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Boom-and-Bust Shrimp Aquaculture; a Feebate Policy for Sustainability

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Abstract

Well intentioned policies which fail to perceive environmental feedback often exacerbate over-exploitation of renewable natural resources, especially when the resource exploitation is driven by powerful market forces. The purpose of this paper is to consider such a situation, the world shrimp aquaculture industry, and to explore one localized case where a policy intervention of "feebate" may offer a potential balancing effect.

Key words
Shrimp farming, shrimp aquaculture, sustainability, feebate, system dynamics

Introduction

In this paper we examine the implications of a feebate policy in the management of a commodity production system heavily dependent on renewable natural resources. Feebates are combinations of fees and rebates designed to enlist market forces to encourage desired patterns of resource usage (Collinge 1997, Ford 1999). Feebates have been proposed for reducing vehicle emissions (Ford 1995a, 1995b, Jansen and Denis 1999) and promoting conservation of water resources (Collinge 1996). Feebates are considered appealing because they achieve their aims without resorting to prescriptive regulations and are self-financing (Collinge 1997, Ford 1999).

Extending this research, we examine the shrimp aquaculture industry in Thailand. The industry has grown impressively over the past two decades but has displayed recurrent boom-and-bust patterns linked to over exploitation of renewable natural resources. With the aid of a system dynamics model we examine how a form of feebate may help the industry achieve sustainability and preserve the natural resource base on which it is dependent by favouring producers with decision-rules that foster long term benefits.

In the next section we provide background for our case study and develop a problem definition. The section after elaborates our hypothesis of the causal structure underlying the problem scenario and describes the structure and behaviour of the model. We then describe simulations of export taxation and feebate policies and discuss their implications for promoting sustainability of the industry. We conclude with a discussion of key assumptions underlying the feebate policy that are relevant to the feasibility of a feebate policy in this instance.

Problem description

Boom and bust in the international shrimp aquaculture industry

Growing international demand for shrimp and stagnating catches of wild shrimp in the early 1980s created an opportunity for the development of export orientated shrimp aquaculture industries (Csavas 1995). Countries with climate and natural resources suitable for shrimp farming, particularly in Asia and Latin America, seized on the opportunity, transforming vast stretches of coastline into shrimp farms. Growth in the sector has been spectacular over the past two decades (figure 1). In 1982 shrimp aquaculture accounted for only about 5% of world shrimp supply, by 1994 this figure had risen to 30% (Flaherty, Vandergeest, and Miller 1999). Globally, farmer earnings from shrimp farming were estimated at over US$6 billion in 1996 with retail value 3 times that amount (Flaherty and Miller 1999). In Thailand, currently the world's largest producer, the industry generated over US$1.7 billion in export earnings in 1996 (Flaherty and Miller 1999). Significant potential for export earnings and rural employment has prompted governments and international development institutions to promote the growth of the industry through subsidies and tax breaks (Huitric et al 2002).

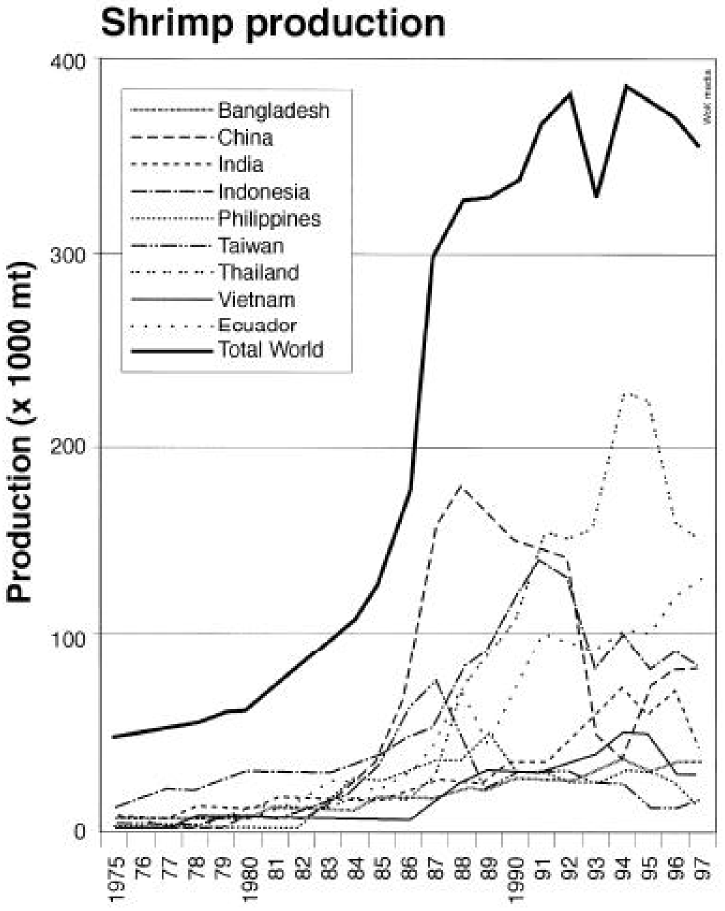

Figure 1. Growth of worldwide shrimp aquaculture production (source: Kautsky, Rönnbäck, Tedengren and Troell, 2000).

Despite the apparently bright picture of growth and export earnings at the global scale, the shrimp farming industry has exhibited an extremely instable pattern of development strongly associated with ecological damage and social disruptions. Careful examination of figure 1 reveals a pattern of boom and bust in the industry. In the early 1980s the industry grew rapidly in Taiwan and China only to suffer dramatic production crashes within a few years. Similar patterns can be observed for The Philippines, Indonesia, and India. Thai production grew dramatically as production in Taiwan and China collapsed, and then took a significant downturn in 1995-1997. These boom and busts have been observed both at the national scale and within countries. In Thailand, for example, the industry has developed rapidly in one region only to crash and migrate to another region (Huitric, Folke, and Kautsky 2002). The production collapses have left a trail of depleted natural resources and have caused social damage through loss of employment in shrimp farming and related side industries.

Why have these production crashes occurred? A brief background description of shrimp farming and its relationship to the environment will facilitate our discussions of the causes of the boom and bust phenomenon.

