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PROFILE

Environmental Issues in Brackish Water Shrimp Aquaculture in Sri Lanka

UPALI SENARATH
Environment Department
Board of Investment of Sri Lanka
14 Sir Baron Jayathilake Mawatha
P.O. Box 1768, Colombo 1, Sri Lanka

C. VISVANATHAN*
Environmental Engineering Program
Asian Institute of Technology
P.O. Box 4
Klong Luang Pathumthani, 12120, Thailand

ABSTRACT / Shrimp exports are one of Sri Lanka's major foreign exchange earners and account for 40%–50% of total aquaculture exports. There has been a recent and rapid expansion of the industry in the Northwestern Province (NWP) of Sri Lanka but the industry has suffered from disease outbreaks and environmental problems. Currently, shrimp farms cover nearly 3000 ha of the coastal area of the NWP.

The environmental impacts of shrimp cultivation in general are well known and numerous research studies have been done. However, little work has been carried out in Sri Lanka. This study provides some necessary background to brackish water shrimp aquaculture in Sri Lanka. It focuses briefly on the development of shrimp aquaculture and the current status of the industry. Emphasis is placed on two broader aspects—impacts on the existing wetland ecosystem and on the environment. These impacts are presumed to be the main causes hindering the growth of the industry and raising widespread public protest. Current ecosystem and environmental management practices are discussed. Finally, strategic issues for management and sustainable growth are discussed.

Shrimp aquaculture has many impacts on the surrounding environment. The extent and depth of these impacts varies with conditions including geography, destruction of natural habitats, type of cultivation practice, waste assimilation capacity of natural systems, consumption of water, wastewater generation and treatment, type of chemicals used as feed and medicines, and geological and hydrological conditions. The nature and extent of these impacts are well known (Dierberg and Kiattisimkul 1996, Flaherty and Vandergeest 1998, Gujja and Finger-Stich 1996) for other countries. However, few studies (Amarasinghe and others 1998, Corea and others 1995, Siriwardena and others 1989) can be found on Sri Lanka where substantial impacts from shrimp aquaculture can be seen in the coastline area. Major public protests organized by NGOs are key indicator of the growing awareness among residents of the area.

Loss of production and earnings due to disease has led farmers to rethink cultivation practices that do not address conservation of natural bodies necessary to assimilate waste. It is now clear that waste is affecting the environment to an extent that will lead to natural disaster. At the same time, shrimp cultivation is an important foreign exchange earner and employs many people. Promotion is required at both ends of the spectrum and can best be achieved by developing techniques and management strategies that reduce impacts to within tolerable limits of natural assimilation capacity. This field survey has been carried out to collect information from farmers, inhabitants, and officials involved in the industry to further understanding of the issues.

KEY WORDS: Shrimp aquaculture; Sri Lanka; Environmental impacts; Brackish ecosystem; Wetland ecosystem; Mangrove; White spot disease

*Author to whom correspondence should be addressed: *email:* visu@ait.ac.th

Shrimp Aquaculture in Sri Lanka

Potentially suitable land for shrimp aquaculture has been estimated at 6000 ha (Samaranayake 1986), 57% of which is situated along the north and the east coasts. Most of these brackish waterbodies have been used as traditional fishing grounds by small fishing communities.

Interest in shrimp farming developed in the late 1970s and was inspired by the huge success of shrimp production in other Asian countries. With various government incentives, a number of small-scale entrepreneurs and a few large multinational companies ventured into shrimp farming in the early 1980s. Significant advances were achieved in rearing techniques and farming soon reached industrial dimen-

Figure 1. Brackish waterbodies of Northwestern Province of Sri Lanka.

sions, especially along the coast of the Northwestern Province (NWP) (Figure 1).

Data from the Ministry of Fisheries and Aquatic Resources Development (MFARD) of the Central Government and the Provincial Fisheries Ministry (PFM) of the NWP shows the total extent of land occupied by the industry is nearly 3000 ha (Table 1), 66% percent of which belongs to the state and the rest in private hands.

Shrimp farms are found mostly along the intertidal and supertidal areas around the Dutch Canal and Chilaw, Mundel, and Puttalam lagoons (Jayasinghe 1996). One of the requirements is a large volume of saltwater for recycling during the grow-out period, which explains why more than 70% of the farms are located here. Within this area are large numbers of unauthorized farms of less than 2 ha (Table 2). However, there

Table 1. Status of farms approved by Provincial Fisheries Ministry of NWP and Ministry of Fisheries and Aquatic Resources Development (MFARD)

Status	Farms (*N*)	Area (ha)	Approved (%)	Area occupied (%)
PFM (1989–1997)				
On state lands	107	500	24.5	16.9
On private lands	273	535	62.5	17.9
MFARD (1986–1989, 1993–1997)				
On state lands	39	1469	8.9	49.3
On private lands	18	474	4.1	15.9
Total	437	2978		

Table 2. Distribution of farms on government and private land and its status

Category	Government Land		Private Land		Total	
	Projects	Area (ha)	Projects	Area (ha)	Projects	Area (ha)
Approved	177	1407	63	306	240	1713
Developed	172	1216	57	292	229	1508
Unauthorized	243	187	216	221	459	408
Abandoned	8	11	5	7	13	18

Data Source: Report on the Puttalam/Mundel Estuarine Systems and Associated Coastal Waters (Amarasinghe 1988).

Table 3. Shrimp production and export earnings from 1985 to 1993

Year	Production	Value (million Rs)
1985	1648	303
1986	1973	427
1987	1231	339
1988	1826	526
1989	2598	762
1990	1855	472
1991	942	454
1992	1246	613
1993	1426	808

Source: Data Management Unit of MFARD.

are no documented data on these farms at either state or provincial ministry levels.

Penaeus monodon, commonly called black tiger shrimp, is the major species grown in Sri Lanka. Annual shrimp production and foreign exchange earnings are shown in Table 3. Shrimp exports constitute about 60% of total seafood exports for the country. Farms are monoculture and either semiintensive or intensive (Jayasinghe 1995). The major differences are in stocking density and aeration. In semiintensive farming, the stocking density is around 5–12 postlarvae (PL)/m^2 without aeration. Intensive stocking density is 12–25 PL/m^2 with aeration. In comparison, stocking density in Thailand for semiintensive and intensive levels are 5–10 PL/m^2 and 50–100 PL/m^2 (Dierberg and Kiattisimkul 1996). Other differences are related to average farm size, production capacity, investment type, and land ownership.

