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ORIGINAL PAPER

Challenges of a transition to a sustainably managed shrimp culture agro-ecosystem in the Mahakam delta, East Kalimantan, Indonesia

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Abstract Around 1990, when in other countries mangrove protection took off, massive conversion of mangrove forest into shrimp ponds started in the Mahakam delta. To identify constraints to and options for sustainable management we analysed institutions and constraints with stakeholders. In 3 sites we used participatory tools and a complementary survey to assess the livelihood framework. Since 1970, ponds for shrimp farming gradually replaced 75% of mangrove forested area. After 2004, recovery of mangrove took off, as, mainly due to low shrimp yields, ponds were abandoned. In 2008, 54% of the delta was dedicated to ponds for shrimp production. Around 80% of livelihood activities of pond-farmers, pond caretakers, and fishermen was related to mangroves. The involvement of men and women in these activities varied between sites and types. Poor households depended more on mangroves. Most activities resulted in seasonal income peaks; only a few activities resulted in a full daily livelihood. Ponds, on the other hand, provide 50% of households' livelihood, but this remains vulnerable in the context of the risky shrimp production. Skewed land holding, unequal sharing of benefits, competing claims and vested interests of stakeholders pose a great challenge to a transition to a more sustainable use of the mangrove area. In particular, ponds located on peat soils are non-sustainable and would require full restoration into mangrove; ponds on other soils could best be transformed into a mixed mangrove-pond system using a 'green-water' technology.

Keywords Mangrove · Wetlands · Sustainability · Livelihoods · Aquaculture · Indonesia

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Introduction

Over the past decades, mangrove areas have continued to decrease due to urbanisation and aquaculture of mainly shrimp in various American and Asian countries (Hopkins et al. 1995; Bhatta and Bhat 1998), but also due to oil, gas, wood exploitation and other economic activities (Primavera 2006). Mangroves protect the land from storm surges and from erosion by currents and waves; shelter aquatic organisms from heat and predators; and serve as nursery, spawning and feeding areas by fish, crustaceans, and molluscs (Primavera 1997). Thus intact mangrove ecosystems contribute to sustaining livelihoods of fishermen from outside the area, and of local households by providing these last, next to fishery products, firewood, timber, and primary materials for housing and fishing. Study of the destruction and subsequent recovery process provide lessons for governance of remaining mangroves areas threatened by various industries (Hopkins et al. 1995; Bhatta and Bhat 1998). In her recent overview, Rivera-Ferre (2009) showed that this industry contributed (temporary) to increased GDPs, but that transforming mangrove had non-accounted negative environmental impacts and increased inequality especially locally; both are negative for long term economic development.

We aim to analyse the destruction process of the mangrove forest in the Mahakam delta for shrimp aquaculture, and propose a roadmap to its recovery while maintaining livelihood opportunities. Through an analysis of (1) the settlement history of the delta; (2) the direct and indirect contributions of the formerly mangrove-forested areas in the Mahakam delta to the livelihoods of their inhabitants, and (3) the institutional context of the destruction process, we discuss options for sustainable management.

Methods

The paper is based on (1) literature and secondary database search; (2) expert consultations and focus group discussions, (3) participatory assessment, and (4) household surveys to collect data on natural resources, livelihood activities, and institutional context of mangrove use. Participatory assessment, institutional analysis and household surveys were carried out in three sites. We encoded data in MS-excel® for storage and for calculating averages with standard deviations. Further statistical analysis was done by using PASW®. For qualitative analysis, we used the livelihood framework approach (Scoones 1998). Some non-refereed sources of secondary data are listed in Table 7.

Site selection

For primary data collection, we selected three sites on the northern fringe of the Mahakam delta (Fig. 1a).

