).

Municipal Boards Act (ch. 57):
- charges MB with responsibility for:
  - "sewers, drains, sewage treatment works, sanitary fitments, latrines and dustbins" (section 4[c][i]);
  - "the construction and maintenance of works for the treatment and/or conveyance of sewage; the laying of sewers and drains...; the maintenance and modification of sewers vested in the Municipal Board; the maintenance of lawful use of sewers...." (section 4[d]);
  - "all other matters, whether similar or not to those mentioned above, connected with the conservancy and the improvements of the area subject to its control" (section 4[q]);
- requires MB to pass by-laws as may from time to time be prescribed by HMIC "not inconsistent with the provisions of this Act or any other Act for the time being in force...and to prescribe penalties for breach thereof" (section 5);
- states that if a person contravenes any such by-law "for the breach of which no penalty is otherwise expressly provided...he shall be guilty of an offence: penalty, a fine of $3,000, or in the case of a continuing offence, a fine of $100 for every day during which said offence is continued" (section 7).

Minor Offences Act (ch. 30):
- declares in violation of the law any person who:
  - "places, deposits or throws any dust, dirt, paper, ashes, carcass, refuse, box, barrel, bale or other article or thing in any public place" (section 12[1][a]);
  - "keeps or leaves any article or thing whatsoever in any place where it or particles therefrom have passed or are likely to pass into any public place" (section 12[1][b]);
  - "throws, places, spills or scatters any blood, brine, swill, noxious liquid or other offensive or filthy matter of any kind in such manner as to run or fall into any public place" (section 12[1][c]);
  - "drops, spills or scatters any dirt, sand, earth, gravel, clay, loam, stone, grass, straw, shavings, sawdust, ashes, garden refuse, stable refuse, trade refuse, manure, garbage or any other thing or matter in any public place...." (section 12[1][d]);
- imposes, upon conviction of violation of one of these prohibitions, a fine of $1,000 for the first offence and a fine of $3,000 in the case of a second or subsequent conviction (section 12[1]).

Penal Code (ch. 22)
- declares as illegal any act or omission "which causes any common injury, danger or annoyance to the public or to the people in general who dwell or occupy property in the vicinity, or which must necessarily cause injury, obstruction, danger or annoyance to persons who may have occasion to use a public right" (section 268);
- requires punishment for whomever:
  - "unlawfully or negligently does any act which is, or which he knows or has reason to believe is likely to spread infection or any disease dangerous to life...." (section 269);
  - "voluntarily corrupts or fouls the water of any public spring or reservoir, so as to render it less fit for the purpose for which it is ordinarily used...." (section 277);
  - does "with any poisonous substance, any act in a manner so rash or negligent as to endanger human life, or to be likely to cause hurt or injury to any person, or knowingly or negligently omits to take such order with any poisonous substance in his possession as is sufficient to guard against probable danger to human life from such poisonous substance...." (section 284);
- establishes the punishment for violation:
  - of section 269 to include simple imprisonment or rigorous imprisonment with hard labour for up to 6 months, or a fine, or both;

- of section 277 to include either imprisonment for up to 3 months, or a fine of up to $3,000, or both;
- of section 284 to include simple imprisonment or rigorous imprisonment with hard labour for up to 12 months, or a fine of up to $4,000, or both.

Appendix 3

Selected Legal Provisions for Control of Pesticide Use

Poisons Act (ch. 114):