The industry has been developed commercially by the private sector with government assistance. The same pattern occurred in Thailand where government assistance helped the industry flourish. The Fisheries and Aquatic Resources Act No. 2 of 1996 helps ensure proper resource management and issues fisheries licenses for different sectors engaged in fisheries and aquaculture production. The Ministry of Fisheries and Aquatic Resources Development (MFARD) acts as a project-approving agency under National Environmental Act No. 47 of 1980 (amended by Act No. 56 of 1988). Under the act, any aquaculture project larger than 4 ha must undergo environmental impact assessment or initial environmental examination. This makes the act the de facto national charter for the protection and management of the environment. The MFARD and the Provincial Fisheries Ministry (PFM) are directly linked with cultivators. The Provincial Council Act give the PFM legal and administrative powers in the Northwestern Provincial Council (NWPC). Other agencies that coordinate with the ministry provide services such as acquiring land and issuing permits.

White Spot Disease

The industry in Sri Lanka has been suffering from severe outbreaks of white spot disease since May 1996. White spot disease is caused by an acute viral infection known as white spot syndrome and is thought to be caused by accumulation of wastes, which increases susceptibility to the virus. Cumulative mortalities up to 100% were recorded in farms along Puttalam Lagoon. The disease spread rapidly to other brackish water systems and many farms became nonfunctional within three months. Farmers restarted cultivation in mid-December 1996, but a second outbreak took place. About 90% of the farms either closed down or were heavily impaired and there was a virtual collapse of the industry. The financial burden fell heavily on farmers.

Impacts of Brackish Water Shrimp Cultivation

Although the growth of the industry has had obvious social and economic benefits, there has been a significant natural and environmental cost. The expansion of brackish water shrimp cultivation has resulted in considerable impacts on the coastal environment and land-use patterns. Similar impacts occurred in Thailand where shrimp cultivation started long before it did in Sri Lanka (Dierberg and Kiattisimkul 1996). The significance of these impacts is well established for other

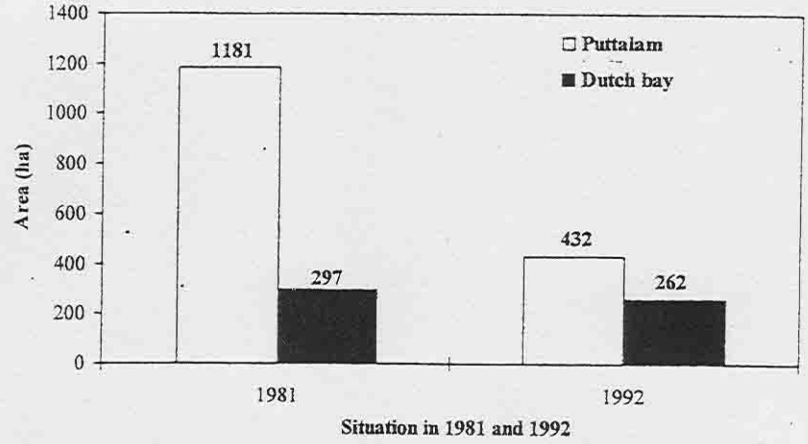

Figure 2. Mangrove distribution of Puttalam Lagoon and Dutch Bay in 1981 and 1992.

countries (Gujja and Finger-Stich 1996, Flaherty and Vandergeest 1998). In Sri Lanka, the following impacts are most significant: (1) Destruction of coastal ecosystems including wetlands, mangrove stands, shrub lands, grasslands, salt marshes, and river plains; (2) degradation of receiving waterbodies, canals, groundwater, and land; and (3) changes in traditional livelihood patterns and health hazards.

Environmental Impacts and Changes

Wetland Destruction

Shrimp farming areas contain other environmentally significant ecological habitats such as mangrove stands, salt marshes, sea grass beds, and mud flats, and there is growing evidence of degradation of these resources in Sri Lanka. Most of the wetlands in demand for aquaculture development are located in flood plains. In Puttalam, nearly 180 ha have been used for shrimp aquaculture. Farmers are clearly ignoring the ecological importance of mangrove areas, mud flats, and buffer zones around lagoons, streams, and rivers.

Mangroves

A recent remote sensing survey estimated mangrove coverage along the shores of the Puttalam Lagoon, Dutch Bay, and Portugal Bay complex (Figure 2). Considerable areas have disappeared in Puttalam Lagoon (64%) and Dutch Bay (11%). Of a total area of 1083 ha utilized for brackish water shrimp farming on the NWP coast in 1987, 359 ha (33%) were located in healthy mangrove areas (Jayasinghe 1995). Similarly, in Thailand, a 12%–25% loss was estimated from 1961 to 1993 (Dierberg and Kiattisimkul 1996). However, not all the responsibility for mangrove destruction lies with shrimp farming. In Sri Lanka, mangrove destruction started earlier than the advent of shrimp cultivation. Mangrove was used as firewood by 55% of all households in the mid-1980s and consumption further increased with an influx of political refugees (Amarasinghe 1988) to this study area. The extent of mangrove destruction due to shrimp cultivation alone is still a point of controversy, although it has most certainly accelerated the destruction.

Mangrove stands are an important constituent of maritime wetland ecosystems. They help in coastline stabilization and act as nurseries for aquatic organisms, trap nutrients and sediments, remove waste by reducing biochemical oxygen demand (BOD), and produce important organic compounds required for water conservation. Mangrove sediments have high denitrification capabilities, particularly in areas near sewage discharge outlets (Nedwell 1975). They are also a cheap source of fuel wood and make excellent charcoal. With the changes in mangrove swamps come alterations of the saprobic status of the receiving waters, effects on benthic communities, microbial flora and fauna, and wild life. Some economic analyses favor higher returns from intensive shrimp cultivation over intact mangrove swamps, but these become doubtful when long-term sustainability is taken into consideration (Dierberg and Kiattisimkul 1996).

