CONCEPT OF ENVIRONMENTAL CAPACITY, AND ITS APPLICATION TO PLANNING AND MANAGEMENT OF COASTAL AQUACULTURE

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One of the most widely accepted criteria for sustainable development is that development activities should not exceed the carrying capacity of the environment. Despite this, there has been little research on what constitutes carrying or environmental capacity, and how this relates to specific developments or sectors, especially in tropical countries. It is also apparent that environmental capacity has, by some definitions, been exceeded in some areas of intensive aquaculture activity.

Significant work has been undertaken in the UK, New Zealand, Norway and N. America on the capacity of the coastal environment to assimilate waste products from cage mariculture. There have been several studies on the production of organic matter and nutrients from intensive shrimp culture in tropical countries. Some authors have used global production statistics to estimate carrying capacity in terms of the intensity of aquaculture production, which can be sustained per unit length of coastline. However, rather little research has been directed at estimating the actual environmental (or assimilative) capacity of tropical coastal ecosystems. Since it is likely that the rate of assimilation is significantly higher in the tropics (current estimates put this at 4 to 5 times higher), specific studies are required if tropical coastal aquaculture and other activities taking place in the coastal zone are to manage on a sustainable basis.

This paper reviews existing knowledge relating to both the outputs from tropical aquaculture, and the environmental capacity of a range of tropical coastal ecosystems, including mangrove, sea grass, coral reef, and exposed sandy or rocky shores. Some preliminary rules of thumb are presented for estimating environmental capacity in relation to tropical coastal aquaculture and agriculture, and the various models which may be used to assess more accurately the capacity in particular locations are also discussed. The way in which these estimates may be used in the planning and management of aquaculture development is considered. Particular attention is paid to the issue of "allocation" of environmental capacity to different users or activities.

KEYWORDS: environmental capacity; environmental impact; sustainable development; tropical coastal aquaculture

Introduction

Long term sustainable production of aquaculture industry is largely related to the carrying capacity of the environment it is associated with. As an obvious affect of rapid unplanned expansion of coastal aquaculture in the tropics, especially with high level of intensification based on high input, the industry has faced several crashes in recent years in different countries of Asia and South America. These crashes occurred mainly due to over expansion of aquaculture exceeding the carrying capacity, which along with over exploitation of natural resources, caused a severe pollution to the environment and in combination with the industrial pollutants resulted in the devastation of the industry (Lin 1990). With the high growth rate of aquaculture, other concerns like diversity in aquaculture, diversity in species and systems, diversity in farmers and finally, diversity in impacts and environment are coming up as an important area of research (Barg et al. 1996).

Environmental impacts of aquaculture have been associated mainly with *High-input High-output intensive systems*, (as such culture of salmonids, common carps or tilapia). Effluent from this *High-input High-output intensive systems* enriched recipient waters with high nutrient and organic loading that attributed to building up of anoxic sediments, changes in benthic communities, and finally, eutrophication of the adjacent water body. *Large-scale shrimp culture* has resulted in degradation of wetlands, salination of agricultural land and drinking water supplies, and land subsidence due to ground water abstraction. Mollusc culture has been responsible for local anoxia of bottom sedimentation and increased siltation from pseudofeces pollution. Most of the studies are performed on temperate region to assess the capacity of coastal environment, especially impact of marine cage culture. As for example, UK (e.g. Gillibrand and Turrel 1997), Japan (e.g. Horiya et. al.1991; Tsutsumi 1995), France (e.g. De Casabianca et. al.1995), and North America (e.g. Dellapena et. al.1998; Manickchand-Heileman et. al.1998, Goldburg and Triplett 1997). A very few studies have also been done on tropics- Israel (e.g. Kress and Herut 1998) with specific emphasis on environmental assessment or nutrient budget of shrimp farming or assimilative capacity of mangrove (e.g. Briggs and Funge-smith 1994; Chaiyakum and Sangsangjinda 1992; Muthuwan 1991; Menavasteva 1996; Robertson and Phillips 1994; Satapornvit 1993), Coastal environmental capacity (EC) can be defined as ‘the demarcation line that fixes the limit of carrying capacity of a particular coastal environment for sustainable utilization of the resources’. The evaluation of EC involves the explanation of environmental impacts against coastal fisheries and their boundaries, and understanding the effect of environmental factors at different life stages of fishery organisms (Kenji et al. 1991). Environmental capacity of a particular coastal area depends on tidal flushing, current and assimilative capacity of the water body to pollutants. Overall and specific assessment of the environmental capacity for coastal ecosystem (upland, estuary, near-shore), and for individual aquaculture system (pond, cage, raft, pen) respectively with different rate of intensification has evolved as an important necessity for sustainable and environment friendly or at least, environment neutral aquaculture.

