# 2 Aquatic Resources and Environmental Variability in Bac Lieu Province (Southern Vietnam)

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**Abstract**
The dynamics of aquatic resources in the canals of Bac Lieu Province, in southern Vietnam, are detailed and synthesized in this study. Nekton and eight environmental parameters were monitored in this province between 2004 and 2006, at 14 sites sampled three times a year. The study area, located along the coastal zone, is characterized by a variable environment subject to saline, freshwater and acidic pulses. The spatio-temporal dynamics of aquatic resources and their relationships with environmental parameters are detailed. The dominance of either freshwater or estuarine fauna, the dynamics of assemblages and the catches of fishers appear to be largely influenced by the management of sluice gates built along the coastal zone.

## Introduction

In this study, we summarize the results of aquatic resources monitoring in Bac Lieu Province, southern Vietnam (Fig. 2.1) during the period from 2004 to 2006. The study area, located along the coastal zone, is characterized by a dense canal network and a variable environment subject to saline, freshwater and acidic pulses. The environmental characteristics of this area have been described in Hoanh (1996) and its socio-economic and agricultural conditions in Hoanh *et al*. (2006a). An important feature of the study area is a series of sluice gates built along the coastline between 1994 and 2000 to control the intrusion of seawater during the dry season, thus protecting rice agriculture. This water control system dramatically influences the inland coastal hydrology and water quality in the province (Kam *et al*., 2001; Hoanh *et al*., 2006b). It therefore has implications for the environmental and biodiversity features of the canals (Hoanh *et al*., 2003; Gowing *et al*., 2006a), and ultimately for farming practices and land use in the province (Hoanh *et al*., 2001; Tuong *et al*., 2003; Kam *et al*., 2006).

In this context, the goals of this study were: (i) to characterize the environmental and aquatic diversity and variability of the study area subject to saltwater management; and (ii) to develop a comprehensive model of aquatic resources in the province (Baran *et al*., 2006). The latter undertaking aimed to improve the operation of the sluice gates by adding ecological considerations to the water management objectives, which were formerly focused on agronomic criteria only.

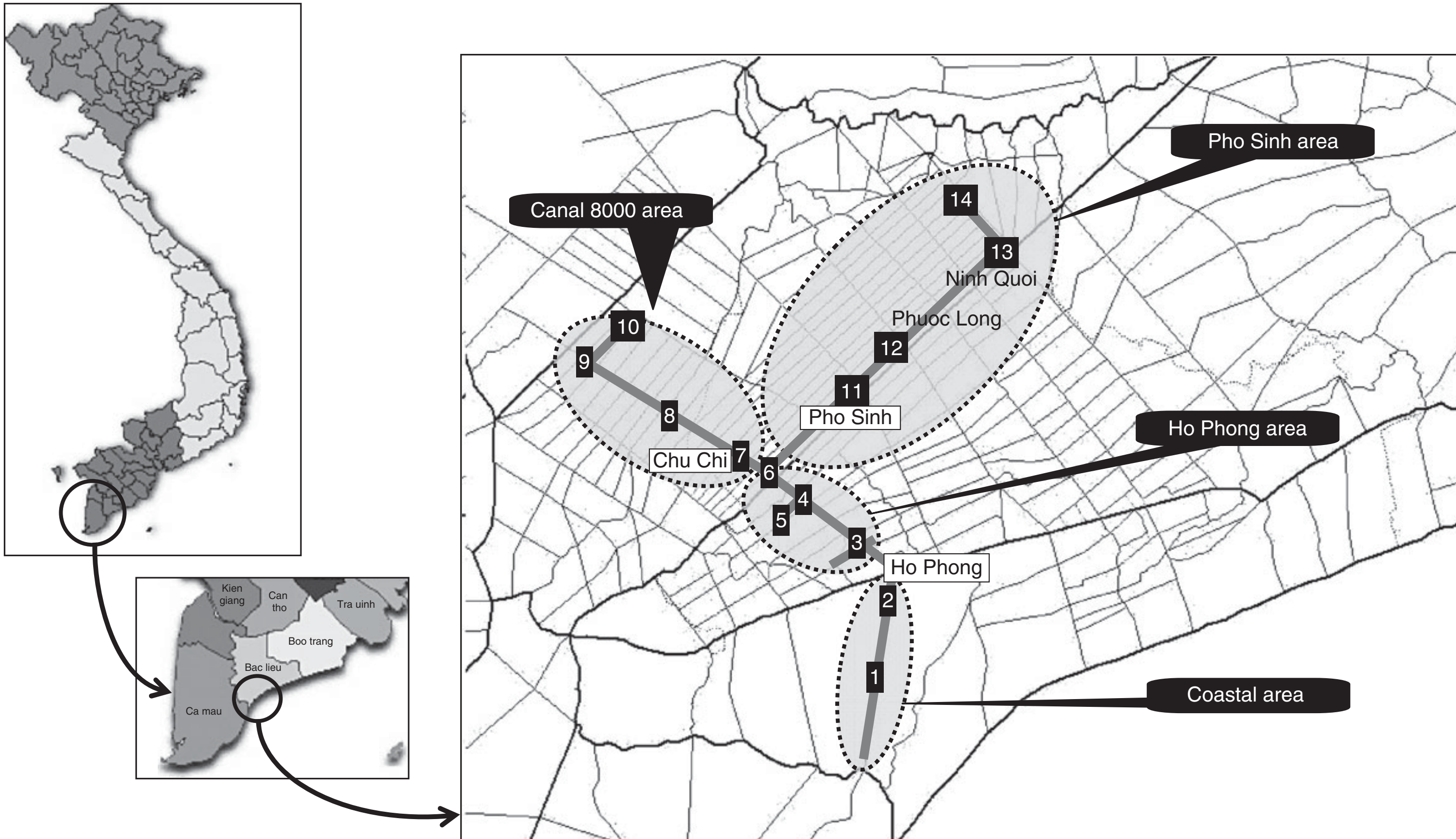


**Fig. 2.1.** Map showing location of the study area.

The fish fauna of Bac Lieu Province has been described in Yen and Trong (1988) and Khoa and Huong (1993) and the environmental variability has been subject to extensive studies (e.g. Hoanh, 1996; Tran *et al*., 2005), but the seasonal variability of the fish fauna has only been addressed superficially (Dung *et al*., 2002) and, to our knowledge, no study has covered the relationships between faunal and environmental parameters.

The spatio-temporal dynamics of water quality and of aquatic resources in the inland coastal area of Bac Lieu presented here are a synthesis of the seasonal analyses detailed in several project reports (Baran and Chheng, 2004; Chheng, 2004a, b; Chheng and Toan, 2005a, b; Toan and Chheng, 2005). The relationships between faunal and environmental patterns are detailed in this chapter, and the potential influence of sluice gates on the abundance and diversity of aquatic resources is highlighted.

## Material and Methods

### Sampling protocol

Sampling of aquatic resources took place in the primary and secondary canals inside and outside the area protected by sluice gates in four zones located around Ho Phong town in Bac Lieu Province: the coastal zone area outside of Ho Phong sluice gate; Ho Phong (inside Ho Phong sluice gate); around Canal 8000; and around Pho Sinh (Fig. 2.1). In total, 14 sites in the study area were sampled to capture the spatial variability of environmental parameters in each season.

Sampling was undertaken from June 2004 to March 2006. It covered three distinct seasons in each of the two year-long periods: (i) the dry/saline season, with seawater intrusion inland peaking in March; (ii) the acidic season (acidity released by acid sulfate soils following the first monsoon rains, with a peak in June); and (iii) the rainy/freshwater season, with a flood peak in October corresponding to a pulse of fresh water from the Mekong system during the monsoon. In each season, sampling at all sites took place within a period of 5 days. Since the first sampling was carried out in June 2004, the first year of sampling comprised June 2004, October 2004 and March 2005, and the second year covered June 2005, October 2005 and March 2006.

Sampling information was supplemented by interviews with local fishers. Questions in these interviews pertained to details of fishing activities, variability in water quality, variability in aquatic resources, the influence of sluice gates (before/after construction, open/closed periods) and relationships between water quality and aquatic resources.

### Description of the environment

Eight variables describing water quality were measured: water temperature (°C, thermometer); pH (probe); salinity (g/l, field probe); total dissolved solids (TDS, mg/l, weighing); dissolved oxygen concentration (DO, mg/l, Winkler method); hydrogen sulfide concentration ($H_2S$, mg/l, standard iodine method); ammonium concentration ($NH_4^+$, mg/l, indo-phenol blue method); and phosphate concentration ($PO_4^{3-}$, mg/l, molybdate-ascorbic acid method).

### Description of aquatic resources

Aquatic resources were sampled using two complementary methods: trawling and gillnet fishing.

*Trawling* is the dominant fishing method in the study area and has been recommended as the best sampling approach by most fishers during interviews (Baran and Chheng, 2004). Sampling was done with a local traditional bottom trawl on skates (1 × 4 m mouth and 25 mm mesh size), dragged for approximately 120 min along the canal. GPS was used to determine the geographic position of the boat, as well as ground speed and trawling distance. These trawl parameters were used to estimate the volume of sampled water required for calculating catch per unit effort (CPUE).

*Gillnet* fishing is commonly applied in estuarine zones (e.g. Fagade and Olaniyan, 1973; Dorr *et al*., 1985) and is standard in ichthyological studies (Lévêque *et al*., 1988). Sampling was undertaken three times in each season in the Ho Phong zone and two times in the other sampling zones, using two sets of nets made of three monofilament panels of different mesh sizes (10 mm, 20 mm and 40 mm). Each of these nets was 20 m long and 1 m high. At each site, these two sets were used simultaneously across canals, between 4.00 a.m. and 10.00 a.m.

Fish were preserved in formalin and then numbered, identified at the species level and measured and weighed individually. All data gathered were analysed at the laboratory of the College of Aquaculture and Fisheries of Can Tho University, Vietnam.