Background: brackish water shrimp farming and the environment

The form of shrimp farming we are examining is known as "brackish water" shrimp farming. Several species are farmed but all are marine species and require salt water. For this reason shrimp farms are typically found along coastal margins, often on the shores of estuaries and embayments lined or formerly lined with mangrove forests. Mangroves are the dominant ecosystem type found in shrimp farming areas and are important for maintaining water quality through assimilation of nutrients and pollutants and for a host of other ecological services important to the well being of fisheries, biodiversity, and rural incomes to name a few (Baran and Hambrey 1998, Huitric 2002, Rönnbäck 1999).

Shrimp farming is usually considered to fall into three categories. "Extensive" shrimp farming has been practised in Asia for centuries. The farmer relies on feed occurring naturally in the coastal waters, inputs are minimal and there is little release of waste into the environment. Yields are comparatively low, in the range of 0.5 to 1.5 metric tons per hectare of pond per year. "Intensive" farming is dependent on heavy inputs of commercial feed and chemical treatments, and investments in facilities such as electric lights, pumps, and aeration devices. Yields are much higher, in the range of 7 to 15 tons (Kautsky et al 2000). Demands on the ecosystem are also much greater. Intensive farming produces large amounts of wastewater contaminated with dissolved feed, dead shrimps, faecal matter, etc which must be flushed from the pond and replaced with clean intake water on a daily basis. Also, 100 to 500 MT of sediments per hectare per year of extremely high organic content are produced and must be disposed of (Flaherty and Miller 1999, Lin 1995). The third category "semi-intensive" farming is intermediate to extensive and intensive in terms of inputs, yields, and environmental impact. It follows that the greater the farming intensity, the greater the demands placed on the ecosystem for waste assimilation and clean intake water, and the more problematic the environmental sustainability of the farming operation.

Kautsky et al (2000) have developed the concepts of "ecological footprint" and carrying capacity for shrimp farms. The ecological footprint is the area of intact ecosystem required to sustain production per unit area of shrimp pond, and the size of the footprint is directly related to farming intensity (Kautsky et al 2000). The footprint concept then provides a useful indication of the carrying capacity of a given area to support shrimp farms. If the carrying capacity is exceeded, water quality deteriorates and yields fall due to pollution and, in particular, high concentrations of disease pathogens that thrive in contaminated water and sediments.

Causes of production crashes in shrimp aquaculture

Boom and busts patterns of shrimp aquaculture development have occurred because public policy has failed to (i) perceive the ecological feedback structure of which the industry is a part (Huitric 2002) and (ii) conserve common property resources on which the industry is dependent. Compelling experimental work by Moxnes (2000) has demonstrated that these two policy failings are closely related. Quoting Moxnes:

> …misperceptions (of environmental feedback) disguise the need for policies and institutions to solve commons problems in due time before the exploitation rates exceed limits for maximum sustainable resource extraction.

The above quote summarises well the policy failures underlying the repeated collapses of shrimp farming industries. In the rush to cash in on high prices, farms have been allowed to proliferate over coastal areas in numbers far exceeding the ecological carrying capacity (Flaherty 1999, Kautsky 2000). High profit potential has also encouraged intensive farming in order to maximize yields, putting even more pressure on the carrying capacity. The majority of farms often have been established in commonly owned coastal mangrove forests, which has directly reduced the ecological carrying capacity through the clearing of mangroves for pond, facilities, canals, and access roads. The common property nature of coastal mangroves and the services they provide has greatly contributed to the production crashes. Common property resources are typically over-exploited because, in the absence of property rights, no single appropriator can capture the benefits of conservation (Collinge 1997). This is the essence of the "tragedy of the commons" described by Hardin (1967). In the case of shrimp farming, farmers who have appropriated commonly owned mangroves have no incentive to invest in conservation measures, and instead opt to maximize farming intensity, and profits, in the short run. Because mangroves as common property are undervalued (Rönnbäck 1999), it is more cost effective for farmers to deplete mangrove resources until yields drop to uneconomic levels, abandon the area, and move their operations on to unspoilt mangroves, in place of investing in facilities or following management practices that would provide for more sustainable production. Thus failure of policy in regard to regulating the shrimp aquaculture industry and managing the commonly owned mangrove ecosystem has contributed not only to boom and busts in the shrimp farming industry but to widespread destruction of ecologically and economically important mangrove ecosystems.

Sustainability in the shrimp farming industry

Regulation of land use is a key to achieving sustainability in the shrimp farming industry. Shrimp farming generally occurs on two broad classes of land, mangroves and coastal inland. The "coastal inland" we consider to be inland areas adjacent to mangrove areas, suitable for various forms of agriculture, but still near enough to the shore for shrimp farms to economically access coastal water. We have discussed above how the common property characteristic of mangroves, and the decision-rules of shrimp farmers in mangroves, render mangroves unsuitable for sustainable shrimp farming. Also, farming within the mangrove areas destroys the very base of ecosystem services on which shrimp farms are dependent. Inland farmers, in contrast to mangrove farmers, generally hold title to their land and are concerned about long-term returns to their investment, in other words their decision-rules are more likely to foster sustainable production. Inland producers have incentive to produce shrimp sustainably, making use of the ecological services of adjacent mangroves. However, the historical pattern has been that farms have crowded into the mangrove areas, overwhelming the ecological carrying capacity for both themselves and adjacent inland farms (pers. conv. D. Fagan, Aquastar Co., Thailand; S. Blanchard, Bectel Corp., Thailand). It follows that policy for sustainability in the industry should protect the mangrove ecosystems and promote sustainable inland farming.

Shrimp aquaculture in Thailand

Extensive shrimp farming for household consumption and the local market had traditionally been practised for many decades in Thailand with insignificant environmental impact. Commercial scale production for export began in earnest with the introduction of intensive shrimp farming technology from Taiwan in the early 1980s (Huitric et al 2002). The collapse of the shrimp farming industry in Taiwan in 1987 opened a niche that Thailand quickly filled and by 1991 Thailand had become the largest producer and exporter of farmed shrimp in the world, a position it has held to date. The growth of the industry in Thailand has been given impetus through government subsidies and tax breaks and by implicit natural subsidies in the forms of undervalued mangrove lands, free intake water and waste disposal (Huitric et al 2002).

