17 Aquatic Food Production in the Coastal Zone: Data-based Perceptions on the Trade-off between Mariculture and Fisheries Production of the Mahakam Delta and Estuary, East Kalimantan, Indonesia

P.A.M. van Zwieten,[1] A.S. Sidik,[2] Noryadi,[2] I. Suyatna[2] and Abdunnur[2]
[1]*Aquaculture and Fisheries Group, Wageningen University, Wageningen, The Netherlands, e-mail: paul.vanzwieten@wur.nl*
[2]*Faculty of Fisheries and Marine Sciences, University of Mulawarman, Samarinda, East Kalimantan, Indonesia*

Abstract

In less than two decades, from 45,000 to 70,000 ha, or up to 70%, of the mangroves in the Mahakam Delta, East Kalimantan, were converted to shrimp ponds. This is expected to affect the productive and buffering function of intact mangroves, observable as shifts in composition and a possible reduction in productivity of the coastal fisheries. The trade-off between mariculture and fisheries is explored with data from fisheries statistics, surveys and reported information. Analysis of trends and developments in total catch, catch by species category, catch rate, fishing effort, pond production and productivity gave no direct quantitative evidence of reduced coastal production and productivity. Shrimp-pond productivity (125 kg/ha/year) is low, stable and highly variable (CV = 69%) at the aggregated level of the delta. Since 1989, fishing efforts have increased and patterns diversified, but aggregated catch rates did not decrease. Catches of rays and sharks decreased and the pelagic/demersal catch ratio increased. A shift towards more resilient species categories with a high turnover rate took place from 1993 to 1999, 4 to 10 years after the boom in pond construction. However, these clear shifts are not self-evidently related to mangrove conversion. Reasons for this are discussed. The potential for detection of changes in resource outcome and assessment of the trade-off between mariculture and fisheries, at both the local level and through aggregated fisheries statistics, is limited because of the high variability in outcome. This implies a limited capacity for resolution of resource-use conflicts when evaluating competing claims informed by existing data and information on resource change.

Introduction

Can coastal aquaculture increase the total aquatic production of estuarine and coastal marine areas of the Mahakam Delta in East Kalimantan in a sustainable way? Mangrove forests have important functions in the life histories of fish and crustaceans: as a corridor

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for diadromous species and as nursery, spawning and feeding areas for a host of maritime species. Annually, nearly 3000 km^2, or 2%, of the world mangrove area is converted, for instance, for pond mariculture. Conversion to ponds changes (essential) fish and crustacean habitats by closing off areas to the dynamics of sea–river–land interactions. This results in increased cultured production, but there is evidence that it also leads to decreased coastal productivity and diversity (Turner, 1977; Turner and Boesch, 1987; Blaber, 2002; Mumby *et al.*, 2004). Thus, pond culture competes with other natural resource-use claims, such as fisheries and biodiversity conservation, in both mangroves and adjacent estuarine and coastal habitats. Informed decision-making in the management of estuarine systems requires a quantified view of the ecological impacts of pond production on adjacent marine ecosystems that depend on well-functioning mangroves. The capacity of stakeholders using and managing aquatic resources to develop an informed view on the trade-offs in marine resources is hampered by the high diversity and variability of the estuarine environment as well as by the high diversity and adaptability of its uses. A first requisite for enabling the development of evaluative capacity is a thorough examination of trends, shifts and variabilities in relevant existing data and information, for instance, from statistical monitoring of fisheries.

Essential in the development of a shared view by users and managers on the state of aquatic resources and the assessment of trade-offs in resource use is the capacity to detect trends and shifts in coastal aquatic production, productivity and diversity. This capacity is dependent on the predictability and size of the daily, seasonal and inter-annual variability in outcome of the various resources. Variability in outcome obscures the perception of changes and trends, while aggregation of data or observations reduces temporal and spatial detail. This inherently means that different stakeholders using and managing a resource have differing capacities to evaluate trends depending on their position in the decision-making process with regard to the flow of information from the resource (van Densen, 2001). A high variability in resource outcome leads to a limited capacity to: (i) perceive trends and changes as they occur; (ii) attribute changes to causes; and (iii) relate individual experience to aggregated information, and, with that, to agree on the state of a resource and on the causes of change by stakeholders who have differential access to information. This in turn results in difficulties in communication between and among stakeholders. If informed agreement on states (and causes) of changes cannot be reached, the capacity to resolve conflicts will be hampered.

Within 20 years, up to 70% of the mangrove forest of the Mahakam Delta (Fig. 17.1) was converted to shrimp ponds, resulting in the destruction of large tracts of essential fish habitat. We can reasonably hypothesize that these rapid changes will be reflected in the daily and annual resource outcome of coastal fishermen and pond farmers as well as in the existing time-series of fisheries monitoring data. We explore the capacity for perception of changes in resource outcome of pond farmers, fishermen and fisheries managers in the Mahakam Delta by examining existing data and information on fisheries and brackish-water mariculture production and productivity. While shrimp culture in the 'mining mode' leads to habitat destruction, resulting (potential) shifts in diversity and productivity of natural resources that could represent a long-term threat to the resource base and use options will not appear to be evident.

Time-series of fisheries-dependent data collected by fisheries management institutions through monitoring of catch, fishing effort and other production statistics, and existing data and information collected through specific surveys on fisheries and shrimp-pond production, were used to address the following questions:

1. What are the developments in fisheries (effort, catch and catch rates) and mariculture (area, production and productivity)?
2. Is there evidence of a decreased productivity of shrimp ponds (= *tambaks*) over time for cultured shrimp (*Udang windu*, *Peneaus monodon*) and wild shrimp (*U. bintik*, *Metapeneaus monoceros* and *M. brevirostris*)?

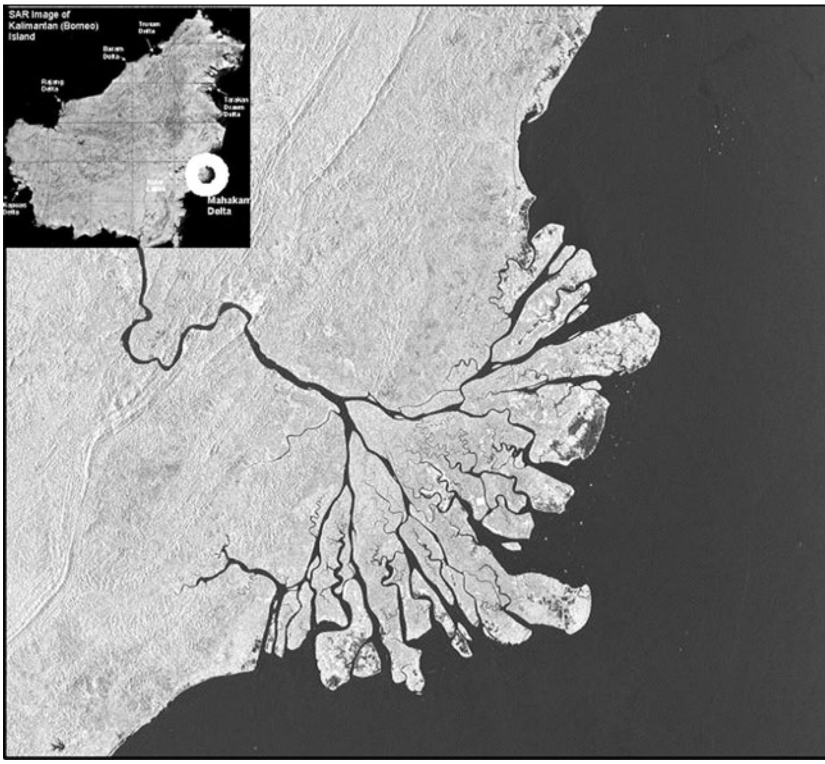

Fig. 17.1. Borneo (inset), indicating the position of the Mahakam Delta.