Other Habitats

Salt marshes are common along the landward side of the mangrove forests in the semiarid Puttalam–Mundel estuarine system, of which 160 ha have been legally approved for shrimp farming. The extent the destruction is shown in Figure 3. These losses are more critical in Puttalam Lagoon (51%) than in the Dutch Bay

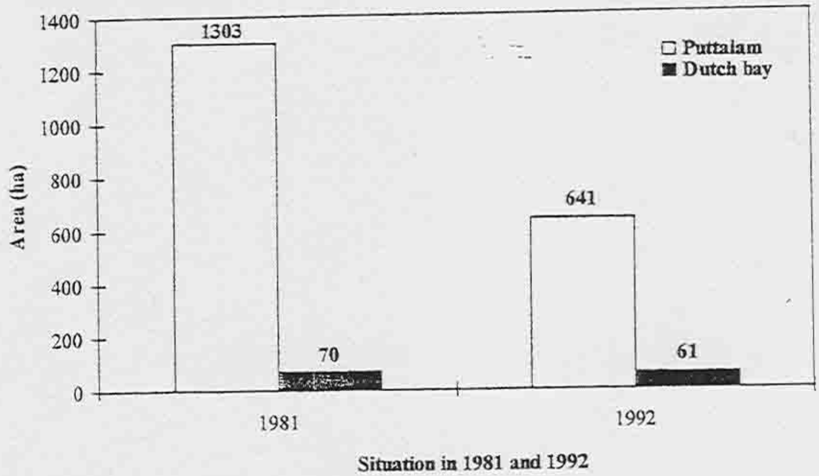

Figure 3. Salt marsh distribution of Puttalam Lagoon and Dutch Bay in 1981 and 1992.

(14%). Sea grass beds and mud flats are also destroyed. The full extent of destruction has yet to be determined. River floodplains have also been severely threatened by the advent of shrimp farming in the area causing changes in the entire micro- and macroclimate of the region. Soil erosion, surface, and subsurface saltwater intrusion to paddy fields, prolonged water inundation, and growth of different types of organisms are very common. The long-term effect will be loss of biodiversity, changes in rainfall patterns, changes in climate, and accumulation of organic compounds in the soil and water.

Receiving Waterbodies

In addition to habitat disturbances, severe environmental impacts can be observed due to pollution loads from shrimp pond wastewater, domestic waste from urbanization, and other nonpoint sources such as overland flow. The major impacts on the receiving waterbodies are eutrophication, silting, oxygen depletion, and toxicity from sulfide, ammonia, and other chemicals used in shrimp cultivation.

Dutch Canal and the lagoons are the major waterbodies for receiving wastewater from shrimp farms (Corea and others 1995), and there is potential for direct contamination of these water sources. The identified contaminants in the effluents are excessive nitrogen, phosphorus, and sulfur compounds; suspended particles; and organic pollutants. Figure 4 explains the potential impacts on water quality and their consequences. These data are based on information collected from farmers and interviews with experts during field visit surveys.

In 1996, the discharge of organic matter into waterbodies was nearly 3308 t/yr and the percentage discharge of nitrogen and phosphorous was 62% and 89%, respectively. In Thailand, it is estimated that nearly 77% of the nitrogen and 86% of the phosphorus applied as feed is uneaten (Lin 1995). High organic load increases the oxygen demand in water bodies, and this eventually reduces dissolved oxygen levels. This increases the anaerobic condition in the water, inducing ecological stress on aquatic organisms. Excessive nitrogen and phosphorus content lead to eutrophication and algae bloom, severely reducing water quality. Added to this is the flash loading of wastewater especially during harvest when the entire contents of ponds are discharged. Water stagnation in Dutch Canal during dry seasons further inhibits the process of natural recovery.

Changes in the physicochemical parameters of the water such as pH, salinity, suspended solids, and the presence of chemicals and toxins in receiving streams also affect the carrying capacity of water sources. Carrying capacity is based on the balance between the quantity of waste products generated and the capacity of microorganisms in the receiving waterbodies to assimilate those wastes. Carrying capacity is probably the most important criterion quantifying natural treatment and recovery of waste. In many cases, these stresses can severely impair this capacity.

Effects on Groundwater and Land

Groundwater is also affected by shrimp cultivation. During dry seasons, high levels of salinity (more than 35 ppt) are noted due to evaporation from ponds. In regions of water scarcity, farmers pump groundwater to reduce salinity to mitigate outbreaks of disease. This drawdown has a significant effect on the water table and will eventually result in land subsidence. Available

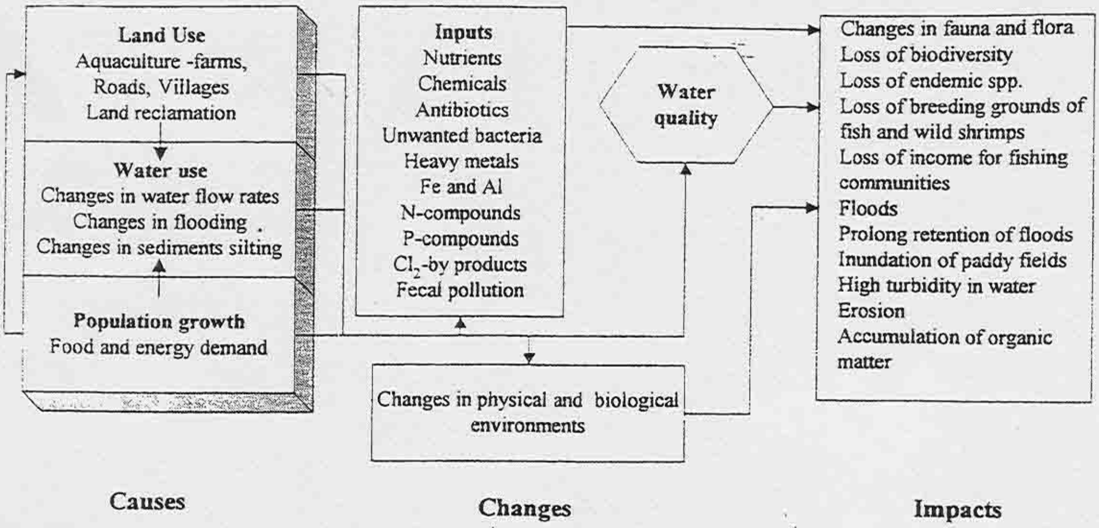

Figure 4. Summary of potential pollution aspects of Dutch Canal.

drinking water can also be scarce and contamination of groundwater from wastewater intrusion is a serious threat to community health.