Sequential boom and bust of the commercial shrimp farming industry in Thailand has been well documented (Huitric et al 2002). Since its beginnings in the early to mid 1980s, the industry has shifted from one coastal region to another, first from the central to the western Gulf of Siam, then to the eastern Gulf, and finally to the Andaman seacoast. It is estimated that Thailand lost approximately half of its mangroves during this time and that at least half of this loss resulted directly from expansion and migration of the shrimp farming industry (Barbier and Cox 2002, Huitric et al 2002). Most recently there has been a significant move of shrimp farming into the interior inland, in particular to the central Chao Phraya River basin, using seawater brought in by truck and special rearing technology (Flaherty and Miller 1999). This recent move far inland is due in large part to the growing difficulty of obtaining clean water in costal areas suitable for shrimp farming (Huitric et al 2002). Recent government restrictions on inland shrimp farming have evoked concerns that renewed pressure may be placed on coastal mangroves (Barbier and Cox 2002). As we write Thailand remains the largest producer of farmed shrimp in the world. However, the growth trend in aggregate national production has belied a number of production booms and crashes within Thailand and a shifting pattern of farming which has resulted in much ecological and economic damage. The industry appears to be at a crossroads at this time as much of the coastal ecosystem is depleted of mangrove cover and serious environmental problems are emerging with inland shrimp farming.

Shrimp farming policy in Thailand

In the early stages investors rushed into shrimp farming with virtually no regulation. The government encouraged rapid growth of the industry by providing subsidies on feeds and other inputs, tax breaks and low interest loans (Huitric et al 2002). The World Bank and the Asian Development Bank identified shrimp farming as a key industry for rural development and supported growth of the industry in Thailand (Flaherty 1999). As national and international recognition of the environmental damage wrought by the industry increased through coverage in the popular press and through research studies, the Thai government changed its formal position on the industry. The 1991 Thai Fisheries Act enacted a number of measures to regulate shrimp farming including a ban on all shrimp farming within mangrove areas and prohibited loans for farms in mangroves. Ministerial regulations placed requirements on pond effluents and required that all shrimp be registered. Inland shrimp farming also presents its share of environmental challenges. Salinisation of surroundings, problems associated with disposal of wastewater and sludge, and conflict with neighbouring rice farmers has prompted the government to ban shrimp farming in inland areas with the exception of designated areas fringing the coasts (Flaherty and Miller 1999). Thus, the legally sanctioned areas for shrimp farming in Thailand are now the inland areas adjoining the coasts and officially designated as suitable for shrimp farming (Flaherty 1999).

Policy changes in Thailand indicate that there is now perception among policy makers of the feedback processes linking the industry and the environment. However, policies addressing environmental problems of the shrimp farming industry have not proven effectual to date. For example, despite the ban on farming in mangroves encroachment on officially protected mangroves continues. Also, regulations on pond effluents are commonly ignored (Huitric et al 2002). Reasons cited for non-compliance of regulations include inadequate fines and inadequate departmental staff to monitor mangrove encroachment, farming practises and enforce regulations (Flaherty and Miller 1999, Huitric et al 2002, MIDAS 1995).

Prescriptive policies can create conflict with resource appropriators and are expensive to implement. In light of the failure of prescriptive policies to regulate the shrimp farming industry, we suggest that policies involving market incentives are worth investigating. In the section that follows we describe a model in which we attempt to capture the key economic and ecological feedbacks and agent decision-rules that lead to the problematic pattern of boom and bust shrimp aquaculture in Thailand. We then use the model to experiment with policies that alter market incentives in order to push the system toward sustainability.

Model description

The model is divided into three interacting sectors, (1) *world shrimp commodity system*, (2) *Thai mangrove shrimp production*, and (3) *Thai inland shrimp production*. The *world shrimp commodity system* sector is based on Meadows' General Dynamic Commodity System model (1970) and mimics the dynamics of world shrimp consumption, world production (excluding Thai aquaculture production), and price determination. The *Thai mangrove shrimp production* and the *Thai inland shrimp production* sectors are disaggregated from world production in order to study ecological feedbacks and decision rules influencing the sustainability of shrimp production in mangrove and in inland environments. Figure 2 shows the principle interactions between the sectors and lists key assumptions embodied within each sector.

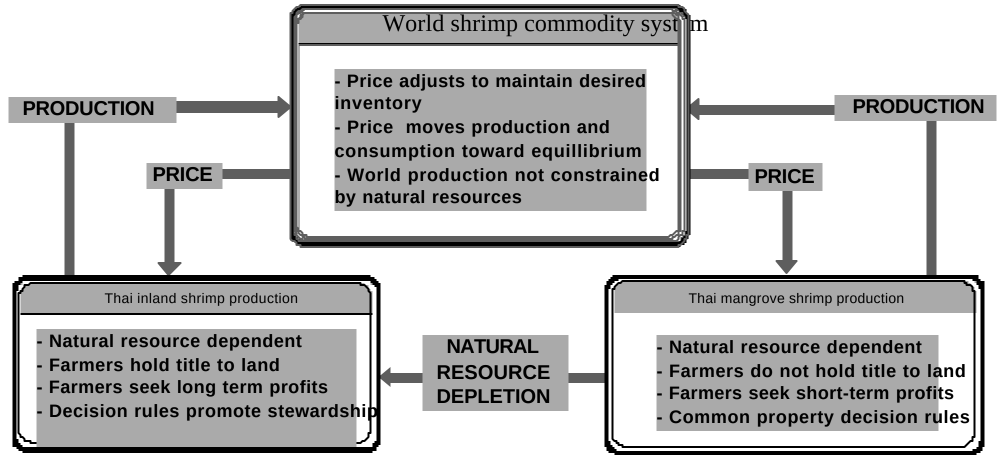

Figure 2. Model sector interactions and key assumptions

In figures 3 through 6 we use causal loop diagrams to explain the information structure of each model sector. In the causal loop diagrams we have not explicitly indicted stock and flow variables. A positive causal link polarity should be interpreted as: an increase (decrease) in the independent variable causes the dependent variable to be greater (less) than what it would be otherwise. A negative polarity should be interpreted as: an increase (decrease) in the independent variable causes the dependent variable to be less (greater) than what it would be otherwise (Richardson 1997, Sterman 2000).