### Description of statistical methods used

The analysis of environmental patterns (eight continuous variables) and corresponding faunal patterns (species richness and CPUE) was done using principal components analysis (PCA). This multivariate method has proven very efficient for extracting and synthesizing information from chemical or environmental data (e.g. Wold *et al*., 1987) and to analyse animal/habitat relationships (e.g. Rottenberry and Wiens, 1981). The result of the analysis is a 'factorial map' that consists of the projection of the multi-dimensional space of variables on to an optimal plane, where correlations can be interpreted visually (Carrel *et al*., 1986). The nature of data analysed here (variables of different nature, multiple units) prompted us to use the centred and normalized option of the PCA.

The analysis focusing on species–environment dynamics was based on eight environmental variables and on trawling CPUE data; it was done with a correspondence analysis that emphasized species distribution (Thioulouse and Chessel, 1992). This analytical method enables a separation of phenomena in time and space and an identification of environmental gradients (Esteve, 1978; Prodon and Lebreton, 1981).

The software ADE-4 (Analyse de Données de l'Environnement; Thioulouse *et al*., 1997), freely available at http://pbil.univ-lyon1.fr, was used for this analysis.

Beyond standard factorial maps, the results have been presented in the form of choremes, i.e. conceptual maps displaying information or processes in a spatial context (Brunet, 1980, 1993). Choremes have been recommended to facilitate the communication of notions in a complex spatio-temporal context (Klippel, 2003; Klippel *et al*., 2005) and have been employed in this chapter to summarize processes and patterns influencing water quality and nekton parameters among sites, seasons and years.

## Results

### Environment

The study area is characterized by high variability between years, between seasons and between sampling zones (Table 2.1).

**Dry season (March)**. In March 2005 and 2006, water temperatures were relatively uniform over the study area (28.4–31.5 °C). The time of day when samples were taken may account for much of the variability. Water pH was relatively uniform among sites and campaigns (6.9–7.8), the water being slightly more basic near the river mouth because of the influence of seawater. Although water was brackish throughout the entire area, salinity was variable because of the operation of the sluice gates: in Ho Phong zone, salinity was low because it was measured while the gates were closed. At other sites, salinity was higher because sampling was done on the following day when the gates were opened; this highlighted the rapid effect of sluice gate operation on salinity. TDS closely followed salinity patterns. DO concentrations were not high (average 4.9 mg/l) but sufficient for most freshwater fishes of the region (Baran *et al*., 2007a). In March 2005, $H_2S$ concentration was variable but generally high, averaging 0.18 mg/l; this reflected a pollution level unsuitable for the development of eggs and larvae of many fish species. $NH_4^+$ levels were variable, but never critical to fish health (0.01–0.4 mg/l). $PO_4^{3-}$ was high (0.01–1.2 mg/l), particularly in March 2005, but was generally below the threshold triggering

**Table 2.1.** Environmental parameters in the study area (individual values in the 14 sampling sites have been averaged per zone).

| Campaign | Year | Month | Season | Zone | Temp | pH | Salinity | TDS | DO | $H_2S$ | $NH_4^+$ | $PO_4^{3-}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2004–2005 | 2004 | June | Acidic | Canal 8000 | 30.0 | 6.5 | 12.7 | 12.19 | 7.12 | 0.14 | 0.31 | 0.02 |
| | | | | Pho Sinh | 30.3 | 5.1 | 8.5 | 8.17 | 6.43 | 0.07 | 0.32 | 0.09 |
| | | | | Coast | 29.4 | 7.3 | 17.1 | 15.69 | 5.40 | 0.10 | 0.15 | 0.03 |
| | | | | Ho Phong | 29.5 | 6.7 | 16.2 | 16.56 | 6.16 | 0.16 | 0.62 | 0.01 |
| | | October | Flood | Canal 8000 | 29.8 | 7.1 | 4.7 | 4.60 | 4.05 | 0.52 | 0.29 | 0.03 |
| | | | | Pho Sinh | 29.9 | 6.9 | 1.1 | 1.11 | 2.45 | 0.21 | 0.18 | 0.07 |
| | | | | Coast | 29.8 | 7.2 | 7.0 | 6.75 | 6.48 | 0.45 | 0.34 | 0.03 |
| | | | | Ho Phong | 30.1 | 7.2 | 5.1 | 4.90 | 4.67 | 0.49 | 0.33 | 0.03 |
| | 2005 | March | Dry | Canal 8000 | 29.3 | 7.1 | 29.2 | 28.10 | 4.60 | 0.13 | 0.05 | 0.22 |
| | | | | Pho Sinh | 30.0 | 7.2 | 20.5 | 19.70 | 4.21 | 0.25 | 0.04 | 0.58 |
| | | | | Coast | 29.5 | 7.5 | 29.8 | 28.65 | 4.72 | 0.17 | 0.07 | 0.29 |
| | | | | Ho Phong | 29.7 | 7.3 | 29.7 | 30.10 | 3.57 | 0.16 | 0.03 | 0.26 |
| 2005–2006 | 2005 | June | Acidic | Canal 8000 | 30.6 | 7.2 | 27.7 | 26.57 | 2.22 | 0.03 | 0.47 | 0.19 |
| | | | | Pho Sinh | 30.2 | 6.5 | 17.6 | 16.87 | 2.95 | 0.08 | 0.73 | 0.14 |
| | | | | Coast | 30.3 | 7.6 | 22.9 | 22.00 | 4.56 | 0.30 | 0.18 | 0.06 |
| | | | | Ho Phong | 30.3 | 7.4 | 25.6 | 24.70 | 4.74 | 0.06 | 0.31 | 0.05 |
| | | October | Flood | Canal 8000 | 29.3 | 7.5 | 3.0 | 2.91 | 4.80 | 0.06 | 0.18 | 0.01 |
| | | | | Pho Sinh | 29.2 | 7.5 | 0.3 | 0.31 | 3.03 | 0.06 | 0.24 | 0.08 |
| | | | | Coast | 30.4 | 7.7 | 4.0 | 3.91 | 5.44 | 0.07 | 0.33 | 0.01 |
| | | | | Ho Phong | 29.6 | 7.6 | 3.8 | 3.82 | 5.76 | 0.06 | 0.22 | 0.02 |
| | 2006 | March | Dry | Canal 8000 | 29.3 | 7.0 | 30.4 | 29.30 | 5.65 | 0.01 | 0.04 | 0.06 |
| | | | | Pho Sinh | 29.7 | 7.6 | 18.7 | 18.27 | 3.79 | 0.02 | 0.12 | 0.05 |
| | | | | Coast | 30.8 | 7.7 | 30.2 | 28.80 | 6.52 | 0.01 | 0.02 | 0.05 |
| | | | | Ho Phong | 31.0 | 7.7 | 2.8 | 2.76 | 5.36 | 0.01 | 0.08 | 0.05 |

algal blooms. $PO_4^{3-}$ was more concentrated around Phuoc Long in the rice cultivation area (particularly in March 2005); in this zone, enrichment of canal waters with agricultural fertilizers is probable.

**Acidic season (June).** In June 2004 and 2005, temperature was uniform throughout the study area, averaging 30 °C. Although the range of pH values was similar between years (4.2–7.8), in June 2004 the water was acidic at 13 of the 14 sites, whereas in June 2005 it was acidic at only two sites. Water pH was, in general, lower near the sea and higher further inland, as a result of acidity leached out from the sulfate soils during the first rains of the monsoon season. Salinity decreased with increased distance from the sea, but only reached freshwater levels in the north-east corner of the study area. TDS closely followed salinity patterns, with the lowest concentrations in the north-east area. DO was unsuitable for fish at numerous sites. The $H_2S$ level was variable but higher in June 2004 than in June 2005 and generally unbearable for the early stages of fish species. $NH_4^+$ concentrations were quite variable (0.1–1.1 mg/l) and increased with increasing distance from the sea. $PO_4^{3-}$ levels were also highly variable among sites and between years, with the highest concentrations in secondary canals.

**Rainy season (October).** In October 2004 and 2005, water temperature was uniform throughout the study area (28.9–30.7 °C). Similarly, water pH was relatively uniform among sites and between campaigns (6.8–7.9). Two distinct salinity zones were evident each year: from the coast to the end of Canal 8000, where salinities were notably higher, and from Chu Chi to Ninh Quoi. Low salinity (0.1–8.5 g/l) in this latter zone reflected the influx of Mekong fresh water during this period. However, the maximum salinity in October 2005 was less than half that of October 2004, which reflected interannual differences in flood timing and/or intensity. TDS showed spatial and interannual variability similar to salinity. DO (1.52–7.52 mg/l) decreased with distance from the sea. $H_2S$ levels were highly variable in space, with higher concentrations at sites characterized by a higher population density. $H_2S$ concentrations were also notably higher in October 2004 than in October 2005, reaching a pollution level (0.84 mg/l) unsuitable for fish eggs and larvae. $NH_4^+$ levels were reasonably variable among sites but consistent between years (range: 0.15–0.52 mg/l). As in March, $PO_4^{3-}$ concentration was highest in the rice cultivation area around Ninh Quoi.

**Synthesis of water environmental parameters.** Temperature was relatively constant among all sites, seasons and years. Although salinity and pH were influenced by sluice gate operation, in general salinity and pH variations did follow the seasonal variation of rainfall and these differences were most pronounced at the north-east sites. Salinity peaked in March, which corresponded to the dry season and the period of greatest saline intrusion under natural conditions. Acidity peaked in June, particularly in the north-east sites, when the first rains of the year released acidity from the acid sulfate soils and washed it into canals. In October, during the monsoon, the canal water approached freshwater conditions, particularly in the north-east sites.

Although water quality parameters did vary seasonally as expected, March 2006 data showed that they were also clearly affected by the fact that the sluice gates were opened or closed at the time of sampling. Therefore, without details of gate operation, it was difficult to determine whether seasonal differences in observed concentrations described above were a result of changes in natural conditions or were the product of the water management regime. Rapid influxes of salt water when sluice gates were opened might also have influenced other parameters by diluting concentrations of pollutants. Environmental indicators also showed that the water was considerably more polluted in the first campaign than in the second, particularly in June and October. These trends were not identified in seasonal analyses, highlighting the value of long-term investigation.