Another source of groundwater pollution is leaching of heavy metals (Cr, Pb, Zn, Cu) found in sediments. Sediments consist of unconsumed food particulates, shrimp excreta, chemicals, dolomite, and disturbed natural soil in pond banks and bottoms due to shrimp activity. The sediment that accumulates during each cycle amounts to 185–199 tons dry weight/ha or 139–150 m^3/ha (Dierberg and Kiattisimkul 1996). Although confirmed data on sediment production and characteristics are limited, an estimated generation for 1 ha is 230 tons. For 2000 ha of pond area, it would be 460,000 tons/cycle. Illegal disposal of untreated and partially treated sediments on land and into waterbodies adds to the organic load on these natural bodies.

Changes in Traditional Livelihoods and Health Hazards

The advent of shrimp cultivation has brought about social change in local communities. Development of shrimp-related industries and urbanization has increased the population, creating further stress on habitats and natural resources. Land-use patterns have changed as more agricultural land is converted to shrimp cultivation. Pond construction behind the mangrove zones in the freshwater wetlands and agricultural areas has reduced traditional agriculture. Fisheries are affected as the focus shifts to quick profits from shrimp cultivation. These areas are affected by surface and subsurface salt-water intrusion generated by the new ponds leading to changes in salinity of fresh water once used for irrigation and drinking. Although there has been high economic growth in the region, the long term effects remain open to question. In Thailand, ponds were abandoned after some years of unprofitable production (Dierberg and Kiattisimkul 1996) and the land left unsuitable for agriculture. Current methods of land reclamation have not proven to be highly successful (Gujja and Finger-Stich 1996) and community livelihoods have been badly affected.

The widespread use of drugs and antibiotics used to prevent disease affects consumers. About 20%–30% of the antibiotics administered to the feed are ingested by the shrimp and the rest goes into the environment. In Sri Lanka, use of chemicals such as formalin, potassium permanganate, and copper sulfate poses a serious threat. The waste generated inside the ponds is harmful to the shrimp, and there is a demonstrated link to the outbreak of white spot disease.

Waste Characterization from Shrimp Cultivation

Every shrimp pond generates two streams of waste: wastewater and sediment. The following discussion deals with these two aspects. Only estimates can be calculated because, in practice, it is difficult to differentiate pond water and wastewater because of the continuous water exchange. During harvest, the entire pond is discharged, resulting in a sudden increase of pollution loads on receiving waters. Table 4 shows an estimation of pond water discharge during the culture period in a typical 12,900-m^3 pond.

Physicochemical pond water parameters measured

Table 4. Estimation of pond water discharge and organic load during culture period

Days of harvesting	Water exchange (%)	Total discharge (m^3/day)	BOD_5 (mg/liter)	Total organic load (kg)
1–30	5	645	7.5	145
30–90	12.5	1,612	7.5	725
90–120	20	2,580	23.5	1,806
Days of harvesting		12,900	31.5	402
Total				3,078

Table 5. Physicochemical parameters of pond water during a culture cycle

Parameter	Stage: Initial	Stage: Middle	Prior to harvesting
pH	8.46	8.02	7.76
BOD_5 (mg/liter)	7.5	23.34	31.17
TSS (mg/liter)	28	56.33	94
Turbidity (mg/liter)	11.67	23.33	30.33
Salinity (ppt)	27.67	28	27.33

during different stages of the culture cycle are presented in Table 5. There are no significant changes in pH and salinity during the culture period because pH is maintained by adding dolomite and quick lime. Salinity is normally determined from the quality of water sources.

The levels of BOD, total suspended solids (TSS), and turbidity increased within the culture period. Table 4 summarizes the estimated organic load as BOD_5 for the 12,900 m^3 pond. The estimated total discharge of BOD_5 is 2386 kg/ha/cycle. Taking the total pond area used by Northwestern Province farmers as nearly 2000 ha, the total discharge would be 4772 tons per cycle. With two shrimp production cycles per year, the total annual BOD discharge is 9544 tons. Values of BOD and TSS recorded in Thailand closely match these figures. Organic pollution from shrimp cultivation is significant compared to other industries and, because shrimp ponds are located in restricted areas in close proximity, the impact is even more pronounced.

Sediment Characteristics

Limited data are available on sediment characteristics. Data collected from ponds at different locations are given in Table 6. Accumulated sediment on the pond bottom is normally black. After drying, the color of the top sediment layers return to the normal soil color of the area. Oxidation of the organic matter and ferrous sulfide during the drying period may explain the change.

The pH values vary within a small range from 7.37 to 7.81 and sediment appears to be alkaline. However, the content of Ca^{2+} was high compared to Mg^{2+} and K^+. This indicates overuse of lime and dolomite to increase soil pH. Most farms where sediment samples were collected are 5–6 years old. Farm 1 (Table 6) is one of first farms established in Sri Lanka and shows a fairly high Ca^{2+} content. It was constructed on a cleared mangrove area, and it is likely that excess loads of lime and dolomite were used to reduce the soil pH.

Organic matter can accumulate in ponds during the culture period, and reported concentrations of organic carbon are relatively high in the range of 3%–5%. This is somewhat higher in comparison with sediments in other countries (Boyd and others 1994a,b). This indicates either low microbial activity or limiting factors that can inhibit the degradation of organic matter on the pond bottom during a culture period. Variations of nitrogen content are within the levels reported in other countries.

Levels of K^+ were lower when compared to levels of Ca^{2+} and Mg^{2+}. Total phosphorus values varied. The concentration of phosphorus may depend on the level of phosphorus fertilizer application, soil type, and clay fraction of the soil. High Na^+ content of sediments indicates salinity. Concentrations of all elements, pH, and total nitrogen are within the levels of sediments reported in the region (Boyd and others 1994a,b).

Heavy Metals in Sediments

Table 7 shows concentrations of heavy metals from seven farms and Table 8 the concentration of heavy metals in sediment and sewage sludge from other countries. Lead and zinc are found in fixed and exchangeable forms. Lead content was slightly higher compared to the values reported by Boyd and others (1994a,b). High pH levels due to application of lime would increase the precipitation of most heavy metals received by ponds. Pond water is exchanged at 5%–20% of volume per day, which may further lead to precipitation and accumulation of heavy metals on the bottom. Heavy metal deposits can come from anthropogenic sources, natural sources, or both.