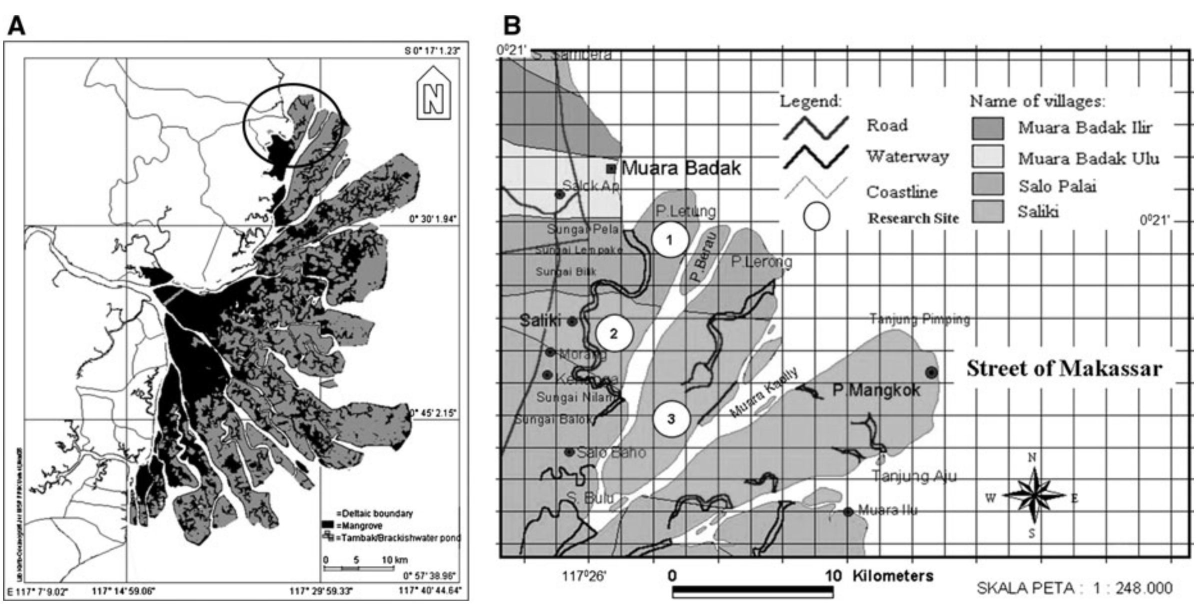

Fig. 1 **a** The Mahakam deltaic plain (limited by the *light grey line*) with the location of the project' research sites within the *black oval* and the areal occupation of shrimp ponds (*grey*) and vegetation (*black*) in 2007. Source: Sidik (2008), FPIK-Unmul; digitized from Quick Bird Image 2007. **b** Map of research villages; Taduttan is the island of which the coastal section is called 'P. Lerong, the research focuses on Saliki's section of this island (site 3); Joppang is the island of which the coastal section is called P. Letung; site 2 is in Saliki and site 1 is in Salo Palai village

The sites were in located in the villages Salo-Palai and Saliki, sub-district Muara Badak (Fig. 1b). The selection was based on the following criteria: year-round accessibility, readiness of inhabitants to collaborate in research, remaining mangrove vegetation, involvement of NGO and local government in replanting, availability of secondary data, diversity of livelihoods in the community, and representativeness for the delta with regard to residence of owners inside and outside the hamlets. The sites were: (1) Salo-Palai's hamlet numbers 2 and 3 exploiting ponds on Joppang island; (2) Saliki's hamlet numbers 1, 2, and 3 located also on Joppang island, hereafter called Saliki; and (3) Saliki's hamlet numbers 7, 8, and 9 on the island of Taduttan, hereafter called Taduttan.

Primary data collection

We carried out a situation analyses, complementary household surveys and an institutional analysis. The situation analyses was done in six steps: a preliminary survey to select research villages, study of secondary data, pond farmer meetings for a participatory assessment (PRA), individual interviews, focus group discussions with stakeholders, and a stakeholder workshop to cross-check the results.

The PRA team comprised one female University staff and a Fisheries Service's agent. The PRA, organised in May 2007, addressed households whose livelihoods were based at least partly on the mangrove ecosystem (fishing, collecting, pond farming). We used PRA tools addressing the entire group, as mapping of livelihood activities and gender involvement, activity and context calendar, diagrams for market chain and institutional network, as well as focus groups discussing site mapping (by gender), problem trees (by main profession) and rating of the relative contribution to livelihood (by gender).

In January 2010, the complementary individual household surveys addressed 30 individual households. In Taduttan, 4 out of the 5 surveyed households did not stay in the farm when no shrimp was stocked (December to February), and had returned temporarily to the household's main residence. For these four households only quantitative information from the village register was available.

The institutional analysis was based on locally available literature, personal information of two of the authors with long term experience in the Delta, and a meeting with policymakers.

Settlement history of the Mahakam delta

The Mahakam delta is slightly larger than 1,070 km^2 and consists, except for its land-side fringe, of a collection of islands (Fig. 1a). All-weather and dirt roads are present only on the delta's fringe. They lead to main villages from where islands, poor in infrastructure, are accessible by boat only. Numerous pipelines cross the delta; dirt roads were constructed for their maintenance by the oil and gas companies.