Future studies should acknowledge that environmental data need to be considered in relation to sluice gate operation at the time of sampling. They should also consider interannual variability in order to understand fully the ecological context and to improve predictive

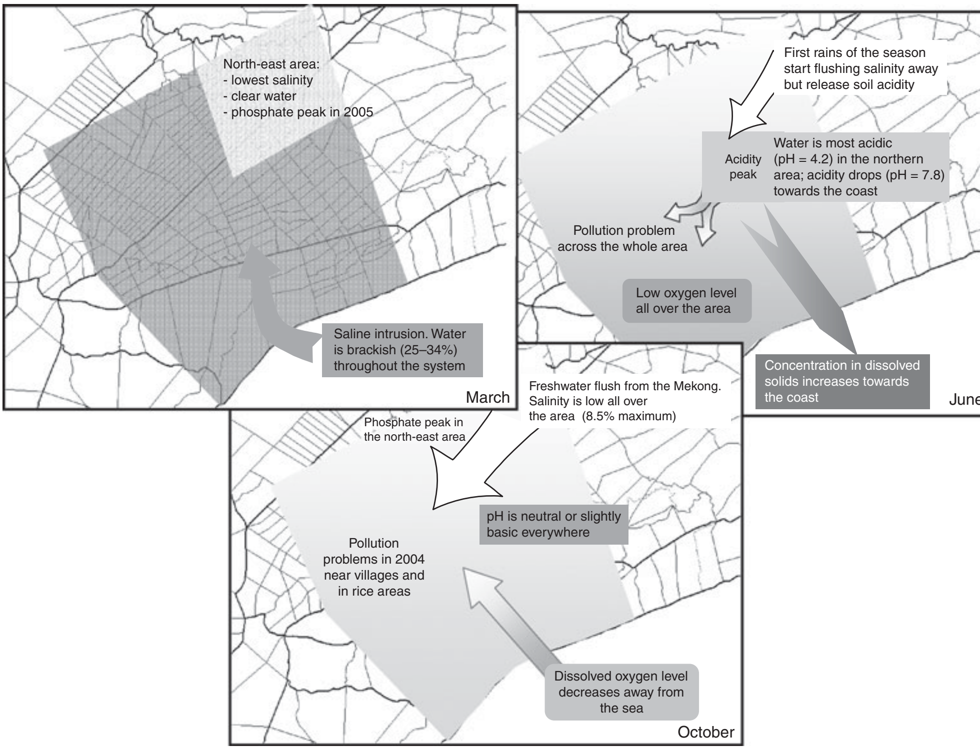


**Fig. 2.2.** Seasonal variation of water quality factors in the study area.

capabilities. An overview of the seasonal patterns is proposed in Fig. 2.2.

## Nekton

### *Nekton species richness*

The sampling of aquatic resources in the study area resulted in the catch and identification of 78 species, including 53 fish species (belonging to 36 families), 16 shrimp species (mainly Penaeids), six crab species and three miscellaneous species, as detailed in Table 2.2. It should be noted that one fish species, *Chimaera phantasma* (No 10), is a marine species known to live on continental shelf edges between 90 and 540 m deep; this probable misidentification is excluded from the analyses.

Of the 53 fish species, 11% are known in FishBase (see www.fishbase.org) as freshwater species, 15% as marine species and 74% as species found in brackish water (this latter category itself is comprised of 26% of species also caught in the marine realm, 12% of purely brackish origin and 36% of species also found in freshwater environments). Among the fish species on the list, six are considered in FishBase as reef-associated; it is surprising to find them inland in this brackish and turbid environment. Overall, 70 species were caught by trawler and 33 by gillnets. Forty-five species were caught by trawler only, eight by gillnets only and 25 species were caught using both gears. The use of gillnets in addition to trawlers increased the species richness of samples by 11%.

The analysis of species diversity in space and time (Table 2.3) shows that March, the period of high salinity, has higher species richness than June and October. This pattern is common in tropical estuarine zones and is explained by the richness of the marine realm, whose species make incursions into coastal zones during the dry/saline season (Baran *et al*., 1999; Baran, 2000).

In space, biodiversity seemed to be slightly higher at the two extreme sites of the study

**Table 2.2.** Nekton species sampled during the study.

| Family | Species name (Latin) | Species name (Vietnamese) | Water type | Habitat |
|---|---|---|---|---|
| Fish | | | | |
| Ambassidae | *Ambassis gymnocephalus* | *Cá són đầu trần* | F/B/M | Demersal |
| Ambassidae | *Ambassis nalua* | *Cá són* | F/B/M | Demersal |
| Anabantidae | *Anabas testudineus* | *Cá rô đồng* | F/B | Demersal |
| Ariidae | *Arius leptonotacanthus* | *Cá úc* | B/M | Demersal |
| Bagridae | *Mystus gulio* | *Cá chốt* | F/B | Demersal |
| Bagridae | *Mystus wolffii* | *Cá chốt* | F/B | Demersal |
| Carangidae | *Selar boops* | *Cá ngân* | M | Reef-associated |
| Carangidae | *Selaroides leptolepis* | *Cá chi vàng* | B/M | Reef-associated |
| Channidae | *Channa striata* | *Cá lóc* | F/B | Benthopelagic |
| Chimaeridae | *Chimaera phantasma* | *Cá chim* | M | Bathydemersal |
| Cichlidae | *Oreochromis niloticus* | *Cá rô phi* | F/B | Benthopelagic |
| Cichlidae | *Oreochromis* sp. | *Cá phi* | F/B | Benthopelagic |
| Clariidae | *Clarias batrachus* | *Cá trê trắng* | F/B | Demersal |
| Clariidae | *Clarias macrocephalus* | *Cá trê vàng* | F | Benthopelagic |
| Clupeidae | *Clupanodon thrissa* | *Cá mòi* | F/B | Pelagic |
| Cobitidae | *Botia modesta* | *Cá heo* | F | Demersal |
| Cynoglossidae | *Cynoglossus lingua* | *Cá lưỡi trâu* | F/B/M | Demersal |
| Cyprinidae | *Barbonymus gonionotus* | *Cá mè vinh* | F | Benthopelagic |
| Cyprinidae | *Rasbora lateristriata* | *Cá lòng tong* | F | Benthopelagic |
| Dasyatidae | *Himantura imbricata* | *Cá đuối* | F/B/M | Demersal |
| Eleotridae | *Butis butis* | *Cá bống trân* | F/B/M | Demersal |
| Eleotridae | *Eleotris balia* | *Cá bống trúng* | F/B/M | Demersal |
| Eleotridae | *Ophiocara porocephala* | *Cá bống sộp* | F/B/M | Demersal |
| Eleotridae | *Oxyeleotris urophthalmus* | *Cá bống dúa* | F/B | Demersal |
| Engraulidae | *Coilia rebentischii* | *Cá mào gà* | B/M | Pelagic |
| Engraulidae | *Setipinna taty* | *Cá lep trắng* | B/M | Pelagic |
| Engraulidae | *Stolephorus commersonii* | *Cá cóm* | B/M | Pelagic |
| Gobiidae | *Cryptocentrus russus* | *Cá bống sao* | M | Demersal |
| Gobiidae | *Glossogobius giuris* | *Cá bống cát* | F/B/M | Benthopelagic |
| Gobiidae | *Pseudapocryptes elongatus* | *Cá kèo* | F/B | Demersal |
| Gobiidae | *Trypauchen vagina* | *Cá bống kèo đỏ* | B/M | Demersal |
| Harpadontinae | *Harpadon nehereus* | *Cá khoai* | B/M | Benthopelagic |

*Continued*

**Table 2.2.** Continued.

| Family | Species name (Latin) | Species name (Vietnamese) | Water type | Habitat |
|---|---|---|---|---|
| Hemiramphidae | *Zenarchopterus pappenheimi* | *Cá lìm kìm gai* | B/M | Pelagic |
| Latidae | *Lates calcarifer* | *Cá chẽm* | F/B/M | Demersal |
| Mastacembelidae | *Macrognathus aculeatus* | *Cá chạch sông* | F/B | Benthopelagic |
| Mugilidae | *Mugil cephalus* | *Cá đối* | F/B/M | Benthopelagic |
| Muraenesocidae | *Congresox talabon* | *Cá lạc* | B/M | Demersal |
| Ophichthiidae | *Ophichthus rutidoderma* | *Cá lác dây* | F/B | Demersal |
| Osphronemidae | *Trichogaster microlepis* | *Cá sâc điệp* | F | Demersal |
| Osphronemidae | *Trichogaster trichopterus* | *Cá sặc bướm* | F | Benthopelagic |
| Platycephalidae | *Sorsogona tuberculata* | *Cá chai* | M | Demersal |
| Plotosidae | *Plotosus canius* | *Cá ngát* | F/B/M | Demersal |
| Polynemidae | *Eleutheronema tetradactylum* | *Cá chét* | F/B/M | Pelagic |
| Polynemidae | *Polynemus paradiseus* | *Cá phèn trắng* | F/B/M | Demersal |
| Scatophagidae | *Scatophagus argus* | *Cá nâu* | F/B/M | Reef-associated |
| Sciaenidae | *Pennahia pawak* | *Cá đâú* | M | Benthopelagic |
| Scombridae | *Scomberomorus commerson* | *Cá thu* | M | Reef-associated |
| Siganidae | *Siganus javus* | *Cá dìa* | B/M | Reef-associated |
| Sillaginidae | *Sillago aeolus* | *Cá nhống* | M | Demersal |
| Siluridae | *Wallago* sp. | *Cá gúng* | F/B | Demersal |
| Synbranchidae | *Ophisternon bengalense* | *Lịch* | F/B/M | Demersal |
| Synbranchidae | *Synbranchus bengalensis* | *Lịch* | F/B | Demersal |
| Synodontidae | *Saurida tumbil* | *Cá mối* | M | Reef-associated |
| Shrimps/prawns | | | | |
| Alpheidae | *Alpheus euphrosyne* | *Tôm tích sông* | | |
| Palaemonidae | *Exopalaemon styliferus* | *Tôm vát giáo* | | |
| Palaemonidae | *Macrobrachium equidens* | *Tôm trúng* | | |
| Palaemonidae | *Macrobrachium lar* | *Tép bầu* | | |
| Palaemonidae | *Macrobrachium rosenbergii* | *Tôm càng xanh* | | |
| Penaeidae | *Metapenaeopsis barbata* | *Tôm gậy* | | |
| Penaeidae | *Metapenaeus affinis* | *Tôm chì* | | |
| Penaeidae | *Metapenaeus ensis* | *Tôm dất* | | |