World shrimp commodity system

The basic information structure of the *world shrimp commodity system* sector is shown in figure 3. World price is determined by the collective action of world inventory holders who seek to maintain inventories at a desired level. The two balancing feedback loops act in concert to equilibrate production and consumption in accordance with a desired level of inventory. Delays associated with adjustment of consumption, price recognition, up scaling or down scaling production capacity, and crop production give rise to commodity cycles. In the world shrimp commodity system sector we assume that production is always able to meet demand by moving its base to unexploited regions and thus we do not consider land tenure or other issues effecting sustainability. The commodity cycles induced by the information delays in the sector structure should not be confused with the boom and bust patterns associated with environmental degradation induced by shrimp farming.

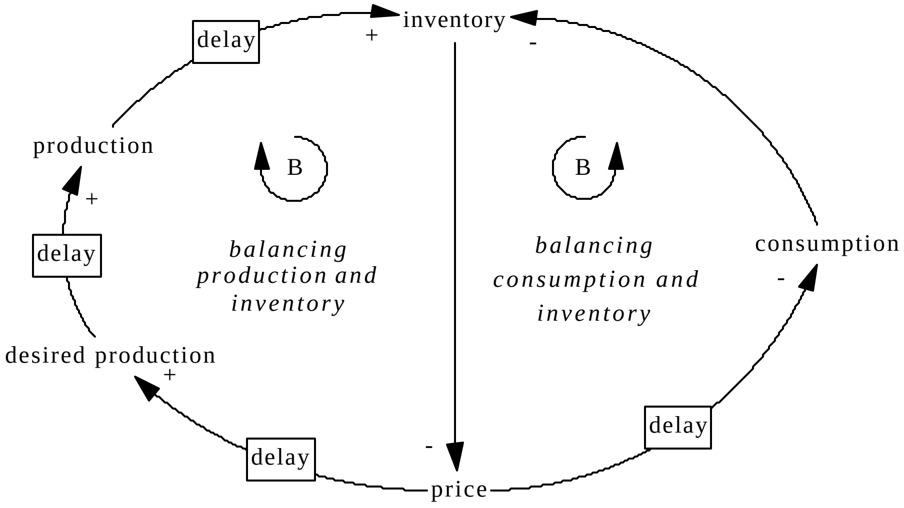

Figure 3. Information structure of world shrimp commodity sector

The purpose of Meadow’s model (1970) was to develop a dynamic theory of commodity cycles and explore policies for moderating these cycles. Our purpose is to study the causes of boom and bust in shrimp aquaculture and explore policies for environmental sustainability of the industry. Thus, we have made use of the Meadows model as an archetypal structure to mimic the information flows of the world shrimp commodity system that drive natural resource exploitation. This approach was taken by Arquitt (1995) in his study of Thai shrimp industry and by Johnston, Solderquist, and Meadows (2001) in their study of the world shrimp market. The two sectors described below model ecological feedbacks and decision rules influencing sustainability of shrimp production within specific geographical settings.

Thai mangrove shrimp production sector

We assume that all shrimp farms in the *Thai mangrove shrimp production* sector are situated in coastal mangroves that are publicly owned. We assume that the mangrove ecosystem serves as both a source of intake water and as a sink for wastes from shrimp farms and that it has a limited carrying capacity for sustaining farms. We further assume that individual farmers cannot capture the benefits of conservation and, hence, follow decision rules that maximize short run benefits as discussed previously.

Figure 4 shows the information structure that drives expansion of the Thai mangrove shrimp production sector and its linkage to the world shrimp commodity system.

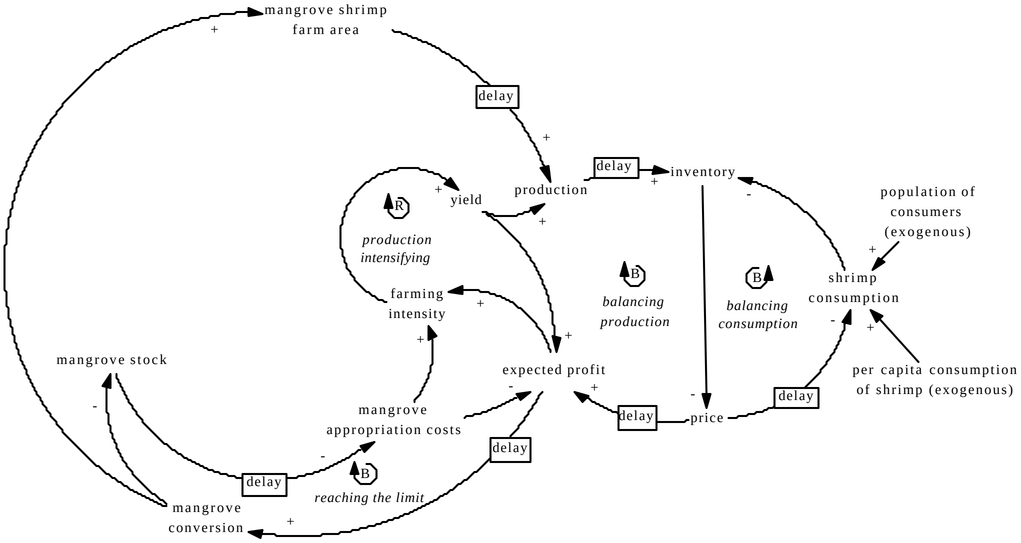

Figure 4. Information structure of Thai mangrove shrimp production sector and its linkage with the world shrimp commodity system sector.

