# Marine Fisheries Resources of the North Coast of Central Java, Indonesia: An Ecosystem Analysis

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## Abstract

A trophic model of the marine fisheries resources of the north coast of Central Java, Indonesia was constructed using the Ecopath with Ecosim software and data from a trawl survey conducted in the area in 1979. The model consists of 27 ecological groups with a mean trophic level of 3.04. The exploited fishery was then a moderately mature and relatively stable system. The impact of the fishery at the time was low to moderate in comparison with the fisheries in other systems and notably in later time periods.

## Introduction

The Sunda shelf of Southeast Asian waters is one of the most extensive continental shelves in the world, covering some 1 850 000 km$^2$ with most of the area shallower than 100 m depth. Mud, muddy sand, and sand are the predominant bottom sediment, and several large areas were, before the onset of trawling, densely covered by giant cup sponges. Exploitation of the demersal resources has a long history (Butcher 1996), but the intensity of exploitation has not spread uniformly over the whole area, causing several areas to be overexploited, especially on the north coast of Java (Martosubroto 1996). Most fishers exploit nearshore areas using traditional fishing gears. However, trawlers began operating near the coast in the early 1970s, soon leading to conflicts and concerns about the resource situation. In the 1980s, all trawl operations in Western Indonesia were banned, and most trawlers on the north coast of Java were converted to purse seiners. Purse seine effort then developed rapidly, while the demersal fishes and shrimps were largely left for traditional fishers to exploit.

Stock assessments indicate that the demersal resources along the north coast of Java are overexploited (Dwiponggo et al. 1986), implying the need for management. Owing to the complexity of the fisheries and the resources management, using ecosystem approaches are required. Although problems remain in adopting an ecosystem-based approach in the area, the Ecopath with Ecosim software which include time- and spatial-dynamic simulation models, may be used as a tool to study fisheries resources in an ecosystem context and for exploring management options (Christensen et al. 2000; Pauly et al. 2000).

## Materials and Methods
### Study Area and Data Sources

This study is based on the Ecopath with Ecosim mass-balance trophic modeling approach and describes the fisheries resources along the north coast of Central Java (Fig. 1).

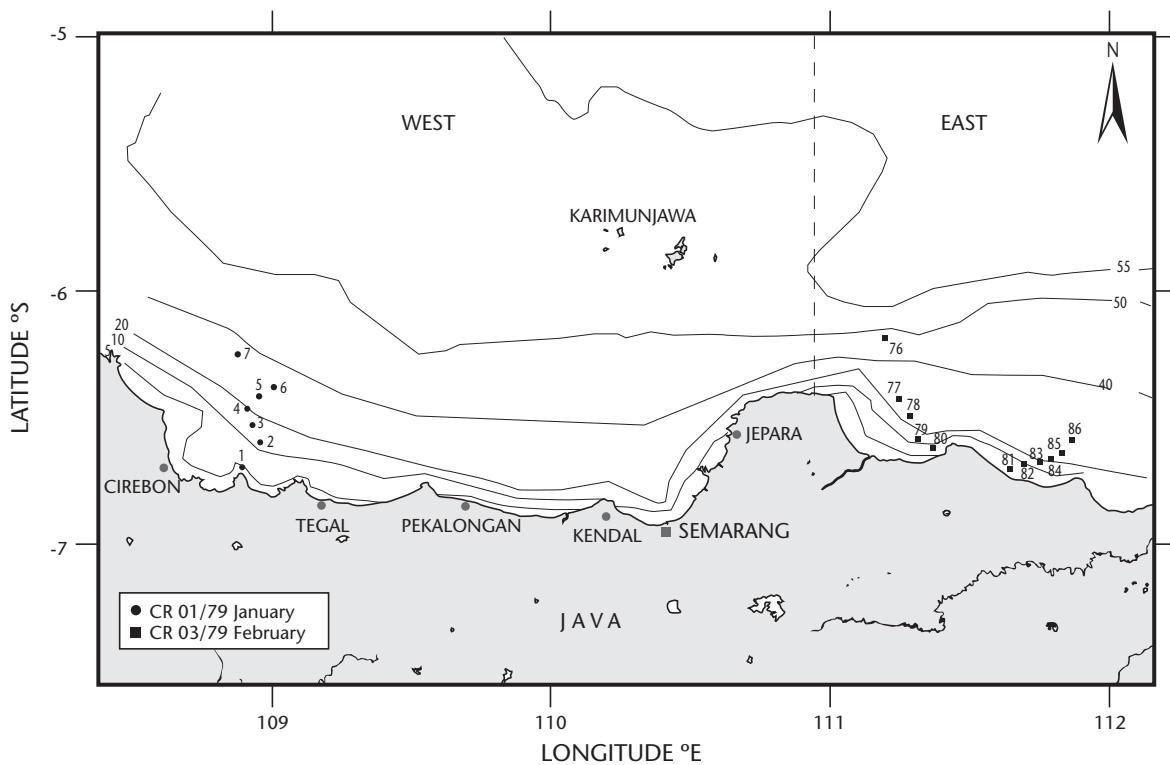Data and information used to build the ecosystem

**Fig. 1. Map of the Java Sea showing the bathymetry and areas covered by the trawl surveys in 1979.**

model involved both published and unpublished reports (hard-to-access). To build the Ecopath model, data from within the actual study area (*viz.* the Java Sea) were used. The primary source for this purpose was the trawl survey of the *R/V Mutiara IV*, along the north coast of Central Java in 1979, as well as various surveys conducted by the oceanographic institute LON-LIPI from 1977 to 1979 in the area (Pauly and Martosubroto 1996).

