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Mangrove dependence and socio-economic concerns in shrimp hatcheries of Andhra Pradesh, India

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SUMMARY

There are many environmental and socio-economic concerns about the shrimp aquaculture industry. This study, based on interviews, direct observations and literature reviews, shows that the Indian hatchery industry is heavily dependent upon the continuous support of natural resources and ecosystem services generated by marine, freshwater and terrestrial ecosystems. The mangrove ecosystem support area ('ecological footprint') needed to supply the hatcheries with *Penaeus monodon* shrimp broodstock, and the aquaculture grow-out ponds with postlarvae, exemplify the dependence on external ecosystems. Each hectare of mangrove in the Godavari River delta generated an annual fisheries catch of 0.8–1.5 *P. monodon* spawners (gravid females), valued at US$ 92–184. The entire Godavari mangrove delta had a partial gross economic value of US$ 3.0–6.0 million per year for the provision of shrimp spawners alone. The average hatchery, producing 75 million postlarvae annually, had an ecological footprint of 534 ha mangrove for the life-support input of shrimp spawners. The ecological footprint of intensive shrimp ponds was up to 11 times the pond area for postlarval input alone. The shrimp ponds in the State of Andhra Pradesh needed 35 000–138 000 ha of mangroves to satisfy the spawner requirement to hatcheries, and this implied a need to appropriate mangroves in other regions. Hatcheries were prepared to pay up to US$ 2000 for a single shrimp spawner, which also illustrated that the mangrove support areas regionally available were too small. Other concerns about the industry are the net loss of employment if hatcheries replace wild postlarvae collection, the extensive use of groundwater creating direct resource-use conflicts, by-catch problems in broodstock fisheries, and pollution by effluents. The risk of hatcheries introducing, amplifying and propagating disease affecting both cultured organisms and wild biota is another concern that can, and should, be addressed.

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INTRODUCTION

The shrimp aquaculture industry has been criticized severely for causing environmental and socio-economic problems in India and elsewhere (Beveridge *et al*. 1997; Shiva & Karir 1997; Primavera 1998*a*; Naylor *et al*. 2000; Rönnbäck 2001; Hein 2002). Critical studies have focused mainly on aquaculture grow-out systems, and consequently other components of the production cycle such as shrimp hatcheries have not received sufficient ecological and socio-economic analysis.

During the 1990s, there was a rapid growth in shrimp cultivation in India, which now contributes to almost 10% of the global shrimp aquaculture output (FAO [Food and Agricultural Organization of the United Nations] 2003). Tiger shrimp, *Penaeus monodon*, dominates Indian shrimp aquaculture production (70 000 tonnes yr^{-1} in 1991–2000; FAO 2003). Andhra Pradesh is the national centre for both shrimp ponds and hatcheries. In 1999, there were 84 300 ha of ponds within the state (more than half of the total culture area in India; James 1999; Hein 2002), and 128 (Bhatt 1999) out of India's 225 hatcheries (Rosenberry 1999).

The wild shrimp postlarvae (seed) that are stocked in grow-out ponds are either allowed to enter traditional ponds with incoming tidal waters or caught by seed fishers and subsequently stocked in ponds. Shrimp postlarvae can also be produced in hatcheries, which depend upon continual inputs of wild-caught broodstock. The broodstock can be separated into immature brooders, allowed to maturate in captivity, and already gravid female spawners.

It is important to acknowledge the non-valued and often unrecognized work of nature that forms the basis for industrial aquaculture (Folke *et al*. 1998; Kautsky *et al*. 2000). For instance, the shrimps belonging to the genus *Penaeus* have a life cycle where they spawn at sea and, after a few weeks, the postlarval shrimps settle in inshore and estuarine waters, which they use as nurseries during their critical early life stages (reviewed by Dall *et al*. 1990). The major factor influencing the productivity of penaeid shrimp fisheries is the survival during the prerecruitment stages, when the larvae of many species use mangrove environments (Garcia 1985;

Rönnbäck 1999). Both de Freitas (1986) and Primavera (1998*b*) found that *Penaeus monodon* prefers mangroves as nursery grounds.

Apart from shrimp postlarvae and broodstock, mangrove ecosystems also provide feed inputs, water quality maintenance and control against natural disturbances like erosion, storms and floods (Beveridge *et al.* 1997; Rönnbäck 1999). The productivity and sustainability of the shrimp aquaculture industry is thus directly dependent on the continuous support of natural resources and ecosystem services from viable mangrove ecosystems. However, as a paradox, the establishment of shrimp aquaculture ponds has been the main cause of recent mangrove loss in many countries (Hamilton *et al.* 1989; Primavera 1998*a*). The inability to appreciate the economic importance of mangrove ecosystem services has been a major driving force in the conversion of this ecosystem into alternative uses such as shrimp ponds (Barbier 1994; Rönnbäck 1999).