Increasing shrimp consumption worldwide decrease world inventories. Inventory holders respond by raising prices. Expected profits are attractive because of high price, high expected yields associated with intensive farming, and low cost of appropriating mangroves. Investors respond by converting mangroves to shrimp farms and intensifying production. This increases aggregate production, which links with the *world shrimp commodity system* sector. The balancing influence of the feedback "*balancing production*" has limited moderating influence on mangrove conversion and intensification in the early development phase because Thai production is a relatively insignificant fraction of world production. However, as Thailand gains a larger share of world production this feedback becomes stronger. The balancing loop *"reaching the limit"* becomes dominant as mangroves are depleted, increasing mangrove appropriation costs and decreasing expected profits. Mangrove appropriation costs can be construed as the actual price paid for the right to use mangroves through legal concessions or increased risk of punitive action or increased illegal compensation in the case of encroachment on legally protected mangroves. This structure gives rise to an s-shaped growth pattern of production. However, when feedback from the ecosystem and common property decision rules are added to the structure the story is different.

Figure 5 includes environmental feedbacks. Research by Kautsky, Ronnback, Tedengren, and Troell (2000) demonstrates that shrimp farming depends on ecological services provided by nature, including wastewater assimilation and supply of clean intake water. We have borrowed concepts of "ecological footprint" and "carrying capacity" which were developed by Kautsky et al (2000) to aid in planning and decision making for the shrimp farming industry. The ecological footprint is the unit area of intact mangrove ecosystem required to sustain a unit area under shrimp farming. The ecological carrying capacity for shrimp farming is then the area of farms that an area of intact mangroves can sustain. The area of the ecological footprint is directly related to farming intensity.

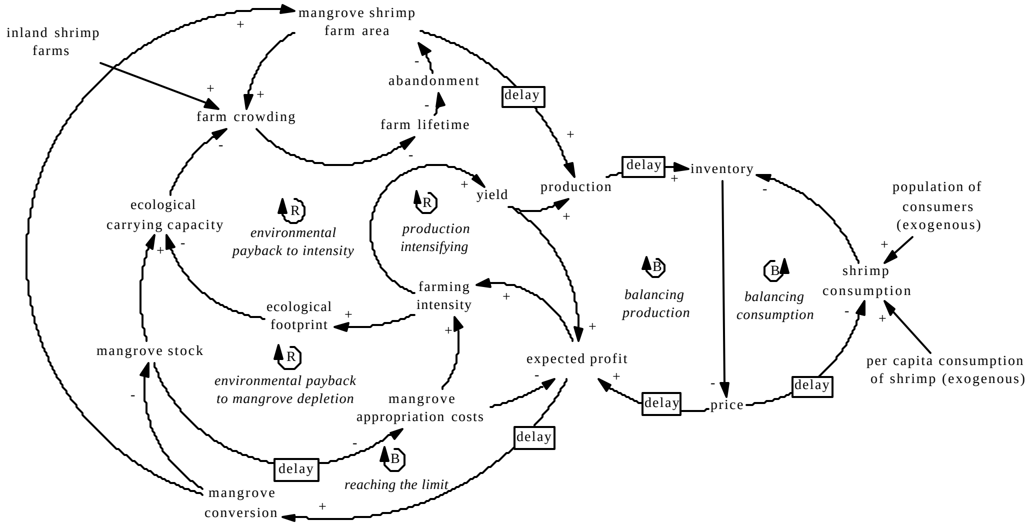

Figure 5. Structure of Thai mangrove shrimp production sector with environmental feedback loops in place.

Two reinforcing feedback loops, *"environmental payback to mangrove depletion"* and *"environmental payback to intensity"* cause production crashes. As mangroves are converted to shrimp ponds, the mangrove stock is diminished and the ecological carrying capacity declines. Intensification places greater demand on ecological services and increases the ecological footprint, which also reduces the carrying capacity. As intensive shrimp farms crowd into an area, the ecological carrying capacity is exceeded, and the average farm lifetime drops due to contamination and associated disease outbreaks. Farms are then abandoned, decreasing the total area of mangrove shrimp farms. This puts downward pressure on aggregate production and upward pressure on price through the inventory mechanism. Expected profits remain attractive and shrimp farmers move on to exploit unspoilt mangrove areas until the mangrove appropriation costs becomes prohibitive.

Thai inland shrimp production sector

In the inland shrimp production sector we assume that farms are located in the inland immediately adjacent to the mangrove belt. We assume that the inland farms also depend on the mangrove ecosystem for intake water and waste assimilation and that the mangrove ecosystem has a limited carrying capacity to sustain adjacent inland farms. We assume that inland farmers own their land, and will take conservation measures to sustain long-term production and property value. In particular we assume that farmers will reduce their farming intensity when their yields decline due to feedback from the ecosystem.

Figure 6 shows the information structure for inland farms including feedbacks for growth, environmental pressures, and decision-making.

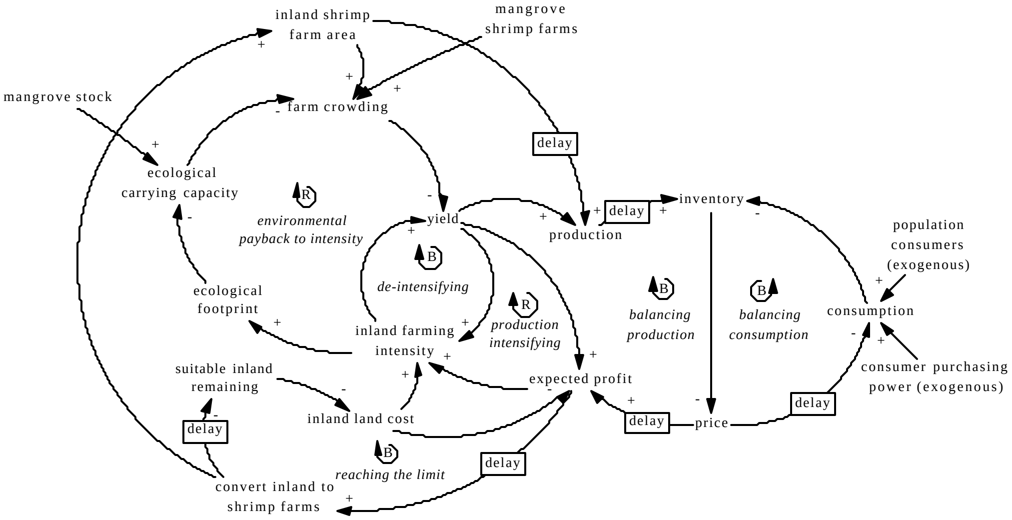

Figure 6. Structure of Thai inland shrimp production sector and its linkage to the world shrimp commodity system sector.