3. What is the potential for detection of changes in productivity by fishermen and pond farmers given their daily catches and pond harvests?
4. What is the potential for detection of changes in marine aquatic production and productivity based on aggregated statistical fisheries information?
5. What are the quantitative indications of a trade-off between the two marine production activities?

Study Site: Development of Shrimp Culture and Fisheries

The Mahakam Delta is about 150,000 ha, of which around 110,000 ha are categorized as salt- or brackish-water mangrove. Administratively, it is located in the regency of Kutai Kartanegara. The landscape is a deltaic plain, with the meanders of the Mahakam River ending in a complex fan-shaped network of multiple distribution channels and small rivers subject to tidal influence. Before 1950, the natural vegetation was a typical mangrove forest in an upstream to seashore succession of mixed-freshwater forest to dense *Rhizophora* spp., with some degraded forest where oil palm plantations had been present. *Nypa* stands dominated, with 55% of the area covered, ahead of freshwater mangroves (17%) and dense *Avicennia* stands.

With the onset of the 20th century, the delta had few settlements: fishermen and coconut planters who had settled in its early decades largely left during World War II. This situation remained until the early 1970s, when oil exploration and production caused an influx of people – mainly from Sarawak – attracted by the labour opportunities. In their wake, fisheries became important as well. With limited possibilities for preservation and transport, local fishermen did not consider shrimp to be valuable – small-sized shrimp were sun-dried and sold as *ebi* (salted dried shrimp) – until two cold-storage facilities built in the early 1970s provided capital to fishermen for modernization of their boats and fishing equipment. Around 1975, the introduction of trawls increased shrimp catches considerably. In 1980, a decision by the Indonesian government put an end to all trawl fishing, a ruling carried out over the next few years. A few milkfish ponds, developed with methods from South Sulawesi, were already established in the delta as early as 1932: trials for the introduction of shrimp to substitute for the loss of trawl production and to cater to increased international demand achieved success in the early 1980s. This initiated a new immigration wave from Sulawesi. The pond opening rate increased after the introduction of excavators, which replaced manual labour around 1989, and again after the monetary crisis of 1997 (Fig. 17.2). The resulting boom in shrimp production turned the Mahakam Delta into one of the wealthiest areas in Indonesia.

Most stakeholders – pond owners, fishermen, oil companies, government and NGOs – are pessimistic about the future of the delta, which, in their view, will increasingly become 'an ecological and economic desert under the combined assault of mangrove clearing, erosion, pond development, diseases, salinity, and productivity and income decreases'. The most important issues are related to land conflicts and erosion. Furthermore, all stakeholders agreed that maintaining the sustainability of shrimp-pond production and protecting or improving mangrove areas for the reproduction of fish and crustaceans have a high priority, indicating local awareness of potential trade-offs in natural resource use. Nevertheless, when weighing ecological and economic issues, it appeared that mangroves were seen mainly as valuable if cleared for ponds. Only fishermen did not appear to be much troubled by the concerns expressed by other stakeholders, except on the issue of protection of nursery and breeding areas, indicating local awareness of potentially conflicting resource use (Bourgeois *et al.*, 2002).

Data and Methods of Analysis

Data

Fisheries monitoring data available from 1980 to 2004 in statistical yearbooks were obtained from the Dinas Kelautan dan Perikanan in Samarinda (provincial office) and Tenggarong (regency office). They were used to examine developments in fisheries and mariculture (question 1), trends in overall productivity of ponds (question 2), the potential to detect changes in marine production (question 4) and evidence of trade-offs between the two activities (question 5). The two offices monitor catch by species category and gear type, effort by gear type and pond production by species category by district and by fresh and marine waters. All data presented and analysed refer to the Regency of Kutai that encompasses the Mahakam Delta.

Detection of trends in pond productivity (question 2) and in changes by pond farmers (question 3) was examined with data obtained from a survey on the management and productivity of the tambak culture conducted by the Faculty of Fisheries and Marine Science, Mulawarman University, Samarinda (UNMUL-FPIK), commissioned by Total Indonesia. The survey encompassed 18 locations distributed over the delta in different mangrove habitats, indicated by salinity. Between July and September 2003, 125 farmers were interviewed. Physical and chemical parameters were measured from a selected pond managed by the people interviewed. We used the following data:

- Production of the last harvest (kg/ha) of stocked *P. monodon* and wild *Metapenaeus* spp. (n = 96)
- Total area and number of ponds (n = 125),
- Year of pond construction (pond age) (n = 124); and
- Management factors: (i) salinity (n = 125); pH (n = 124), % water exchange (n = 120); (ii) stocking density of tiger shrimp (n = 118); and (iii) input of nitrogen, phosphate and potassium (NPK) fertilizers (n = 59), triple superphosphate (TSP) (n = 49) and lime (n = 15) (all kg/ha).

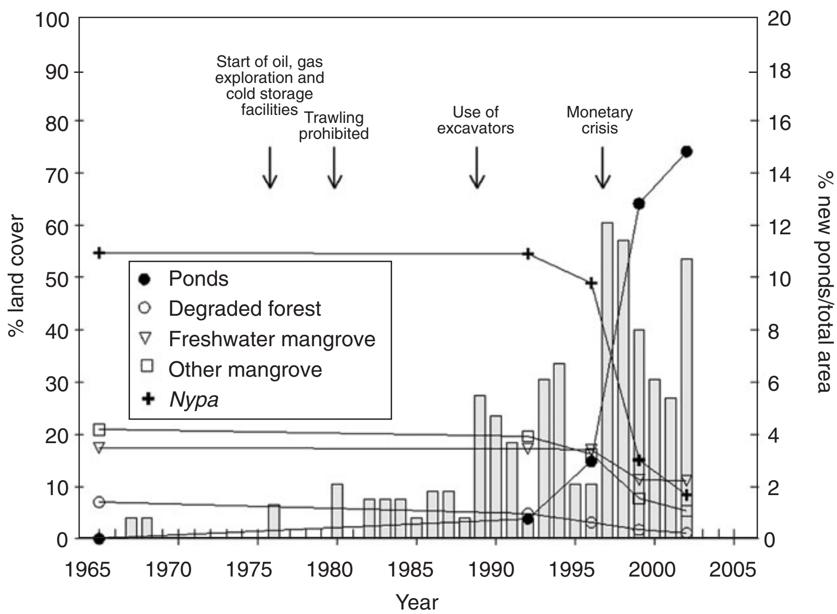

Fig. 17.2. Estimated pond opening rate (bars) related to specific events (arrows) and land cover in the Mahakam Delta (lines with markers). Based on a GIS database constructed from historic settlement analysis, maps, aerial photographs and satellite photographs (adapted from Bourgeois *et al.*, 2002).

Shrimp ponds are stocked and harvested two to three times a year. All parameters in the survey referred to the last harvest period, except for salinity and pH, which were measured *in situ*. For each factor with n <125, the value of the non-recorded observations = 0, except for stocking density, which was not known when not recorded, as often multiple stockings take place over a harvest period because of the scarcity of shrimp postlarvae. Analysis of variance was used to examine the significance of difference ($\alpha \leqslant 0.05$) in the mean harvest of ponds with non-zero values for a parameter vis-à-vis those with observations = 0 or not known. This was never the case.