- "The substances specified in the Poisons List shall be deemed to be poisons within the meaning of this Act" (section 1);
- "No person shall without a license from a Licensing Officer import, possess for sale, sell or offer for sale any poison" (section 5);
- It is unlawful to sell any poison unless "the sale is effected in accordance with the provisions of the license and with any conditions specified therein" (section 6[1][a][ii]);
- "It shall not be lawful for a person to sell any poison unless the container of the poison is labeled:
  - with the name of the poison;
  - in the case of a preparation which contains a poison as one of the ingredients thereof, with particulars as to the proportion which the poison contained in the preparation bears to the total ingredients;
  - with the word 'Poison' or other prescribed indication of the character thereof; and
  - with the name of the seller of the poison and the address of the premises on which it was sold" (section 6[2]);
- "Subject to any rules made under this Act dispensing with or relaxing any of the requirements of this subsection:
  - it shall not be lawful to sell any poison to any person unless that person is known by the seller or by some person in the employment of the seller at the premises where the sale is effected, or is introduced by some person known to the seller as a person to whom the poison may properly be sold; and
  - the seller of any poison shall not deliver it until:
    - he has made or caused to be made an entry in a book to be kept for that purpose stating the date of the sale, the name and address of the purchaser and of the person, if any, introducing him, the name and quantity of the substance sold and the purpose for which it is stated by the purchaser to be required" (section 6[3]);
- "A Licensing Officer may issue to any person, subject to such special conditions and limitations as the Licensing Officer may think fit" (section 10[21]):
  - licenses to import and store poisons;
  - wholesale and retail licenses to deal generally in poisons;
  - wholesale licenses to keep and sell the poisons specified in such licenses; or
  - retail licenses to keep and sell the poisons specified in such licenses" (section 11[1]);
- "There shall be implied in every license issued under this Act the conditions that the licensee is bound to comply:
  - with all terms and conditions set out in the license;
  - with all provisions of this Act; and
  - with all the provisions of any rule that may from time to time be made under this Act" (section 11[2]);
- "His Majesty in Council may make rules to carry out the purposes of this Act...or for any of the following purposes:
  - the importation, use and control of poisons, and any other precautionary measures relating thereto;
  - the storage, transport and labeling of poisons" (section 21);
- "Any person who acts in contravention of any of the provisions of this Act or any rule or order made thereunder, shall...be guilty of an offence: penalty, a fine of $8,000 or, in default of payment, imprisonment for 6 months; provided that if the act or omission charged amounts...to such a degree of negligence as to endanger or be likely to endanger, human life, then such person shall be guilty of an offence: penalty, a fine of $16,000 and imprisonment for 12 months" (section 17[1]).

Appendices

Program of Activities

Tuesday, 30 April
A.M.

Registration

Welcome Address: *Awg. Hj. Matdanan bin Hj. Jaafar*
Opening Address: *Yang Berbahagia Dato Paduka Malai Ali bin Malai Othman*
Keynote Address: *Dr. Chua Thia-Eng*
Audiovisual Presentation: Sustainable Management of Coastal Resources
Presentation of Papers
  Mangrove Resources and Management: *Dr. Prescillano Zamora*
  Capture Fisheries Management: *Mr. Geronimo Silvestre*
  Aquaculture Management: *Mr. Beato Pudadera, Jr.*
Discussion

P.M.

Presentation of Papers
  Coral and Artificial Reef Management: *Dr. Chou Loke Ming*
  Island Management Strategy: *Dr. M.W.R.N. De Silva*
Discussion
  Water Quality Management: *Dr. M.W.R.N. De Silva* for *Dr. Lim Poh Eng*
  Red Tide Action Plan: *Awg. Hj. Matdanan bin Hj. Jaafar*
Discussion

Wednesday, 1 May
A.M.

Presentation of Papers
  Proposed Oil Spill Response Scheme: *Awg. Bolkini bin Hj. Abd. Rahman*
  Brunei Shell Petroleum's Oil Spill Contingency Plan: *Dr. Robin Wright*
  Prediction of Oil Slick Movement: *Dr. Jorge De las Alas*
Discussion
  Socioeconomic Considerations: *Ms. Madeleine Dalusung*
  Legal/Institutional Considerations: *Dr. Rogelio Juliano* for *Dr. Richard Tobin*
  Coastal Resources Management Issues and Problems: *Dr. Rogelio Juliano*
Discussion

P.M.

Overview of Coastal Area Management Plan: *Dr. Rogelio Juliano*
Discussion
Workshop Summary and Closing Remarks: *Awg. Hj. Matdanan bin Hj. Jaafar*

List of Participants

Brunei Darussalam

Government Agencies

Ministry of Communications

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Civil Aviation

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Marine Department

Awg. Hj. Mohd. Esa bin Hj. Abd. Rahman
Marine Department

Awg. Aripin bin Hj. Ahmad
Ports Department

Pg. Hassanan bin Pg. Johari
Ports Department

Ministry of Culture

Pg. Karim bin Pg. Othman
Museums Department

Dr. Marina Wong
Museums Department

Ministry of Development

Dy. Evelyn Han
Department of Town and Country Planning

Dy. Soraya bte Dato Hamid
Department of Town and Country Planning

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Awg. Bakar bin Apong
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Dy. Hjh. Rosni bte Hj. Tungkat
Economic Planning Unit

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Medical and Health Services Department

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Dy. Dulima Jali

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Syed Mohammad and Hooi Sdn. Bhd.

Mr. Jacob George

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Mr. Felimon C. Gayanilo

ICLARM PUBLICATIONS ON COASTAL AREA MANAGEMENT

Conference Proceedings

Towards sustainable development of the coastal resources of Lingayen Gulf, Philippines. G. Silvestre, E. Miclat and T.-E. Chua, editors. 1989. No. 17, 200 p. US$9 surface; $15 airmail.