One way to identify human demands for natural resources and ecosystem services is by estimating the functional ecosystem area ('ecological footprint') required to support human activities. A number of studies have used the ecological footprint approach to illustrate the dependence of aquaculture and fisheries production on the work of marine and coastal ecosystems (Larsson *et al.* 1994; Kautsky *et al.* 1997; Berg *et al.* 1996; Folke *et al.* 1998). In a study of food inputs, nursery areas, clean water and waste processing, the ecological footprint of a semi-intensive Colombian shrimp farm was 35–190 times the surface area of the farm (Larsson *et al.* 1994; Kautsky *et al.* 1997). The mangrove nursery area required to produce the wild-caught shrimp postlarvae for stocking was the largest support system, covering 10–160 times the pond area, based on farming practices where 10–50% of stocked postlarvae were wild-caught. No attempt was made to estimate the ecological footprint of shrimp postlarvae produced in hatcheries, which was the alternative seed source (Larsson e*t al.* 1994).

The main objective of this paper is to investigate the degree of dependence on ecosystem support in shrimp hatcheries of Andhra Pradesh, India, by identifying the required inputs of natural resources and ecosystem services. Focus is placed on estimating the mangrove ecosystem support area needed to supply shrimp hatcheries with *Penaeus monodon* broodstock and shrimp ponds with postlarvae. The ecological footprint results are compared with data on mangrove cover to analyse if shrimp ponds in Andhra Pradesh need to appropriate mangrove ecosystem support from other states or countries. A partial economic value of mangroves is presented based on the provision of shrimp broodstock. This paper also illustrates environmental and socio-economic concerns about the shrimp hatchery in Andhra Pradesh, India. Aspects such as social structure, water and feed management practices and chemical uses are studied in the context of employment generation, water resource-use conflicts, disease problems and polluting effluents.

METHODS

Study area

The State of Andhra Pradesh (Fig. 1) has a coastline of 1014 km and 58 200 ha of mangroves, representing 9% of India's mangroves (Naskar & Mandal 1999). The river deltas of Krishna and Godavari have the most extensive mangrove cover, with Godavari delta alone having 32 600 ha of mangroves.

The shrimp hatcheries are mainly situated in three regions close to the cities of Vishakhapatnam, Kakinada and Nellore (Fig. 1). Many hatcheries are located along the coast north of the Godavari River delta, due to the proximity to potential markets for the ready-to-sell postlarvae and markets for purchase of broodstock. Shrimp aquaculture ponds surround the Godavari delta, and the catches of *Penaeus monodon* spawners are high in the nearby coastal waters. Kakinada has since the early 1990s attracted attention for broodstock collection; 20 000 *P. monodon* brooders were landed there in 1993 to cater to the needs of hatcheries in Andhra Pradesh as well as other states (Somayajulu *et al.* 1994).

Hatchery survey

The fieldwork of this study focused on the industry in the districts of East Godavari and Vishakhapatnam (Fig. 1).

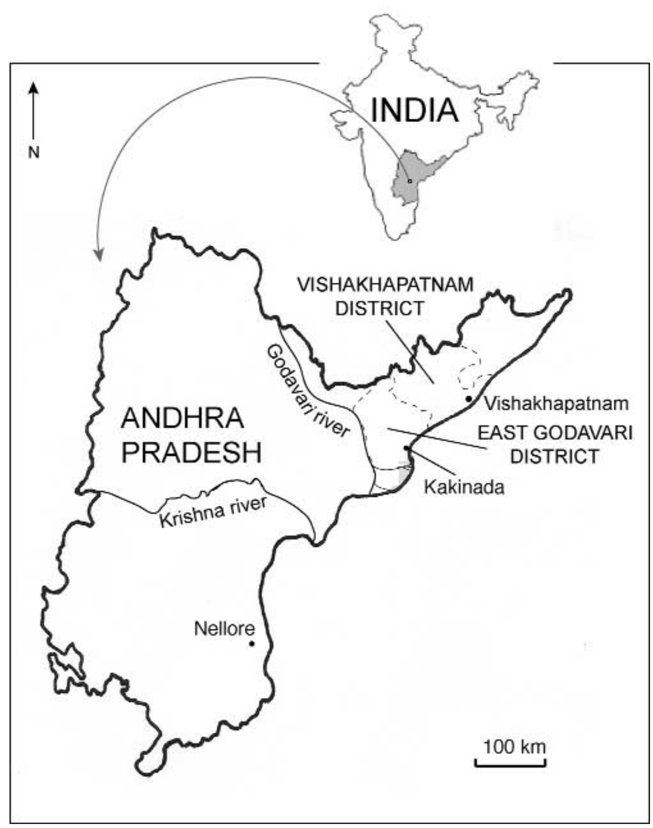

Figure 1 Map of the Godavari River mangrove delta, and the East Godavari and Vishakhapatnam Districts in the State of Andhra Pradesh, India.

There are 64 hatcheries in these districts, but only 61 of them were in production at the start of this study.