*Continued*

**Table 2.2.** Continued.

| Family | Species name (Latin) | Species name (Vietnamese) | Water type | Habitat |
|---|---|---|---|---|
| Penaeidae | *Metapenaeus lysianassa* | *Tép bạc* | | |
| Penaeidae | *Metapenaeus tenuipes* | *Tôm bạc* | | |
| Penaeidae | *Parapenaeopsis cultrirostris* | *Tôm sắt* | | |
| Penaeidae | *Parapenaeopsis gracillima* | *Tôm giang mỡ* | | |
| Penaeidae | *Penaeus merguiensis* | *Tôm thé* | | |
| Penaeidae | *Penaeus monodon* | *Tôm sú* | | |
| Penaeidae | *Penaeus semisulcatus* | *Tôm vằn* | | |
| Sergestidae | *Acetes vulgaris* | *Ruốc* | | |
| Crabs | | | | |
| Portunidae | *Charybdis affinis* | *Ghẹđá* | | |
| Portunidae | *Portunus pelagicus* | *Ghexanh* | | |
| Portunidae | *Scylla olivacea* | *Cua đá* | | |
| Portunidae | *Scylla serrata* | *Cua biển* | | |
| Parathelfusidae | *Somanniathelpusa* sp. | *Cua đồng* | | |
| Grapsidae | *Varuna litterata* | *Ghẹm* | | |
| Miscellaneous | | | | |
| Octopodidae | *Octopus marginatus* | *Bạch tuột* | Octopus | |
| Sepiidae | *Sepiella inermis* | *Mụ* | Squid | |
| Squillidae | *Harpiosquilla harpax* | *Tôm tích* | Squilla | |

F, fresh water; B, brackish water; M, marine.

**Table 2.3.** Aquatic species diversity in time and space in the study area.

| Campaign | Number of species | Season | Number of species | Zone | Number of species |
|---|---|---|---|---|---|
| 2004–2005 | 52 | March | 58 | Pho Sinh | 54 |
| 2005–2006 | 43 | June | 47 | Canal 8000 | 47 |
| | | October | 46 | Ho Phong | 49 |
| | | | | Coast | 56 |

area: (i) around Pho Sinh, the site most influenced by the Mekong River, reportedly the third most biodiversity-rich river system in the world (Dudgeon, 2000); and (ii) in the coastal zone (coastal zones being characterized globally by a very high biodiversity; Ricklefs, 1990).

### *Nekton abundance patterns*

Overall, the catch was very poor in the study area (Table 2.4), with very small fish caught and very small catches in gears (on average 55 g in gillnets and 373 g in trawl per fishing operation). The average individual weight of fish was 46 g, whereas that of shrimp amounted to 39 g; this indicated that the shrimps caught were mainly large individuals that had escaped from aquaculture ponds (as confirmed by farmers' interviews) and that the fish were just small individuals, possibly juveniles that are dominant in all tropical estuarine zones.

**Table 2.4.** Catch per gear during the study period.

| Gear | Campaign | Month | Abundance (number of individuals) | Biomass (g) | Average biomass (g) per individual | Average biomass (g) per fishing operation |
|---|---|---|---|---|---|---|
| Gillnet | 2004–2005 | March | 7 | 190 | 27.2 | 27 |
| | | June | 52 | 451 | 8.6 | 64 |
| | | October | 59 | 1088 | 18.4 | 155 |
| | 2005–2006 | March | 34 | 719 | 21.2 | 60 |
| | | June | 2 | 26 | 13.0 | 4 |
| | | October | 8 | 153 | 19.1 | 22 |
| Trawl | 2004–2005 | March | 4097 | 5352 | 1.3 | 446 |
| | | June | 410 | 2416 | 5.9 | 201 |
| | | October | 962 | 4149 | 4.3 | 346 |
| | 2005–2006 | March | 2844 | 6952 | 2.4 | 579 |
| | | June | 1797 | 3825 | 2.1 | 319 |
| | | October | 1690 | 4134 | 2.4 | 345 |

The overall temporal variability and spatial variability of the aquatic resources are shown in Table 2.5. Results are based on trawling, whose catch per fishing session is 6.7 times higher than that of gillnets and almost double in terms of species richness.

**Interannual variability.** Interannual variations of aquatic resources were highly significant, with the trawling CPUE being 59% higher in the second campaign than in the first. The total number of species, however, was comparable between years. A detailed analysis of species caught showed that *Penaeus merguiensis* dominated samples in 2005, accounting for more than 50% of the total catch, but was barely present in 2006.

**Seasonal variability.** Variations of aquatic resources between seasons were also high, with 67% variation between the months of least abundance (June and October) and the month of highest abundance (March). Thus, for aquatic resources, the season of highest abundance is the dry season, which is also the season of highest biodiversity.

**Geographic variability.** The zone with the highest abundance of aquatic resources was Ho Phong, but the variability was not very high between Ho Phong, Pho Sinh and the coastal zone; Canal 8000, in contrast, clearly had the least abundant aquatic resources and the lowest biodiversity, possibly because this zone was characterized by acid sulfate soils. A detailed analysis showed that in the first sampling campaign, CPUE (biomass) was highest in the coastal zone and decreased further inland, suggesting the dominance of marine and estuarine species. However, in the second campaign, there was ambiguity about March 2006, as the sluice gates were opened during the sampling

**Table 2.5.** Average catch per unit effort in time and space (g/m$^3$ trawled).

| Campaign | Average catch per unit effort | Season | Average catch per unit effort | Area | Average catch per unit effort |
|---|---|---|---|---|---|
| 2004–2005 | 0.039 | March | 0.069 | Pho Sinh | 0.059 |
| 2005–2006 | 0.062 | June | 0.041 | Canal 8000 | 0.031 |
| Variation (%) | 59 | October | 0.042 | Ho Phong | 0.062 |
| | | Variation (%) | 67 | Coast | 0.050 |
| | | | | Variation (%) | 104 |

period, which might have modified the fish distribution pattern significantly.

Complementary gillnet sampling (also possible in secondary canals, unlike trawling), showed that the catch was much lower in secondary canals than in primary canals. This result was consistent with other studies that concluded that fish diversity and abundance were proportional to the size of the estuarine water body sampled (Baran, 1995, 2000).

## Relationships between aquatic resources and the environment

The relationship between aquatic resources and environmental parameters is analysed below in terms of: (i) environmental variability and biodiversity descriptors; and (ii) environmental variability and dominant species. Again, analyses were based on trawling CPUE data, since trawling caught 6.7 times more biomass per operation and, overall, two times more species than gillnets.

### *Environmental variability and biodiversity descriptors*

The analysis of environmental and biodiversity variability is based on the eight environmental variables referred to in Table 2.1, on trawling CPUEs and on species richness as global descriptors of the biodiversity. The method used is a correlation matrix PCA (e.g. centred and normalized PCA, justified by the presence of multiple variables all continuous but of different units; see Nichols, 1977, and Wold *et al.*, 1987). In the figures below, the factorial maps of sites and variables were superimposed for interpretation (Carrel *et al.*, 1986).

The PCA eigenvalues indicate that 49.8% of the total information in the data (e.g. total inertia) is summarized in the first two axes and that the first four axes represent 75.6% of the total information of the data set. Emphasis is thus put below on the first two axes and complemented by the following two axes (Fig. 2.3).

The factorial map clearly highlights the correlation between species richness and salinity or concentration of dissolved solids (e.g. marine influence; left-hand part of the factorial map). Actually, all the sites are associated with high values of salinity and TDS; this reflects the homogenization of the whole area that is species rich and under strong marine influence in March and, to some extent, in June. As opposed to this pattern, the distribution in October (upper right corner of the factorial map) is also relatively homogeneous (dots of all areas are close) but characterized by low turbidity and fresh water (anticorrelation with salinity and dissolved solids). Therefore, a first cluster defines a marine–freshwater gradient and its associated sites over time.

On the second axis (vertical), high CPUE is illustrated by a particular zone: Ho Phong, in March 2006, whose CPUE is four times higher than the average CPUE in all other samples. The high CPUE is mainly a result of *Parapenaeopsis cultrirostris*, *Metapenaeus tenuipes* and *M. affinis*. It is also clear that high CPUE and species richness (upper left corner of the map) are anticorrelated to high levels of ammonium and hydrogen sulfide (lower right corner of the map): this illustrates clearly the negative impact of pollution on the abundance and diversity of aquatic resources in the study area. Therefore, a second cluster defines an aquatic resources–pollution gradient.

Interestingly, all stations characterized by high pollution pertain to the first campaign (year 2004–2005) and to the months of June and October exclusively, which indicates that the Mekong flood does not suffice to dissolve or eliminate the pollution, and that allowing marine influence through the opening of the sluice gates is beneficial to both pollution level and abundance of aquatic resources.

On the second map, the third axis of the PCA is dedicated to the anticorrelation between pH and temperature, which clarifies the first map where temperature and pH are projected in the same area and results in the impression that they are correlated. The fourth axis highlights the negative correlation between dissolved oxygen and temperature, another anticorrelation well known in environmental data.

Figure 2.3 is distilled further to become a choreme, i.e. a two-dimensional figure expressing spatio-temporal processes (but usually based on geographic maps, not on factorial maps); it synthesizes the evolution over time of the study sites in terms of faunal and environmental factors (Fig. 2.4).