Landing data from the Java Sea were obtained from the Directorate General of Fisheries (DGF) for the year 1979. Unless otherwise specified, information on diet composition was obtained from FishBase (www.fishbase.org). Information on diet composition for non-fish groups was derived from various models documented in Christensen and Pauly (1993) and Pauly and Christensen (1993).

Cross checking compilations of species records from the study area was conducted, (based on Buchary 1999; Dwiponggo et al. 1986; Losse and Dwiponggo 1977; Martosubroto and Pauly 1976; Pauly and Martosubroto 1996), and DGF landings statistics.

Attributes of non-fish species from the north coast of Central Java Sea were adapted from (Buchary 1999), who relied on both direct and indirect sources. Direct sources included: (1) periodic oceanographic surveys conducted in the study area from the 1970s to 1980s by the oceanographic institute LON-LIPI, (2) DGF fisheries statistics (Dwiponggo 1987), (3) research articles of the *Snellius II* Expedition, (which covers mainly the eastern part of Indonesia, but also the eastern tip of the Java Sea), and (4) other literature about the study area. Indirect sources included: (1) literature covering neighbouring areas, and (2) Ecopath models of neighbouring ecosystems. Most notable among these were: the Gulf of Thailand model (Christensen 1998) the South China Sea models (Pauly and Christensen 1993), the Brunei coast model (Silvestre et al. 1993), the Bolinao reef (Philippines) model (Aliño et al. 1993; Pauly et al. 1993), and to a much lesser extent the Caribbean coral reef model of (Opitz 1996).

## Data Analysis and Model Parameterization

Where several data sets were available, input

parameters for the functional groups were calculated as arithmetic mean, without weighing. The aggregation process into ecological groups was performed based on similarities in habitat, body size, growth and mortality rates and diet composition, after the method described by Christensen and Pauly (1996).

Fish were allocated into functional groups first by habitat preferences, then by body size. Size ranges were specified so that fish with an average or maximum body length of less than 40 cm were considered "small". Fish with an average or maximum body length between 40 and 60 cm were considered "medium"; those that were greater than 60 cm were considered "large". For some species groups, the allocation process was quite straightforward because of their significant contribution to landings, (e.g. clupeoids, *Decapterus* spp.) and/or in the trawl surveys, (e.g. leiognathids). These therefore formed individual functional groups.

Some groups other than fish, however, presented problems. For instance, the marine mammal species proved difficult to handle. Based on a literature search, the following marine mammals were reported to occur in the Java Sea: dugongs, resident dolphins, and transient whales (Buchary 1999; Jefferson et al. 1993; Klinowska 1991; Rice 1989; Tas'an and Leatherwood 1984; White 1983). In the process of data analysis and model parameterization, a number of modifications were found necessary to balance the model and are described below:

1. As an endangered species that receives very little attention in Indonesia, the population of dugong in the Java Sea is probably very small, though actual counts of this species in the study area do not exist. However, an account was made of the dugong's distribution, based on unstructured interviews with local people throughout its suspected distribution range, conducted from the late 1960s to the late 1970s (Buchary 1999; Nishiwaki et al. 1979). Assuming that these data provide a relative index of abundance, an estimation of dugong biomass in the Java Sea was obtained which was so low (less than 0.0001 t·km$^{-2}$) that it has no bearing on the trophic dynamics of the ecosystem. Hence,

this group was not included in the model.

2. Dolphins in the Java Sea are considered to be resident (Buchary 1999; Tas'an and Leatherwood 1984). Whales, however, are transient in the system (Buchary 1999; Jefferson et al. 1993; Klinowska 1991; Rice 1989), migrating from the Indian Ocean, through the Java Sea and then to the Pacific Ocean during the winter to breed, and returning during the summer, mainly to feed. Thus, dolphins and whales were initially separated into two functional groups. While balancing the model, however, unrealistic values for the transient whales were obtained, (e.g. respiration exceeded assimilation). The problem was resolved by aggregating these two groups into a single marine mammal group.

Other taxa identified but not accommodated in the model were marine turtles and marine birds, even though their existence in the Java Sea is a matter of record. Marine turtles in the Java Sea (Buchary 1999; White 1983) include the hawksbill turtle (*Eretmochelys imbricata*), and to a lesser extent the green turtle (*Chelonia mydas*). No population estimates are presently available for either species in the study area, but both are considered to be endangered (Buchary 1999; Groombridge 1982). Hence, their population was assumed too small to incorporate into the model. A similar rationale was followed for marine birds, based on the following evidence. White (1983) and Buchary (1999) noted that there are 131 species of marine birds recorded in Indonesia. The majority of them are shorebirds and vagrant waders, which occur in coastal mudflats, marshes and mangroves. Additionally, oceanic seabirds usually form colonies on smaller islands away from the presence of humans. True marine birds are rare in the Java Sea. Consequently, this group was not included in the model.

To perform efficiently, and be both ecologically and biologically realistic, an Ecopath model should have at least a dozen functional groups (Christensen and Pauly 1996). There is no upper limit on how many groups can be accommodated, but existing models typically include 25 - 35 groups. The present model falls within this range with 27 functional groups (Table 1).