During April–June 1999, full interviews were conducted at 50 different hatcheries. A standardized open-ended questionnaire was used during face-to-face interviews with key informants at the hatcheries, such as the managers and head technicians. The main advantage of the method applied was that the respondents all answered the same questions, thus increasing comparability of responses. Another advantage was that the interviewer's effects and bias were reduced. Most of the interviews were conducted in Telugu with translation into English. As a complement to these interviews, direct observations were made both at the hatcheries and at the landing port in Kakinada. The questions asked related to production capacity, social structure, water and feed management, disease prevalence, chemical and drug use, origin, price and quality of broodstock, etc. (the full questionnaire is available upon request). Some of the questions were perceived as sensitive (such as questions concerning chemical use), and thus not all the respondents answered all questions. All of the hatcheries included in this study produced *Penaeus monodon* postlarvae.

Ecological footprint analysis

We estimated the mangrove ecosystem support area ('ecological footprint') needed to supply the continuous input of *Penaeus monodon* spawners to hatcheries, and grow-out ponds with shrimp postlarvae. The footprint calculations initially determined the total quantity of marketed spawners based on the hatchery interviews. This quantity was then correlated with the area covered by the supporting ecosystem, i.e. mangroves, to calculate the footprint of each hatchery as well as the number of spawners that could be generated by each hectare of mangrove under the current fishery exploitation pattern. The market value of spawners was used to attribute a gross financial value to this mangrove support. The ratio of spawners per million postlarvae produced was estimated based on spawner inputs and fecundity, and hatch and mortality rates to postlarval stage. This ratio was finally used to calculate the ecological footprint of shrimp grow-out ponds in Andhra Pradesh in a scenario where all ponds produce two crops per year and are stocked with shrimp postlarvae produced in hatcheries. Extensive culture (1–3 postlarvae [PL] per m^2 as stocking density) is practised in 75% of the shrimp ponds in Andhra Pradesh, whereas semi-intensive (3–10 PL m^{-2}) and intensive (10–50 PL m^{-2}) is practised in 20% and 5% of the ponds, respectively (Rosenberry 1999; Rönnbäck 2001).

RESULTS

Capacity, productivity and marketing

The average production capacity of the hatcheries in East Godavari and Vishakhapatnam Districts was 75.5 ± 10.0 (mean ± SE) million PL yr^{-1}. In total, the 61 hatcheries in production were estimated to have a capacity of more than 4.6 billion PL yr^{-1}, but many of the hatcheries were not using their full capacity, due to low demand or seasonal shortage of broodstock. The actual production was 57.6 ± 4.8 million PL $hatchery^{-1}$ yr^{-1}, and all the hatcheries were estimated to be producing around 3.5 billion PL yr^{-1}.

Most of the shrimp postlarvae from the hatcheries in the East Godavari and Vishakhapatnam Districts were sold to supply the farmers in the Godavari delta. Postlarvae were also being sold to other districts as well as to neighbouring states like Orissa, Tamil Nadu and West Bengal, and even to Bangladesh. Due to strong competition and fluctuating production costs (mainly influenced by the price of spawners), there have been large fluctuations in the price of shrimp postlarvae. During 1999 the prices were 0.05–0.85 Rs PL^{-1}, and at the time of the interviews the average price was 0.34 Rs PL^{-1} (equivalent to US$ 8 per thousand postlarvae). Wild-caught postlarvae were at the same time being sold for 0.25–0.30 Rs PL^{-1}.

Social structure

Each hatchery had 30 ± 2.1 (mean ± SE) employees, 1833 people being employed by the 61 hatcheries in East Godavari and Vishakhapatnam Districts. The ratio of employees to production was 0.6 employees per million shrimp postlarvae produced. Only 2% of the employees were females, whose work was restricted to the microalgae section or cleaning work. The age of the staff ranged from 14–40 years old, mainly unmarried young men in their twenties. Most workers were locals, but the managers and technical staff came from larger cities within Andhra Pradesh. Two of the hatcheries also had personnel from the Philippines and Thailand, while another four have representatives from various states throughout India.

The hatcheries were situated in quite isolated areas, and were surrounded only by other hatcheries and some small villages. Most of the employees lived on the premises and were on duty around the clock, all days of the week, which made it difficult to be a part of a traditional social structure.

Water and chemical use

The hatcheries regulated water salinity by diluting seawater with groundwater. Since the quality of the seawater varied throughout the year many of the hatcheries experienced problems with turbidity, organic material, suspended solids, various pollutants and heavy metals. The intake water was treated through a series of filters and chemical tanks. Furthermore, the shrimp broodstock, eggs, larvae, postlarvae and live feeds were continuously subjected to various chemicals and drugs, such as bleaching powder, antibiotics and fungicides, throughout the production cycle. The effluents were, however, rarely treated. Only 10% of the hatcheries allowed the effluents to filter through sand beds before emission, while another 20% chlorinated the water before it was released.