Daily catch variability (question 4) was examined for four small shrimp trawlers from the village of Muara Badak, located on the north coast of the delta, based on daily log-book recordings over a period of 6 months.

Estimates of total pond area development, taken from four studies (Table 17.1), are based on interpretations of satellite imagery. Dutrieux (2001) and Bourgeois *et al.* (2002) also based their estimates on aerial photography and interpretations of old maps, including historical settlement analysis. These are the most consistent time-series as the interpretations are performed by the same team. However, all studies suffer from a lack of (access to) methodological descriptions and/or limited ground truthing, hampering the evaluation of the discrepancies between the estimates. Despite this, it can be concluded that in 2004 at least 50–70% of the total brackish- and saltwater mangrove had been converted. We have used the estimates of Dutrieux (2001), Bourgeois *et al.* (2002) and Bappeda Kukar (2003) to interpolate and extrapolate the total pond area from 1980 to 2004 through

$$\text{Tambak area (ha)} = 6006 \times 10^{0.17\,(\text{year } 1993)} \qquad (17.1)$$

and checked the results with information on the pond opening rate reconstructed by Bourgeois *et al.* (2002) (Fig. 17.2).

Table 17.1. Area of the Mahakam Delta covered by mangrove, settlements or shrimp ponds (tambak). All analyses are based on interpretation of satellite imagery and GIS maps (see text for an evaluation of the estimates).

Item	Year								
	1984[1]	1991[2]	1992[1]	1996[2]	1998[1]	1999[1]	2001[2]	2001[3]	2004[4]
Mangrove (ha)		105,999		95,096			40,219	–	60,818
Settlements		74		125			129		–
Tambak (ha)	420	3,629	3,687	14,480	52,300	67,000	69,354	50,000 (31,000, in prep.)	45,297 (2,036, in prep.)
Total (ha)	110,000	109,702	110,000	109,702	111,000	110,000	109,702	110,000	108,153

[1] Dutrieux (2001).
[2] Bappeda Kukar (2003).
[3] Bourgeois *et al.* (2002).
[4] From Fakultas Perikanan dan Ilmu Kelautan, 2005 (FPIK) (2005). Produktivitas tambak di kawasan Delta Mahakam (Shrimp pond productivity on Mahakam Delta). Draft Report to Total Indonesia, Balikpapan, March 2005. pag. var.)

Methods of analysis

Data treatment

The 24 statistical yearbooks contain catch information on 60 species (groups); for the regency of Kutai, 39 contain time-series of data. Trends analysed were by: (i) total catch; (ii) catch of demersal/benthopelagic and pelagic species (Froese and Pauly, 2005); and (iii) catch of 38 categories of fish, crustaceans and molluscs (two categories combined). Catch information is collected for 25 fishing methods, but we aggregated the numbers of gears and total catch into the six main categories recorded before 1988: large trawls, small trawls and seines (*Pukat kantong*: shrimp trawls, lampara and Danish, beach and purse seines), gill nets (*Jaring insang*: drift nets, encircling nets, shrimp gill nets, stationary gill nets, trammel nets); lift nets (*Jaring angkat*: boat/raft nets, *bagan*, scoop nets, other lift nets) and hooks and lines (*Pancing*: tuna longlines, longlines, set longlines, other poles and lines, troll lines). A category ‘traps’ (*Perangkap*: guiding barriers, stow nets, portable traps, other traps) was also aggregated with a category ‘others’ (Anadara shell fish, muro-ami and others) recorded only occasionally with low levels of output. Catch rate by gear group was calculated by dividing the annual catch per gear group by the associated number of gears.

The productivity of shrimp ponds was calculated by dividing the total annual production and the production by species category by the estimated area (ha) of ponds in that year.

Data analysis

Trends were analysed with the polynomial regression model:

$$G(m)_i = a + b{*}year_i + c{*}year_i{*}year_i + \epsilon_i \quad (17.2)$$

where $G(m)_i$ is the time-series of catch (fisheries) or production per hectare (tambaks), a is the intercept, b and c are the slope, $year_i$ is the linear regression term; $year_i{*}year_i$ are the quadratic terms; and ϵ_i is the residual error.

Only significant parts of the model ($\alpha \leq 0.05$) were retained, resulting in four possible models: mean, linear, quadratic and polynomial. Concavity and explained variance of the quadratic and linear terms of significant polynomial models were evaluated to obtain an indication of direction, timing and strength of the reversal in long-term trends. Trends were tested over the whole period and over the period from 1989 onward, when pond opening rates increased dramatically. An indication of recent change relative to the long-term trend was obtained by examining the short-term trend over the last

5 years. Serial correlation, producing additional variability obscuring long-term trends, was examined in time-series of shrimp-pond productivity by cross-correlation at lag = 1 (year) of the residuals of the linear trend analysis.

The effect of age on stocked and wild shrimp productivity was assessed by a two-stage regression analysis using general linear modelling (SAS-Institute, 1989). The first variance reduction was achieved with all significant ($\alpha \leqslant 0.05$) factors and sensible interactions that could have an effect on the production of each species and for which data were available. In the next step, the residuals were regressed on age as an explanatory factor. All time-series were orthogonalized before analysis. All data were ^{10}log-transformed to fulfil the assumption of normal distribution of residuals.

Variability, expressed as coefficient of variation (CV is standard deviation scaled by the mean), is used here to scale (basic) uncertainties in fisheries and aquaculture outcomes. CV is a powerful indicator of the capacity to perceive trends and shifts. For instance, low to medium variabilities (CVs of 23–60%) in daily catches are found in trawl fisheries, medium CVs of 50–75% in gill-net fisheries and high to extreme CVs of 80–500% in light fisheries (van Densen, 2001; Oostenbrugge *et al.*, 2002; van Zwieten *et al.*, 2002; Jul-Larsen *et al.*, 2003b). After variance reduction of ^{10}log-transformed data by known (spatial, temporal, management) factors, the residual variance from the models, also called random or basic uncertainty (van Zwieten *et al.*, 2002), can be expressed as CV through (Aitchison and Brown, 1957)

$$CV = 100 * \sqrt{e^{2.303*\sigma^2} - 1} \qquad (17.3)$$

where σ is the standard deviation in the residuals of the ^{10}log-transformed data.

All CVs are directly comparable. Variabilities at higher scales of aggregation are estimated by dividing the variability at a lower scale by $\sqrt{n}$, with n as the number of units aggregated. Similarly, disaggregation is done by multiplying by $\sqrt{n}$. Both procedures assume independence of observations.

Trend perception can be approximated statistically through power analysis. The number of years needed to significantly detect a trend b in the time-series can be calculated iteratively given decision limits α and β, and the trend-to-noise (b/s) ratio following the inequality (van Zwieten *et al.*, 2002):

$$\left|\frac{b}{s}\right| \sqrt{\frac{n(n-1)(n+1)}{12}} \geq (t_{\alpha/2} + t_{\beta}) \qquad (17.4)$$

where b is the trend parameter (slope) in the linear regression, n is the number of observations (year), and $t_{\alpha/2}$ and t_{β} are the decision rules of a t-distribution, where α is the probability of a type I error (a trend is rejected falsely) and β the probability of a type II error (a trend is accepted falsely). In our analysis, $\alpha = \beta = 0.1$; s is the standard deviation of the residuals.