This paper reviews existing knowledge relating to both the outputs from tropical aquaculture, and the environmental capacity of a range of tropical coastal ecosystems, including mangrove, sea grass, coral reef, and exposed sandy or rocky shores. Some preliminary rules of thumb are presented for estimating environmental capacity in relation to tropical coastal aquaculture and agriculture, and the various models which may be used to assess more accurately the capacity in particular locations are also discussed. The way in which these estimates may be used in the planning and management of aquaculture development is considered. Particular attention is paid to the issue of “allocation” of environmental capacity to different users or activities.

Understanding Coastal Ecosystem

A typical coastal ecosystem comprises with three major parts: estuaries, tidal zone or near shore, and off shore area (Figure 1). However, each part has its own dynamic characteristics, which usually vary with region, climates and ocean current flow etc.

Figure 1

Pritchard (1967) defined estuary as “a semi-closed coastal body of water which has a free connection with the open sea, and within which seawater is measurably dilute with freshwater derived from land drainage”. An estuary is a ‘hybrid’ environment incorporating terrestrial and marine, lake and ocean dynamics. Area of a typical estuary ranges from river mouth to the end of saline water. Estuaries are the most interesting part of a coastal ecosystem, where salt and freshwater mixing allows most of the chemical reactions to be happened. It is also one of the most productive zones, where most of the nutrients and sediment carried from watershed area accumulates, and thus plays an important role in the overall productivity of the ecosystem. This is also the most vulnerable zone to natural disruption or human developmental activities. High rate of industrial effluent very often overloaded the estuarine environment and causes severe havoc to natural resources or to the activities those depend on natural environment. It is evident from different study that aquaculture has both positive and negative impact to the estuarine environment. And still, pollution from aquaculture activities on degradation of estuarine environment is not avoidable should be taken into account for any management decision (Beveridge et al. 1997; Menavasteva 1996; Newell 1988).

A tidal zone or near shore area mainly consists of mangroves, lagoons, and salt marshes. Biota of this region composed of mangrove plants, sea grasses, mollusks, bivalves, worms and different fish species. However, a increase in production with the increase of tidal range was mentioned by Mann (1982). Mangroves are natural barriers against storm surges and strong winds, and serves as nursery and feeding ground for many commercially important aquatic species like shrimps, milk fish, mullets, oysters etc. Seagrass beds are important habitats for many species and serve as feeding ground for turtles and dugong (Chua 1991). It bind shallow water sediments, and act as a buffer by reducing water turbidity (Fortes 1990). Many of the seagrass species have reported to produce 300-800 organic dry matter m^{-1} yr^{-1}, which is equivalent to 120-320 g C m^{-1} yr^{-1} (Mann 1982). Seaweed also forms an important community in the ecosystem. Among the seaweeds, net production of Kelps especially for *Laminaria sp* is higher (1000 g C m^{-1} yr^{-1}). Near shore area is the place that disturbed most by natural calamities, and as well as by human activities and interventions. For thousands of years, coastal people are extracting resources from this zone for their livelihood that very often across the capacity with the increase of the development activities due to population pressure. A most diversified species distribution occur in the zone, where mangrove plants, sea grass, and sedentary and motile mollusk (especially bivalves) serve as assimilative factory for the nutrients and wastes that generated from different activities or natural succession.

An off shore area consists of open water or coral reefs and/or islands. Coral reef communities are 'island' of high productivity in 'seas' of low productivity. However, coral reef act magnificently to reduce turbidity and in suctioning nutrients. It also provides shelter to different marine species, and thus plays an important role in conservation of ocean bio-diversity. Coral reefs have the highest primary productivity of any coastal ecosystem, contributing about 10 to 30 percent of total fisheries catch annually (Chua 1991). Lewis (1977) observed a great range of primary production (2-5000 g C m-1 yr-1), and most of this primary production is used by the system itself for respiration. A brief comparison of net productivity for different coastal ecosystems is presented in table 1.

Table 1. Comparisons of net productivity for coastal ecosystems

Type of ecosystems	g C m^{-2} yr^{-1}
Coastal Water	
Upwelling zones	50-220
Shallow shelf	30-150
Coastal bays	50-120
Surf zone	20-30
Sub-tidal	
Seaweed	800-1500
Coral reef	1700-2500
Seagrass	120-350
Inter-tidal	
Rock weeds	100-250
Mollusks	10
Sandy beaches	10-30
Estuarine flats	500-750
Commercial oyster beds	400
Supra-tidal	
Salt marshes	700-1300
Mangroves	350-1200
Sand dunes	400-500

Source: Carter (1988)

Coastal Aquaculture Practices and Their Interaction with Environment

Pond aquaculture

Penaeid shrimps are the leading aquatic animals that cultured in coastal ponds. Other commodities that cultured in a smaller scale are- brine shrimp, milkfish, mud crabs, and seabass. Ponds are covered a wide range of coastal areas from rice field of estuarine areas to coastal mud flats. Along with this large spatial distribution, a variety of culture intensity (from extensive to super intensive) is being practiced in coastal pond aquaculture. Extensive or traditional systems operate in a low-stocking density without any supplemental feed except some fertilization. In improved traditional systems, little amount of supplemental feed is being applied for a segment of the culture period. In semi-intensive and intensive systems, management and fish intensity increased with upgrading of the systems. Seaweed (red seaweed (*Eucheuma sp, gracilaria sp.*) and different mollusk species are also being cultured in ponds in a small proportion.