Each hatchery used 212 ± 22 m^3 (mean ± SE) of seawater per day; 157 ± 19 m^3 seawater being released back to sea. The rest was exported along with the postlarvae and lost through evaporation. For all 61 hatcheries in East Godavari and Vishakhapatnam Districts, an estimated 12 900 m^3 of water were used daily, and 9600 m^3 were returned to the sea.

There was a significant risk of self-pollution of diseases as well as particulate organics and nutrients at individual hatcheries, since the distance between the water intake and outlet averaged only 127 ± 19 m. Furthermore, many hatcheries were situated very close to neighbouring ones, which increased the risk of pumping in waste water released by other hatcheries. However, to ensure uncontaminated water, 4% of the hatcheries separated the intake and outlet pipes by 2–3 km.

Groundwater was the preferred freshwater source, because of its better quality than surface water. Each hatchery was using 38.6 ± 7.5 m^3 daily, and altogether the 61 hatcheries are estimated to have been using 2400 m^3 of fresh water daily.

Feed

From hatched egg to ready-to-stock postlarvae took 3–4 weeks, during which the shrimps developed through nauplius, zoea, mysis and postlarval stages, the last three requiring additional feed. Microalgae for the zoea and mysis larvae were cultured in tanks at the hatchery premises, the algae isolated from samples of seawater and, along with added fertilizers, grown in large quantities.

Artemia (brine shrimp) was used as feed for the mysis and postlarval stages, imported from the USA as dry cysts, and rehydrated at the hatcheries to resume the embryonic development. Broodstock feeds were formulated from agricultural products from the region and fishmeal and oil harvested in other continents. Local feed, such as crabs, shrimps, squids, bivalves and polychaete worms, were also commonly used to feed the postlarvae and broodstock. This farm-made feed was mixed with eggs, cod liver oil, yeast, beef liver, vitamin drops and milk powder. There was thus strong local and global dependence on marine, freshwater and agricultural support systems to maintain production. Many of the hens that supplied the eggs were also fed with the by-catch from the shrimp trawlers, which was another link to the marine support systems.

Spawners

Shrimp broodstock were landed in Andhra Pradesh mainly at Bhairavapalem (south of Kakinada in the heart of the Godavari River delta), Uppada (just north of Kakinada) and Vishakhapatnam (Fig. 1). According to the local fisherfolk, it was mainly the smaller mechanized boats, staying out for shorter periods of 6–12 h, which could capture and keep the adult shrimps alive. In the coastal waters surrounding the Godavari delta most broodstock were caught within 2–3 km of the shoreline, although it was illegal to fish with mechanized boats within 8 km of the shoreline.

Shrimp brooders are induced to spawn by ablating their eyestalk, which produces a gonad inhibitory hormone that controls reproduction. An incision is made across the eyeball with a razor blade and the entire content is squeezed out. The hatcheries had experienced major problems with keeping broodstock alive due to disease prevalence, and therefore immature brooders were rarely used. It was common to depend entirely on already gravid females (spawners) caught from the sea. All spawners were used only once, and were decapitated and sold as seafood after spawning. One of the hatcheries in the study had, however, released the spawners back to the sea. In either case, the basic prerequisite for hatchery production was a constant supply of new spawners, which meant that the industry was both heavily dependent upon the support of natural ecosystems and subject to the natural variability of this support.

The market for *Penaeus monodon* spawners and brooders was basically unregulated, and many of the buyers from the hatcheries gathered at the landing site to bid, resulting in a supply-regulated market, the prices tending to fluctuate heavily along with the availability of spawners. The trend in Andhra Pradesh through the 1990s was an increase in demand with a decreased supply, resulting in a substantial increase in price. In 1994, the market price was as low as 300 Rs (equivalent to US$ 7) per spawner, but in 1998 and the beginning of 1999 the prices rose to 80 000 Rs (almost US$ 2000) per spawner. The average price during April–June 1999 was 5260 Rs $spawner^{-1}$ (US$ 122 per shrimp).

Twenty-five of the hatcheries were able to give detailed information on the number of *Penaeus monodon* spawners purchased. In total, these hatcheries used 22 652 spawners annually, and produced 1547 million postlarvae. Each hatchery uses 17.5 ± 2.0 (mean ± SE) spawners to produce one million postlarvae. This estimation was cross-checked with interview data on spawner fecundity, hatch rate and mortality rate up to postlarval stage. The average spawner released 350 000 eggs at first spawning. Shrimps were not able to spawn a second time, due to disease prevalence. If the eggs are in good condition, 75–90% of them will hatch to nauplii. Eggs of poor quality have lower hatch rate, and consequently the entire batch is discarded. The survival rate from hatched nauplii to postlarvae is 30–50%, and each spawner of good quality thus produces 79 000–158 000 shrimp postlarvae. Spawning rate is 90–95%, i.e. 5–10% of the purchased spawners are unable to spawn in the hatchery. Consequently, 6.7–14.1 spawners are required to produce one million postlarvae.