**Table 1. Composition of the 27 ecological groups used for modeling the fisheries resources of the north coast of Central Java model.**

| Ecological group | Taxa |
|---|---|
| Benthic producers | Marine algae (epilithic algae, endolithic algae, reef turf algae, benthic fleshly algae, macroalgae, and benthic algae) and spermatophytes (sea grass) |
| Phytoplankton | Dominated by diatoms (*Bacteriatrum* spp., *Biddulphia* spp., *Bacillaria* spp., *Chaetoceros* spp., *Coscinodiscus* spp., *Ditylum* spp., *Eucampia* spp., *Hemiaulus* spp., *Hemidiscus* spp., *Lauderia* spp., *Leptocylindricus* spp., *Nitzschia* spp., *Rhizosolenia* spp., *Skeletonema* spp., *Streptotheca* spp., *Thalassiothrix* spp. *Thalassionema* spp. and dinoflagellates (*Ceratium* spp., *Dinophysis* spp., and *Peridinium* spp.) |
| Small herbivorous zooplankton (Small herb. Zoopl.) | Copepods, ostracods, bivalve larvae, cirripedia larvae, cladocerans, echinoderm larvae, larvacea, other mollusc larvae |
| Large herbivorous zooplankton (Lg. Herb. Zoopl) | Mysids, sergestids, euphausiids, amphipods, luciferidae, and other decapod larvae |
| Carnivorous zooplankton | Chaetognaths (*Sagitta* spp.), annelids and ichthyoplankton |
| Jellyfishes | All medusoid form of cnidarians (hydrozoa and scyphozoa only); although scyphozoa medusae dominate |
| Benthic infauna | Includes all burrowing benthos ≤ 1.0 mm, viz., polychaetes, molluscs, echinoderms, crustaceans, sipunculids, and benthic stage larvae of other larger organisms |
| Structure-associated fish (SAF) | Includes all fish that are ecologically dependent (directly and/or indirectly) on living bottom structure (LBS, see group 10) to complete their life cycle. For this model, it includes fish of the families Balistidae, demersal Carangidae, Lethrinidae, Lutjanidae, Pentapodidae, Platacidae, Polynemidae, Sparidae, Sphyraenidae, Scaridae, Acanthuridae, and Tetraodontidae |
| Macrozoobenthos | This group includes all larger (size > 1.0 mm) molluscs and echinoderms, such as conch, oyster, scallops, clams, cockles, mussels, sea urchins, sea cucumbers, and sea stars. |
| Living bottom structure (LBS) | All biogenic organisms that live on and/or are attached to the sea floor, such as sponges (notably giant cup sponges, *viz. Poterion nautilus*, *P. neptuni*, and *P. amphitritae*), gorgonians (sea fans and sea whips), soft coral, sea pens, sea anemones, etc. |
| Juvenile penaeid shrimp (Juv. Pen. Shrimp) | Includes all juvenile shrimps, not just penaeid shrimps. However, parameterization of this group is based on the juveniles of *Penaeus* spp. and *Metapenaeus* spp. |
| Large pelagic predators - juvenile (Lg. Pel. Pred. J) | Juveniles of the families Chirocentridae, large Scombridae, and Trichiuridae |
| Adult penaeid shrimps (Ad. Pen. Shrimps) | Includes all adult shrimps, but data refer only to *Penaeus* spp. and *Metapenaeus* spp. |
| Miscellaneous pelagics (Misc. pelagics) | Belonidae, Carangidae, Harpodontidae, Hemirhamphidae, Lactaridae, Mobulidae, Scianidae (*Kathala axillaris*), and Scombridae (*Auxis sp.*) |
| Leiognathids | *Gazza minuta*, *Leiognathus* spp., and *Secutor* spp. |
| Crabs and Lobsters | Portunidae, Palinuridae, Scyllaridae, etc. |
| Cephalopods | Includes squids (*Loligo* spp.), cuttlefish (*Sepia* spp.) and octopus (*Octopus* spp.) |
| *Decapterus* spp. | *Decapterus macrosoma, D. maruadsi and D. russelli* |
| *Rastrelliger* spp. | *Rastrelliger brachysoma* and *R. kanagurta* |
| Clupeoids | Clupeidae and Engraulidae |

**Table 1. Composition of the 27 ecological groups used for modeling the fisheries resources of the north coast of Central Java model. (continued).**

| Ecological group | Taxa |
|---|---|
| Small demersals | Apogonidae, Ariidae, Ariommatidae, Caesionidae, Cynoglossidae, Dactylopteridae, Drepanidae, Ephippidae, Gerridae, Haemulidae, Holocentridae, Kurtidae, Menidae, Mullidae, Nemipteridae, Priacanthidae, Serranidae, Siganidae, Sillaginidae, Stromatidae, Synodontidae, Teraponidae and Sciaenidae |
| Large demersal predators - juvenile (Lg. Dem. Pred. J) | Juveniles of the families Ariidae (*Arius thalassinus*), Carcharhinidae, Muraenesocidae, Serrandae (*Epinephelus lanceolatus*), Sphyrnidae, Stegostomidae, Pristidae, Rhinidae, and Rhinobatidae |
| Demersal rays | Dasyatidae and Myliobatidae |
| Large pelagic predators - adult (Lg. Dem. Pred. A) | Chirocentridae, large Scombridae and Trichiuridae |
| Large demersal predators - adult (Lg. Dem. Pred. A.) | Ariidae (*Arius thalassinus*), Carcharhinidae, Muraenesocidae, Serranidae (*Ephinephelus lanceolatus*), Sphyrnidae, Stegostomidae, Pristidae, Rhinidae and Rhinobatidae |
| Marine mammals | Comprised of resident dolphins *viz.*, Bottlenose dolphins (*Tursiops* spp.), Spinner dolphins (*Stenella longirostris*), Irrawady dolphins (*Orcaella brevirostris*), finless porpoises (*Neophocaena phocaenoides*), and Indo-Pacific humpbacked dolphins (*Sousa chinensis*); and transient whales, *viz.*, sperm whales (*Physeter catodon*), Bryde's whales (*Balaenoptera edenii*), and minke whales (*B. autorostrata*) |
| Detritus | Particulate and dissolved organic matter |

## Results and Discussion
### Basic Model Results

Final input and output parameters of the model are presented in Table 2 while Table 3 gives the final diet composition matrix; Figure 2 illustrates the Ecopath model derived for the north coast of Central Java (1979).