Rainfall exceeds 2,500 mm in the 25,000 km^2 catchment of the 900 km long Mahakam River that discharges into the Makassar Strait. Increased sedimentation in the delta due to upstream forest logging is counteracted by long-term downward tectonic movements. Impacts of natural compaction and accelerated compaction due to anthropogenic activities, as well as rising sea levels due to climate change are not well known (Syvitksi et al. 2009).

The Mahakam delta was virtually uninhabited prior to 1890, when migrants from Sulawesi settled on the fringes of the delta to crop land, and along its shores for fishing, but until 1970, natural resources were hardly disturbed (Bourgeois et al. 2002). Then, around 1970, exploitation of oil and gas increased, leading to land speculation, and the first cold storage was installed increasing export opportunities of both fished and farmed shrimp. At present, officially around 85,000 people live in the sub-districts that include the Mahakam delta: Muara Badak, Muara Java, Sambodja, Sanga-Sanga and Angana. In Anggana, the only sub-district located entirely in the delta, fishermen and (pond-) farmers constitute officially around 50% of the population.

Since 1970 farming of shrimp started in ponds dug manually. Shrimp farming boosted after trawl fishing was prohibited in 1984 leading to conversion of 5% of the mangrove forest in 1990. The use of excavators from 1990 onwards accelerated conversion to around 15% of the area in 1996. From 1997 to 2000, shrimp were relatively well paid in local currency as a result of the Asian economic crises, which stimulated pond opening mostly by immigrants from other Indonesian islands (Bourgeois et al. 2002). In 2001, 75% of the delta was covered with ponds (Zwieten et al. 2006), and in many places only a narrow strip of the original forest had remained along the shoreline. Subsequently, as a result of both declined productivity (see next section) and lowered shrimp prices (due to recovery of the exchange rates followed by the global economic crises), the area covered by ponds decreased to 63% in 2005 and a recent inventory estimated the productive pond area at 58,000 ha, or 54% (Fig. 1a).

Livelihood analysis

Pond productivity and livelihood vulnerability

To open a pond, a dike is built by creating a ditch, thus leaving a central plateau. The dikes prevent tidal movement of water and the vegetation on the central plateau, remaining after harvest of valuable timber, perishes or is burned. The ponds are filled at high tide. Most of the submerged pond area remains too shallow for efficient shrimp farming. As the central plateau retained its original level, the effective pond size is much smaller explaining both the low average yield and the lower productivity of larger ponds observed by Noryadi et al. (2006). In the first year after opening, an extensively managed pond, i.e., receiving no additional feed, produces between 100 and 300 kg of shrimp ha^{-1} $year^{-1}$, but production gradually declines. According to the scenario resembling shifting cultivation, decline of pond productivity stimulated farmers to open new ponds (Zwieten et al. 2006).

The decline in shrimp production appears after 3–5 years and is caused by gradual acidification of mangrove soils closed off from tidal influences (Avnimelech and Ritvo 2003). Decreased water quality stresses shrimp and comes along with diseases such as White Spot Syndrome of Shrimp and Red Gill disease (Corsin et al. 2001). Consequently, the farmers have a good shrimp harvest once every four cycles only and produce on average close to 45 kg ha^{-1} $year^{-1}$ (Noryadi et al. 2006) which is approximately 10% of the production of improved extensive and integrated mangrove shrimp farming systems in e.g., Vietnam (Joffre and Bosma 2009) and less than 1% of intensively managed ponds. Improved extensive shrimp production systems use selected shrimp to stock the ponds and provide feed, while intensive systems provide aeration, use water purification and prepare the pond bottom mechanically also. Ploughing and drying can prevent the acidification of good pond soils (Beveridge et al. 1994), but these investments can be valued only through further intensification (higher shrimp densities and feeding). Local commercially driven pond owners apply fertilizer, medicines, lime and other chemicals to reduce acidity presupposing that pond production of these extensive traditional systems can be maintained or improved. Given the low densities and yield, this is mostly not cost-efficient (Bunting et al. forthcoming).