The structure for growth of inland farm production is similar to the structure for mangrove farms. The ecosystem feedback structure, however, is somewhat different. Carrying capacity is affected by intensity and ecological footprint as in the Thai mangrove shrimp production sector. However, conversion to shrimp farms does not impact carrying capacity since farm conversion does not involve the clearing of mangroves. Still, the carrying capacity is influenced by the mangrove stock, and by crowding of mangrove shrimp farms modelled in the Thai mangrove shrimp production sector. Inland farmers acting in their personal best interest respond to environmental pressures in ways that foster sustainability. In the inland sector farms are not abandoned. When yields decline due to environmental degradation and disease outbreaks, inland farmers scale back their farming intensity in order to decrease the volume of water intake and the likelihood of contamination (Huitric et al 2002). This also decreases wastewater output and thereby decreases the ecological footprint. The balancing feedback loop *"de-intensifying"* adjusts intensity in line with the carrying capacity and helps to sustain production. If yields fall to the point where expected profits are no longer attractive, inland shrimp farmers will convert to other land uses and conversion of coastal inland to shrimp farms will cease.

Base simulation

Figure 7 shows the dynamic behaviour resulting from the model structure described above. The model is simulated in time increments of years over a time horizon of 100 years. DT is set to .125. The model is set into an initial equilibrium. At time 5 a step function is used to mimic implementation of initial investments in Thai shrimp farming in mangrove and inland sectors. Also at time 5 another step function is used to increase shrimp consumption, mimicking growing international demand for shrimp.

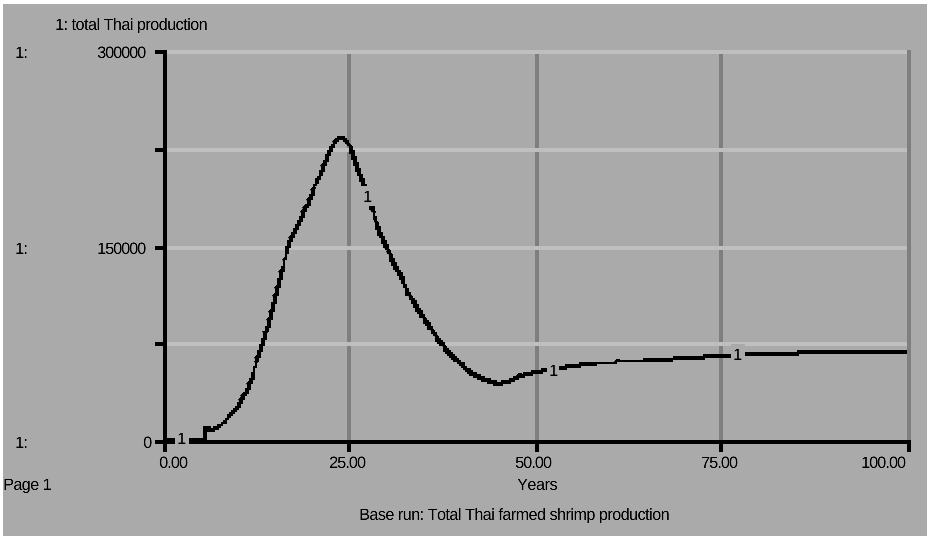

Figure 7. Base run simulation. Total Thai shrimp aquaculture production (metric tons)

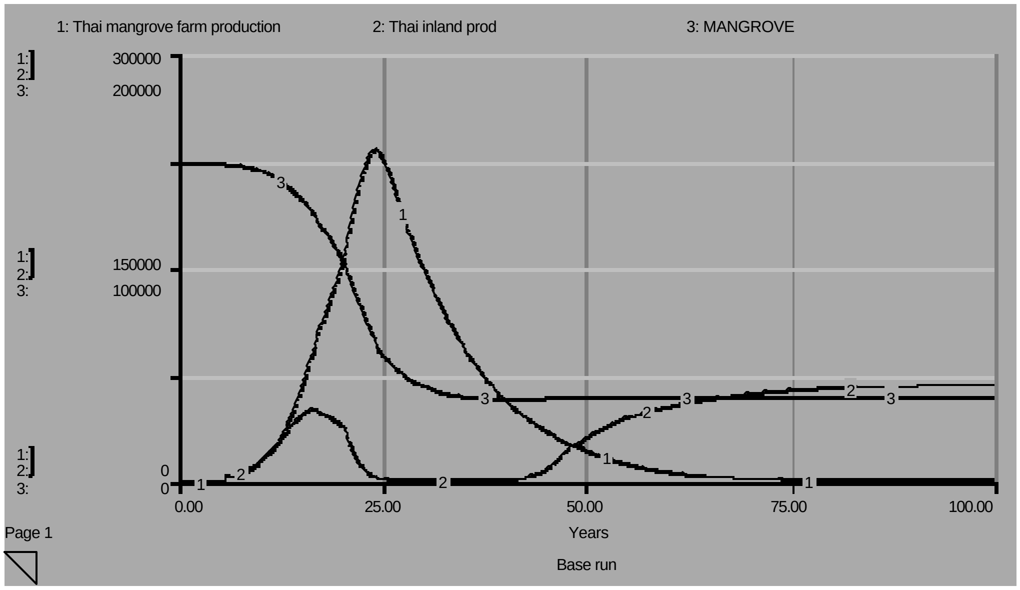

Figure 8. Base simulation. Time path 1 = mangrove shrimp production metric tons); 2 = inland shrimp production (metric tons); 3 = mangrove stock (hectares).

In the base run simulation shown in Figure 7, the pattern of growth and decline of total Thai shrimp production corresponds well with the historical pattern shown in Figure 1, lending us a degree of confidence in our model structure.