Table 6. Characteristics of sediment collected from ponds of seven farms

Parameter	Location						
	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7
pH	7.47	7.37	7.79	7.77	7.39	7.81	7.51
Organic C (%)	5.14	4.18	3.80	3.34	3.83	3.62	2.19
Total solids (%)	90.6	92.5	93.5	93.9	93.1	93.5	96.8
Total N (%)	0.28	0.21	0.07	0.07	0.14	0.207	0.23
Total P (ppm)	740	560	280	400	680	360	660
Extract P (ppm)	50	36	29	30	58	38	41
Exch. K (ppm)	458	417	252	253	285	301	401
Exch. Mg (ppm)	1,745	1,728	1,415	1,549	1,390	1,649	1,668
Exch. Ca (ppm)	14,220	7,845	7,716	8,966	5,851	7,974	6,810
Exch. Na (ppm)	3,290	1,031	6,532	2,291	3,547	4,141	3,576

Table 7. Comparison of extractable and total concentration of heavy metals in sediments collected from seven farms

Parameter (mg/kg)	Location						
	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7
Extractable							
Cd	0.11	0.02	nd	nd	nd	nd	nd
Cr	0.8	nd	nd	nd	nd	nd	nd
Cu	1	nd	nd	nd	2	9	2
Ni	nd	nd	nd	nd	nd	nd	nd
Pb	5.3	3.9	3.8	5.1	4.2	6.0	5.3
Zn	5	3	3	2	4	15	4
Total							
Cd	0.85	0.75	0.6	1.25	0.2	1.25	1.1
Cr	83.5	62.5	30	79.5	39.9	43	62
Cu	20	20	10	15	10	25	20
Ni	nd	nd	nd	nd	nd	nd	nd
Pb	37.5	45	37	52	75.5	75.5	41
Zn	50	50	20	50	40	40	45

nd: not detected.

Levels recorded for heavy metals in the sediments of Sri Lanka are significantly higher than in other countries, and most likely are due to the heavy metal content of the soil itself. Recycling has probably increased the deposition, as is the case when the content in Sri Lankan soil is considered. Because sediments are used as a substitute for sludge fertilizer, it is customary to compare the concentrations. High concentrations in the fertilizer can lead to serious health hazards for consumers. Cr and Pb were high in all locations in comparison to urban wastewater treated sludge (Amarasinghe 1997). The level of Cd, Zn, and Cu are, however, lower. When using sediment as fertilizer, care must be taken to minimize adverse affects from Cr and Pb contamination. Considering other metal concentrations, which are relatively lower, a mixture of sediment and sludge may keep the balance of heavy metal in the fertilizer.

Sources of heavy metals indicated in exchangeable and fixed forms of sediment in Sri Lanka remain unclear, because there are no industries in the farming areas that would generate these metals as by-products. Irrespective of the source, heavy metal occurrence and accumulation in sediments due to water recycling are having a major impact on groundwater, land for agriculture, and receiving waterbodies.

Water Analysis of Receiving Natural Bodies

Table 9 shows values of different physicochemical and biological parameters for different natural waterbodies collected in 1997. There are no significant differences in pH values at different locations. Before shrimp farming was established, the pH in Dutch Canal was 4.5–6.0 (Figure 5) in 1983. Since then, it has increased to 7–8.5. This is attributed to the heavy liming done to moderate the acid sulfate soils, commonly

Table 8. Comparison of heavy metals in sediments and sewage sludge

Variable (mg/kg)	Pond Sediments		Sewage Sludge	
	Sri Lanka	Thailand, Ecuador, Philippines	Bangkok	Tunisia
Cd	0.2–1.25	na	2.3–3.0	4.0–7.0
Cr	3.0–83.5	3.35 ± 0.35	22.3–26.8	51–78
Cu	10–15	7.6 ± 7.16	231–395	150–320
Ni	nd	na	40.8–86	21–51
Pb	37–75.5	5.38 ± 3.71	21.0–23.9	192–526
Zn	20–50	798 ± 1.05	2054–2389	400–982
Source:		Boyd and others (1994a,b)	Amarasinghe (1997)	Bahri (1998)

na: not available, nd: not detectable.

Table 9. Comparison of water quality in main water sources in Sri Lanka.

Parameter	Gembaran-deniya	Chilaw	Dutch Canal	Mundel Lake	Dutch Canal North	Puttalam Lagoon (Mee Oya area)	Acceptable range
pH	7.3–8.2	7.5–8.6	7.4–8.7	7.2–8.7	7.5–8.6	7.2–8.6	6.8–8.7
Salinity (ppt)	2–30	5–31	0–38	2–52	1–46	10–48	10–30
Turbidity (NTU)	6–32	5–35	5–32	9–53	7–30	6–25	
Nitrite (mg/liter)	0.005–0.017	0.002–0.034	0.002–0.51	0.001–0.43	0.003–0.59	0.002–0.14	<0.2
Ammonia (mg/liter)	0.007–0.08	0.01–0.18	0.20–0.56	0.09–0.47	0.27–0.43	0.04–0.15	<0.2
Sulfides (mg/liter)	0.0–0.14	0.04–0.36	0.12–0.72	0.10–0.7	0.16–0.7	0.16–0.6	<0.2
TSS (mg/liter)	na	50–300	100–400	125–425	150–400	100–275	<100
BOD_5 (mg/liter)	na	8.8–20.4	8.6–36.2	6.0–22.4	10.8–48.4	7.8–18.2	<10
DO (mg/liter)	na	6.2–12.2	6.2–13.2	6.8–12.4	5.4–10.8	4.2–9.6	6.8–8.7

na: not available. Source: NARA (Amarasinghe 1988).

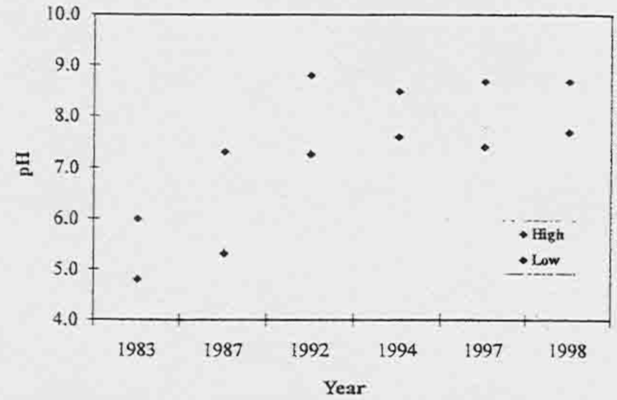

Figure 5. Changes in pH of Dutch Canal from 1983 to 1998.

known as pyretic soils. Most shrimp farms are in pyrite soil areas. Pyrites in the deeper soil layers are exposed during pond construction. Fe_2S reacts with O_2 producing Fe^{3+} and SO^{4-}, which lowers the pH level.