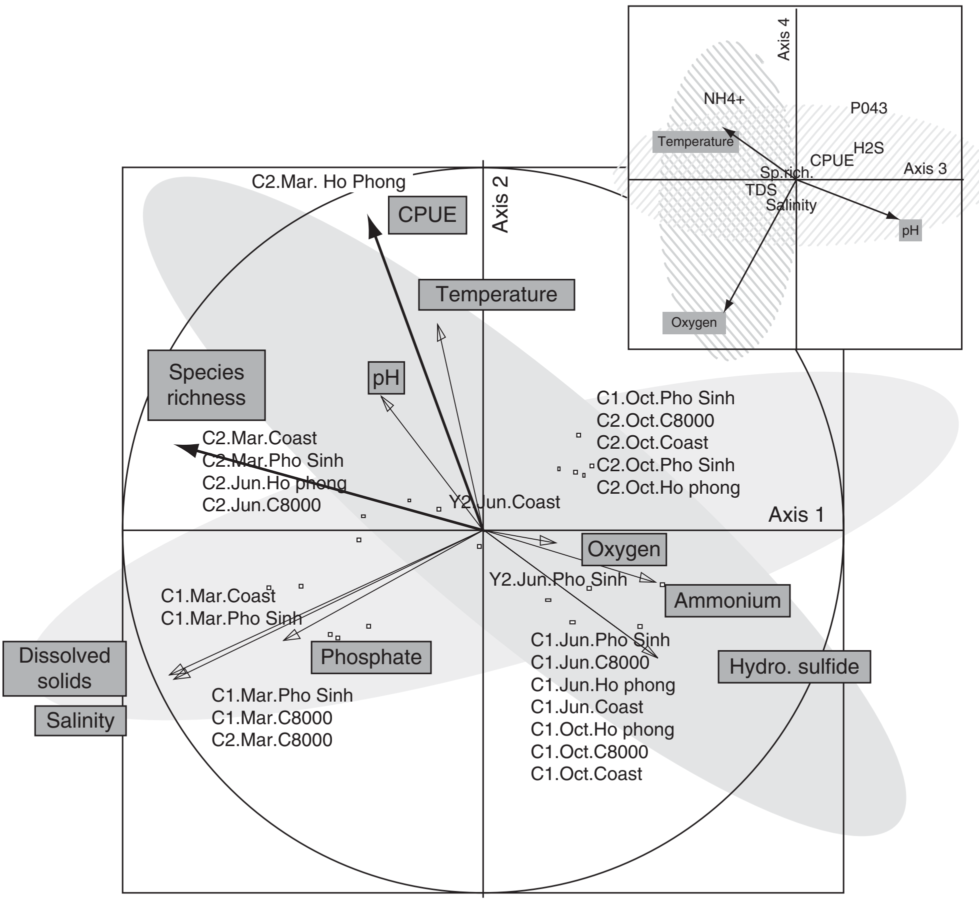


**Fig. 2.3**. Factorial maps of the PCA on environmental and biodiversity variables. Sites are identified by campaign, then month, then zone (e.g. C2.Oct.C8000 = 2005–2006, October, Canal 8000).

Figure 2.4 shows the evolution of the area over time between four main poles: marine, freshwater, pollution and aquatic resources. June 2004 was the campaign characterized by most pollution and the lowest level of aquatic resources; then the situation evolved, with a seasonal fluctuation between marine and freshwater patterns, towards a better ecological situation characterized in March 2006 by the lowest pollution level and the highest abundance and diversity. This improvement in terms of aquatic resources and pollution can be related to opening of the sluice gates (longer in 2006 than in 2004 and 2005), also reflected by a higher salinity in 2006.

Figure 2.4 also clearly indicates that biomass and diversity of aquatic resources are opposed to pollution (the latter being related to the rice-growing eastern part of the study area) and are correlated conversely to both marine and freshwater influences. Thus, both saline intrusion and the Mekong flood play a role in the aquatic biodiversity and biomass of the study area. The consequence of this result is that an environmental modification permanently favouring one single influence (in particular the freshwater influence) would be detrimental to aquatic resources and to the productivity of the area.

### *Environmental variability and dominant species*

This analysis is comprised of two phases: (i) selection of dominant species for quantitative

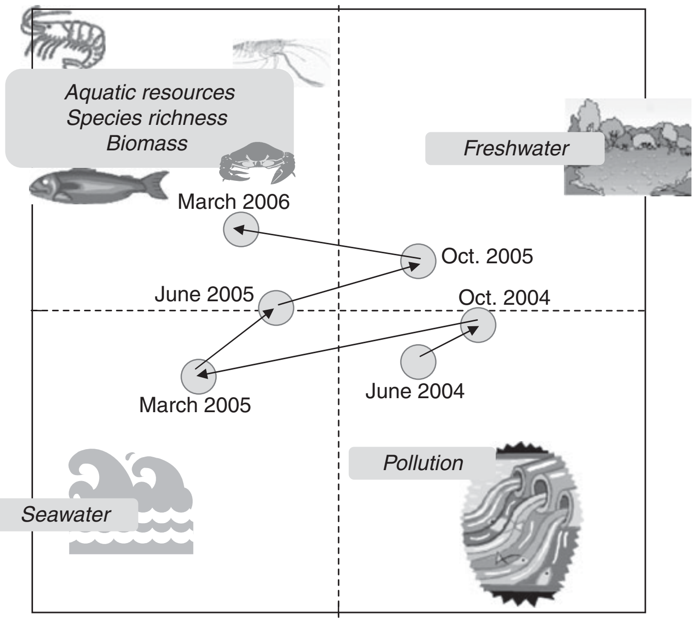


**Fig. 2.4.** Relationships between major environmental factors and aquatic resources in space and time.

analyses; and (ii) environmental dynamics and corresponding species.

Selection of dominant species for quantitative analyses: the application of a quantitative approach requires the exclusion of the species present only once or twice in the samples, whose nil records bias the calculation of correlation coefficients. Dominant species were identified by considering both their abundance and biomass, so that small but abundant species totalling a low biomass as well as rare but big species were not excluded (Fig. 2.5). Twenty-three species were retained out of 55 species caught by the trawler during the two campaigns. These species represented 89% of the total biomass and 95% of the total abundance in the total catches.

Environmental dynamics and corresponding species: the correspondence analysis indicates a very strong structure, with 89% of the total inertia on the first axis and 93% of the information summarized in the first two axes (Fig. 2.6).

The analysis confirms a clear gradient between marine and freshwater influences similar to that of environmental factors, but this time identifies associated species. In March, when the environment is characterized by high salinity and a high level of dissolved solids, the fish species associated are *Coilia* and *Setipinna*, two abundant *Engraulidae* (anchovies) that are typical of coastal zones. Among shrimps, two wild *Palaemonidae* and a *Penaeidae* characterize the community in tropical coastal zones (there are, however, reservations about the identification of *P. gracillima,* which usually exists only at the straits of Malacca and Borneo).

The middle of the gradient is characterized by high environmental variability, in which the species composition in March at some sites (e.g. Ho Phong) can be similar to that in June at other sites (e.g. coastal area). Species of this environment are typically estuarine, such as gobies, mullets or croakers (respectively, *Glossogobius, Mugil* and *Pennahia*), and alpheid or penaeid shrimps.

October is characterized by fresh water and by salinity-tolerant species originating from the freshwater realm: tilapias (*Oreochromis* sp., usually cultured in ponds) or catfishes (*Mystus gulio*, *Clarias batrachus*). The presence of these species in all sites from Pho Sinh to the coastline highlights the homogenization of the study area in October from a faunal viewpoint.

The river shrimp *Macrobrachium rosenbergi* (tolerant to brackish water) and the tiger

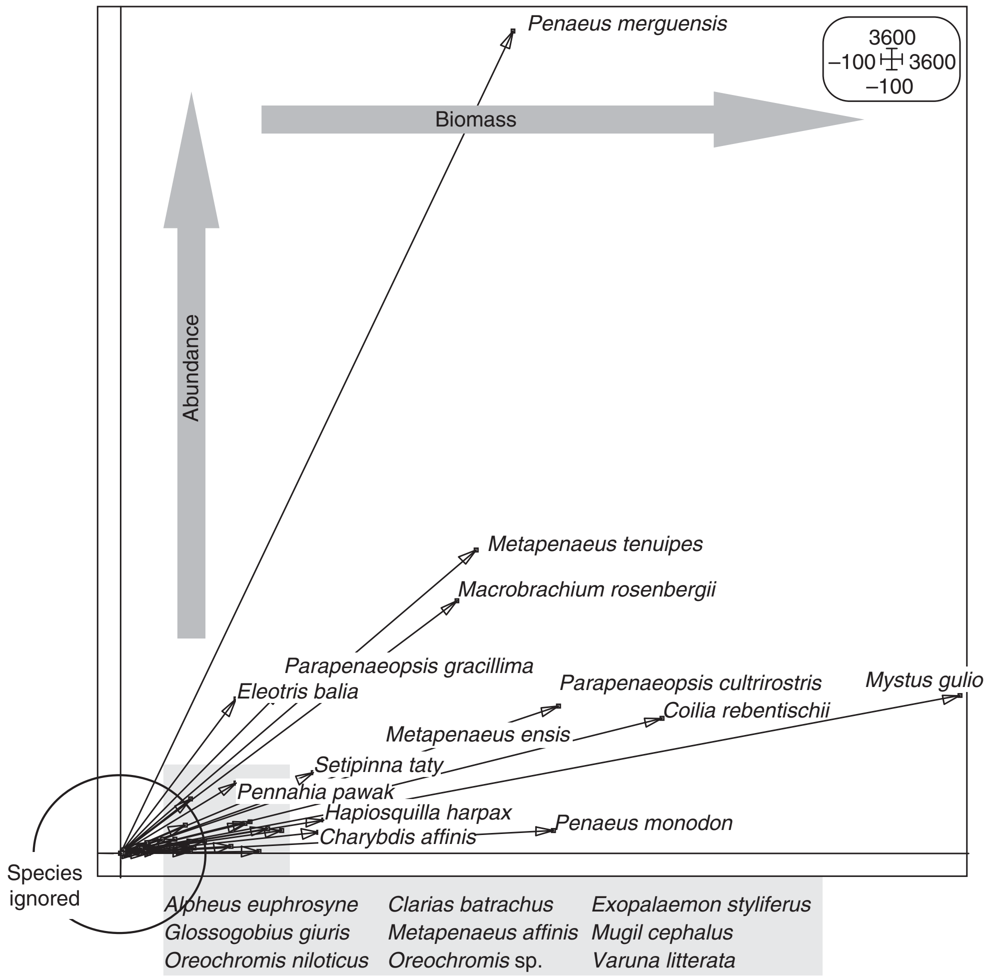


**Fig. 2.5.** Selection of dominant species based on their total biomass and abundance among the species sampled.

prawn *P. monodon* (tolerant to low salinities) are typical of estuarine waters; these giant decapods probably both originate from aquaculture farms, as underlined by fishers in interviews.