The north coast of Central Java ecosystem spans about four trophic levels, with cetaceans and the fishery acting as top predators. The distribution of functional groups among trophic level is relatively equal between low trophic levels (< 2.5) and intermediate trophic levels (2.5 - 3.5). There are 11 groups at low trophic levels, and 12 groups at intermediate trophic level. The remaining five groups have trophic levels greater than 3.5. The relatively high number of groups located at similar trophic levels indicates a situation where strong competition for resources occurs. In such circumstances, the direct impact of a fishery is likely to be amplified throughout the entire system, by direct and indirect interactions.
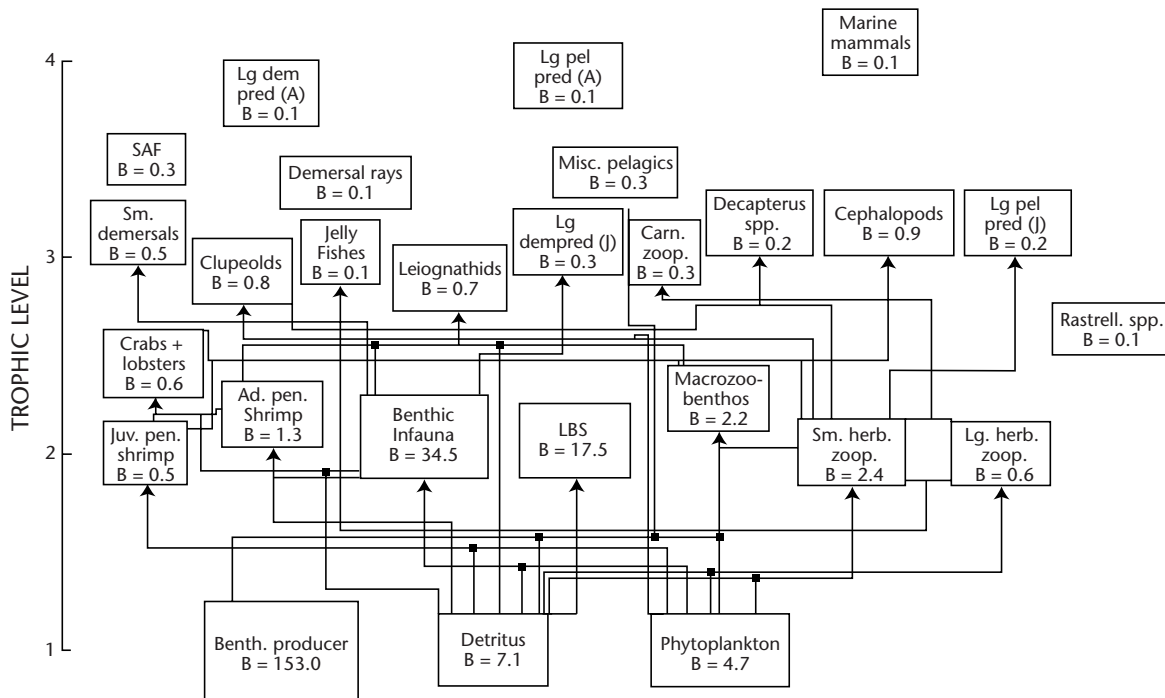


**Fig. 2. Ecopath model of the north coast of Central Java (1979). Only flows exceeding 1 t·km⁻²·year⁻¹ are represented. The groups are arranged by trophic level, and the box size is a function of the biomass of the groups (in 1 t·km⁻²).**

**Table 2. Parameter inputs and outputs (in parentheses) of the Ecopath model for the north coast of Central Java 1979.**