Cage-pen-raft aquaculture

Culture of finfish (flounders, grouper, rainbow trout, salmon, sea bass, yellow tail), shellfish (oysters, mussels) and seaweed are widely practiced though out the world. Cage or pen culture of marine finfish in tropics is not much popular and did not reach the level of their counterpart in temperate areas (Nunes and Parsons 1998). A limited number of marine fish species such as, Rabbit fish- *Siganus canaliculatus*, Sea bass- *Lates calcarifer*, Red snapper- *Lutzanus argentimaculatus*, Grouper- *Epinephalus sp.* are being cultured in tropical coastal areas.

Mussels, oysters and seaweeds are used to culture in raft. However, culture of these commodities is considered as environment friendly due to their nutrient assimilating capacity. Despite of their role in assimilating nutrients, mollusks also cause localized biodeposition of pseudofaeces, which have some impacts similar to those of wastes deposited of marine cage culture.

Commodities in Aquaculture

Finfish and shrimps

Pond culture of marine finfish is contributing less than 20 percent of coastal aquaculture production. Most common species are milk fish- *Chanos chanos* (Philippines, Taiwan, Indonesia), sea bass- *Lates calcarifer* (Taiwan, Thailand, Philippines), Atlantic Salmon- *Salmo salar, Rainbow trout- Oncorhynchus myskiss* (USA, Europe), Grouper- *Epinephelus malabaricus, E. tauvina, and E. ornatus* (Southeast Asia) etc. Among the shellfishes, in spite of major contribution from penaeid shrimp especially *P. monodon*, a variety of species are being cultured in brackishwater ponds. The important commodities are: penaeid shrimp- *Penaeus sp.* (throughout the world in tropics), brine shrimp- *Artemia sp.* (throughout the world), mud crabs- *Scylla serrata* and *S. oceanica tranquibarica* (Southeast Asia), Mussels- *Mytilus edulis* (Southeast Asia) etc.

Farming of fish and shrimp in pond generate wastes from the system and plan-less management of this waste can cause unwanted eutrophication to the aquatic environment. Aquaculture wastes consist of uneaten fish feed, fecal and other excretion, residue of the chemicals used in the systems etc. However, a pulsed waste discharge observed in pond aquaculture, which reached its peak during harvesting and cleaning (Schwartz and Boyd 1994). Secondary and tertiary level impact from aquaculture wastes are mangrove destruction (Table 2), eutrophication of estuaries from pond effluent, effect on human health from over use of chemotherapeutants or other chemical compounds, salinization of agricultural lands, and finally rising social conflict from land use pattern.

Table 2: Percent destruction of mangrove in some countries of South and Southeast Asia

Country	Year	% area destroyed	Source
Bangladesh	1974-86	34 (in south-east)	Shahid and Pramanik, 1986
Equador	1970-90	19	Aiken, 1990
Philippines	Up to 1984	45	Pillay, 1992
Thailand	1961-93	54.7	Menavasteva, 1996

A wide range of chemicals including therapeutics, vaccines, hormones, flesh pigments, anesthetics, disinfectants and water treatment compounds are being used in fish culture. Bell (1992) noted that due to lack of research, there are very few effective, safes and approved therapeutic agents to manage shrimp diseases. In shrimp hatchery, chlroamphenicol, copper sulphate, EDTA, furanace, furazolidone, nitrofurazone, oxytetracycline, treflan and zeolites are being used (Boonyaratpalin, 1990). Indiscriminate use of antibiotics is human health concerns and may lead to development and spread of antibiotic resistance. A list of chemotherapeutants used in mariculture is provided in table 3.

Table 3: Chemotherapeutants used in mariculture

Anti-bacterial agents	Fungicides	Parasiticides
Natural antibiotics	Malachite green	Hydrogen peroxide
Tetracycline	Formalin	Dichlorovos
Macrolide antibiotics		Avermectins
B lactans		Pyrethroids
Aminoglycocides		
Phenicols		
Synthetic antibiotics		
Sulphanamides		
Potentiated sulphanamides		
Quinolones		
Nitrofurans		

Mussels, oysters and crabs

Culture of mussels (*Perna viridis, P. perna, Modiolus senhausenii*), oysters (*Crassostrea iredalei, C. belcheri, C. rhixophorae, C. gigas, Ostrea folium*) and crabs (*Scylla serata*) are widely practiced over the tropics. Though, it is believed that mollusks can effectively remove nutrients and can reduce heavy metal pollution through accumulating nutrients and metals in its body (Cheung and Cheung 1995), onsite pollution from accumulation of feces and pseudofeces from mussel and oysters can not be neglected (Csavas 1993).