## Discussion and Conclusions

This study, which characterizes the aquatic and environmental variability of the area subject to water management in Bac Lieu Province, has highlighted the following points:

- The temporal variability corresponds to three main seasons: March, or dry season, June, or acidic season, and October, or freshwater season. Salinity peaks in March and pH peaks in June, particularly in the north-east corner of the area, when the first monsoon rains release acidity from the acid sulfate soils. This latter area is under the influence of rainfall and freshwater Mekong pulses and approaches freshwater conditions in October during the peak of the monsoon. The study led by Dung *et al*. (2002) confirms that salinity is the parameter that varies most between seasons, but does not highlight the pH peak in June because of lack of sampling in this month.

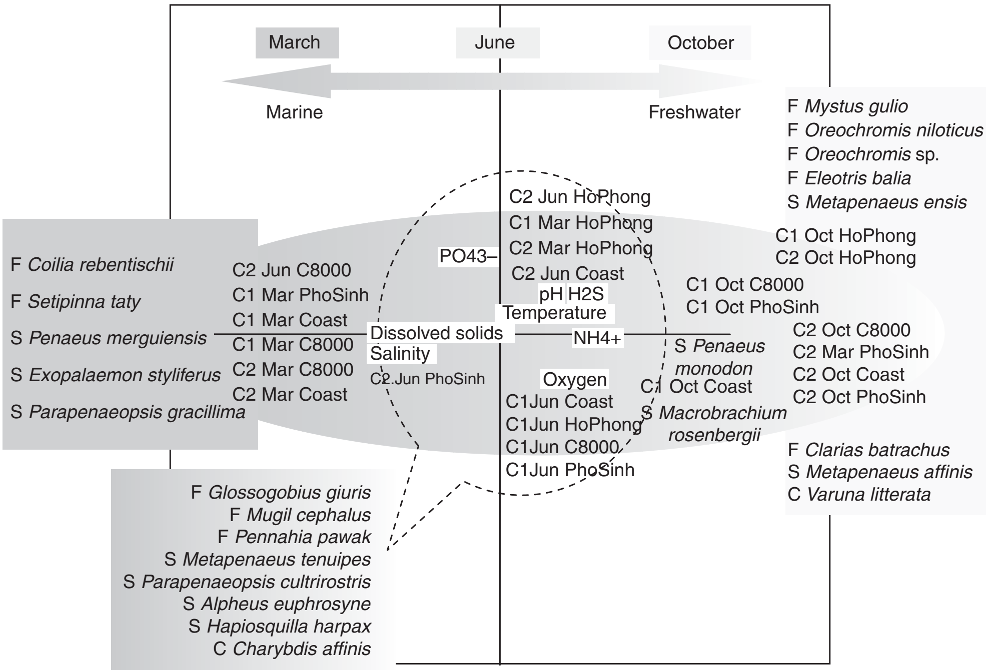


**Fig. 2.6.** Factorial map of the correspondence analysis combining sites, environmental factors and dominant species (sites are identified by campaign, then month, then zone, and species names are preceded by F for fish, S for shrimps and C for crabs).

- Superimposed on the natural environmental variability is a shorter-term variability induced by the operation of the sluice gates; it is reflected but not fully integrated in the current study. Future environmental studies should definitely integrate sluice gate operation and should also consider interannual variability in order to understand the results fully and improve predictive capabilities.
- The aquatic resources sampled included 78 species, comprising 53 fish species, 16 shrimp species and six crab species. This makes the study site relatively rich, considering its surface area, and this biodiversity results from a succession and overlap of marine, estuarine and freshwater faunas, depending on environmental conditions. Species richness is highest in March during the period of peak salinity when marine species make incursions into the estuarine zone. In 2002, Dung *et al.* sampled only 43 species; however, the number of species collected in each sampling session was similar in both studies. This shows that the greater number of species sampled by the present study (and thus the more representative description provided) is mainly a result of additional sampling in June in our study. Only 14 fish species and six shrimp species were common to both studies; less brackish/marine and no exclusively marine species were sampled by Dung *et al.* in 2002. This relatively low level of congruence between the two studies can be attributed to a strong interannual variability (see below). The causes of this variability can be natural (e.g. influenced by the Mekong flood in each year) or human induced (closing or opening of the sluice gates or pollution in some years, as highlighted in our study).
- In contrast to a high species richness, our study shows that abundance is poor, with an average catch of 55g in gillnets and 373g in trawls after 2h. The individual weight of the fish is also small (46g),

whereas that of shrimp amounts to 39g; this indicates that the shrimp are, in fact, mainly large prawns that have escaped from aquaculture farms.

- Interannual variation is substantial in the study area, with a 60% difference in fish catches from year to year. Seasonal variation is also high, with a 67% difference between the months of least abundance (June and October) and the month of highest abundance (March). Spatially, there is little variation in abundance among the different sites, with the exception of Canal 8000, where abundance is less; abundance is also lower in secondary canals than in primary canals.
- There is a high correlation between species richness and salinity and/or the concentration of dissolved solids, i.e. with the marine influence, which is often the case in tropical estuarine environments, where tolerant species from the rich marine realm make incursions (Baran, 2000). Overall, species distribution and assemblage composition is influenced largely by salinity; this is confirmed by Dung *et al*. (2002). Among marine species making incursions inland are anchovies (*Coilia* and *Setipinna* species), as well as shrimps *P. merguiensis* and *Exopalaemon styliferus*. The purely estuarine area is characterized, in March and June in particular, by a high environmental variability and by gobies, mullets or croakers, as well as by alpheid or penaeid shrimps (such as *P. monodon*, which probably originates from aquaculture farms). In October, the system is under a strong freshwater influence that spreads over the entire area and homogenizes the ecosystem, which is then characterized by salinity-tolerant freshwater species (e.g. tilapias, catfishes or *M. rosenbergi* prawns).
- A clear negative correlation can also be noted between pollution (in particular in the populated and rice-growing areas) and the abundance and diversity of aquatic resources. Results also show that the Mekong flood itself is not sufficient to dissolve or eliminate the pollution. This intrusion of Mekong water and fauna, on the other hand, contributes, although not dominantly, to the diversity and abundance of aquatic resources in the study area. In fact, it is the *marine* influence that is most beneficial to the abundance and diversity of aquatic resources in that area. Data gathered over 2 years show a situation gradually improving (despite seasonal variations) from pollution in a freshwater context with low diversity and abundance in 2004, towards more abundance and diversity in a more saline and less polluted context in 2006.
- Interviews with local fishers reiterated the impact that the sluice gates had on water quality and on the type and abundance of aquatic resources. It is clear from these interviews that pollution and acidity are two important factors driving fish abundance, and that pollution becomes a problem when the gates remain closed for extended periods of time. According to fishermen, catches are generally best during periods of marine influence, i.e. during the dry season or when the gates are opened. This is particularly true for shrimp, as when the gates are opened, wild marine shrimp enter the system and are targeted by fishers. When the gates are closed, shrimp catches are dominated by individuals that have escaped from aquaculture ponds or are diseased shrimps released from aquaculture ponds being emptied for cleaning. Because of the lack of a detailed operating schedule of the sluice gates during the whole study period, we could not address, unfortunately, the relationship between gate openings and CPUE or species richness. However, our results make it clear that from the perspective of aquatic biodiversity, the permanent closure of the sluice gates is detrimental to both biodiversity and fish abundance in canals.

Finally, this chapter, although mainly descriptive, contributes to the development of a fine-tuned management approach to the Bac Lieu aquatic environment. This environment, and the fish resources it sustains, makes a significant contribution to the province's productivity and food security (Gowing *et al*., 2006b). However, conflicts between rice, fish and shrimp production requirements call for a better knowledge of all these commodities. Although rice and shrimp production are well known, natural fish production in the canals has been almost undocumented to date, despite its significant contribution to the diet and livelihoods of local communities in the area (Baran *et al.*, 2007b). This highlights the need to integrate in water management models and initiatives, aquatic resources having significant environmental and social dimensions.

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## References

Baran, E. (1995) *Spatio-temporal Dynamics of Estuarine Fish Assemblages in Guinea – Relationships with Abiotic Factors. TDM Volume 142*. Éditions ORSTOM, Paris.

Baran, E. (2000) Biodiversity of estuarine fish faunas in West Africa. *NAGA* 23(4), 4–9.

Baran, E. and Chheng, P. (2004) Analysis of Bac Lieu fishery monitoring data (March 2004) and sampling recommendations. Report for the project 'Managing Water and Land Resources for Sustainable Livelihoods at the Freshwater/Saline Interface in Vietnam and Bangladesh'. WorldFish Center, Phnom Penh, Cambodia.

Baran, E., Albaret, J.J. and Diouf, P.S. (1999) Mangrove fish communities in West Africa. In: Cormier-Salem, M.C. (ed.) *Rivières du Sud – Sociétés et Mangroves Ouest-africaines*. IRD Éditions, Paris, pp. 98–117.

Baran, E., Jantunen, T. and Chheng, P. (2006) Developing a consultative Bayesian model for integrated management of aquatic resources: an inland coastal zone case study. In: Hoanh, C.T., Tuong, T.P., Gowing, J.W. and Hardy, B. (eds) *Environment and Livelihoods in Tropical Coastal Zones. Managing Agriculture–Fishery–Aquaculture Conflicts*. CAB International, Wallingford, UK, pp. 206–218.