Next to the 45 kg ha^{-1} of white tiger prawn (*Peneaus monodon*) on average, farmers produced 375 kg ha^{-1} of milkfish (*Chanos chanos*) from three harvests, if ponds are stocked after filling. Next to this, pond farmers collect on average close to 160 kg $year^{-1}$ of spotted shrimp (*Metapeneaus brevivostris*) and between on average 11 and 80 kg of crab (*Scylla serrata* mainly). The crabs are collected from the dikes and at the fringes of mangrove forests in the estuary, and also harvested when the pond is emptied. Some farmers started culture of mud-crab. Others specialised in producing the highly priced naked crab by housing crabs in individual cages until they shed their carapace. Income from shrimp farming was not regular as harvest period relates to tidal and lunar cycles.

In the three sites, about 40% of the households' livelihoods resources were related to the mangrove forest; this relative contribution increases to 80% if pond farming activities are included (Table 1). The mangrove–estuarine-related activities included catching crab, collecting shrimp and crab seed for pond farming, fisheries, and collecting fire-wood, and primary materials for roof covers of houses and cabins, and for traps of crabs and fish. Women were involved in fishing-related activities such as construction of fishing equipment, and drying and salting fish, and peeling of shrimp.

Wealth rank (well-off = 1, to poor = 3) correlated positively to the mangrove-related activities' contribution to consumption (rho = 0.39), but negatively to the relative contribution to cash (rho = −0.23). This indicates that the poor are more mangrove dependent for their subsistence: their cash expenditure is mainly for food (Table 2). These households showed a higher diversification of livelihood activities related to the natural resources as compared with that of the poor. The first two categories also had other activities that generated cash or products for consumption.

Table 1 The main livelihood activities in the 3 sites, their gender differentiation and their relative contribution to livelihood (not representative; sample size: 9, 12 and 8 households respectively)

Livelihood activities	Gender division[a]		Relative contribution to livelihood activity (%)		
	♂	♀	Salo-Palai	Saliki–Joppang	Saliki–Taddutan
Fishing	100	0	14	21	6
Make traps and roof covers	100	75	1	1	5
Prepare dry salted fish	42	83	7	1	6
Pond farmer	100	45	36	29	57
Pond care-taker	100	25		13	3
Off-farm pond worker	100	70	9	1	2
Collect fish for market	100	30	5	6	6
Catch mud crab	100	24	7	11	14
Bake (and sell) cookies	0	100	8	2	0
Crop and livestock farming	83	50	5	5	0
Non-farming[b]	86	30	9	10	2

[a] % of the male and of the female members involved in the activity of the households

[b] Making boat, salaried labour, renting and trading for Salo-Palai and Joppang; collect firewood for Taddutan

Table 2 The dependency of three categories of wealth on mangrove resources for their livelihood

Wealth rank	*n*	Relative contribution to livelihood of					
		Mangrove related activities			Plus pond farming		
		Total	Cash	Consumption	Total	Cash	Consumption
Well-off	5	40	18	22	67	40	27
Medium	16	30	17	13	74	55	19
Poor	8	64	55	10	95	78	17

Well-being ranking correlated highly to land size (rho = 0.54; $P < 0.01$). Households with more land had less contractual arrangements ($P < 0.05$), while fishermen had more. Households having fishing as the main livelihood more often accumulated savings. Credit from the state bank was not accessible for pond-farmers and fishermen. Consequently, pond caretakers and resource-poor farmers depended for financial capital required for pond inputs and for sustaining their livelihood in times of crisis on credit from collectors and their bosses. Several financial relationships between pond owner and care-taker existed, but most sharing arrangements were unequal as most benefits accrued to the pond owner (Table 3).

As the relative contribution of pond farming to household income was close to 50% on average, households were highly vulnerable to decreased pond productivity and shocks. Due to the frequent incidence of shrimp diseases, once in a 2-year period only shrimp farming provided enough cash to reimburse debts and to invest.