Ecological footprint analysis

The ratio of 7–14 spawners per million postlarvae produced was used to estimate the mangrove ecosystem support area

Table 1 An estimate of the mangrove ecosystem support to fisheries production of *Penaeus monodon* spawners that supply shrimp hatcheries in Andhra Pradesh, India.

Factor	*East Godavari and Vishakhapatnam Districts*	*State of Andhra Pradesh*
Number of hatcheries	61	128
Annual production (million PL)	3514	7374
Spawners per million PL produced	7–14	7–14
Total input of spawners	24 600–49 200	51 600–103 200
Mangrove cover (ha)	32 600	58 200
Spawners per hectare of mangrove	0.8–1.5	0.9–1.8
Partial mangrove value (US\$ ha^{-1})	92–184	108–216

needed to supply hatcheries with spawners and shrimp postlarvae to grow-out ponds. The total input of *Penaeus monodon* spawners to shrimp hatcheries in East Godavari and Vishakhapatnam Districts was 25 000–49 000 spawners annually (Table 1). If the mangrove ecosystem in the Godavari delta had supported this entire fisheries catch, each hectare of mangrove would have generated 0.8–1.5 *P. monodon* spawners per year under the current fisheries exploitation pattern. A partial gross economic value of US\$ 92–184 ha^{-1} could be attributed to the Godavari mangroves, based on an average market price of US\$ 122 per spawner. The entire Godavari delta would thus have had a partial gross economic value of US\$ 3.0–6.0 million per year for the provision of *P. monodon* spawners alone.

We cannot claim that the mangroves in the Godavari delta solely supported all hatcheries in East Godavari and Vishakhapatnam Districts, or that the Godavari mangroves only supported hatcheries in these two districts. We therefore estimated the relationship between shrimp hatcheries and mangroves in the whole State of Andhra Pradesh. There were 128 hatcheries producing 7374 million *Penaeus monodon* PL yr^{-1}, and 58 200 ha of mangroves in the State (Table 1). These mangroves support a fisheries catch of 52 000–103 000 spawners, and each hectare of mangrove thus generated 0.9–1.8 spawners, valued at US\$ 108–216, annually.

The shrimp hatcheries in East Godavari and Vishakhapatnam Districts have appropriated 32 600 ha of mangroves, and each hatchery in operation had an average ecological footprint of 534 ha of mangroves for the input of *Penaeus monodon* spawners alone. The corresponding ecological footprint calculated for the entire State of Andhra Pradesh was 455 ha mangroves per hatchery.

We developed a conceptual framework for the ecological footprint of shrimp aquaculture grow-out ponds stocked entirely with hatchery-produced shrimp postlarvae (Table 2). The shrimp ponds in Andhra Pradesh appropriated 35 000–138 000 ha of mangrove for the provision of *Penaeus monodon* spawners to shrimp hatcheries (Table 2, Fig. 2), assuming that all ponds were stocked entirely with hatchery-produced postlarvae. If all extensive ponds had been stocked with wild-caught postlarvae, the semi-intensive and intensive

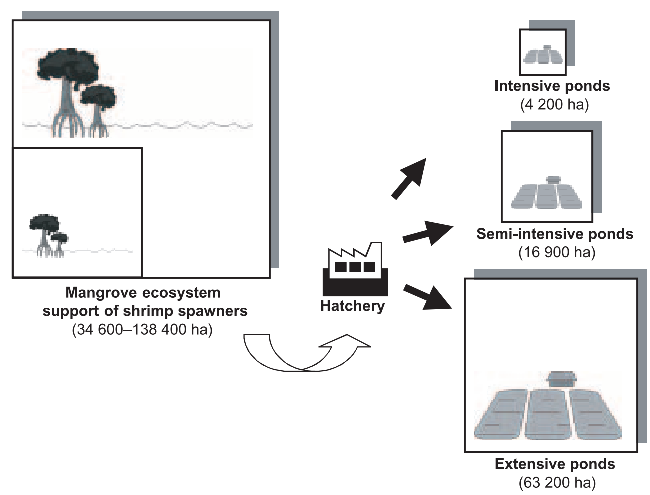

Figure 2 The mangrove ecosystem support area ('ecological footprint') needed to support shrimp aquaculture ponds with postlarvae produced by shrimp hatcheries in Andhra Pradesh, India. Culture practices: extensive (2 PL m^{-2}, 2 crops yr^{-1}), semi-intensive (7 PL m^{-2}, 2 crops yr^{-1}), and intensive (30 PL m^{-2}, 2 crops yr^{-1}).