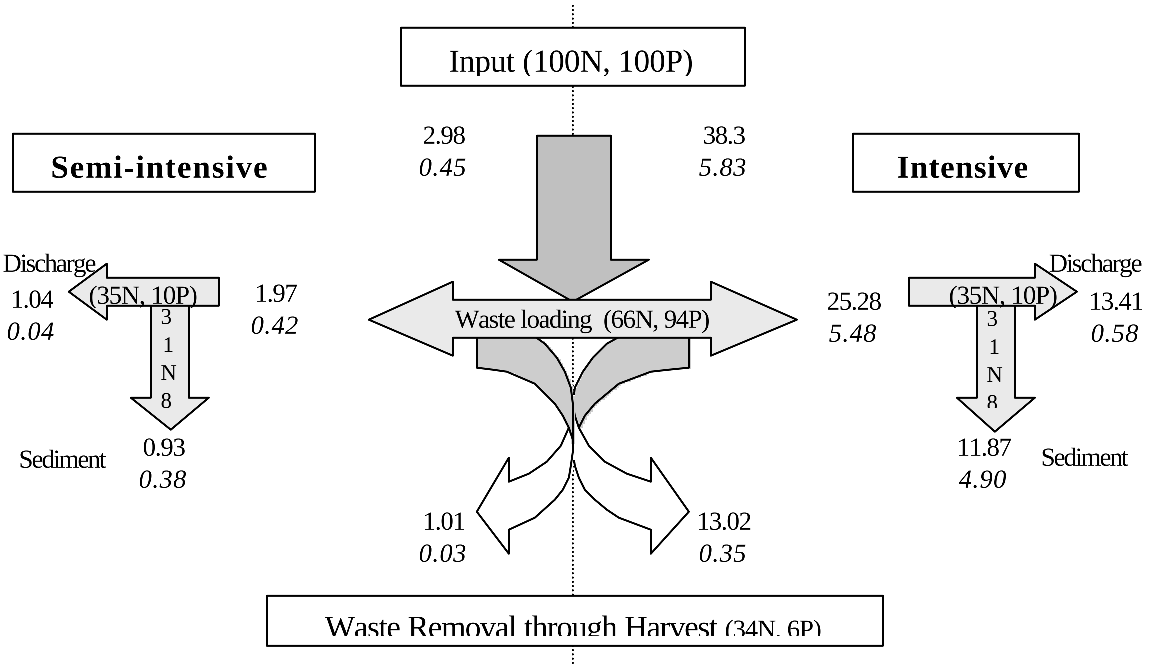
Seaweed

In the tropics, seaweed is a rapidly growing aquaculture industry and currently occupying a large proportion of world aquaculture production in wet weight basis. Commonly cultured species are- *Eucheuma sp* (Indonesia, Philippines), *Kappaphycus sp.* (Indonesia), *Gracilaria sp* (Indonesia, Philippines, Fiji), *Porphyra sp*, *Nori sp* (Japan), *Enteromorpha sp* (Japan, USA), *Caulerpa sp*, *Codium sp*, *Hypnea sp*, *Soliera sp*, and *Acanthophora sp* (Fiji).

Release of Nutrients from Aquaculture to Environment

Pond Culture

A large amount of nutrients and chemicals are contributed to environment from pond aquaculture, which largely varies upon culture intensity, level of chemical use and species cultured. Dissolved material from farm effluent are mixed with the water column where as, largest proportion of solid wastes accumulated in the pond bottom or in the immediate vicinity of the farm. Higher amount and proportion of discharged nitrogen remain in water in compare to phosphorus, most of which accumulated into the sediment. Fate of nutrients applied in an intensive shrimp pond is described in the figure 2.



Keys: N_2- normal; and P- *italic*. Figures are in MT ha^{-1} yr^{-1}. Figures in parenthesis and arrows indicate percentage

Figure 2. Fate of nutrients from 1 ha semi-intensive and intensive shrimp culture ponds (information source: Briggs and FungSmith 1994; Muthuwan 1991; Satapornvit 1993).

Aquaculture is very often solely accused for pollution of aquatic environment, though there are so many examples that can oppose the blame. However, aquaculture effluent also carry bacteria or disease borne microorganisms, which is not as harmful as domestic sewage to human health, since microbes that vandalistic for fish are not always harmful to human. In terms of nutrient loading, various studies also revealed that amount of effluent from aquaculture is far below than the other sources, which is about 1 percent of rivers, 3.7 percent of agriculture, and about 3 percent of industries and municipal sources (Ackefores and Enell 1990). Quality of shrimp pond effluent in compare to domestic sewage is presented in the table 4. Urban mechanical treatment plants are seemed to be efficient to reduce solids and increase BOD_5 standard than other nutrients like nitrogen and phosphorus. Still, after secondary treatment, standard of domestic effluent can not reach the standard of untreated effluent from shrimp pond except a reduction in solid concentration (Beveridge et al. 1997).