There was no significant variation in salinity from 1983 to 1998, except for occasional annual variations within acceptable limits. Similarly, changes in turbidity did not show any remarkable variations, although occasional rises are noted. In contrast, changes in TSS are quite significant after the establishment of shrimp farms and vary from 50 to 400 mg/liter and above acceptable limits. Similarly, recorded values of BOD are also above acceptable limits. Jayasinghe (1995) noted high concentrations of iron, aluminum, and manganese due to probable release from pyretic soil at low pH in the water. This indicates that the quality of natural waterbodies near the shrimp ponds is approaching a dangerously low level.

Current Environmental Management Practices

Management of Pond Water Quality

The adverse affects of poor water quality became apparent in the 1996 outbreaks of water-borne diseases. Farmers have since realized that water quality

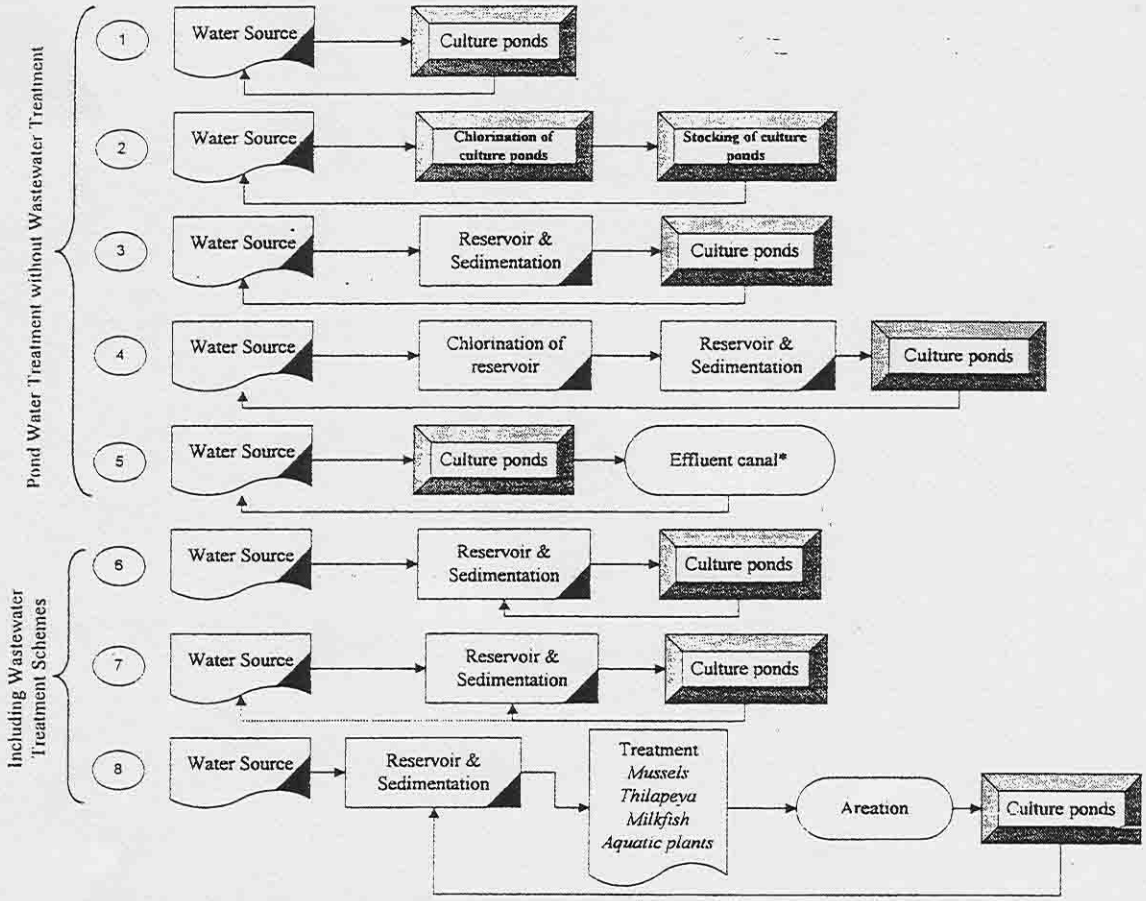

Figure 6. Water and wastewater treatment systems in Sri Lankan shrimp farms. Water source: surface water of lagoons and canals or groundwater. *Effluent canals were also found in other systems. Groundwater could be used for dilution of lagoon water or used directly as water source where the ground water was salty. 1: Direct intake and discharge; 2: Cl_2 before stocking; 3: storing of water at sedimentation to remove SS; 4: Cl_2 before reservoir; 5: effluent canal to remove SS; 6: closed system; 7: semiclosed system; 8: closed system with biofiltration. Note: chlorination may be used at the beginning of the water intakes in any system.

is critical to the health of the industry, and pond management procedures are now aimed at improving chemical and biological conditions. Although water quality encompasses all physical, chemical, and biological variables that affect production, according to farmers, pH and salinity are the most important. Salinity is controlled by adding water, and pH is controlled by adding lime and dolomite during the grow-out period.

In regions of water scarcity and during dry seasons, groundwater is pumped for recycling. Farmers in areas with high salinity are limited to one culture cycle per year. In areas with low salinity throughout the year, farmers sometimes run 2.2 cycles. Apart from the addition of chemical fertilizers, antibiotics and vitamins are also widely used to obtain better yields and protect shrimp from disease.

Water treatment systems currently used are shown in Figure 6 (schemes 1–5). Farmers are now more inclined to use water treatment in combination with recycling systems that circulate wastewater into ponds after physical and biological treatment—a clear sign of better pond management practices.

Table 10 presents typical physicochemical parameters measured in the culture cycle of a well-managed pond. In comparison to other parameters, pond TSS is always higher than the acceptable limit. Hydrogen sulfide, ammonia, nitrite, and BOD levels of some ponds are also above acceptable levels. The quality of water changes quickly in response to inputs of large quantities of feed. As a consequence, TSS and organic matter in the ponds also increases. The presence of hydrogen sulfide indicates some form of anaerobic condition. The overall indication is that much remains to be done to improve pond water quality management.