Table 2 The mangrove ecosystem support area ('ecological footprint') needed to support shrimp aquaculture ponds with *Penaeus monodon* postlarvae produced by shrimp hatcheries in Andhra Pradesh, India. Calculations assume two shrimps crops per year, all stocked postlarvae (PL) are hatchery produced, 7–14 spawners needed to produce one million postlarvae, and 0.8–1.5 spawners generated per ha mangrove annually. Sources: [a] James (1999) and Rosenberry (1999); [b] Rönnbäck (2001).

Factor	*Extensive*	*Semi-intensive*	*Intensive*	*Total*
Pond area (ha)[a]	63 225	16 860	4215	84 300
Mean stocking rate (PL m^{-2})[b]	2	7	30	
Mean annual production (t ha^{-1})[b]	1	4	10	
Postlarvae requirement (10^6)	2530	2360	2530	7420
Spawner input	17 700–35 400	16 500–33 000	17 700–35 400	51 900–103 800
Mangrove support area (ha)	11 800–47 200	11 000–44 000	11 800–47 200	34 600–138 400
Ecological footprint				
m^2 mangrove per m^2 pond	0.2–0.7	0.7–2.6	2.8–11.2	0.2–2.4
m^2 mangrove per kg shrimp	1.9–7.5	1.6–6.5	2.8–11.2	

ponds would still have appropriated up to 91 000 ha of mangroves for the required postlarval input from hatcheries (Table 2). The ecological footprint for all shrimp ponds in the State amounted to 0.4–1.6 times the total pond cover. The mangrove ecosystem support area ranged from 0.2–0.7 to 2.8–11.2 times the pond area for extensive and intensive systems, respectively (Table 2). The difference in appropriated ecosystem support area is less pronounced when the ecological footprint calculations are based on shrimp biomass produced in the individual systems (Table 2).

DISCUSSION

The shrimp hatchery industry is dependent on a wide variety of industrial inputs and natural resources from local, regional and global systems (Fig. 3). For instance, feed inputs range from microalgae and polychaetes harvested from local ecosystems, to *Artemia* and fishmeal generated by ecosystems in other continents. The hatcheries could be described as through-put systems, where resources are collected over large areas, introduced and used in the hatcheries, and returned back to the environment in concentrated forms. Consequently, many hatcheries may pollute surrounding waters with untreated effluents carrying nutrients, chemicals, antibiotics, diseases, exotic species, etc. (Fig. 3).

Ecological footprint analysis

The non-valued and often unrecognized work of nature is perhaps best exemplified by the mangrove ecosystem support area needed to supply hatcheries with *Penaeus monodon* spawners and, indirectly, aquaculture grow-out ponds with postlarvae (Fig. 3). Each hatchery in the East Godavari and Vishakhapatnam Districts had an average ecological footprint of 534 ha mangrove for their life-support inputs of *P. monodon* spawners alone. The corresponding ecological footprint for extensive shrimp ponds is less than the pond area, whereas intensive ponds may require a mangrove ecosystem support area up to 11 times the pond cover. The footprint for the relatively more productive intensive systems was, however, similar in magnitude to extensive and semi-intensive systems when calculations were based on the shrimp biomass produced. It must be emphasized that this study has only estimated the ecosystem area needed to supply one input, namely the postlarvae produced in hatcheries. The inclusion of other ecosystem services, such as feed inputs and water quality maintenance in the ponds and the recipient, would have significantly increased the size of the ecological footprint. Intensive culture systems will generally appropriate larger ecosystem areas to produce a given volume of shrimps compared to extensive systems, which have tighter nutrient recirculation resulting in reduced dependence on feed inputs and lowered nutrient levels in effluents. For instance, Robertson and Phillips (1995) estimated that 3 ha of mangrove forest would be required to filter the nitrogen and phosphorus loads from effluents produced from 1 ha of semi-intensive shrimp pond, and 22 ha of mangrove forest would be required for 1 ha of intensive shrimp pond. The risk of disease also seems to increase with intensity of farming (Kautsky *et al*. 2000), and consequently chemical and drug use is more frequent in intensive farming.

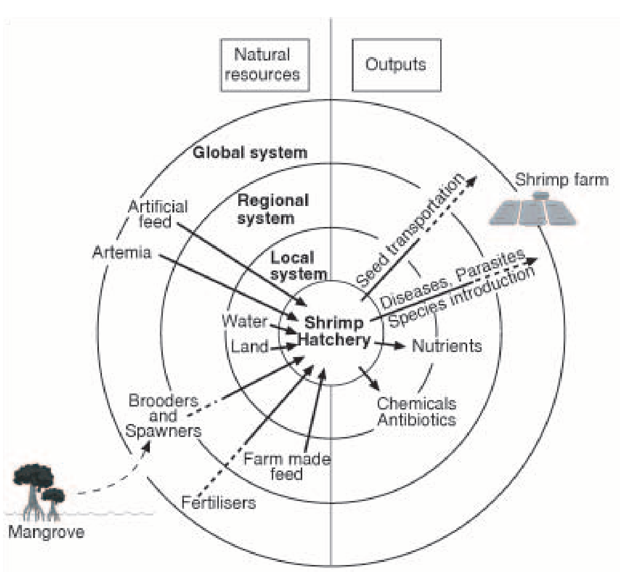

Figure 3 The shrimp hatchery industry's dependence and impact on ecosystem services at local, regional and global scales.