Human capital

The official statistics underestimate the number of inhabitants and of households depending on aquaculture and fishing. Not including full-time engaged wage labourers, the average household size was close to six persons (Table 4), while official statistics indicated about four (BPS 2005). Officially 390 households were registered as fishermen or pond-farmers in the six hamlets of Saliki covered by the study (BPS 2005). However, hamlets 1, 2, and 3 stated to have 170, 50, and 80 respectively, while Taduttan alone claimed to have around 350 shrimp farmers and fishers, which totals to 650. The non-registered people mainly were

Table 3 The share of production inputs (seed stock, fertilizer, feed) provided by either owner or caretakers in seven types of harvest sharing between pond owners and care-takers in Saliki and Taddutan

Type of harvest sharing		Share of production inputs (%)	
		Owner	Caretaker
1	Sharing of tiger prawn and spotted	66	34
2	Prawn identical to cost sharing;	80	20
3	Crab all for care-taker	50	50
4	Equal share of tiger prawn for both;	Land + 100%	Hire worker
5	Spotted prawn and crabs for caretaker	Land	100%
6	20% for caretaker, 80% owner	Land + 100%	0%

In scenario 1–3 the owner has the responsibility to provide the caretaker with consumables and expense for religious ceremony and for medical cost

Source Erwiantono, 2006, personal communication FPIK, Mulawarman University

Table 4 The averages of size, of number of years the household (HH) head received formal education, of the year of settlement, and of the total land and pond area, of the sampled HH in the 3 hamlets in the Mahakam delta, Indonesia

Commune (number of HH in survey)	Household size	Years formal education	Year of settlement	Total HH land area (ha)	Pond area (ha) and *n*
Saliki (17)	5.1 ± 2.1	8.3 ± 3.9	1987 ± 9	7.4 ± 11.4	6.0 ± 6.7 (14)
Salopalai (12)	7.0 ± 2.3	7.6 ± 3.5	1988 ± 16	6.0 ± 6.8	7.0 ± 7.5 (6)
Tadutan (7)	5.8 ± 1.6	8.6 ± 4.3	1999 ± 8	11.6 ± 12.2	11.6 ± 12.2 (5)
Total (30)	5.7 ± 2.1	8.2 ± 3.7	1988 ± 11	7.7 ± 10.3	7.4 ± 8.1 (25)

households of caretakers hired by absentee owners and by owners of larger ponds. In Taduttan, the percentage of households involved in pond-farming and fishing was close to 100%, in the other sites around 50%. Thus the number of inhabitants is probably twice the official 2,500 and 1,200, for Saliki and Salo-Palai respectively (BPS 2005).

Average time since first settlement was about 20 years for Saliki and Salopalai but was half in Taduttan. Salo-Palai and Saliki had a mixed population of residents and recent immigrants; Taduttan was entirely composed of recent immigrants. Households were mostly composed of nuclear families, but elderly people usually share their house with one of the married sons and his household. The public schools and the public administration premises associated with the hamlets are located on the mainland. On the islands the people have build mosques and Koran schools.

Natural resources

Soil type in the research area is loamy varying from silt loam to clay loam, except for the coastline which is loam with sand. The subsoil of some islands, e.g., Taduttan, is peat which makes their coast lines very sensitive to erosion and abrasion. Pond rent varies between 200 and 600 US\$ ha^{-1} but is lowest in Taduttan both as a result of its distance from a road network and of its soil type that causes the average shrimp harvest to be only half of that of Saliki. Pond farmers and fishermen share the notion of a lack of spawning grounds, nurseries and refuge for fish. The problem tree reflected the protective, aquatic and livelihood functions attributed to mangrove forests. Both pond farmers and fishermen felt threatened by a near complete destruction of the mangrove forests. In particular pond farmers fear the broken dikes and subsequent loss of harvest; during the research period, one household in the sample moved away because of insufficient means to repair the dike of their pond.

The total pond area in the three sites was close to 5,000 ha, of which 3,000 ha was registered by owners residing in the village. Thus 40% of the site's pond area was developed by absentee owners, leaving pond management to caretakers under various sharing contracts. Over half of the population owns just over

400 ha, divided into ponds smaller than 5 ha (Fig. 2). The skewed land distribution is confirmed by high standard deviations in land size of households (Table 5) and in average land area per hamlet (Table 4). Maximum pond area was 33 ha and maximum cropland area 35 ha. Taduttan' households had on average the largest area but did not have cropland nor a homestead, only a house above the dike next to their ponds.

Institutional network and market chain

Government officers in the village were teachers and administrators; there were no technicians for agriculture or aquaculture. The Fishery Service was active in Saliki only, and had no contact with farmers in Salo-Palai or Taduttan.

The number of community based organisations was small: two associations of youngsters and women in Salo-Palai, one association of fishermen in Saliki, and one pond farmers' organisation in Taduttan aiming to replant mangroves. According to Saliki's Fisheries Service's agent, two local NGO's are active in the region: one for rural credit in Salo-Palai and one for replanting mangrove trees. Households having pond farming as main livelihood were less often member of an organisation.