Baran, E., Jantunen, T., Chheng, P. and Hakalin, M. (2007a) BayFish — Tonle Sap: a model of the Tonle Sap fish resource. Report for the project 'Influence of Built Structures on the Fisheries of the Tonle Sap'. WorldFish Center, Phnom Penh, Cambodia.

Baran, E., Jantunen, T. and Chong, C.K. (2007b) *Values of Inland Fisheries in the Mekong River Basin*. WorldFish Center, Phnom Penh, Cambodia.

Brunet, R. (1980) La composition des modèles dans l'analyse spatiale. *L'Espace Géographique* 4, 253–265.

Brunet, R. (1993) Building models for spatial analysis. In: GIP-RECLUS (ed.) *Two Decades of l'Espace Geographique*. GIP-RECLUS, Montpellier, France, pp. 109–123.

Carrel, G., Barthelemy, D., Auda, Y. and Chessel, D. (1986) Approche graphique de l'analyse en composantes principales normée: utilisation en hydrobiologie. *Acta Oecologica, Oecologia Generalis* 7(2), 189–203.

Chheng, P. (2004a) Analysis of the fishery monitoring data (June 2004) and sampling recommendations. Report for the project 'Managing Water and Land Resources for Sustainable Livelihoods at the Freshwater/Saline Interface in Vietnam and Bangladesh'. WorldFish Center, Phnom Penh, Cambodia.

Chheng, P. (2004b) Analysis of the fishery monitoring data (October 2004) and sampling recommendations. Report for the project 'Managing Water and Land Resources for Sustainable Livelihoods at the Freshwater/Saline Interface in Vietnam and Bangladesh'. WorldFish Center, Phnom Penh, Cambodia.

Chheng, P. and Toan, V.T. (2005a) Analysis of the fishery monitoring data (October 2005) and sampling recommendations. Report for the project 'Managing Water and Land Resources for Sustainable Livelihoods at the Freshwater/Saline Interface in Vietnam and Bangladesh'. WorldFish Center, Phnom Penh, Cambodia.

Chheng, P. and Toan, V.T. (2005b) Analysis of the fishery monitoring data (March 2005) and sampling recommendations. Report for the project 'Managing Water and Land Resources for Sustainable Livelihoods at the Freshwater/Saline Interface in Vietnam and Bangladesh'. WorldFish Center, Phnom Penh, Cambodia.

Dorr, J.A. III, Schneeberger, P.J., Tin, H.T. and Flath, L.E. (1985) *Studies on Adult, Juvenile and Larval Fishes of the Gambia River, West Africa, 1983–1984. Great Lakes and Marine Waters Center International Programs*. The University of Michigan, Ann Arbor, Michigan.

Dudgeon, D. (2000) Large-scale hydrological changes in tropical Asia: prospects for riverine biodiversity. *BioScience* 50(9), 793–806.

Dung, D.T., Cong, N.C. and Prein, M. (2002) Detrend of nectonic species assemblage in the salinity intrusion area of Bac Lieu Province, Mekong Delta, Vietnam. Paper presented at the Mid-term Review of the DfID-CRF R7467C Project, 26–28 June 2002, Bac Lieu, Vietnam.

Esteve, J. (1978) Les méthodes d'ordination: éléments pour une discussion. In: Legay, J.M. and Tomassone, R. (eds) *Biométrie et écologie*. Société Française de Biométrie, Paris, pp. 223–250.

Fagade, S.O. and Olaniyan, C.I.O. (1973) Seasonal distribution of the fish fauna of the Lagos Lagoon. *Bulletin de l'IFAN* 34A(1), 244–252.

Gowing, J.W., Tuong, T.P., Hoanh, C.T. and Khiem, N.T. (2006a) Social and environment impact of rapid change in the coastal zone of Vietnam: an assessment of sustainability issues. In: Hoanh, C.T., Tuong, T.P., Gowing, J.W. and Hardy, B. (eds) *Environment and Livelihoods in Tropical Coastal Zones. Managing Agriculture–Fishery–Aquaculture Conflicts*. CAB International, Wallingford, UK, pp. 48–60.

Gowing, J.W., Tuong, T.P. and Hoanh, C.T. (2006b) Land and water management in coastal zones: dealing with agriculture–aquaculture–fishery conflicts. In: Hoanh, C.T., Tuong, T.P., Gowing, J.W. and Hardy, B. (eds) *Environment and Livelihoods in Tropical Coastal Zones. Managing Agriculture–Fishery–Aquaculture Conflicts*. CAB International, Wallingford, UK, pp. 1–16.

Hoanh, C.T. (1996) Development of a computerized aid to integrated land use planning (CAILUP) at regional level in irrigated areas: a case study for the Quan Lo Phung Hiep region in the Mekong Delta, Vietnam. International Institute for Aerospace Survey and Earth Science (ITC) Publication No 38, Enschede, the Netherlands.

Hoanh, C.T., Tuong, T.P., Kam, S.P., Phong, N.D., Ngoc, N.V. and Lehmann, E. (2001) Using GIS-linked hydraulic model for managing water quality conflict for shrimp and rice production in the Mekong River Delta, Vietnam. In: Ghassemi, F., Post, D., Sivapalan, M. and Vertessy, R. (eds) *Proceedings of International Congress on Modelling and Simulation (MODSIM)*, Canberra, Australia, 10–13 December, 2001. Volume 1: Natural Systems (Part one). Modelling and Simulation Society of Australia and New Zealand, Canberra, Australia, pp. 221–226 (http://www.mssanz.org.au/html/body_publications.html, accessed 10 October 2008).

Hoanh, C.T., Tuong, T.P., Gallop, K.M., Gowing, J.W., Kam, S.P., Khiem, N.T. and Phong, N.D. (2003) Livelihood impacts of water policy changes: evidence from a coastal area of the Mekong river delta. *Water Policy* 5, 475–488.

Hoanh, C.T., Tuong, T.P., Gowing, J.W. and Hardy, B. (2006a) *Environment and Livelihoods in Tropical Coastal Zones. Managing Agriculture–Fishery–Aquaculture Conflicts*. CAB International, Wallingford, UK.

Hoanh, C.T., Phong, N.D., Gowing, J.W., Tuong, T.P., Hien, N.X. and Dat, N.D. (2006b) Predicting impacts of water management in coastal zones by hydraulic and salinity modeling. In: Voinov, A., Jakeman, A. and Rizzoli, A. (eds) *Proceedings of the iEMSs Third Biennial Meeting 'Summit on Environmental Modelling and Software'*. International Environmental Modelling and Software Society, Burlington, Vermont.

Kam, S.P., Hoanh, C.T., Tuong, T.P., Khiem, N.T., Dung, L.C., Phong, N.D., Barr, J. and Ben, D.C. (2001) Managing water and land resources under conflicting demands of shrimp and rice production for sustainable livelihoods in the Mekong River Delta, Vietnam. Proceeding of the Workshop on 'Integrated Management for Sustainable Agriculture, Forestry and Fisheries', 28–31 August 2001. CIAT, Cali, Colombia.

Kam, S.P., Nhan, N.V., Tuong, T.P., Hoanh, C.T., Be Nam, V.T. and Maunahan, A. (2006) Applying the resource management domain (RMD) concept to land and water use and management in the coastal zone: case study of Bac Lieu Province, Vietnam. In: Hoanh, C.T., Tuong, T.P., Gowing, J.W. and Hardy. B. (eds) *Environment and Livelihoods in Topical Coastal Zones. Managing Agriculture–Fishery–Aquaculture Conflicts*. CAB International, Wallingford, UK, pp. 293–205.

Khoa, T.T. and Huong, T.T.T. (1993) Freshwater fish classification in the Mekong Delta. Faculty of Fisheries – Can Tho University, Vietnam.

Klippel, A. (2003) Wayfinding choremes. In: Kuhn, W., Worboys, M. and Timpf, S. (eds) *Spatial Information Theory. Foundations of Geographic Information Science*. Springer-Verlag, Berlin, pp. 349–361.

Klippel, A., Tappe, H., Kulik, L. and Lee, P.U. (2005) Wayfinding choremes: a language for modeling conceptual route knowledge. *Journal of Visual Languages and Computing* 16(4), 311–329.

Lévêque, C., Fairhurst, C.P., Abban, K., Paugy, D., Curtis, M.S. and Traore, K. (1988) Onchoceriasis control program in West Africa: ten years monitoring of fish populations. *Chemosphere* 17(2), 421–440.

Nichols, S. (1977) On the interpretation of principal components analysis in ecological contexts. *Vegetatio* 34, 191–197.

Prodon, R. and Lebreton, J.D. (1981) Breeding avifauna of a Mediterranean succession: the holm oak and cork oak series in the eastern Pyrénées. 1-Analysis and modelling of the structure gradient. *Oïkos* 37, 21–38.

Ricklefs, R.E. (1990) *Ecology*. Freeman, New York.

Rottenberry, J.T. and Wiens, J.A. (1981) A synthetic approach to principal component analysis of bird/habitat relationships. In: Capen, D.E. (ed.) *The Use of Multivariate Statistics in Studies of Wildlife Habitat*. USDA Forest Service General Technical Report, RM-87, Rocky Mountain Forest and Range Experiment Station, Fort-Collins, Colorado, pp. 197–208.

Thioulouse, J. and Chessel, D. (1992) A method for reciprocal scaling of species tolerance and sample diversity. *Ecology* 73, 670–680.

Thioulouse, J., Chessel, D., Dolédec, S. and Olivier, J.M. (1997) ADE-4: a multivariate analysis and graphical display software. *Statistics and Computing* 7(1), 75–83.

Toan, V.T. and Chheng, P. (2005) Analysis of the fishery monitoring data (June 2005) and sampling recommendations. Report for the project 'Managing Water and Land Resources for Sustainable Livelihoods at the Freshwater/Saline Interface in Vietnam and Bangladesh'. WorldFish Center, Phnom Penh, Cambodia.