Table 10. Pond Water Quality Analysis

Parameter	Farm 1	Farm 2	Farm 3	Acceptable range
pH	8.2–8.6	—	—	7.5–8.7
Temperature (°C)	29–30	—	29–30	26–33
Turbidity (NTU)	16–36	—	—	0–150
TSS (mg/liter)	30–59	34–75	—	2–14
DO (mg/liter)	5.7–10.5	—	5.9–6.3	3–12
Salinity (ppt)	11–28	—	—	10–35
Nitrate (mg/liter)	—	0.43–0.69	0.03–0.036	0–200
Nitrite (mg/liter)	0.01–0.17	0.03–0.47	0.005–0.014	<0.25
NH_4 (un-ionized) (mg/liter)	—	0.25–0.62	0.05–0.058	<0.25
H_2S (mg/liter)	0.17–0.19	0.28–0.80	—	<0.25
PO_4^{3-} (mg/liter)	—	0.36–0.72	0.017–0.031	—
BOD_5 (mg/liter)	5.2–14.6	—	3.9–4.3	<10

Source: Corea and others (1995) and Edirisinghe and others (1997).

Wastewater Treatment

Field survey results indicate that nearly 85% of all farms discharge wastewater directly into canals or lagoons without treatment. However, recent disease outbreaks and low water quality sources are forcing farmers to recirculate wastewater into culture ponds to minimize discharge and intake. Prior to any serious outbreak of disease, farmers were reluctant to spend money and time or use land for waste treatment. They felt it was unnecessary, and there was no enforcement of the regulations. Small farmers complained that large farmers spread disease and pollute water sources by discharging untreated wastewater. Disputes between the two groups continue to hurt the industry.

At present, only 15% of farmers use any kind of wastewater treatment process. During the 1980s, natural recovery of water quality was sufficient to sustain farming. In the early stages of the industry, authorities concerned with environmental issues recommended drains and seepage canals for sedimentation of suspended solids. Haphazard development has destroyed the natural recovery systems, causing severe water quality problems. Figure 6 (schemes 6–8) shows the systems in use presently. Farmers are now more or less compelled to use wastewater treatment. Farmers having more than 5 ha can spare 10% of land for sedimentation or stock tanks. However, small-scale farmers are not in a position to spare land. A related difficulty faced by small farmers is the lack of coordination with neighboring farmers to arrange common land for sedimentation tanks. In practice, methods recommended by the authorities can be implemented only by medium- and large-scale farmers. Lack of common intakes and outlets for neighboring farms adds to the difficulty of implementing the recommended systems.

It is also useful to compare the quality of shrimp farm effluent with wastes from other potential sources of pollution. These comparisons show that the pollution potential of effluent from well-managed shrimp farms is considerably less than that from domestic or industrial wastewater. Although the actual quality of shrimp farm effluent is less noxious than many other sources of coastal effluent, water pollution problems may arise because of the large volumes and high concentrations discharged. This becomes significant when shrimp farms become too concentrated in an area with a limited water supply or have poor flushing capacities, as in Sri Lanka.

Sediment Management

Accumulated sediment is removed or allowed to oxidize after each production cycle as a safeguard for the next cycle. The sediments are allowed to dry for two to three weeks in the pond after harvesting and removed by scraping 5–10 cm of top soil from the pond bottom.

Sulfuric acid is formed due to the oxidation of ferrous sulfide. This reduces pH, so farmers apply dolomite and lime to increase the pH to an optimum level.

In Thailand, some ponds are lined, which reduces the chances of leaching and infiltration and mixing with natural soil. Ponds in Sri Lanka are not lined and sediments are often discharged into canals by flushing or, more commonly, dumped on pond dikes, neighboring land and roads, or used as fertilizer for nearby coconut plantations. Currently, disposal is not a major concern for farmers, and proper treatment and disposal methods are seldom used. Some farmers and environmentalists complain of increased silting in Dutch Canal during rainy seasons due to disposal of untreated pond sediment.

Proposed Management Plans

1. Conservation and rehabilitation of mangrove swamps and salt marshes is badly needed. The currently recommended 100-m buffer zone from the upper water level requires reconsideration as it results in encroachment of shrimp farms onto the river floodplains and cultivatable farm area. Salinization and contamination of groundwater is another consequence.
2. Stopping and reversing the degradation of natural waterbodies is urgently required. The government could take measures to slow or stop untreated discharge. For example, water exchange in Dutch Canal could be improved by removing sand barriers and reducing farm density in the Mundel and Puttalam lagoons. Farmers could be advised to carry out one cycle during periods of low salinity.
3. Good pond water quality reduces disease and creation of waste and results in economic gains. At present, most farmers use chemicals, feed, and energy (in the form of aeration) without sufficient knowledge. The rate and amount of consumption need to be optimized, which requires exchange of technical know-how and expert consultancy at both government and farm level. Accredited training courses, seminars, workshops, and funded research would help achieve this goal.
4. Environmental management and protection measures vary depending on farmers' abilities to acquire funds, land, technical information, and their knowledge of environmental regulations. In spite of the conditions laid down by authorities at the time of project approval, there is little incentive within the industry to engage in good environmental management and protection practices. This is largely due to lack of enforcement and poor monitoring. The main priorities have been pond management and disease control. However, since the devastating outbreaks in 1996, there has been some inclusion of environmental management systems to manage pond water quality, but guidelines for wastewater treatment facilities have to be included. Care must be taken to ensure that small farmers have the required financial resources. Regional cooperation among small farmers on common wastewater treatment facilities or municipal pumping and treatment systems is a viable option. Financial assistance and governmental intervention could help facilitate this.

Solid waste management of sediment and discharge needs to be addressed and the possibility for pond lining in Sri Lanka needs to be evaluated. Use of sediment as fertilizers or landfilling sediment after proper treatment are other options. Provincial authorities could help formulate solid waste management strategies to help farmers.

Role of Internal and External Actors in Integrated Aquaculture Management

Integrated aquaculture management requires technical, environmental, institutional and financial expertise, but most of all sociopolitical participation. Economic and legislative tools alone will not lead to sustainable development. Internal issues in an aquaculture management include factors such as algal bloom in ponds, mortalities, molting, toxicological stress, growth rate, and stress on shrimp. Management of internal factors is directly linked to activities of farm management, water quality and wastewater treatment, type of feed and chemicals used and disease control mechanisms. External issues include laws and regulations, research and development, consultation and monitoring activities (Figure 7).