For fishermen and pond farmers in the three sites the collectors are the direct contact in the chain beyond the local market. Pond-farmers sell their harvest to collectors who come to the farm, while fishers mostly bring their catch to collection points in specific landing sites. The farmers who also fish, consume and market their catch locally; excess fish are often salted and dried before sale to a collector. The collectors are specialised by product (fish, crab, shrimp) as well as by market: e.g., some collect crab for export only. The collectors work for 'bosses' including the so-called '*Pungawwa*', local elite with a high social status and with political influence. These 'bosses' deliver to the processors for export beyond the provincial market. Through these collectors and vendors the bosses provide technical advice and all types of inputs.

'Bosses' had generally accumulated capital through trading and shrimp farming; *Pungawwa* were complementary involved in a wide social network. Both may have started as small shrimp farmers in the early days of the shrimp-pond production in the delta. They imposed their prices and interest rates on the farmers that depended entirely on them.

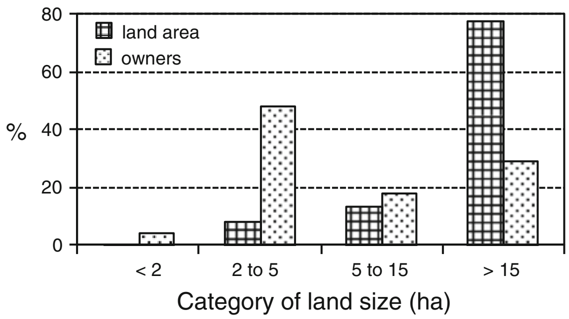

Fig. 2 The distribution of the total land area (5,000 ha) over 4 categories of land size and the frequency distribution of the number of land owners

Institutional analysis of the mangrove destruction process

International market incentives lured people looking for livelihood opportunities into shrimp farming, while the open access status of the forest eased the destruction of the mangrove ecosystem (Fig. 3). This destruction was possible in the framework of unclear land tenure regulations and conflicting policies, emanating from overlapping government sectors all claiming their authority to manage the delta

Table 5 Average pond size, rank of well-being, number of livelihood (LLH) activities and the total number of disease outbreaks in shrimp ponds in the past 3 years, for three categories of farm area

Land size category	N	Total area (ha)	Pond area (ha)	Shrimp diseases in past 3 years (n)	LLH (n) activities[a]	Rank of wellbeing
ha < 1	4	0.1 ± 0.2	0.0 ± 0.0	–	2.2 ± 1.8	1.8 ± 0.4
1 < ha < 5	11	3.1 ± 0.9	3.1 ± 0.9	5.5 ± 1.2	3.5 ± 0.8	2.0 ± 0.4
ha > 5	10	14.8 ± 12.5	10.2 ± 8.2	4.9 ± 3.2	3.9 ± 1.1	2.5 ± 0.7

[a] Difference significant at 5%

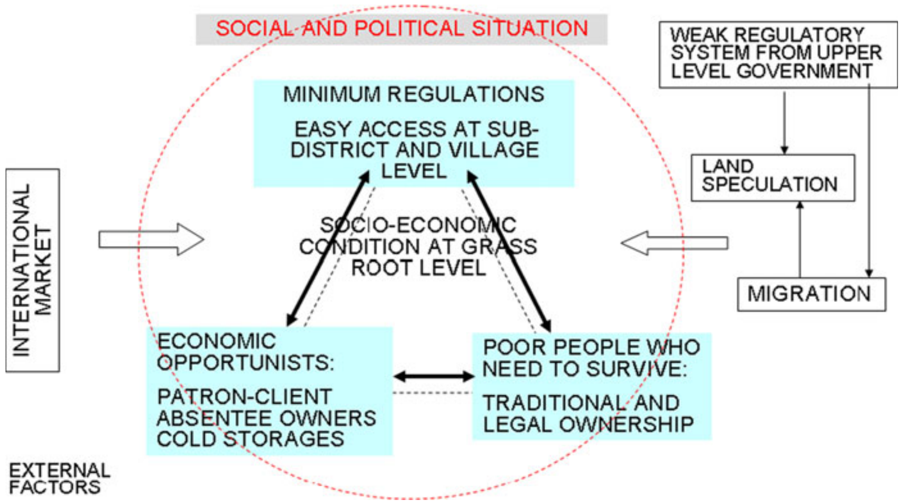

Fig. 3 The socio-political triangle that stimulated the loss of mangroves in the Mahakam delta (adapted from Sidik 2008)