Table 4. Characteristics of shrimp ponds effluent in comparison with domestic sewage (mg l^{-1})

Effluent characteristics	Shrimp pond effluent		Domestic water		
	Study 1	Study 2	Untreated	Primary treatment	Secondary treatment
BOD_5 (mg l^{-1})	4.0-10.2	7.4-8.4	300	200	30
Total N (mg l^{-1})	0.03-5.06	2.19-3.45	75	60	40
Total P (mg l^{-1})	0.05-2.02	0.29-0.40	20	15	12
Solids (mg l^{-1})	119-225	120-165	500	-	15

Source: Beveridge et al. 1997

Cage Culture

Information on nutrient pathway analysis for tropical marine finfish aquaculture in net-pen cages is very scarce. The major difference in tropical and temperate environment is the nutrient assimilating capacity, which is much higher in tropics. Despite of this difference, other factors such as, amount of nutrients released and their physical, chemical and biological effects are equivalent in both the regions. Estimated flux of particulate matter released from fish cage of tropics is 4.5 g C m^{-2} d^{-1} and covered about 17000 m^2 (approx.) under the fish farm (Angel et al. 1996). Rate of organic matter decomposition under fish cages of the Gulf of Aqaba, suggested that the capacity of sediments to absorb organic matter loading may be 3-4 times higher in warm than temperate water (Angel 1992).

Nutrient budget from finfish cage culture is presented in the figure 3. A large feed loss (80 percent) has been observed that released to the environment. The effect of finfish cage farming includes a reduction in redox potential, increase in sedimentary C and N, and increase in H_2S, CH_4, and increase of BOD_5 in the sediment. Major changes occur in the community structure of benthic fauna beneath the cages or rafts (Tsutsumi 1995). With the increase of pollutants, faunal dominance changes from mollusks to polychaetes. Very often, organic enrichment from marine cage-pen culture contributes to the development of infectious disease as deteriorated environment weakens the immune systems of the confined fish (Kusuda 1990).

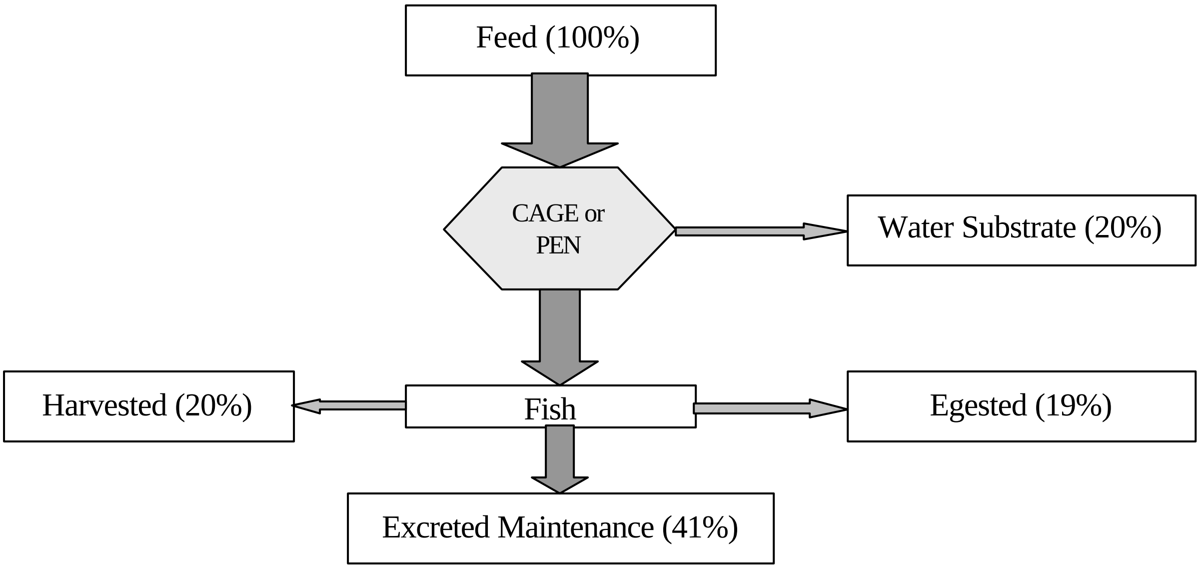


Figure 3. Estimated average flux of nutrients in a fish cage (Source: Nunes and Parsons 1998)

Raft or Rack Culture

Though mussels or oysters act as a magnificent bio-filter, organic pollution from large mussel or oyster culture lot in form of pseudofeces can not be neglected. For example, an individual mussel produces 5.7 mg organic matter per day (Dankers and Zuidema 1995). A typical oyster rack with 420,000 oysters can generate 16 t of fecal and pseudofecal material during the nine months culture period. Deposited organic matter that originated from mollusk farms stimulates microbial activity, thus increase BOD_5, sulfate reduction and denitrification (Nunes and Parsons 1998).