In a scenario where all shrimp ponds in Andhra Pradesh were stocked with postlarvae produced in hatcheries, these ponds would appropriate up to 138 000 ha of mangroves simply to satisfy the spawner requirement at the hatcheries. The total mangrove cover in Andhra Pradesh is only 58 200 ha, which implies that the shrimp ponds may need to appropriate mangrove ecosystems in other states or countries to fulfil this scenario. Hatcheries were occasionally paying up to US$ 2000 for a single shrimp spawner, which also illustrates that the mangrove support areas regionally available are too small. It is therefore unfortunate that mangrove clearance has created around 50% of the shrimp aquaculture pond area in the State (Shree Krishna 1994). If this is extrapolated to the current pond coverage, the mangrove loss (50% of 84 400 ha) corresponds to more than 70% of the remaining mangrove area in the State of Andhra Pradesh. The ecological footprint is always a snapshot in time and space (Deutsch *et al*. 2000; Troell *et al*. 2002), in this paper based on current management practices at the hatcheries, fisheries exploitation patterns for all life stages of *P. monodon*, and mangrove status in the region. The same approach can, however, be used to recalculate the ecological footprint as these parameters change over time or between regions.

Every effort to illustrate and value the life-support functions of mangroves is essential, considering that the inability to acknowledge the economic importance of this ecosystem has been a major driving force behind its deforestation and degradation (Barbier 1994; Rönnbäck 1999). Each hectare of mangrove in the Godavari River delta generates a fisheries catch of 0.8–1.5 *Penaeus monodon* spawners per year, valued at US$ 92–184. It is striking to note that the entire Godavari mangrove delta has a partial economic value of US$ 3.0–6.0 million per year for the provision of shrimp spawners alone. Additional efforts to estimate the economic value of natural resources and ecosystem services generated by mangroves would further highlight the significant value of this ecosystem and its support to subsistence, local and national economies. It is also clear that restoring mangroves can create considerable economic benefits, at a one-time cost of a few hundred US dollars per hectare in developing countries (P.L.A. Erftemeijer & R.R. Lewis, unpublished work 1999).

The net flux of spawners between regions was evaluated by estimating the ecological footprint for two different regions (the Districts of East Godavari and Vishakhapatnam, and the entire State of Andhra Pradesh). The results were strikingly similar concerning the estimated support from mangroves in these two areas: 0.8–1.5 and 0.9–1.8 spawners ha^{-1}, respectively. In the larger Indian context, the general view among local scientists, hatchery managers and fisherfolk was of a limited net export of spawners from Andhra Pradesh to other states in India. This suggests that the estimated life-support value of the Godavari mangroves is somewhat conservative.

One critical aspect of the quantified mangrove support function is that *Penaeus monodon* may not be exclusively found in mangroves during their 'critical period'. The early life stages are, at least to some extent, likely to use other ecosystems in the coastal seascape, such as seagrass beds or unvegetated shallows. However, through biophysical interactions, mangroves also support the productivity and viability of surrounding ecosystems (Rönnbäck 1999; Rönnbäck *et al.* 2002). The relative importance of mangroves is likely to be most significant in large river deltas that harbour vast stretches of mangroves, such as the Godavari River delta. In this type of setting, mangroves have a strong influence on coastal water quality by functioning as a flood control mechanism, an effective binder of shoreline and riverbank sediments, as well as by trapping particulate matter and assimilating nutrients in river run-off. All these mechanisms indirectly support the fisheries associated with neighbouring ecosystems.

The exploitation level of fisheries is another critical aspect. In the case of an underdeveloped *P. monodon* spawner fishery, the potential life-support value of mangroves is underestimated because more spawners could be harvested from the area. However, the trend of decreased supply of spawners in Andhra Pradesh throughout the late 1990s indicates that this resource is fully exploited or even overexploited. A reduction in spawner landings would decrease the mangrove value, but increase the ecological footprint. The fisheries that harvest earlier life stages also influence the availability of wild *P. monodon* spawners. Overexploitation of juvenile and sub-adult stages by shrimp trawlers will, of course, reduce the wild spawner stock. Furthermore, East Godavari District is a major centre for the collection of wild *P. monodon* postlarvae. This fishery has been prohibited since 1995, but due to lack of implementation and enforcement of regulations, seed collection still supports major fishery operations in the district. Naturally, wild seed collection has a direct impact on the recruitment to spawner fisheries, although the relative importance of this impact requires further investigation.