Table 6 Procedures for access to land ownership at sub-district and village level

Rules for traditional land ownership
Anyone who cuts the mangrove the first time is the owner of the land
The borders of land ownership are agreed among community members
No limit of ownership
This kind of land ownership is very strong, even without legal proof
Forestry regulations for community ownership (HPHH)
Community members who want to own land should form a co-operative with a minimum of 25 persons
Each member gets a maximum of 2 ha of land and the borders are agreed by community members
Sub-district and village authority issue formal letter called tillage permit
This kind of ownership is strong and reduces land conflicts
Notes
Absentee owners usually buy the land from either traditional owners or those registered as a farmer co-operative
Maximum 2 ha is meant for one household, but in practice it is applied by individual members of a household
Land ownership may be also a speculation to get compensation claim from oil and gas companies

(Simarmata 2008, cited by Sidik 2008). Four different government sectors lay claims on the management of the Mahakam delta: Forestry, Fishery, Interior, and Environment. Consequently many rules and regulations on natural resources management were not operational at the level of implementation that endorsed this capture of resources by opening ponds, which makes it difficult to reclaim these resource as common (Bourgeois et al. 2002). As mangrove areas were considered of low value various stakeholders thus could freely gain or claim land property rights (Table 6). The appropriation of areas usually was legalised through a village head; in only one village the area that could be claimed per person was limited. In some villages, the head was owner of, or related to the owner of, an excavator used to open ponds and construct dikes. Those who made use of the excavators became indebted to these investors and entered in a dependent boss–client relationship. The easy access to land attracted immigrants, who were also brought in by investors from other Indonesian islands.

A Management Counsel for the Mahakam delta was created in 2004 after the presentation of the report of Bourgeois et al. (2002) but it was never called to meet. Other initiatives to improve the land-use of the Mahakam delta were taken (Table 7): e.g., the Forestry services recovered 20,000 ha of deserted ponds to start replanting. Salopia and Saliki scheduled planting 200 ha in 2010. The oil and gas companies also reclaim and re-enforce their land concessions

Table 7 The initiatives to organise and structure the management of the Mahakam delta

Year	Description
2001	Establishment of 'Integrated Management Council of Mahakam delta'
2003	Adoption of 'Detailed Spatial Planning of Mahakam delta Area'
2004	Creation of 'Management Counsel for the Mahakam delta'
2005	Adoption of a 'Land-Use Planning 2005–2025'
2006	Establishment of 'Mahakam delta Community Empowerment'
2007	'Spatial planning for the Coastal Zone 2008–2027'
2007	'Strategic Planning for Integrated Management of the Mahakam delta'

Sources Anonymous (2003) Detail Spatial Planning of Mahakam delta Area. A cooperation between development planning agency Kutai Kartanegara with LAPI Bandung Institute of Technology (in Indonesian only). Bappeda Kukar, Tenggarong, East-Kalimantan

Anonymous (2006) 'Review RDTR Kawasan delta Mahakam' Kerjasama, Total EandP dan Lapi ITB Bandung. Bappeda Kukar, Samarinda, East-Kalimantan

DKP (2007) The use management of Mahakam delta Area, District of Kutai Kartanegara, East Kalimantan Province (in Bahasa). Jakarta

which leads to conflicts with the local inhabitants. The Nature Conservancy and the World Wildlife Fund both strongly influence policy in the domain of forestry, fishery and environment. The succession of reports with little change on the ground and the strong influence of NGOs is characteristic for a frontier state with a weak law enforcement capacity and weak institutions (Ribot et al. 2008).

Discussion

Restoring mangrove is the best option for areas that are not appropriate for pond production due to poor soil quality or required for coastal protection. However, recovery of the ecosystem' functions of the mangrove forest takes about 20 years (Primavera and Esteban 2008), and there's no guarantee that a sufficient area can be recovered to fulfil the functions attributed to this ecosystem. In the past the pond farmers thought they had no active role in mangrove maintenance or recovery and pointed to the responsibility of authorities (district, village) and oil companies (Bourgeois et al. 2002). At present, pond farmers replant mangrove individually and in associations. The question is how such initiatives can be guided to optimise both restoring mangrove ecosystem functions as well as establishing sustainable pond production, as first proposed by Hopkins et al. (1995). Kutty (2005) demonstrated that lessons can be learned but that the implication of measures remains a concern.