Assimilation of Nutrients

Mollusks

Culture of mollusks help in breaking down organic matter effectively and serve as an important food source for a range of organisms, either directly or indirectly by providing shelter and creating space for associated organisms. An individual mussel can filter between 2-5 l of water hr^{-1}, and a rope of mussel more than 90000 l d^{-1} (Nunes and Parsons 1998). Majority of the organic matter that filtered by mussel deposited as pseudofeces. In a high dense culture of mussel, half of the pseudofeces again consumed by the suspension feeders rather than contributing to the primary production. Figure 3 describes the mass balance of phytoplankton and detritus filter feeding by mollusks.

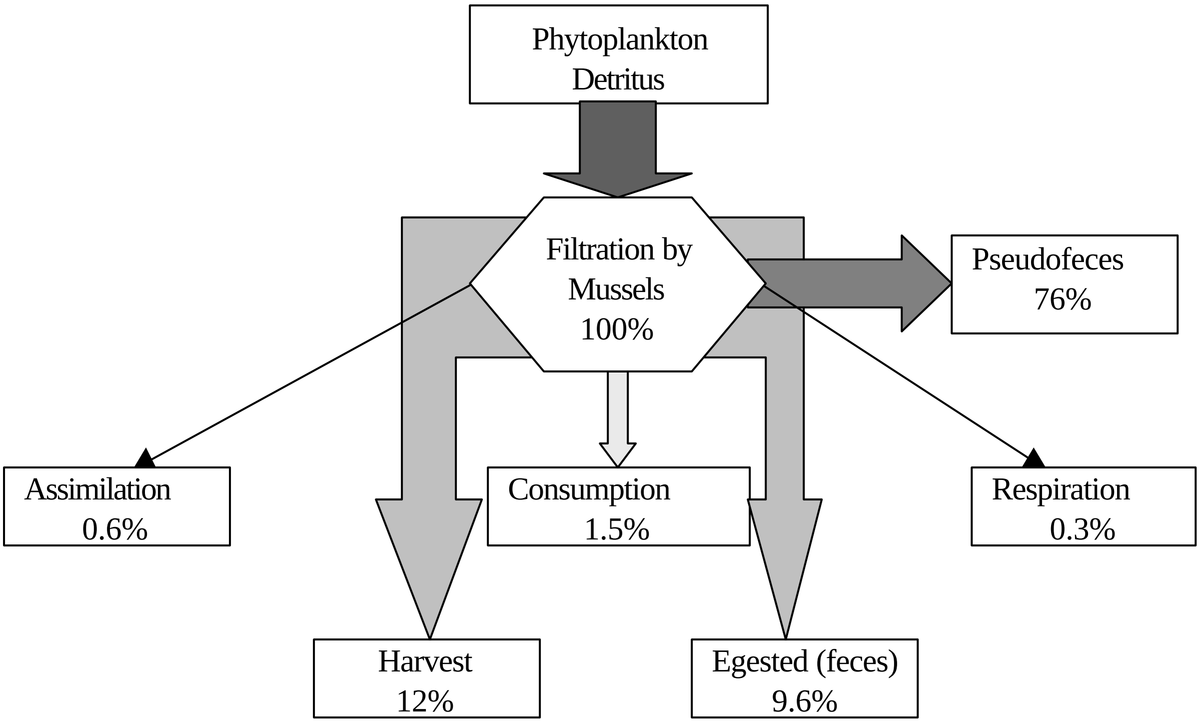


Figure 4. Mass balance of phytoplankton and detritus filter feeding by mussel (information source: Dankers and Zuidema 1995)

Oysters can remove nitrogen and solids very efficiently than the mussels. Nitrogen and total suspended solids removal efficiency of oyster is 94 percent and 48 percent respectively (Ryther et al 1995), which is much higher than that of green mussel (68 percent TN removal efficiency) stated by

Jones and Preston (1996). Problems with this high nutrient assimilation capacity are human health concern from accumulation of pathogens or toxic substances, which is not very unlikely to be happened (Csavas 1993).

Seaweeds

Seaweeds are considered as the net nutrient remover from aquatic ecosystem. Apart from mollusks, to remove nutrients from effluent seaweed can also absorb nutrients that can not be absorbed by mollusks (Chandrkrachang et al. 1991). N and P removal efficiency of seaweed is about 32 percent and 19 percent respectively. Problem associated with seaweed farming mainly is- probability of heavy metal and industrial discharge accumulation (FAO/NACA 1995).