Environmental and socio-economic concerns

The environmental and socio-economic problems of penaeid shrimp aquaculture have been widely debated, although focus has mainly been on grow-out pond systems. One of the arguments to start up the hatchery industry was that it would provide additional employment for the rural population, and many local men are indeed employed as labour at the hatcheries. However, if the industry is compared to the wild postlarvae collection that it is supposed to replace, the argument becomes weak. Deb *et al.* (1994) estimated that 10–21 fisherfolk were needed to collect one million of *Penaeus monodon* postlarvae in Bangladesh. In the hatcheries of East Godavari and Vishakhapatnam Districts, only 0.6 employees are needed to produce one million postlarvae. Similar to most grow-out pond systems, the shrimp hatchery industry is capital-intensive, rather than labour-intensive, and employment of local people is often limited to low-paid, unskilled jobs, whereas technical and managerial positions are reserved for outsiders.

The risk of declining wild fisheries stocks due to overexploitation of broodstock and by-catch of incidental species is one example of environmental impacts associated with shrimp hatcheries. However, since the by-catch is discarded at sea, the negative impact is less detrimental compared to wild postlarvae fisheries where the entire by-catch is killed. Broodstock fisheries are also less wasteful, because some of the by-catch is kept and landed by the fisherfolk.

The extensive use of groundwater is another concern, which also creates a direct resource-use conflict. During the dry season freshwater sources were reported to be very scarce in the study area, and thus there is a direct conflict between the hatcheries and other areas of use, such as agriculture and domestic use. Extracting large volumes of groundwater to achieve brackish water salinity may lead to lowering of groundwater levels, emptying of aquifers, and salinization of adjacent land and waterways. Improved water management using recirculating systems would reduce the severity of these concerns, and at the same time reduce the risk of polluting surrounding waters.

The environmental and socio-economic concerns above should be viewed in the context of financial support from funding agencies, like MPEDA (Marine Products Exports Development Authority, which serves under the Ministry of Commerce) and the World Bank. MPEDA has provided subsidy assistance at 25% on capital investment up to a maximum of Rs 500 000 (about US$ 12 000) to a private party or individual (MPEDA 1994). In 1999, 91 of the 128 hatcheries in the State had received financial assistance from

MPEDA (Bhatt 1999). The market is considered to be saturated today, with strong competition between the hatcheries. No further expansion is planned and no bank loans would be granted for new establishments.

Disease problems

The shrimp aquaculture industry has suffered enormous losses due to disease outbreaks in recent times. It has been estimated that India is losing 15 000–18 000 tonnes of cultured shrimp every year due to the whitespot viral disease alone (Rosenberry 1999). In this study, all hatcheries were experiencing major disease problems and, unfortunately, hatcheries may themselves introduce, amplify, sustain and propagate diseases (Lightner & Redman 1992; Beveridge *et al*. 1997; Kautsky *et al*. 2000; Ravindranath 2000). Exotic diseases can be introduced with imported broodstock and postlarvae. At the hatchery, endemic as well as exotic diseases may be amplified when already infected broodstock encounters stressful conditions during transportation and handling. Excessive drug use may also generate antibiotic-resistant and highly virulent bacteria strains. The release of untreated effluent water at most hatcheries also propagates shrimp diseases when infected shrimp larvae as well as free pathogens are discharged into coastal waters. Besides affecting wild populations this may also cause self-pollution among hatcheries in the area. There is a clear self-pollution risk caused by overcrowding of hatcheries or insufficient separation between water intake and outlet pipe at individual hatcheries.

Improved water management and no overcrowding of hatcheries are key aspects to ameliorate disease problems. Furthermore, only native species should be cultured in closed cycle (captive breeding) practices to minimize the need for worldwide transfer of shrimp postlarvae and broodstock. None of the hatcheries had experienced or knew of techniques that had obtained any good results with captive breeding of *Penaeus monodon*. It was considered extremely difficult to grow the shrimp up to mature age and to induce spawning, and once again problems with diseases have played a major part.

CONCLUSIONS

Contrary to common belief, technical and economic inputs such as construction materials, energy and labour, form only a small part of the many inputs needed for aquaculture. The main and critical inputs are instead natural resources and ecosystem services, which ultimately determine the limits for the local and global expansion of aquaculture. It is evident that the shrimp hatchery industry in Andhra Pradesh is heavily dependent upon the continuous support of natural resources and ecosystem services generated by marine, freshwater and terrestrial ecosystems. The supporting ecosystems may not always be located close to the hatcheries and, consequently, these systems are often overlooked in management plans, environmental impact assessments and policy decisions. The shrimp hatchery industry is, for example, heavily dependent on the continuous input of wild-caught *Penaeus monodon* spawners generated by mangrove ecosystems. Policy and decision makers, as well as representatives of the shrimp aquaculture industry, must be trained to acknowledge this and other life-support functions of mangroves that sustain aquaculture production. Increased awareness can hopefully reduce large-scale conversion of mangroves to accommodate shrimp ponds, and initiate restoration programs in areas where shrimp aquaculture development has caused significant damage to this ecosystem.

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