Data-based Perceptions on Changes in Aquatic Food Production

Over 24 years, the total fishery and mariculture production in Kutai has increased by 3.3% per year from 5700 to 27,200 t. Total fish catch increased at a slower rate of 2.9% per year from 5400 to 17,100 t. After a drop in levels in the late 1980s, crustacean catches reached 1300 t in 2001, the same level as the average catch of 1980 to 1987. The crustacean fishery decreased in importance from around 20% of the total production in the early 1980s to 4–5% at present. From 1980 onward, shrimp culture increased from 5% (285 t) of the total production to 29% (7803 t) in 2004 (Fig. 17.3).

Mariculture

Total annual pond production increased linearly with the area under cultivation, while the shrimp production increased by a factor of 1.24 (Fig. 17.4). Over a 24-year period, fisheries statistics indicate a shift in mariculture from fish to prawns around 1995 (Fig. 17.5). Initially, stocked *P. monodon* dominated shrimp production. From 1990 to 2000, during the boom in pond construction, wild

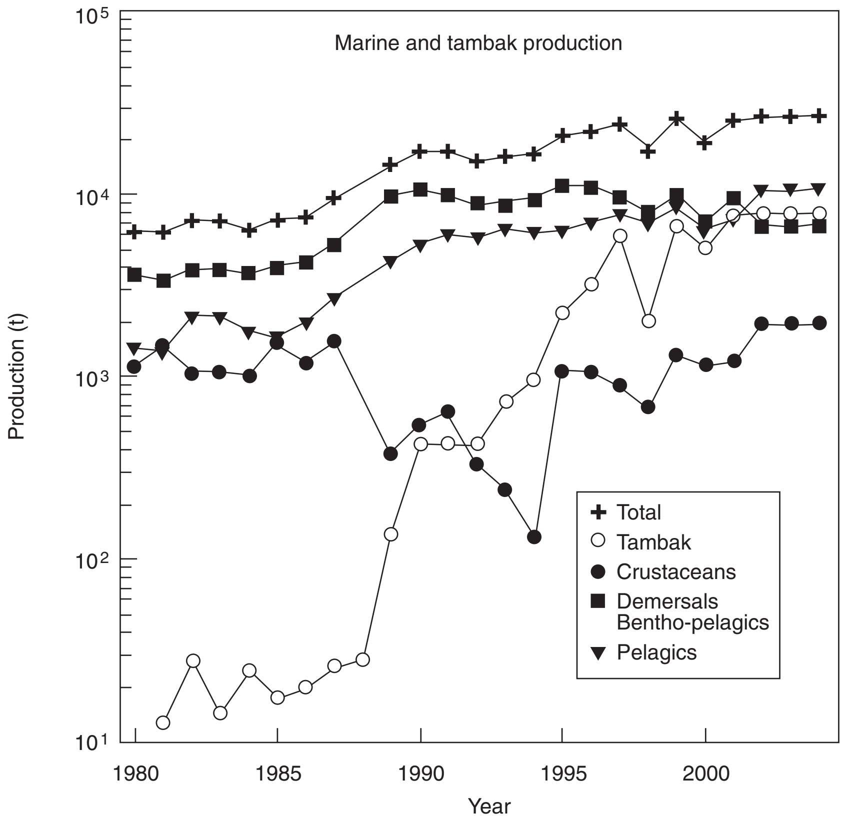

Fig. 17.3. The development of the total marine and brackish-water fisheries and tambak culture production of the regency in Kutai, East Kalimantan. Closed markers, capture fisheries; total, aggregated fisheries and culture production (data from statistical yearbooks, Fisheries Service).

Metapeneaus spp. formed 63–81% of the total production. Presently, about 50% of the production again is stocked *P. monodon*. The production of mullet and milkfish increased concurrently, until 1997, to 1357 and 1059 t, respectively. Mullet decreased to about 300 t and milkfish remained stable. The production of other fish species (wild stocks of, for instance, *Lates calcarifer*), never important, is now zero. Inter-annual variability in production is high for all species, ranging from a CV of 93% (*P. monodon*) to 179% (mullet). Over the last 5 years, the production of all categories has stabilized.

Tambaks are cultured extensively: with 125.4 kg/ha, long-term productivity is stable and low, but with a high inter-annual variability (CV of 69%) at the aggregated level of the delta. Since 1980, productivity of both stocked and wild shrimp has increased by a factor of 1.09/year, and both have a residual inter-annual CV of, respectively, 76% and 125%. Stocked shrimp productivity has stabilized at 41 kg/ha over the last 5 years, but wild shrimp decreased to a stable level of 44 kg/ha after a peak in 1997. In both cases, only the linear trends were significant ($\alpha \leqslant 0.05$), but with low power: the observed trends could be detected only with 20–26 years of data ($\alpha = \beta = 0.1$) (Table 17.2). No evidence of serial correlation was found in the residual time-series of stocked shrimp productivity. But the residual productivity of wild shrimp of subsequent years is strongly correlated ($\rho = 0.55$, $r^2 = 0.30$, $P < 0.01$), indicating that natural processes regulating the overall productivity of wild shrimp in the delta are important for cultured productivity.

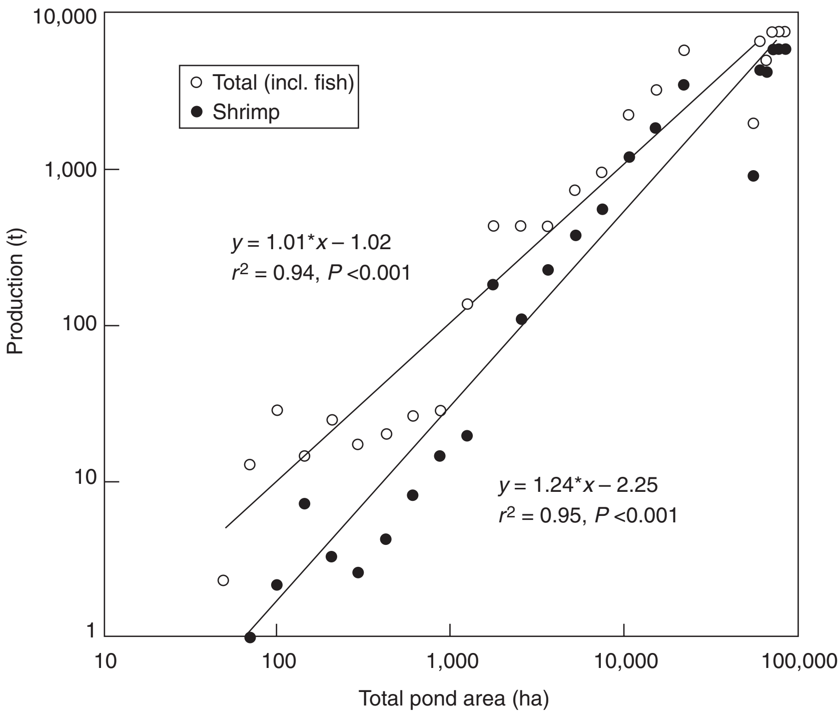

Fig. 17.4. Total and shrimp production in the mariculture of the Mahakam Delta related to area under cultivation (total pond area). See text for the estimation procedure of total pond area.