Mangroves

Buffering capacity of mangrove plays an important role in sustaining any coastal ecosystem. Robertson and Phillips (1994) provided an estimate on requirement of *Rhizopora* forest area per ha of intensive or semi-intensive shrimp ponds to remove nitrogen and phosphorus from the pond effluent (Table 5). Requirement of mangrove area to remove phosphorus (21.7 ha) from effluent of a 1 ha shrimp pond is three times higher than to remove nitrogen (7.2 ha), which indicates low P assimilating capacity of *Rhizopora* mangrove forest.

Table 5. Estimates of *Rhizopora* mangrove forest area (ha) required to remove nitrogen and phosphorus loads produced during the operation of 1 ha of semi-intensive and intensive shrimp ponds (Source: Robertson and Phillips 1994)

Element from Effluent	Mangrove Forest Required (ha)	
	Semi-intensive shrimp ponds	Intensive shrimp ponds
Nitrogen	2.4	7.2
Phosphorus	2.8	21.7

Measuring Environmental Carrying Capacity

References

Ackefores, H. and Enell, M. 1990. Discharge of nutrients from Swedish fish farms adjacent to sea areas. *Ambio,* 19(1): 28-35.

Aiken, D. (1990) Shrimp farming in Ecuador: An aquaculture success story. *World Aquaculture* 21:7-16

Angel, D., Kurt, P. and Silvert, B. 1996. Benthic effect of fish cages farming in the Gulf of Aqaba, Red Sea. *http:// dfomr.dfo.ca/science/msd/heleim/papers/angel.html.*

Angel, D., Kurt, P. and Silvert, B. 1996. The turnover of organic matter in hypertrophic sediments below a floating fish farms in the oligotrophic Gulf of Eilat. *Bamidegh,* 44: 43-44.

Barg, U. C., Bartley, D. M., Tacon, A. G. J. and Welcomme, R. L. (1996) Aquaculture and its environment: a case for collaboration. Paper presented in the 2nd World Fisheries Congress, Brisbane, Australia, 28 July – 2 August, 1996.

Bell, T.A. (1992) Principles of shrimp culture chemotherapy, p. 227-237. *In* J. A. Wyban (ed.), Proceedings of the Special Session on Shrimp Farming. World Aquaculture Society, Baton Rouge, Louisiana.

Beveridge, M. C. M., Phillips, M. J. and Mackintosh, D. J. 1997. Aquaculture and the environment: the supply of demand for environmental goods and services by Asian aquaculture and the implications for sustainability. *Aquaculture Research,* 28, 797-807

Beveridge, M.C.M., Ross, L.G. and Stewart, J.A. (1996) The development of mariculture and its implications for biodiversity, *In* Marine Biodiversity: Patterns and Process, Eds. R.F.G. Ormound, J. D. Gage & M.V. Angel, Cambridge University Press, 372-393

Boonyaratpalin, S. (1990) Shrimp larval diseases, p. 158-167. *In* M. B. New, de Saram, H. and Singh, T. (eds), Technical and Economic Aspects of Shrimp Farming. Proceedings of the Aquatec '90 Conference, Kualalampur, Malaysia.

Boyd, C. E. and Tucker, C. S. 1995. Sustainability of channel catfish farming. *World Aquaculture*, 26(3): 45-53.

Briggs, M.R.P. and Fung-smith S.J. (1994) A nutrient budget of some intensive marine shrimp ponds in Thailand. *Aquaculture and Fisheries Management*. 25:789-811

Carter, R. W. G. 1988. *Coastal Environments: An* introduction to the physical, ecological and cultural systems of coastlines. Academic Press, 617p.

Chaiyakum, K. and Sangsangjinda, P. (1992) Quality and quantity of wastewater from intensive shrimp culture, Amphore Ranod, Songkhola Province, Tech. Paper no. 5/1992, NICA. DoF, Ministry of Agri. and Cooperatives, Thailand. 26p (in Thai)

Chandrkrachang, S., Chinadit, U., Chandayot, P and Supasiri, T. (1991) Profitable spin-offs from shrimp-seaweed polyculture. *Infofish International*. 6:26-28

Chua, T.-E. 1991. Managing coastal resources for sustainable development: the ASEAN initiative, p. 21- 35. Chua and L. F. Scura (eds.) Managing coastal resources for sustainable development: roles of policy makers, scientists, donors, media and communities. ICLARM Conference Proceedings 30, 125p, Philippines.

Csavas, I. (1993) Aquaculture development and environmental issues in the developing countries of Asia. P 74-101. *In* R. S. V. Pullin, H. Rosenthal and J. L. Maclean (eds), *Environment and Aquaculture in Developing countries*.ICLARM Conference Proceedings 31:359p

Dankers, N. and Zuidema, D.R. (1995) The role of the mussel (*Mytilus edulis* L.) and mussel culture in the Dutch Wadden Sea. *Estuaries* 18 (1A):71-80.

De Casabianca, M. L., M. L., Laugier, T. and Collart, D. 1995. Impact of shellfish farming eutrophication on benthic macrophyte communities in the Thau lagoon, France. *Aquaculture International*, 5: 301-314.