| Ecological Groups | Biomass (t·km⁻²) | P/B (year⁻¹) | Q/B (year⁻¹) | EE | GE | Landings (t·km⁻² ·year⁻¹) | Flow to detritus (t·km⁻² ·year⁻¹) | Trophic level | Omnivory index | R/A (year⁻¹) | R/B (year⁻¹) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Benthic producers | 153.00 | 11.86 | – | < (0.01) | – | 0 | 1 813.15 | 1.0 | 0 | – | – |
| Phytoplankton | (4.68) | 135.00 | – | 0.95 | – | 0 | 31.60 | 1.0 | 0 | – | – |
| Small herb. Zoopl. | 2.43 | 60.22 | 220.00 | (0.46) | 0.46 | 0 | 29.59 | 2.0 | 0 | (0.54) | (71.78) |
| Lg. Herb. Zoopl. | 0.56 | 20.00 | 70.00 | (0.92) | 0.48 | 0.02 | 16.62 | 2.0 | 0 | (0.52) | (22.00) |
| Carn. Zoopl. | 0.31 | 42.58 | 135.05 | (0.21) | 0.40 | 0 | 18.84 | 3.0 | 0 | (0.61) | (65.46) |
| Jelly fishes | 0.10 | 5.01 | 25.05 | (0.53) | 0.25 | 0.05 | 0.74 | 3.0 | 0 | (0.75) | (15.03) |
| Benthic infauna | 34.48 | 6.57 | 27.40 | (0.43) | 0.30 | 0 | 318.95 | 2.1 | 0.09 | (0.70) | (15.35) |
| SAF | 0.32 | (3.81) | 7.63 | (0.30) | 0.62 | 0.03 | 1.33 | 3.5 | 0.24 | (0.38) | (2.29) |
| Macrozoobenthos | (2.21) | 3.00 | 12.50 | 0.75 | 0.30 | 0.01 | 7.18 | 2.3 | 0.35 | (0.70) | (7.00) |
| LBS | (17.48) | 0.10 | 0.50 | 0.95 | 0.25 | 0.26 | 1.84 | 2.1 | 0.09 | (0.75) | (0.30) |
| Juv.pen.shrimp | (0.47) | 13.00 | 70.00 | 0.95 | 0.23 | 0.02 | 6.92 | 2.0 | 0 | (0.77) | (43.00) |
| Lg.pel.pred.(J) | (0.19) | (4.73) | 15.75 | 0.95 | 0.38 | 0.71 | 0.65 | 3.2 | 0.14 | (0.62) | (7.88) |
| Ad.pen.shrimps | (1.27) | 5.000 | 28.94 | 0.95 | 0.22 | 0.10 | 7.67 | 2.2 | 0.19 | (0.78) | (18.16) |
| Misc.pelagic | (0.30) | (2.91) | 14.57 | 0.95 | 0.25 | 0.43 | 0.92 | 3.5 | 0.48 | (0.75) | (8.74) |
| Leiognathids | 0.71 | (3.52) | 15.59 | (0.28) | 0.28 | 0.20 | 4.03 | 2.9 | 0.24 | (0.75) | (8.95) |
| Crabs and Lobster | (0.63) | 4.00 | 21.90 | 0.95 | 0.23 | 0.00 | 2.87 | 2.5 | 0.31 | (0.77) | (13.52) |
| Cephalopods | (0.90) | 3.10 | 20.32 | 0.95 | 0.19 | 0.05 | 3.77 | 3.2 | 0.11 | (0.81) | (13.15) |
| *Decapterus* spp. | (0.24) | (3.73) | 13.89 | 0.95 | 0.34 | 0.63 | 0.71 | 3.2 | 0.57 | (0.66) | (7.38) |
| *Rastrelliger* spp. | (0.12) | (4.43) | 14.16 | 0.95 | 0.34 | 0.39 | 0.37 | 2.6 | 0.23 | (0.63) | (7.08) |
| Clupeoids | (0.81) | 6.20 | 15.75 | 0.95 | 0.49 | 0.71 | 2.82 | 2.9 | 0.10 | (0.51) | (6.40) |
| Small demersals | 0.50 | 3.25 | 15.24 | (0.98) | 0.27 | 0.39 | 1.54 | 3.1 | 0.17 | (0.73) | (8.94) |
| Lg.dem.pred.(J) | (0.32) | 3.254 | 15.2 | 0.95 | 0.27 | 0.39 | 1.02 | 3.1 | 0.18 | (0.73) | (8.94) |
| Demersal rays | (0.09) | (0.17) | 9.10 | 0.95 | 0.02 | 0.01 | 0.16 | 3.4 | 0.10 | (0.98) | (7.11) |
| Lg.pel.pred (A) | (0.09) | (2.28) | 11.39 | 0.95 | 0.25 | 0.18 | 0.21 | 4.0 | 0.12 | (0.75) | (6.88) |
| Lg.dem.pred (A) | (0.07) | (3.50) | 7.49 | (0.26) | 0.58 | 0.07 | 0.30 | 3.9 | 0.20 | (0.42) | (2.49) |
| Marine mammals | 0.14 | 0.04 | 15.36 | (0.09) | 0.00 | 0.01 | 0.43 | 4.1 | 0.05 | (0.10) | (12.24) |
| Detritus | 17.14 | – | – | (0.372) | – | 0 | 0.00 | 1.0 | 0.26 | – | – |

**Note:** P/B = Production/Biomass ratio, Q/B = Consumption/Biomass ratio, EE = Ecotrophic efficiency, GE = Gross efficiency, Q/B = , R/A = Respiration/assimilation ratio, R/B = Respiration/Biomass ratio.

**Table 3. Diet composition matrix for functional groups in the Java Sea in the mid-1970's. Values represent the proportion (on a weight or volume basis) each prey contributes to the diet of the predator.**