Consultants

Experienced consultants on sustainable farming techniques are badly needed, and the government could help by establishing a registration procedure. Farm activities could be carried out in coordination with these consultants. The consultant would meet with farm managers, aquaculturists, and owners. He would be free to carry out investigations and suggest technical changes. Consultants could have a significant influence on practices, choice of technology, and transfer of information. The recently established Aquaculture Service Center of the Industrial Service Bureau (ISB) hopes to provide consultancy and laboratory facilities to small- and medium-scale farmers who face problems due to the shortage of affordable consultants.

NGOs

NGO participation in the industry has a high profile and their activity has raised general awareness among local residents on many critical issues. There was a period when the government had to stop approving shrimp farms as a result of NGO-initiated public protest on environmental issues. MFARD recognized the role of NGOs by including them in technical working groups in the environmental impact assessment (EIA) procedures. Their further involvement could be beneficial to the industry.

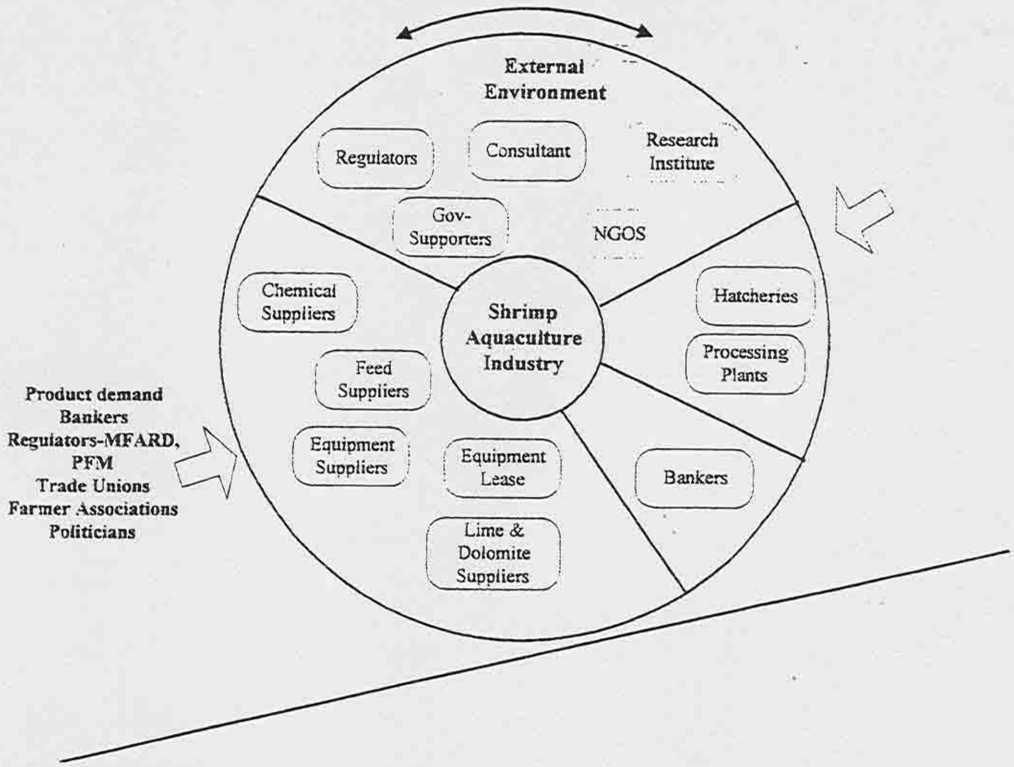

Figure 7. External actors of shrimp industry.

Research Institutes and Laboratory Facilities

The National Aquatic Resources Agency (NARA) plays a major role in providing laboratory facilities for soil and water quality testing during the preliminary site selection for zonal clearance. NARA also carries out research, collection of baseline information, sampling and analysis of water, and determination of diseases. However, NARA laboratories are located near Colombo. Branches or sublaboratories nearer the farms would be a great asset to the industry. Data collected by NARA could be used to formulate guidelines for farmers and environmental engineering applications.

The CP laboratory, which belongs to the CP Feed Company of Thailand, provides free laboratory services to farmers for water quality analysis, disease determination, and other requirements. In addition to support services, the CP laboratory carries out water quality analysis for Dutch Canal and the lagoons. Local feed suppliers also provide laboratory facilities to farmers, and some farmers perform routine analysis of water quality themselves. A plan to manage these laboratories and develop research would greatly improve technological assistance to the industry.

Hatcheries

Shrimp grow-out ponds depend entirely on postlarval production from existing hatcheries. Distribution of hatcheries is scattered, but most are located in the NWP. Relatively small amounts of chemicals are used. When compared to the water exchange of shrimp culture ponds, the daily water exchange in hatcheries is small. Most hatcheries discharge wastewater into the sea, which also has environmental impacts. Improved hatchery management is needed along with better technology.

Feed and Equipment Suppliers

Most feed used is imported under different brand names from Thailand, Malaysia, Indonesia, and India. They all provide feed for larval to grow-out stages. There are four Sri Lankan distributors and numerous local suppliers. Most suppliers also provide feed and supply equipment and chemicals. Suppliers may also provide credit facilities, marketing, information on feed and market trends, and consultancy on chemical application and disease control.

Equipment is employed mainly during the construction and operational stages. There is a big demand for heavy machinery for pond construction and canal preparation. Most water pumps and paddle wheels are imported by dealers, and servicing is done by local agents. Local businesses provide services on a hire or lease basis. There is also heavy demand for electricity. Development of these support industries may help reduce unemployment and make the industry more self-supporting.

Conclusion

Sustainable shrimp cultivation in Sri Lanka will depend on development of an integrated management plan and the quality of the interaction among the various actors involved. These management plans and procedures are required to focus on the key environmental issues as well as restoration and conservation of important local ecosystems. Technical aspects of the present environmental degradation and improvement in the techniques of production need to be addressed with high priority. Improved and proven techniques for environmental and ecosystem protection can be established in conformance with past experience gained by other Asian countries that are actively involved with shrimp aquaculture. In regard to the interactions among actors, a first step would be to analyze the roles and extent of participation of external and internal actors and their level of dependence on each other. The choice of technology and policy formulation needs to take local conditions into account, including the financial capabilities of farmers. Relevant concerns include reliable technologies, efficiency, and identification of problems and appropriate solutions. The outcomes depend on an organizational environment conducive to rationale policy formulation. Training needs have to be defined and government support provided with a minimum of bureaucratic interference.

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