Figure 8 shows the base run behaviour of Thai mangrove shrimp production (time path 1), inland shrimp production (time path 2) and the mangrove stock (time path 3). Mangrove farm production grows exponentially while mangroves are plentiful and appropriation costs low. However, the ecosystem's carrying capacity is quickly exceeded as intensive shrimp farms replace mangroves. The initial growth of inland production corresponds closely with mangrove production but quickly peaks and declines steeply due to dropping yields caused by the crowding of intensive mangrove farms. As mangroves are depleted and the ecosystem's carrying capacity diminishes, mangrove farm lifetime shortens, the abandonment rate increases, and production plummets. Increasing mangrove appropriation costs prevents new mangrove farm start-ups and some areas of intact mangrove are thereby preserved. Based on the ecological services provided by the remaining stock of mangroves, inland farmers are able to increase their production. As the carrying capacity for inland farming is approached, farmers downscale their farming intensity and are able to sustain production in balance with the ecosystem's carrying capacity. Inland farm start-ups cease when expected returns from shrimp farming are equal to returns from alternative land use. The final level of sustainable inland production is determined by the extent to which the mangrove ecosystem is preserved.

Policy simulations

As discussed in earlier sections prescriptive policies such as bans on shrimp farming in certain areas or requirements that wastewater be treated before release have not proven effective in regulating the shrimp farming industry in Thailand. We suggest that market incentives through taxes and rebates may provide a more effective means of regulating the industry.

Export tax on shrimp

Export taxes on Thai shrimp exports have been proposed by MIDAS (1995) and Arquitt (1995). In Thailand over 90 percent of shrimp production is for export markets. The export tax policy operates under the key assumption that the tax would be passed down from export merchants to producers. The idea is that the tax would force some of the externalised costs of production onto producers and would thereby slow the rate of ecosystem exploitation.

Figure 9 shows the simulation results when a 10 percent export tax is placed on shrimp exports, implemented at time 10.

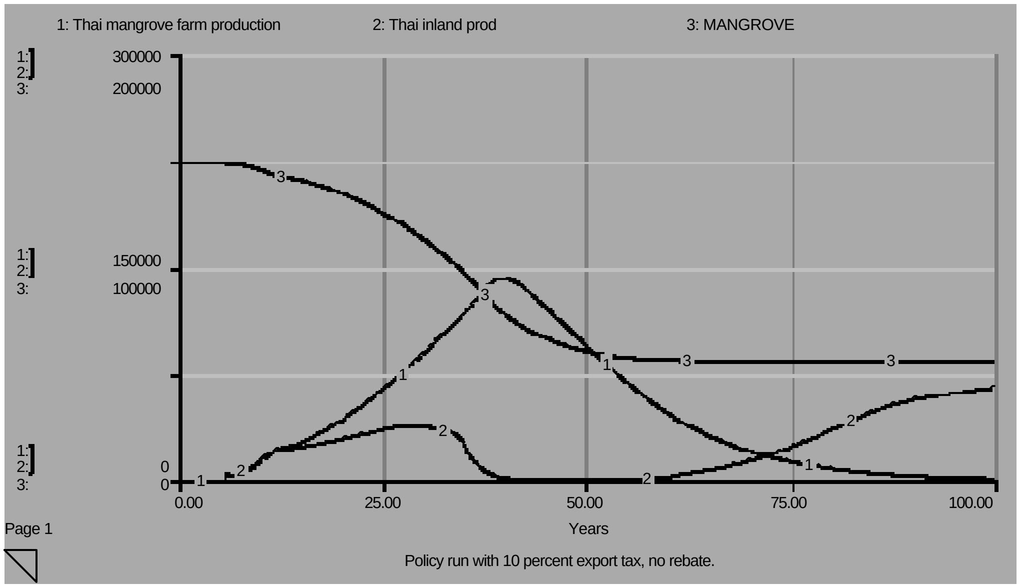

Figure 9. Simulation of export tax policy, implemented at time 10. Time path 1=Thai mangrove shrimp production (metric tons), time path 2= Thai inland shrimp production (metric tons), time path 3=mangrove stock (hectares).

The export tax slows the rate of mangrove exploitation because expected profits are less attractive. Still, by time 75 mangrove cover has been reduced by over 50 percent. The growth of shrimp production is slowed but is still not sustainable because the decision rules of mangrove producers remain unaltered. Inland producers whose decision rules foster sustainability are taxed at the same rate. Inland production increases to a sustainable level after collapse of mangrove farm production, however approximately 25 years later than in the base simulation (figure 8). The export tax slows resource exploitation but does not conserve mangrove resources or sustain production.

Feebate policy

The results of the base simulation imply that it is desirable to halt shrimp farming within the mangrove areas and to preserve mangrove resources to sustain inland shrimp production. A means of accomplishing this might be to place a tax on mangrove shrimp farmers while not taxing inland farmers. This, however, appears to be impracticable owning to the fact that many mangrove shrimp farmers are operating illegally. We suggest that a form of feebate may be a more workable solution. The feebate program would assess an export tax on the shrimp aquaculture industry and refund the forthcoming revenues to inland producers. As with the export tax described above a key assumption is that the cost of the tax is passed down from export merchants to producers. Then the revenues are refunded to registered producers who are operating in areas deemed suitable for shrimp farming.

Figure 10 shows the simulation results when this feebate policy is put into place at time 10. The feebate involves a 20 percent tax on exports and rebate of the tax revenues to inland producers. We assume that 10 percent of the tax revenue is allotted to administrative costs and that there is a one-year delay before the rebate is reallocated.