| Prey | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Benthic producers | - | - | - | - | - | 0.01 | 0.15 | 0.10 | - | - | <0.01 | - | - | - | - | - | - | <0.01 | 0.02 | - | - | - | - | - |
| 2. Phytoplankton | 0.70 | 0.70 | - | - | 0.17 | - | 0.29 | 0.04 | 0.80 | - | - | 0.10 | 0.01 | - | - | 0.23 | 0.37 | 0.08 | - | 0.07 | - | - | - | - |
| 3. Small herb. Zoopl. | - | - | 0.80 | - | - | - | 0.14 | 0.04 | - | 0.77 | 0.02 | 0.11 | 0.01 | - | 0.540 | 0.32 | 0.58 | 0.85 | 0.05 | 0.14 | - | - | - | - |
| 4. Lg. Herb. Zoopl. | - | - | 0.20 | 0.60 | - | 0.02 | 0.01 | 0.01 | - | <0.01 | <0.01 | 0.04 | 0.01 | - | 0.010 | 0.03 | 0.01 | <0.01 | 0.01 | <0.01 | - | - | - | <0.01 |
| 5. Carn. Zoopl. | - | - | - | 0.40 | - | 0.01 | 0.07 | - | - | 0.02 | - | 0.03 | 0.01 | - | - | - | - | 0.02 | 0.02 | - | - | - | - | - |
| 6. Jelly fishes | - | - | - | - | - | - | - | - | - | - | - | 0.04 | - | - | - | - | - | <0.01 | - | - | - | - | - | - |
| 7. Benthic infauna | - | - | - | - | 0.08 | 0.07 | - | - | - | - | 0.17 | 0.05 | 0.45 | 0.15 | 0.020 | - | - | 0.02 | 0.51 | 0.56 | 0.15 | - | <0.01 | - |
| 8. SAF | - | - | - | - | - | <0.01 | - | - | - | - | - | 0.03 | - | - | - | - | - | - | - | 0.02 | - | 0.04 | 0.12 | - |
| 9. Macrozoobenthos | - | - | - | - | - | 0.11 | - | - | - | - | - | 0.07 | 0.10 | 0.05 | 0.060 | - | - | - | 0.10 | 0.05 | 0.50 | - | 0.14 | - |
| 10. LBS | - | - | - | - | - | 0.07 | 0.01 | - | - | - | 0.01 | - | <0.01 | 0.01 | - | - | - | - | 0.02 | - | <0.01 | - | - | - |
| 11. Juv.pen.shrimp | - | - | - | - | - | 0.06 | - | - | - | 0.03 | - | 0.03 | 0.01 | 0.10 | 0.150 | 0.01 | 0.05 | 0.03 | 0.06 | 0.05 | - | 0.03 | <0.01 | 0.02 |
| 12. Lg. pel. pred.(J) | - | - | - | - | - | - | - | - | - | - | - | <0.01 | - | - | - | - | - | - | <0.01 | - | - | 0.03 | <0.01 | 0.02 |
| 13. Ad.pen.shrimps | - | - | - | - | - | 0.07 | - | - | - | - | - | 0.10 | 0.20 | 0.10 | 0.030 | - | - | - | 0.08 | 0.05 | 0.10 | 0.13 | 0.15 | 0.02 |
| 14. Misc. pelagics | - | - | - | - | - | - | - | - | - | - | - | >0.01 | - | - | - | - | - | - | <0.01 | - | - | 0.15 | - | 0.09 |
| 15. Leiognathids | - | - | - | - | - | 0.01 | - | - | - | - | - | 0.08 | 0.01 | - | 0.001 | 0.01 | - | - | <0.01 | <0.01 | <0.01 | 0.02 | 0.01 | 0.01 |
| 16. Crabs+Lobster | - | - | - | - | - | 0.11 | - | - | - | - | - | <0.01 | - | - | 0.100 | - | - | - | 0.02 | - | 0.10 | <0.01 | 0.05 | - |
| 17. Cephalopods | - | - | - | - | - | 0.02 | - | - | - | - | - | 0.08 | - | - | 0.040 | - | - | - | 0.02 | 0.05 | 0.05 | 0.10 | 0.09 | 0.41 |
| 18. *Decapterus* spp. | - | - | - | - | - | - | - | - | - | - | - | 0.03 | - | - | - | - | - | - | - | - | - | <0.01 | - | 0.04 |
| 19. *Rastrelliger* spp. | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.01 | - | - | <0.01 | - | 0.04 |
| 20. Clupeoids | - | - | - | - | - | - | - | - | - | 0.18 | - | 0.12 | - | - | 0.028 | 0.40 | - | - | 0.02 | - | - | 0.47 | <0.01 | 0.27 |
| 21. Small demersals | - | - | - | - | - | 0.13 | - | - | - | - | - | 0.05 | <0.01 | - | 0.010 | - | - | - | 0.01 | - | 0.10 | - | 0.21 | 0.10 |
| 22. Lg.dem.pred | - | - | - | - | - | 0.17 | - | - | - | - | - | - | - | - | 0.001 | - | - | - | - | - | - | 0.05 | 217 | - |
| 23. Demersal rays | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | <0.01 | - |
| 24. Lg.pel.pred (A) | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | <0.01 | <0.01 |
| 25. Lg.dem.pred (A) | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | |
| 26. Marine mammals | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.01 | - |
| 27. Detritus | 0.30 | 0.30 | - | - | 0.75 | 0.01 | 0.34 | 0.80 | 0.20 | - | 0.08 | 0.02 | 0.20 | 0.59 | 0.010 | - | - | - | 0.05 | - | - | - | - | - |
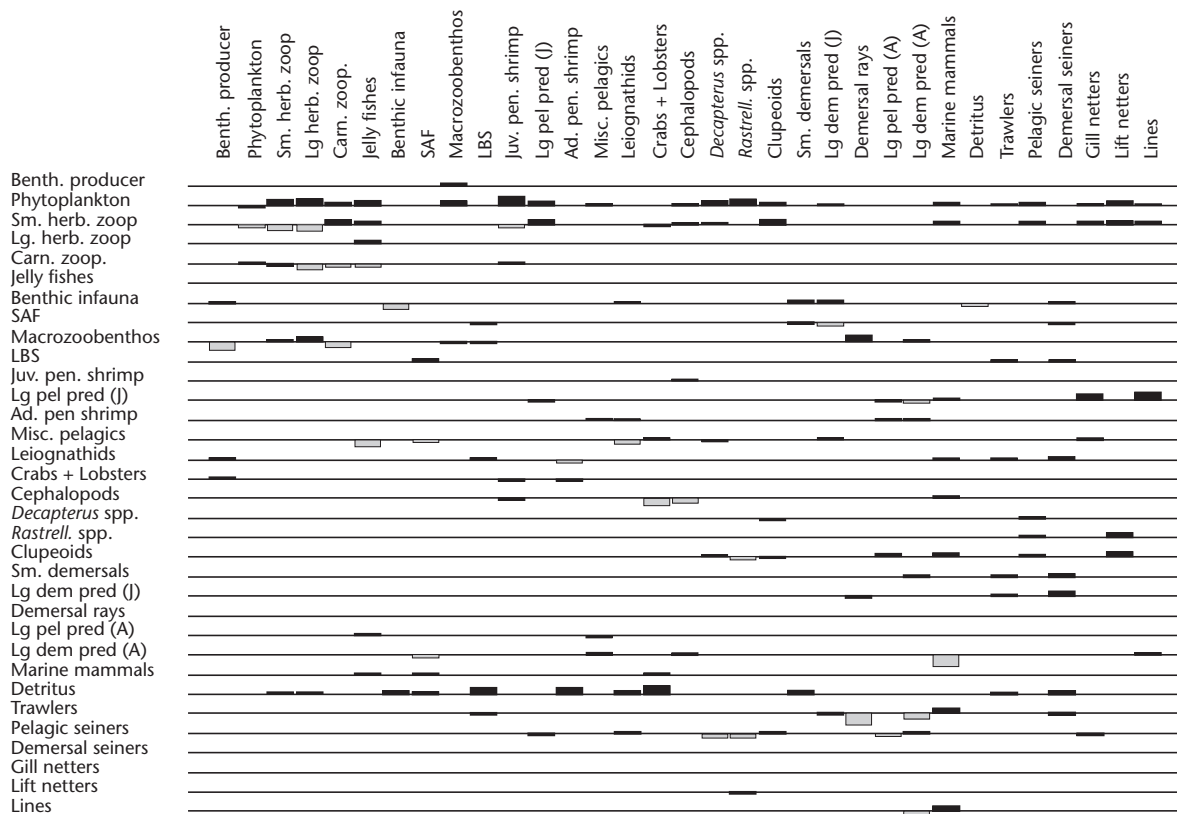
**Fig. 3. Mixed trophic impacts in the 1979 model of the north coast of Central Java ecosystem. The graph shows the direct or indirect trophic impacts the groups to the left (rows) have on the groups mentioned above (columns). Positive impacts are shown above the baseline, and negative below. The impacts are relative but comparable between groups.**