Dellapena, T. M., Kuehl, S. A. and Schaffner, L. C. 1998 Sea-bed mixing and particle residence times in biologically and physically dominated estuarine systems: a comparison of lower Chesapeake bay and the York river sub-estuary. *Estuarine, Coastal and Shelf Science*, 46(6): 777-795.

FAO/NACA (1995) Regional study and workshop on the environmental assessment and management of aquaculture development (TCP/RAS/2253). NACA Environmental and Aquaculture Development Series No.1, Network for Aquaculture Centers in Asia-Pacific, Bangkok

Fortes, M. D. 1990. Seagrasses: a resource unknown in the ASEAN region. ICLARM Education Series 5, 46p, International Center for Living Aquatic Resources Management, Manila, Philippines.

Gillibrand, P. A. and Turrel, W. R. 1997. The use of simple models in the regulation of the impact of fish farms on water quality in Scottish sea lochs. *Aquaculture*, 159: 33-46.

Goldburg, R. and Triplett, T. 1997. Murky Waters: Environmental effects of aquaculture in the US. The Environmental Defense Fund, USA, 197p.

Horriya, K., Hiraano, T., Hosoda, M. and Hirano, T. 1991. Evaluating method of the marine environmental capacity for coastal fisheries and its application to Osaka Bay. *Marine Pollution Bulletin*. 23: 253-257.

Jones, A.B. and Preston, N.G. (1996) Bio-filtration of shrimp pond effluent by oysters in a raceway system. World Aquaculture ’96. Book of Abstracts. The 1997 Annual Meeting of Was.

Kress, N. and Herut, B. 1998. Hypernutrification in the oligotrophic Eastern Mediterranean: a study in Haifa bay (Israel). *Estuarine, Coastal and Shelf Science*, 46(5): 645-656.

Kusuda, R. (1990) Fish diseases. *In* T. Watanabe (ed.) *Coastal Fish Farms and the Environment*. Tokyo.

Lewis, J. B. 1977. Processes of organic production on coral reefs. *Biological Review*, 52: 304-47.

Manickchand-Heileman, S., Soto, L. A. and Escobar, E. 1998. A preliminary model of the continental shelf, South-western Gulf of Mexico. *Estuarine, Coastal and Shelf Science*, 46(6): 885-899.

Mann, K. H. 1982. Ecology of coastal waters. *In* Anderson, D. J., Greig-smith, P. and Pitelka, F. A. (eds.) Studies in Ecology, Vol. 3. Blackwell Sci. Pub., 322p.

Menavasteva, P. (1996) Mangrove destruction and shrimp culture systems. *http://www.agri-aqua.ait.ac.th/mangroves/Preconten.html*

Muthuwan, V. 1991 Nutrient budget and water quality in intensive marine shrimp culture ponds. M.Sc. Thesis, AIT, 112p

Newell, R.E. (1988) Ecological changes in Chesapeake Bay: Are they the result of overharvesting the American oyster, *Crassostrea virginica*, p. 536-546. *In* M. P. Lynch and E.C. Krome (Eds.), understanding the Estuary: Advances in Chesapeake Bay Research, Chesapeake Research Consortium, Solomons, Maryland.

Nunes, A. J. P. and Parsons, G. J. 1998. Dynamics of tropical coastal aquaculture systems and the consequences to waste production, *World Aquaculture*, 29(2): 27-37.

Pillay, T.V.R. (1990) *Aquaculture and the environment.* Fishing News Books, Oxford, United Kingdom.

Pritchard, D. W. 1967. What is an estuary: Physical viewpoint. *In* Lauff, G. H. (ed.) *Estuaries*, pp. 3-5. American Association for the Advancement of Science, Washington, D. C., USA.

Robertson, A. and Phillips, M.J. (1994) Mangroves as filters of shrimp pond effluent: predictions and biogeochemical research needs. *Hydrobiologia*.

Ryther, J.H., Goldman, J.C., Gifford, C.E., Huguenins, J.E., Wing, S.E., Charman, J.P., Williams, L.D. and Laponite, B.E. (1995) Physical model of integrated waste recyvling-manure polyculture system. *Aquaculture* 5:163-177.

Satapornvit, K. (1993) The environmental impact of shrimp farm effluent. M.Sc. thesis, AIT, 153p

Shahid, M.A. and Pramanik, M.A.H. (1986) The application of remote sensing to study the relationship between the shrimp/fish farms and the mangrove ecosystems of the Bangladesh coastal region. Proceedings of the Regional Seminar on the Application of Remote Sensing Techniques to the Coastal Zone Management and Environmental Monitoring. Bangladesh Space Research and Remote Sensing Organization, Dhaka.

Tsutsumi, H. (1995) Impact of fish net pen culture on the benthic environment of a cove in south Japan. *Estuaries* 18(1A):108-115