Average shrimp productivity of one harvest calculated from the UNMUL-FPIK survey is 66 kg/ha ($CV_{harvest}$ = 119). With two to three harvests per year, this amounts to an annual productivity of 130–190 kg/ha, with a $CV_{year} = CV_{harvest}/\sqrt{n}$ = 84% – 68%. The average productivity per harvest of stocked *P. monodon* is 42.5 kg/ha ($CV_{harvest}$ = 117%; CV_{year} = 83% – 68%) and of wild *Metapeneaus* spp. is 25 kg/ha ($CV_{harvest}$ = 163%; CV_{year} = 115% – 94%). Thus, the annual average productivity is higher than the estimate from fisheries statistics. However, the variabilities are in the same order of magnitude, which is unexpected as aggregation of pond production over the whole delta scaled by the total pond area should lower variability. The high variability in fisheries statistics could be due to data collection methods, to our estimation procedure of the area under cultivation or to high co-variance in the production per pond inducing increased variability. The latter may result, for example, from overall harvest failure induced by weather or through variable availability of shrimp larval production.

Larger-sized ponds had lower productivity, also noted by Bourgeois *et al.* (2002), but pond size explained more variation in wild shrimp (13%) than in stocked shrimp (4%) (Table 17.3). None of the management factors had a significant effect on stocked *P. monodon* productivity. Fertilizer application had a significant positive effect on wild *Metapenaeus* spp. (Table 17.3). However, as the mean harvest of fertilized ponds did not differ significantly from that of non-fertilized ponds, the effect was cancelled in the overall variability. Lowered productivity with increasing age was observed with stocked shrimp, but the age effect explained only 5% of the residual variance after correction for size (Table 17.3).

Fisheries

The fisheries around the delta are small-scale and multigear and have a limited spatial range: at present, up to 50% of the vessels are

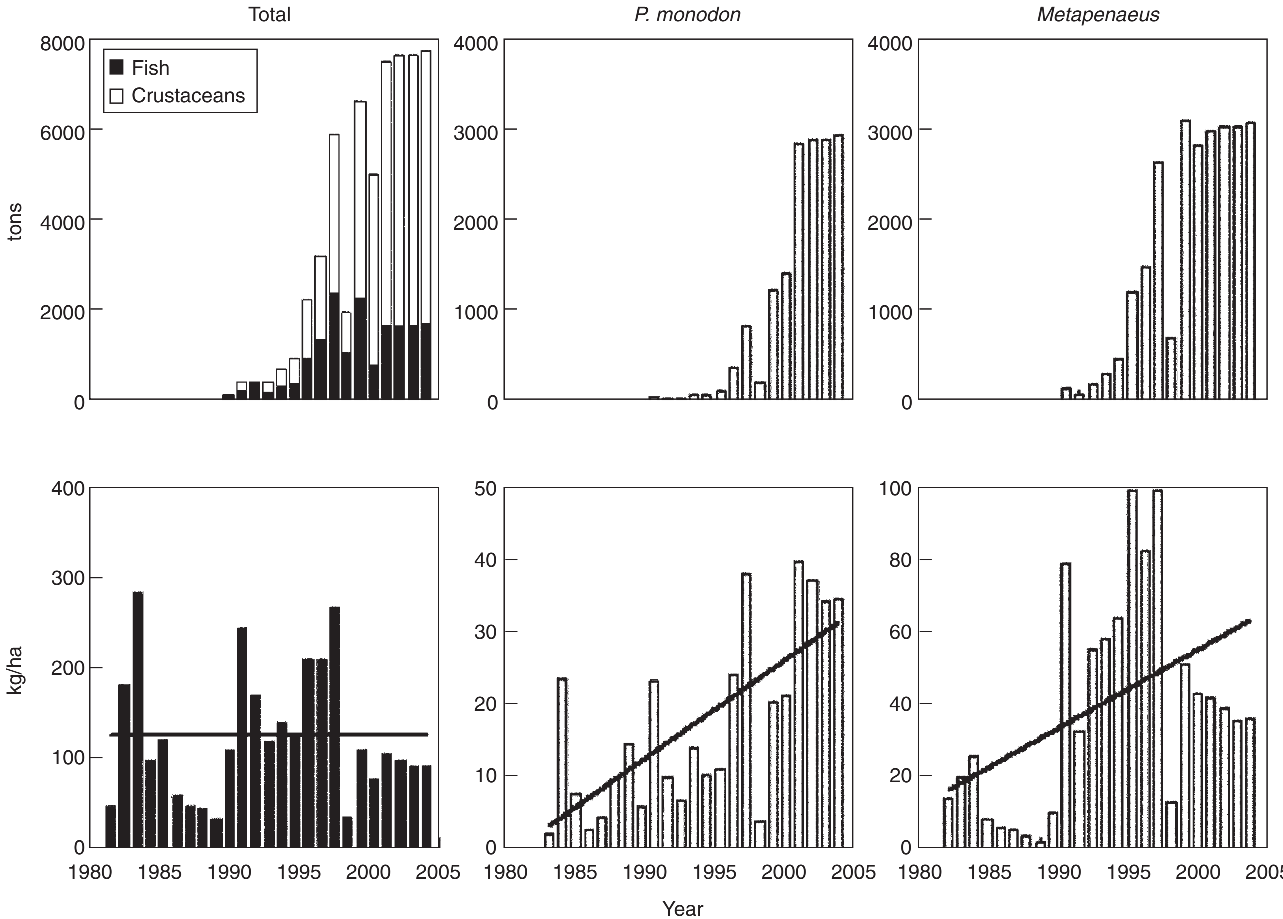

Fig. 17.5. Development of the total, and shrimp, production (top panels) and productivity (bottom panels) in the Mahakam Delta, 1980–2004. The mean of the time-series is displayed if the trend is not significant ($\alpha \leqslant 0.05$) (data from statistical yearbooks, Fisheries Service).

Table 17.2. Trend and power analysis of the marine catch (1989–2004) and tambak productivity (1980–2004).

Species	PDT	df	CV	B	B:S	*n*	Model	r^2	Year of trend reversal	Slope/concavity
Marine catch (tons)										
Rays (Rajiformes) – 10	H	15	70	–0.14	0.49	9	Lin	0.85		–
Sharks (Elasmobranchii) – 10	H	15	83	–0.06	0.19	16	Lin	0.46		–
Croakers, drums (Sciaenidae) – 9	L	15	5	–0.02	0.82	6	Pol	0.67	1995	–
Grunters, sweetlips (Haemulidae) – 5	M	15	45	0.02	0.12	21	Pol	0.62	1998	–
Yellow-tail fusiliers (Caesionidae) – 9	M	14	51	–0.03	0.13	21	Pol	0.86	1996	–
Skipjack tuna (Scombridae) – 4	M	14	54	0.03	0.15	18	Pol	0.57	1999	–
Big eyes (Holocentridae) – 9	L	15	84				Pol	0.82	1996	–
Trevallies (Carangidae) – 2	M	14	32				Qua	0.32	1996/7	–
Goatfish (Mullidae) – 5	L	15	69				Qua	0.59	1996/7	–
Scads (Carangidae) – 2	L	15	117				Qua	0.54	1996/7	–
I. halibut (Pleuronectiform) – 5	M	15	130				Qua	0.37	1996/7	–
Rainbow sardine (Clupeidae) – 3	L	14	44	0.04	0.21	15	Lin	0.51		+
Common squid (Cephalopoda)	L	9	46	0.08	0.43	10	Lin	0.61		+
Pony f./slipmouths (Leiognathidae) – 5	L	14	87	0.08	0.24	14	Lin	0.55		+
Mud crabs (Portunidae) – 12	L	15	93	0.10	0.28	12	Lin	0.66		+
Metapenaeus shrimp (Penaeidae) – 15	L	14	95	0.08	0.21	15	Lin	0.50		+
Giant tiger prawn (Penaeidae) – 13	L	13	96	0.10	0.29	12	Lin	0.62		+
Sea cat-fishes (Ariidae) – 5	M	15	37				Pol	0.68	1995	+
Threadfins (Polynemidae) – 11	L	15	39	0.02	0.12	22	Pol	0.53	1994	+
Anchovies (Engraulidae) – 3	L	15	60	0.05	0.20	16	Pol	0.68	1993	+
Fringescale sardinella (Clupeidae) – 3	L	15	62	0.03	0.11	23	Pol	0.66	1995	+
Mullets (Mugilidae) – 11	M	15	81				Pol	0.63	1998	+
Black pomfrets (Carangidae) – 6	M	15	63				Qua	0.40	1996/7	+
Eastern little tuna (Scombridae) – 4	L	15	71				Qua	0.29	1996/7	+
Barramundi (Centropomidae) – 7	H	15	81				Qua	0.56	1996/7	+
Narrow band king mackerel (Scombridae) – 4	M	15	114				Qua	0.59	1996/7	+
Indopac king mackerel (Scombridae) – 4	M	14	123				Qua	0.60	1996/7	+
Other fish		12	185	–0.14	0.27	13	Lin	0.54		–
Other shrimp – 16		14	45	0.05	0.28	12	Lin	0.67		+
Total catch – 1		15	10	0.006	0.14	19	Lin	0.34		+
Tambak productivity (kg/ha)										
Penaeus monodon		23	76	0.04	0.13	20	Lin	0.44		+
Metapenaeus spp.		23	126	0.04	0.09	26	Lin	0.29		+
Total tambak productivity		23	69				Mean	ns		