## Trophic Impact Assessment

Figure 3 presents the trophic interactions of the ecosystem under study. All functional groups appear to respond negatively to an increase in their own biomass. This is due to an increase within group competition for food resources.

Trawlers and pelagic seiners were the two fleets that showed the most impact on the ecosystem. The fishery was positively affected mostly by lower and intermediate trophic levels, as indicated by the positive impact of phytoplankton, small herbivorous zooplankton, *Rastrelliger* spp., and clupeoids on many fisheries. The fishery exhibits the largest positive increases from increases in primary productivity and zooplankton biomass.

As indicated earlier, the fishery and the cetacean group have similar trophic levels (i.e. 4.1), hence, competition is clearly a possibility. The trophic impact routine confirms this, although the effect appears slight. An increase in marine mammal biomass slightly decreased the fishery (i.e. -0.02, -0.05, -0.01, -0.05 for trawl, pelagic seiners, demersal seiners, gillnets, liftnets and line respectively), while an increase in fishing effort produced a variable impact on the marine mammals (i.e. -0.07 to 0.001) depending on the fishing gear used.

## Maturity of the Java Sea Ecosystem

A system for describing the maturity of an ecosystem was first described by Odum (1969). Ulanowicz (1986) developed this further to include a new interpretation of ecosystem growth and development, using concepts mainly drawn from thermodynamics and information theory. Key concepts that are parts of Odum's and Ulanowicz's theories are available as Ecopath routines (Christensen and

Pauly 1992a; Christensen and Pauly 1992b). These routines were used (Christensen 1994; Christensen 1995) to compare the maturity and stability levels of 41 aquatic ecosystems represented by Ecopath models. A comparison between the north coast of Central Java ecosystem, and these 41 aquatic systems, can provide a relative assessment of the maturity of the north coast of Central Java system, and perhaps elucidate possible responses to perturbation.

Table 4 presents the summary statistics, while Table 5 and Table 6 list network flow indices and transfer efficiencies, respectively, for the north coast of Central Java model in 1979.

Table 4. Summary statistics of the Ecopath model for the north coast of Central Java (1979).

| Property (units) | Value |
|---|---|
| Sum of all consumption (t·km$^{-2}$·year$^{-1}$): | 1 756 |
| Sum of all exports (t·km$^{-2}$·year$^{-1}$): | 1 596 |
| Sum of all respiratory flows (t·km$^{-2}$·year$^{-1}$): | 851 |
| Sum of all flows into detritus (t·km$^{-2}$·year$^{-1}$): | 2 538 |
| Total system throughput (t·km$^{-2}$·year$^{-1}$): | 6 745 |
| Sum of all production (t·km$^{-2}$·year$^{-1}$): | 2 891 |
| Mean trophic level of the catch: | 3.04 |
| Gross efficiency (catch/net primary production): | 0.0019 |
| Calculated total net primary production (t·km$^{-2}$·year$^{-1}$): | 24 502 |
| Total primary production/total respiration ($P_p$/R): | 2.87 |
| Net system production (t·km$^{-2}$·year$^{-1}$): | 1 598 |
| Total primary production/total biomass ($P_p$/R) (year$^{-1}$): | 11.0 |
| Total biomass/total throughput (year): | 0.03 |
| Total biomass (excluding detritus) (t·km$^{-2}$): | 222 |
| Total catches (t·km$^{-2}$·year$^{-1}$): | 4.67 |
| Connectance Index: | 0.284 |
| System Omnivory Index: | 0.138 |

In 1979, the north coast of Central Java was moderately dependent on detritus (Table 6); half of the flows originated from detritus. Odum (1969) stated that as ecosystems mature, they should become more dependent on detrital flows and less on flows from primary producers.

Odum (1969) indicated that the ratio between total primary production and total respiration ($P_p$/R) is a functional index of the relative maturity of an ecosystem. This ratio would approach 1 as systems mature. In their comparative study of 41 aquatic ecosystems, Christensen and Pauly (1993) found that the bulk of $P_p$/R ratios were in the range between 0.8 and 3.2, although the extreme values were < 0.8 and > 6.4. The $P_p$/R ratio of the north coast of Central Java in 1979 was 2.9 (Table 4).