Initiatives should consider the market context (Pradhan and Flaherty 2008) in which investors will continue to open new ponds in still virgin natural resources elsewhere and attract immigrants to take care of these, if this is the only way to produce (more) shrimp to satisfy market demand and make profits. If pond farming does not provide a livelihood to the immigrants, logging or mining are all alternative local options next to opening ponds in other mangrove deltas. Household residing on the mainland have more resilient diversified farming systems. In Vietnam shrimp farmers reduced the vulnerability of their livelihoods through on-farm diversification, off-farm labour and activities, including the culture of other fish of rice or producing salt (Ha et al. forthcoming; Joffre and Schmitt 2010). However market opportunities in Kalimantan are not as broad as in the Mekong Delta. Diversification of livelihood activities at higher scale of the labour market also will hardly constitute an outlet for low educated fishermen and pond farmers losing their livelihood based on the mangrove ecosystem as shown in Bangladesh (Hossain et al. 2004) and Vietnam (Joffre and Schmitt 2010). The sharing arrangements between (absentee) land owners and care-takers constrain transition to more sustainable practices as it is not in the interest for a care-taker to obtain a high productivity from the pond by investing capital or labour if most of the earnings go to the owner. However, increasing pond productivity and improving farmers' income through ponds integrated in the mangrove ecosystem seems the best option to sustain the livelihoods of the small pond farmers in the Mahakam delta.

As the dependency of the poor on mangrove based systems is large increasing the forestry area is crucial for poverty reduction. Between 2005 and 2008, the Fishery Service carried out a program funded by an oil and gas company introducing the 'komplagan' system (Fishery Services Muara Badak, pers. comm.). Following the Philippine' example, Komplagan separates the pond in two areas, the river side area being replanted with mangrove (Primavera and Esteban 2008). Recent epidemiological research showed that next to good aquaculture practices, a high ratio of mangrove in the vicinity and preparing the water in a filtering 'green water' pond with seabass and tilapia, are important for a low frequency and low impact of WSSV outbreaks (Tendencia et al. 2011). Conducting a pilot, showing specific examples or demonstration sites is often the best way to learn complex behaviours (Manzanilla et al. 2004, cited by Calumpang 2007). It might be wise to implement pilot projects converting ponds located in good production areas into a modified 'komplagan' system, in which the pond is divided in a deep filter pond and a shrimp pond. The shrimp pond uses water from the filter pond, where aquafarmers produce a carnivorous and an omnivorous fish species, thereby diversifying their income. Tilapia is an exotic species in the Mahakam delta that could have adverse effects on local biodiversity. The milkfish is not as effective as tilapia in controlling the luminous bacteria that increase the risk on WSSV in shrimp (Tendencia et al. 2006). Research is needed to identify local aquatic species that can replace tilapia in filter ponds.

The unsustainable production system in the Mahakam delta emerges from clearing mangroves to provide ponds for shrimp production in the backdrop of unclear land tenure regulations and conflicting policies from government sectors, skewed land ownership while larger landowners are mostly absent, and self-vested interest of different stakeholders. The categories of stakeholders and their interests correspond by and large to those identified by Stonich and Bailey (2000). To overcome these constraints and transform the area in a sustainably managed aquatic agro-ecosystem, experience from the Philippines suggests a threefold approach: create political will, demonstrate that the forestry policy can be enforced through engaging in legal procedures, and enforce responsibility and authority of a management body (Calumpang 2007). A strong broker, a NGO, journalist or scientist, can engage a legal procedure to create jurisprudence. Enforcing responsibility and authority can be achieved through a Multi-Sectoral Dialogue, supported by an information, education and communication campaign. Authorities might need to provide a legal safeguard (cadastre or contract) to secure land ownership (Karsenty 2008). It can be considered to attribute forest land titles to larger owners converting their ponds (partly) into mangrove forest to gain income from REDD (Reduce Emissions from Deforestation and Degradation) carbon payment schemes.

Higher consumer prices are inevitable when all environmental cost are internalised, but broader development goals need to be considered (Rivera-Ferre 2009). Specific programs are needed to support the conversion of smaller farms, also given the credit rates asked by the collectors, e.g., alongside the introduction of certification schemes for sustainable production systems.

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