Mean models were obtained with red snapper (Lutjanidae) – 8 (CV = 29, PDT = M); Spiny lobster (Palinuridae) – 12 (36, L); Indian mackerel (Scombridae) – 4 (38, L); Jack trevallies (Carangidae) – 2 (42, M); Groupers (Serranidae) – 8 (44, M); Silver pomfret (Stromateidae) – 6 (44, M); Wolf herrings (Chirocentridae) – 3 (51, L); Banana prawns (Penaeidae) – 14 (76, L); and other marine catch (207).

PDT, population doubling time (H, high, > 4.4–14 years; M, medium, > 1.4–4.4 years; L, low, < 15 months); df, degrees of freedom; CV, coefficient of variation; b, slope of the linear trend (significance $\alpha \leqslant 0.05$); b/s, trend-to-noise ratio; *n*, number of years of data needed to detect trend b ($\alpha = \beta = 0.1$); Lin, linear; Pol, polynomial; Qua, quadratic; r^2, coefficient of determination; ns, non-significant; −, negative slope/downward concavity; +, positive slope/upward concavity. Numbers associated with names refer to the species aggregations in Fig. 17.8.

Table 17.3. Variance reduction in productivity (kg/ha) of wild (*Metapenaeus monoceros*) and stocked (*Penaeus monodon*) shrimp in four models with pond size, age and management factors as explanatory factors.

	Wild shrimp				Stocked shrimp				
Model	df	MSE	r^2	b	df	MSE	r^2	b	Trend to noise ratio (b:s)
Total	85	0.296			95	0.213			
Res size	84	0.262[c]	0.13	−0.579	94	0.207[a]	0.04	−0.308	
Res size age	83	n.s.	–	–	93	0.198[a]	0.09	−0.021	0.048
Total	33	0.379							
Res TSP	32	0.296[b]	0.24	0.448					
TSP size	31	0.274[b]	0.32	−0.653					
Total	29	0.515							
TSP*NPK	28	0.300[b]	0.30	0.235					
TSP*NPK size	27	0.224[b]	0.49	−1.069					

[a] Significance ≤ 0.05.
[b] Significance ≤ 0.01.
[c] Significance ≤ 0.001; n.s., non-significant.
df, degrees of freedom; MSE, mean square error; r^2, coefficient of determination; b, slope; s, standard deviation; Res, residuals; size, pond size; age, number of years since pond construction; TSP, triple superphosphate; NPK, nitrogen, phosphate, potassium; TSP*NPK, interaction term (from FPIK-UNMUL survey on 125 tambaks in the Mahakam Delta).

non-motorized; the remainder have diesel engines of < 5 hp or outboard engines. Most gears are more or less stationary: gill nets and traps/barriers each account for about 30% of the gears and lift nets/bagans account for another 18%. The active fishing gears, trolls and lines, and trawls each account for about 10% of the gears (Fig. 17.6). The annual catch of 1000–3500 kg/gear/year is comparable with that of any small-scale fishery (Jul-Larsen *et al.*, 2003a). Three gear categories show variable but increasing catch rates over the past 15 years (gill nets, trawls and lift nets/bagans), whereas those of lines and traps are variable but stable (Fig. 17.7). This is contrary to expectation as increased effort generally leads to decreased catch rates. Changes in gear, catchability resulting from increased gear efficiency, target species, spatial allocation of effort or changes in carrying capacity due to environmental forcing could each result in the observed developments. As yet, none of these explanations can be excluded.

Since 1980, the marine fisheries showed an increasing and (in recent years) stabilizing catch of pelagic and demersal/benthopelagic species, but with a shift in importance to pelagics (the ratio of pelagics/demersals increased from 0.4 to 1.6). A long-term overall stable but highly variable catch of shrimp dropped to almost zero around 1988 (Fig. 17.8). Trends reveal a clear shift from shrimp to fish species after 1987, possibly as a result of the trawl ban. After that, shrimp and fish catches, respectively, initially decreased and increased rapidly in concurrence for most species (Fig. 17.8, Table 17.2). Since 1989, rays and sharks, highly vulnerable to fishing pressure (Myers and Worm, 2003) and with high population doubling times (PDT) (Froese and Pauly, 2005), are the only species categories with a significant ($\alpha \leqslant 0.05$) long-term linear decreasing trend. All species with a long-term linear increasing trend had low PDT. From 1995 to 1999, catches in nine categories started decreasing or stabilizing, whereas from 1993 to 1998 ten categories showed a reversal to increasing trend. These reversals indicate a shift from species that are less resilient to a changing environment, including increased fishing effort (high–medium PDT), to species highly resilient to changes but also with highly dynamic population sizes (low PDT). The distribution of high, medium and low PDT

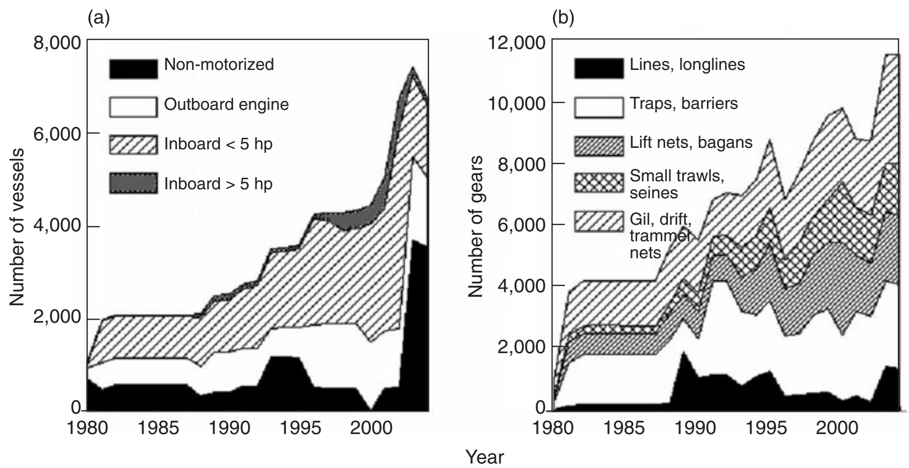

Fig. 17.6. The development in fishing effort around the Mahakam Delta (a) the number of vessels and motorization of vessels; (b) the number of gears by type (data from statistical yearbooks of the Fisheries Service). The number of non-motorized vessels was underestimated before 2003 data collection procedures were changed (pers. info., Fisheries Service, Samarinda).