Christensen and Pauly (1993) indicated that ecosystems with very high $P_p$/R ratio usually will either present problems in model parameterization (especially problems with quantification of assimilation rates, and hence indirectly of respiration), or bacterial activity will have been omitted from the model. In the first case, usually the ratio between total export and system throughput exceeds 0.3 (Christensen and Pauly 1993). In the north coast of Central Java system, this ratio was 0.24 (Table 4). Hence, problems of model parameterization are not likely to be the cause, which lead us to the second case, i.e. omission of bacterial activity. In this study, bacterial activity was not included, which in this case over estimates the $P_p$/R ratio. The north coast of Central Java ecosystem acts as a detrital sink for adjacent land, from which the run-off (i.e. suspended and particulate solids) comes primarily from agriculture sources. This provides an explanation for the high $P_p$/R value obtained for this model.

Buchary (1999) notes that the ratio between total system productivity and total system biomass (P/B) is high in developing systems and low in mature systems. Christensen and Pauly (1993) ranked the P/B ratios of 41 aquatic ecosystems according to the maturity ranking of Odum (1969). Compared to these 41 aquatic systems, the Java Sea, having a total P/B of 7.18 year$^{-1}$ (Table 4), is at an intermediate level of maturity.

Another measure of maturity is cycling, which is assumed to increase as systems mature (Odum 1969). Finn (1976) quantified this using an index now called Finn's Cycling Index (FCI), which expresses the percentages of the total throughput

**Table 5. Network flow indices of the north coast of Central Java as computed by Ecopath.**

| Source | Ascendency | | Overhead | | Capacity | |
|---|---|---|---|---|---|---|
| | **Flowbits** | **%** | **Flowbits** | **%** | **Flowbits** | **%** |
| Import | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Internal flow | 4 986 | 21.1 | 10 983 | 46.6 | 15 970 | 67.7 |
| Export | 2 233 | 9.5 | 1 149 | 4.9 | 3 383 | 14.3 |
| Respiration | 1 689 | 7.2 | 2 538 | 10.8 | 4 227 | 17.9 |
| Totals | 8 909 | 37.8 | 14 671 | 62.2 | 23 581 | 100.0 |
| Finn's Cycling Index | 8.58 (% of total throughput) | | | | | |
| Finn's Mean path length | 2.753 | | | | | |

**Table 6. Transfer efficiencies (TE) and flows at each discrete trophic level in the north coast of Central Java model.**

| Trophic Level | TE (%) | Outflows | | | Inflows |
|---|---|---|---|---|---|
| | | **Consumption by predators** $(t \cdot km^{-2} \cdot year^{-1})$ | **Consumption by fisheries** $(t \cdot km^{-2} \cdot year^{-1})$ | **Sum of all outflows** $(t \cdot km^{-2} \cdot year^{-1})$ | **Throughput** $(t \cdot km^{-2} \cdot year^{-1})$ |
| II | 11.9 | 183.52 | 0.89 | 184.41 | 1 549.77 |
| III | 13.0 | 21.04 | 2.83 | 23.87 | 183.52 |
| IV | 14.5 | 2.19 | 0.86 | 3.05 | 21.04 |
| V | 13.6 | 0.20 | 0.08 | 0.28 | 2.19 |
| VI | 12.3 | 0.02 | < 0.01 | 0.02 | 0.20 |
| VII | 6.25 | < 0.01 | < 0.01 | < 0.01 | 0.02 |

**Proportion of total flow from: Detritus = 0.53; Primary producers = 0.47.**

actually recycled in the system. As maturity *sensu* (Odum 1969) was shown to be related with stability sensu (Christensen and Pauly 1993; Rutledge et al. 1976) it was demonstrated that when FCI is plotted against system overhead for a large number of ecosystems, they provide a parabolic correlation; The apex or inflections are moving away from stability. When the FCI (8.58%, Table 5) and the system overhead (62.2%, Table 5) of the north coast of Central Java are plotted in the parabolic relation of Christensen and Pauly (1993), it indicates the north coast of Central Java as a relatively stable ecosystem. The north coast of Central Java ecosystem is less stable than the Gulf of Thailand and the Brunei coast, but more stable than the Gulf of Mexico continental shelf and Monterey Bay.

Christensen and Pauly (1993) also plotted the FCI of 41 aquatic ecosystems against their total primary production/total respiration ($P_p/R$) ratios, and indicated that $P_p/R$ ratio moves toward unity and FCI increases as ecosystems mature. When the north coast of Central Java's indices of FCI (8.58%, Table 5) and $P_p/R$ (2.87, Table 4) are plotted onto this correlation (Christensen and Pauly 1993, Figure 8), the Java Sea is placed at an intermediate level of maturity.

In terms of the correlation between FCI (8.58%, Table 5) and mean path length (2.75, Table 5), the north coast of Central Java fell within the intermediate range of maturity among all the ecosystem models described in Christensen and Pauly (1993, Figure 9).

As stated by Buchary (1999): "Following Lindeman (1942) definition of trophic transfer efficiencies (TE) and using a method to calculate TE described in Christensen and Pauly (1992a). Christensen and Pauly (1993) calculated TE for all 41 aquatic ecosystem models and plotted them all against their respective discrete trophic levels. Average TE by trophic levels were as follows: 10% for the herbivores/detritivores, 11% for the next trophic level, and lower efficiency (7.5 - 9.0%) on the higher trophic levels. The overall mean TE was 9.2%". The TE of the north coast of Central Java in1979 was almost similar (Table 6).

In summary, the north coast of Central Java ecosystem model in 1979 behaves as can be expected from a tropical shelf system. Furthermore, it can be regarded as moderately mature and relatively stable. The impact of the fishery was low to moderate in comparison with the fisheries of other systems. Therefore, it is anticipated that the Java Sea ecosystem should be moderately resilient to perturbation.

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