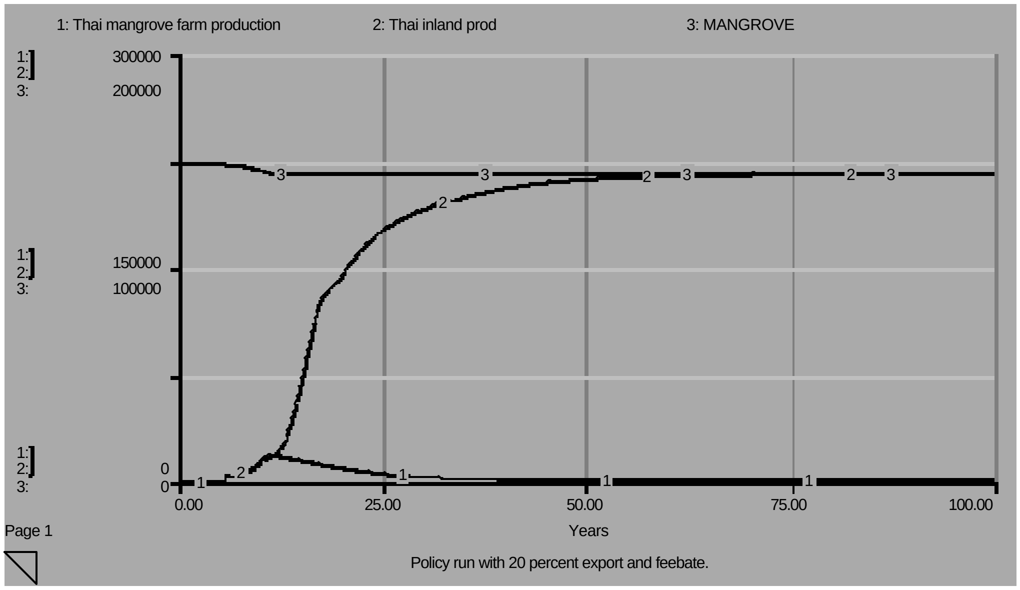

Figure 10. Simulation of feebate policy implemented at time 10. Time path 1=Thai mangrove shrimp production, time path 2=Thai inland shrimp production, time path 3=mangrove stock (hectares).

At time approximately 10, mangrove shrimp production abruptly halts its increase and begins to decline exponentially. Inland production increases sharply, reflecting its costs advantage under the feebate policy. Mangrove conversion halts because the lower price associated with the export tax is inadequate to attract new mangrove shrimp farmers. Based on the ecosystem services of the intact mangroves, inland farmers are able to attain a sustainable level of production similar in volume to the peak of mangrove production in the base simulation.

The simulation below is a sensitivity analysis of a range of percentage values for the tax. In the simulation we compare the effects of varying tax rates on mangrove exploitation.

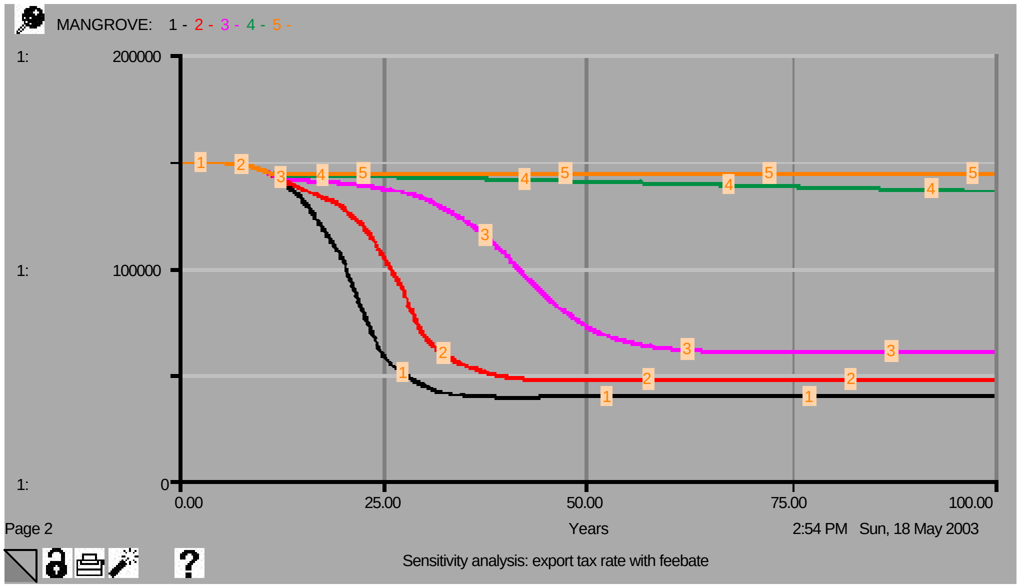

Figure 11. Sensitivity analysis of mangrove stock (in hectares) to taxation with feebate. Time path 1=no tax, 2= 5 percent, time path 3= 10 percent, 4=15 percent, 5=20 percent.

Figure 11 indicates that mangrove exploitation is sensitive to taxation. Only when the tax is significant enough to give a clear cost advantage to the inland producers is the feebate effective. It follows that determinations of the level of appropriate taxation with feebates should carefully consider relative costs of production for both categories of shrimp farmers. Information on shrimp farming production costs is scant (Shang, Leung, and Ling 1998). Comparative production costs for mangrove and inland shrimp farmers will be an important line of investigation for effective implementation of a feebate policy.

Conclusion

The simulation results shown in figures 9 and 10 indicate that a feebate policy may promote sustainable development of the shrimp farming industry and conserve renewable resources, if the associated tax (i.e., the "fee") is adequate to give a clear cost advantage to producers with property rights and decision rules favouring long term benefits. Our model, however, does not consider the institutional challenges of implementing the feebate program. Some of these challenges are related to key assumptions underlying the feebate policy that we have modelled. Important assumptions for investigation are:

The system is taxable. We assume that exports are registered with government authorities and, hence, can be identified for taxation. Threats that would have to be assessed include the possibility that producers could turn to value-added shrimp products and escape taxation, or that exporters would turn to the domestic market.

The export tax is passed down to producers. This would depend on the relative bargaining power of the producers and the export merchants.

The sustainable producers can be identified. An official licensing or registration system for shrimp farms would be required. Thai government regulations now require that all shrimp farmers be registered. Registered shrimp farmers have to meet requirements in terms of farm location.

The feebate beneficiaries believe that they will receive the rebate. Assessing farmers' belief that they will actually receive the rebate is central to determining feasibility of the program.

Without doubt the institutional challenges of implementing a feebate program are considerable, and we are not aware of any attempts, successful or otherwise, to implement a feebate program to manage the sustainability of a commodity system. However, the environmental and social costs of the shrimp farming industry have been enormous, and prescriptive policies have not proven successful in regulating the industry. We believe that feebate policies may offer an effectual alternative, and suggest that the feasibility of feebate policies for the shrimp farming industry or similar systems would be a timely line of research.

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