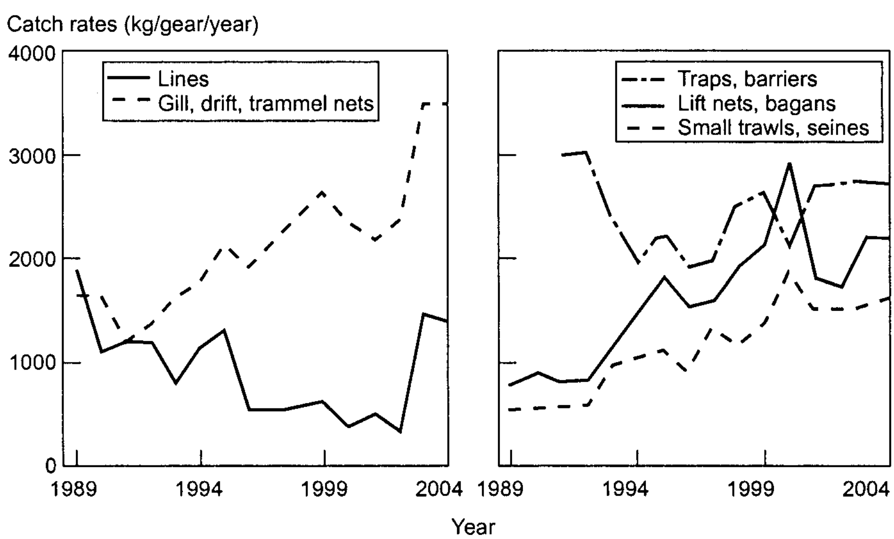

Fig. 17.7. The development in catch per unit of effort (= catch rate) for the main gear groups of the fisheries around the Mahakam Delta.

is, respectively, 2, 9 and 8 for categories that have a long-term, a recently decreasing or no trend, and 1, 5 and 10 for those with increasing trends (Table 17.2).

Inter-annual variability for all categories is extremely high. For instance, the residual inter-annual CV of *Metapeneaus* spp. of 95% is as high as the daily variability experienced by four small shrimp trawler fisheries in the estuary (van Zwieten, unpublished data). Though a shrimp fisher will experience high inter-annual variability because of high variability in annual local shrimp biomass, it can be demonstrated that the CV from the fisheries statistics is outside any ordinary experience of a fisherman. Dis-aggregation over about 1600 (see Fig. 17.6) small-trawler fishermen presently fishing in the estuary

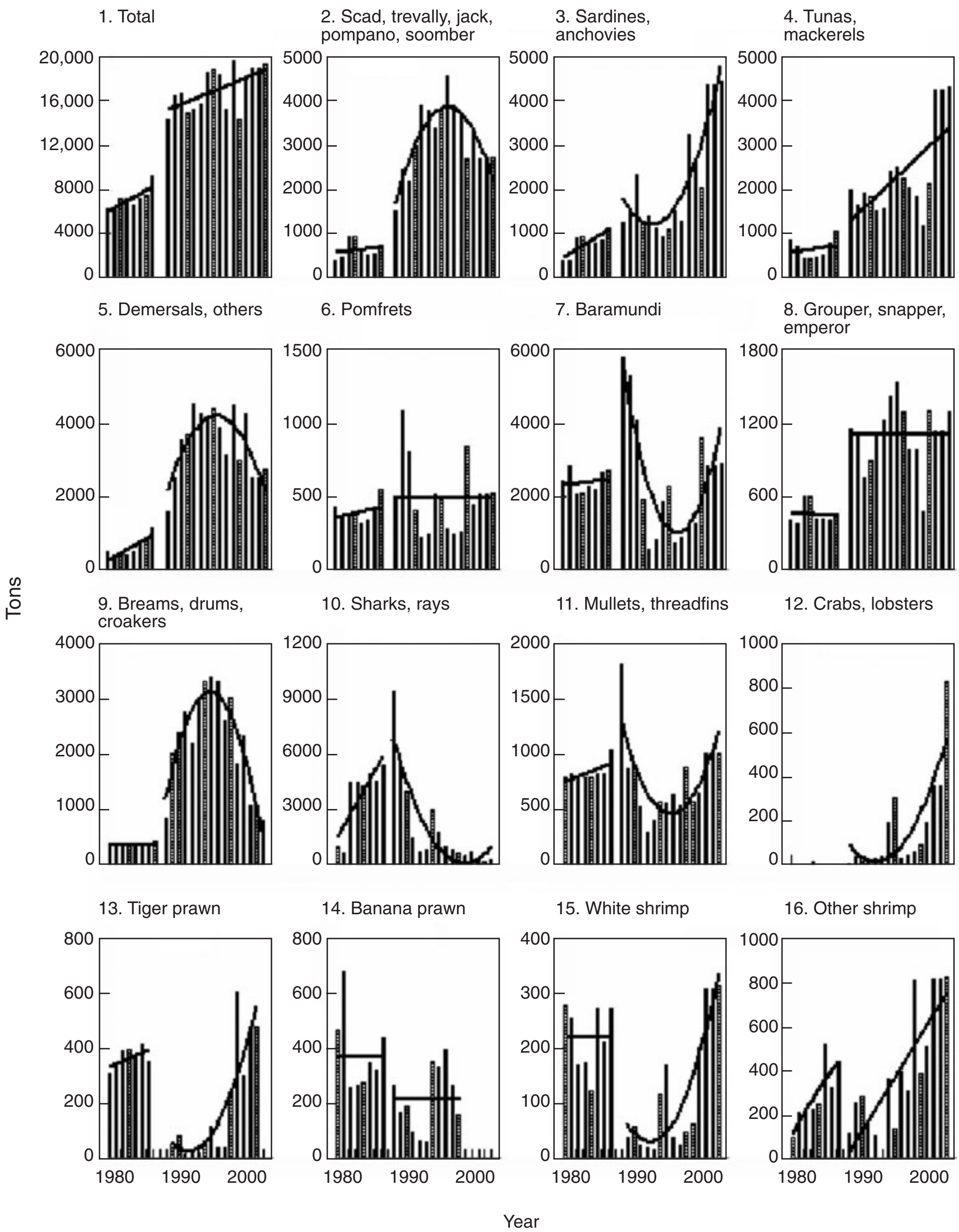

Fig. 17.8. The development of capture fisheries production around the Mahakam Delta, 1980–2004. Top panel, total and pelagic species catch; middle panels, demersal species; lower panel, shrimp species. The aggregation of 39 species categories in the 16 categories presented here is explained in Table 17.2. The mean of the time-series is displayed if the trend is not significant ($\alpha \leqslant 0.05$) (data from statistical yearbooks of the Fisheries Service).

yields a $CV_{dis} = 95*\sqrt{1600} = 3800\%$. The cause of this high variability may be due largely to the data collection methods used. With this caveat on data quality, all categories with long-term linear trends exhibited inter-annual catch variabilities of CV < 80, except crustaceans, pony fish/slipmouths and sharks and rays, which showed higher inter-annual variability. To better compare the capacity for trend perception in all species, we used the highest (b = 0.14) and lowest (b = 0.02) absolute slopes in long-term linear trends to calculate the number of years of data needed for detection according to Equation 17.4. Trend detection for a 38% decrease or increase per year required from 2 (croakers/drums) to 11 (Indian halibut) years of data (Fig. 17.9). Trend detection for a 5% increase or decrease per year requires from 5 to 50 years of data for these two extremes. The four most variable species represent around 20% of the total catch. Of these, the two mackerels (*Scomberomorus commerson* and *S. guttatus*) and the scad (*Decapterus* spp.) are coastal schooling and long-shore migratory pelagics whose populations are probably not local. Two important shrimp categories, known to have high inter-annual fluctuations in population densities, are extremely variable as well.