Tran, Q.B., Nguyen, V.H. and Dehairs, F. (2005) Behavior of nutrients in natural river and shrimp farming area in Bac Lieu Province, Mekong Delta. *Proceedings of the International Symposium 'Sustainable Development in the Mekong River Basin'*, 6–7 October 2005, Ho Chi Minh City, Vietnam. JST–CREST (Japan Science and Technology Agency – Core Research for Environmental Science and Technology project), Tsukuba, Japan, pp. 80–89.

Tuong, T.P., Kam, S.P., Hoanh, C.T., Dung, L.C., Khiem, N.T., Barr, J. and Ben, D.C. (2003) Impact of seawater intrusion control on the environment, land use and household incomes in a coastal area. *Journal of Paddy and Water Environment* 1(2), 65–73.

Wold, S., Esbensen, K. and Geladi, P. (1987) Principal component analysis. *Chemometrics and Intelligent Laboratory Systems* 2, 37–52.

Yen, M.D. and Trong, N.V. (1988) Species composition and distribution of the freshwater fish fauna of Southern Vietnam. *Hydrobiologia* 160, 45–51.

# 3 Integrating Aquaculture in Coastal River Planning: the Case of Dagupan City, Philippines

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**Abstract**

In the Philippines, conflicts between fishing, aquaculture, tourism and other uses of the coastal waters are common because they are not clearly integrated into the management of the coastal zone. Resource use allocation then remains a challenging task for decision makers. Development activities that proceed without proper planning lead to more resource use conflicts and environmental degradation. This chapter presents the findings of a study to identify a strategy for incorporating aquaculture into coastal planning to reduce conflicts in the use of the coastal and river waters of Dagupan City, Philippines. Recommendations to improve coastal planning requirements are discussed. Based on environmental, social, economic and institutional considerations, the river system was subdivided into ten management zones. The zones were further reclassified into priority use zones as 'regulated zone' (Zone 1), 'mariculture and fishing priority zone' (Zones 2–7), 'non-fishery zone' (Zone 8) and 'fishpond priority zone' (Zones 9 and 10). Since unregulated fishpen development was a major concern of the local government, fishpen size and layout were standardized. The output of this study forms part of the legislation, Dagupan City Coastal Fisheries Resources Management Ordinance of Year 2003, Executive Order No 71, Series of 2003. It is intended to promote sustainable aquaculture development, generate livelihood and revenues, institutionalize the production and marketing of milkfish for the domestic and export markets and rationalize the use of coastal resources to ensure social equity and long-term environmental stability.

## Introduction

The coastal zone is a place where resources, users and resource use practices interact (Siar, 2003). Thus, coastal management has become increasingly important as different types of use such as fishing, aquaculture, tourism, shipping, etc., compete for space and resources. Resource use allocation then remains a challenging task for decision makers, especially as the current approach to management is unable to protect human health and maintain ecosystem integrity. Development activities and interventions still proceed without proper planning, leading to more resource use conflicts and environmental degradation. This is because resource planning and management decisions are surrounded by uncertainty and complexity (Bennett *et al.*, 2005). Scientific knowledge on which decisions should be based is often difficult to obtain and, when available, it is hardly utilized. In coastal governance, political leaders are often challenged with equitable allocation of limited resources to a number of resource users.

Conflicts over conservation and development intensify as natural resources become limited and areas for human activity become more concentrated (Brody *et al*., 2004). Thus, proper zoning is crucial in formulating an economically, socially and environmentally sound plan for the management and development of coastal waters.

In the Philippines, the decentralized system of governance mandates the local government to allocate local waters for various uses within 15 km from the shoreline. However, local officials may find it rather difficult to apportion said waters because of their inability or insufficient experience in translating science or technical knowledge into decision making so as to balance resource demand without compromising the integrity of the environment. This is especially true for two important economic activities in the coastal areas, namely fishing and aquaculture. Fishing is categorized either as 'municipal' (or small scale) or 'commercial', depending on the area of jurisdiction, kinds of fishing boats and types of gears as defined in the 1998 Philippine Fisheries Code (RA 8550). Destructive fishing activities alongside an inefficient regulatory framework have left many of the country's major fishing grounds and bays overfished and in a critical condition. In effect, the contribution of fishing to food security and poverty alleviation is negligible, despite increasing trends in fish production from both the commercial and municipal sectors. Aquaculture represents a growing enterprise. Although its contribution was only half as much as commercial or municipal fisheries, the average annual increase in fish production from aquaculture from 1997 to 2004 was 6.8% (excluding seaweeds), higher than that of the commercial and municipal fisheries sectors at 3.6% and 2.2%, respectively. The government supports coastal aquaculture, in particular mariculture. However, without proper planning and zoning, this activity can be detrimental to the coastal environment, and ultimately the economy. The potentially deleterious impacts of aquaculture are widely documented (Read and Fernandes, 2003; Feng *et al*., 2004; Islam, 2005). Boyd (2003) identified conflicts with other resource users and disruption of nearby communities as two of the most serious concerns in aquaculture. In many parts of the country, aquaculture often is in conflict with fishing and other coastal uses because it is not incorporated into the management of the coastal zone.

This chapter is based on a study conducted for the local government of the coastal city of Dagupan, Philippines, in order to provide it with the information necessary to enact measures and implement programmes to promote sustainable aquaculture development and expansion, generate livelihoods from aquaculture and its support industries, generate revenues for the city, institutionalize the production and marketing of the local milkfish for local and export markets and rationalize the use of the river system and coastal waters, taking into consideration social equity and long-term environmental stability.

## Objectives

The main objective of this study was to come up with a strategy to incorporate aquaculture into coastal planning so as to reduce conflicts in the use of the resources. Specifically, the study aimed to:

- evaluate the status of capture fisheries and aquaculture in Dagupan, Philippines; and
- recommend a zoning plan for the multiple use of the river.

## Methodology

### Study area

The coastal city of Dagupan is situated in the northern side of the province of Pangasinan, bordering the southern shore of Lingayen Gulf. It is one of the few cities in the Philippines where a considerable portion of its 'land area' is actually water. Out of a total area of 4364 ha, 38.1% comprises ponds and rivers. It is not surprising then that aquaculture and fishing figure prominently in the economy of the city. Dagupan is famous for its *Bonoan bangus* – widely regarded as the tastiest milkfish (*Chanos chanos*) in the country. A confluence of seven river courses that are flooded annually is believed to create the unique environment that allows the production of the *B. bangus*. The capture fisheries sector can be divided into river based and coastal. The river-based fisheries occupy about 536.69 ha of estuarine rivers (City Agriculture Office, 2002), whereas about 15,000 ha of marine waters in Lingayen Gulf comprise coastal fisheries. Brackishwater fishpond development in Lingayen Gulf began in the 1970s and accelerated in the 1980s (Yap *et al*., 2004).

### Sources of data

Secondary data were collected from the literature and from government offices (e.g. Dagupan City Agriculture Office, Fisheries Resource Management Project of the Bureau of Fisheries and Aquatic Resources). Aerial photograph documentation was conducted on 21 March 2002 to estimate the extent of river use. Key informant interviews and surveys (e.g. of local officials, fish farmers and traders) were conducted to validate existing information and the aerial photographs; and to examine the socio-economic characteristics of capture fisheries and aquaculture in the river system. Actual field sampling was done to measure environmental parameters.

## Results

### Environmental state of coastal and river waters prior to sustainable management

This section analyses the environmental conditions of the coasts and rivers of Dagupan based on available data. It is important to emphasize that these problems are man-made and thus may be mitigated through responsible practices. Similar to other coastal municipalities bordering Lingayen Gulf, the coastal and river waters of Dagupan were already overfished as early as 1985, with catch per unit effort (CPUE) reported as dropping to 1 kg/fisher/day. The rivers used to abound with various fish species, shrimps and crabs because of the extensive mangrove areas. The disappearance of some species, however, is not coincidental but is the result of years of environmental changes (e.g. sublethal levels of dissolved oxygen, ammonia and noxious gases). These changes allowed certain organisms to thrive, yet inhibited others, resulting in a shift in population composition. Shrimps, for example, are unable to tolerate low dissolved oxygen and poor water quality conditions. Loss of biodiversity is caused partly by the destruction of mangroves for charcoal making and conversion to fishponds, industrial sites and human settlements. The records of the Department of Environment and Natural Resources (DENR) show that mangrove areas in Pangasinan used to be 9.9 $km^2$ but decreased to 4 $km^2$ in 2000 (MSI, 2002). A large proportion of the 5.9 $km^2$ lost was in Dagupan.

Padilla *et al*. (1997) classified sources of pollution in Lingayen Gulf as domestic, agricultural and fishery, hog production, aquaculture, manufacturing (e.g. gin bottling, vegetable oil refining, soft drink bottling, galvanized iron sheet, fruit and vegetable processing, gas retailing, electric power generation) and mining. Dagupan receives effluents and industrial byproducts from neighbouring towns (e.g. Calasiao) in the form of organic matter/residues. This has resulted in frequent incidents of fish kills in the part of the river that stretches upstream (near the boundary of Calasiao). Mine tailings (e.g. mercury, cadmium, lead) from the provinces of Benguet and Cordillera Autonomic Regions have been transported to Lingayen Gulf through Dagupan via the Agno River since the 1950s. From 1986 to 1995, of the average annual mine wastes of 5.26 million dry metric tonnes (DMT), 4.0 million DMT (or 75%) were used as backfill or for road construction (Padilla *et al*., 1997).

Modern day commerce endorses the use of plastic products, mainly for packaging purposes. But, plastics create more harm than good when it comes to river management. Being non-biodegradable, they easily clog waterways, drainage systems and even fishpen nets, thus obstructing water exchange, which eventually leads to flooding. When plastics settle on the riverbed, they can create an anoxic bottom condition that generates harmful gases (e.g. hydrogen sulfide and methane) detrimental to aquatic organisms.

The physical structures found in the river also obstruct water circulation. The most important structures are the 95.2 ha of fishpens, occupying about 17.7% of the total river