Coastal area management in Southeast Asia: policies, management strategies and case studies. T.-E. Chua and D. Pauly, editors. 1989. No. 19, 254 p. Out of print - available at cost in photocopied form only.

Towards an integrated management of tropical coastal resources. L.M. Chou, T.-E. Chua, H.W. Khoo, P.E. Lim, J.N. Paw, G.T. Silvestre, M.J. Valencia, A.T. White and P.K. Wong, editors. 1991. No. 22, 455 p. $5 surface; $23 airmail.

Urban coastal area management: the experience of Singapore. L.S. Chia and L.M. Chou, editors. 1991. No. 25, 128 p. $9 surface; $15 airmail.

Coastal area management education in the ASEAN region. T.-E. Chua, editor. 1991. No. 29, 92 p. $9 surface; $15 airmail.

Managing ASEAN's coastal resources for sustainable development: roles of policymakers, scientists, donors, media and communities. T.-E. Chua and L.F. Scura, editors. 1991. No. 30, 125 p. $9 surface; $15 airmail.

Waste management in the coastal areas of the ASEAN region: roles of governments, banking institutions, donor agencies, private sector and communities. T.-E. Chua and L.R. Garces, editors. 1992. No. 33, 218 p. $2 surface; $10 airmail.

The coastal resources of Brunei Darussalam: status, utilization and management. G. Silvestre, H.J.H. Matdanan, P.H.Y. Sharifuddin, M.W.R.N. De Silva and T.-E. Chua, editors. 1992. No. 34, 214 p. $2 surface; $10 airmail.

Technical Reports

The coastal environmental profile of Brunei Darussalam: resource assessment and management issues. T.-E. Chua, L.M. Chou and M.S.M. Sadorra, editors. 1987. No. 18, 193 p. Out of print - available at cost in photocopied form only.

The coastal environmental profile of Ban Don Bay and Phangnga Bay, Thailand. J.N. Paw, S. Bunpapong, A.T. White and M.S.M. Sadorra, editors. 1988. No. 20, 79 p. Out of print - available at cost in photocopied form only.

The coastal environmental profile of Singapore. L.S. Chia and L.M. Chou. 1988. No. 21, 92 p. $1 surface; $5 airmail.

The coastal environmental profile of Lingayen Gulf, Philippines. L.T. McManus and T.-E. Chua, editors. 1990. No. 22, 69 p. $1 surface; $5 airmail.

The coastal environmental profile of South Johore, Malaysia. ASEAN/US CRMP. 1991. No. 24, 65 p. $1 surface; $5 airmail.

The coastal environmental profile of Segara Anakan-Cilacap, South Java, Indonesia. A.T. White, P. Martosubroto and M.S.M. Sadorra, editors. 1989. No. 25, 82 p. $1 surface; $5 airmail.

Education Series

Coral reefs: valuable resources of Southeast Asia. A.T. White. 1987. No. 1, 36 p. Out of print - available at cost in photocopied form only.

Marine parks and reserves: management for coastal environments in Southeast Asia. A.T. White. 1988. No. 2, 36 p. $1.50 surface; $5 airmail.

May pangako mula sa dagat (comics on blast fishing, in Pilipino). L.M. Cabrera. 1988. No. 3, 26 p. Free upon request.

There is still hope (comics on marine parks). 1989. No. 4, 14 p. Out of print - available at cost in photocopied form only.

Seagrasses: a resource unknown in the ASEAN region. M.D. Fortes. 1989. No. 5, 46 p. $1.50 surface; $5 airmail.

Artificial reefs for marine habitat enhancement in Southeast Asia. A.T. White, L.M. Chou, M.W.R.N. De Silva and F.Y. Guarin. 1990. No. 11, 45 p. $1.50 surface; $5 airmail.

Coastal tourism in Southeast Asia. P.P. Wong. 1991. No. 13, 40 p. $1.50 surface; $5 airmail.

Mangroves must live poster. ASEAN/US CRMP in cooperation with Asian Wetland Bureau and WWF Malaysia. 1988. 44.5 x 59.5 cm. $1.25 surface; $3.50 airmail.

Directory

Directory of institutions and scientists in the ASEAN region involved in research and/or management related to coastal areas. T.-E. Chua, M.A.A. Agulto, F.Y. Guarin and S.C. Guerrero, compilers. 1989. 373 p. $2 surface; $10 airmail.

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