Discussion

We can now answer our five questions: after the boom in pond development from 1989 onward, changes were observed in several indicators of fisheries and mariculture production and productivity. Shrimp pond area and fishing effort in all gear categories increased, resulting in an overall increase in production. Productivity for both activities either increased or stabilized.

Management factors and size and age of the pond explained only a limited amount of variability in shrimp productivity, and no evidence of decreased productivity of ponds can be found over the period examined. In the past 5 years, productivity stabilized around 85 kg/ha. The observed decreased productivity over time of wild *Metapenaeus* spp. should be treated with caution and could be the result of chance, as wild shrimp stocks are regulated by natural processes, and influx in ponds is a chance process depending on local availability of shrimp larvae.

A comparison with other production systems reveals that the Mahakam Delta pond productivity and production are low and extremely uncertain, and can best be described as a boom-and-bust operation. The

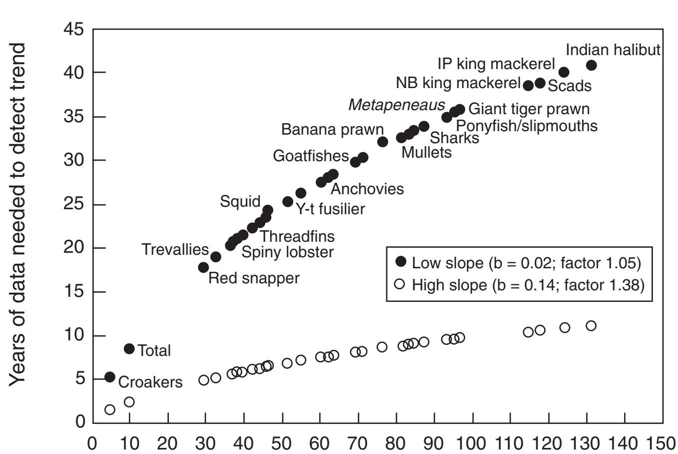

Fig. 17.9. Power analysis for the range of observed linear trends in the catch of species in the Mahakam estuary, expressed as number of years of data needed related to the observed variability in the statistical monitoring data. The data points of the high slopes (closed circles) and low slopes refer to the same species categories (see Table 17.2 and text). CV, coefficient of variation.

average harvest in the extensive shrimp culture in Probolingo, East Java, was 300 kg/ha/crop (Hariati *et al.*, 1998). With an average of 125 kg/ha/year (shrimp: 85 (statistical monitoring) to 130–190 (survey) kg/ha/year) and a mode in farm size in the Mahakam of 4–7 ha (Bourgeois *et al.*, 2002), the annual production per farm was 500–875 kg. The annual shrimp output, fished in around 180 days/year, of four small-scale shrimp trawler fishermen in the estuary is around 900 kg (van Zwieten, unpublished data). The overall CV in their total daily multispecies catch is 75%; taken separately, the four shrimp species in their catch (range 0.15–1.3 kg/day) had a high CV of 100–155%. This CV *per species per day* is comparable to the CV *per harvest* for individual pond owners of 119%. Inter-annual CV in catches from a wide range of fish stocks range from 9% to 100%; inter-annual CV in crop production ranges from 10% (intensively managed agriculture) to 70% (marginal rainfed agriculture) (van Densen, 2001). The extreme variability in the Mahakam pond productivity means that the potential for detecting changes, for instance, as a result of better management practices, is low both on an aggregated level of fisheries statistics and for individual pond owners. This is corroborated by Bourgeois *et al.* (2002): while causes of variability are readily discussed by stakeholders, there is little consensus about them, except for the effect of rainfall. The importance of better management practices and mangrove protection is high on the list of everyone involved, but experience is limited on what this could achieve. It will not be easy to gain this experience barring a long-term commitment to better management practices.

Notwithstanding data aggregation, lowering variability, limited data quality resulted in high variability in fishery statistics, obscuring the potential for detecting changes in marine production and productivity. Nevertheless, the observed trends, variabilities and shifts in fishery catches do have biological realism: the described developments in relative species composition are general trends appearing in many fish communities under stress. Although a significant shift in catch towards shorter-lived species took place from 1993 to 1999, 4 to 10 years after the start of the boom in pond construction, fishery statistics gave no direct evidence of a trade-off between the pond production and fisheries on the aggregated level of the whole estuary. Catch rates, at their aggregated level, show no indication that the fishery in its current operational set-up is affected by the rapidly decreasing mangrove coverage.

The high variabilities in fishery statistics alone already imply that the observability of a trade-off is limited. Multiple causes and non-linearity of the changes taking place will exacerbate the problem. First, the observed 6–9 years' monotonic rise and fall in annual catch of most categories is more likely due to changes in the structure of the fish community through environmental forcing or density-dependent processes (Bjørnstad *et al.*, 1999). Year-class variation in stocks would produce short-term trends of 3–4 years or shorter given the residence time of any year class in an exploited stock of most of the species examined. Whether these changes are cyclical or represent a more irreversible change as a result of mangrove habitat destruction or upstream processes in the Mahakam River cannot be concluded. Next, fishing patterns – gears used, spatial effort allocation – changed with increased effort throughout the 1990s as well. Changing fishing patterns in small-scale fisheries are often an adaptation to changing fish community structures (Jul-Larsen *et al.*, 2003a). Whether the fisheries are adapting to community changes as a result of environmental forcing or are themselves a major cause of the community changes depends on their relative impact. Lastly, while a certain minimum area of mangrove is necessary for the maintenance of coastal productivity, the mangrove area/yield relationship is non-linear (Baran and Hambrey, 1998). Many fish and crustacean species are transients and are not critically dependent on mangroves (Krumme and Saint-Paul, 2003; Mumby *et al.*, 2004). Where forests extend along a coastline and are connected by coastal currents, impacts on coastal fisheries may only be noticeable when most of the functional part of the forest has disappeared. Type, spatial arrangements and connectivity of mangrove forest are important and patterns of mangrove–water interface, tree communities and age of mangrove stands have been suggested as affecting fish and crustacean community structure (Primavera, 1997; Ronnback *et al.*, 1999; Manson *et al.*, 2003).

In the Mahakam Delta, the potential for detection of changes in relevant indicators as a result of management action is limited, while the high variability in individual outcome also limits the utility of local observations of fishermen and shrimp-pond farmers. The acceptability of taking measures to protect mangrove habitat could be reduced as any positive impact will be difficult to observe in the short term on a local level as well as in aggregate fishery statistics, limiting their use for evaluation of impacts. Over the long term, the utility of monitoring data appears to be high, but improved data quality and capacity to evaluate information will be required to increase diagnostic power. The challenge is to devise tools for informed decision-making with limited data in a spatially and temporally complex environment with a high fish and crustacean diversity, starting from what is already available. Better use of existing data, information and knowledge will aid in improving the evaluative capacity of those involved in managing coastal resources.

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