An application of Saeed's environmental mitigation banking model: restoring coastal mangroves in Thailand

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Abstract

In this paper we describe a system dynamics model developed to examine the feasibility of an environmental restoration banking system. Under this proposed system credits are issued by a governing authority to a restoration bank in return for undertaking environmental restorations. Users of the environmental resource are then required to purchase these restoration credits. A case study was developed for restoration of coastal mangrove forests in Thailand. Model simulations show that the restoration banking system may be effective in restoring coastal mangroves and in rehabilitating the coastal shrimp farming industry which is dependent on environmental services provided by the mangrove stock.

Key words: Shrimp farming, mangroves, sustainability, mitigation banking, restoration, system dynamics

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A recent paper by Saeed (2004) presents a system dynamics model developed to facilitate design of effective environmental mitigation banking institutions. Mitigation banks receive credits from an issuing authority in return for restoring depleted natural resources, such as wetlands or forests, to ecological functionality. Restoration credits are then bought by economic enterprises to fulfil legal obligations to restore environmental assets damaged by construction or operation of the enterprise. Under an ideal version of this arrangement net environmental damage is zero because environmental damage is balanced by equal restoration. The current paper describes an effort to adopt the principles of Saeed's mitigation banking model to a specific case, the restoration of coastal mangrove forests in Thailand which have been cleared in large part by expansion of the commercial shrimp farming industry. We will use the term "restoration banking" rather than "mitigation banking" because our objective is restoration of depleted environmental resources over and above current rates of consumption.

"Mangrove" refers to a tropical coastal ecosystem type that is alternately inundated and exposed by tides and dominated by species of salt tolerant trees (Hogarth 2002). The precise area of damaged or depleted mangrove in Thailand is not known but is generally believed to be extensive (Barbier and Cox 2004). Historically mangroves were usually regarded as wastelands in need of "reclamation." It is now widely recognized that mangroves are a unique ecotype providing an abundance of essential natural services. Mangroves provide habitat and nursery grounds for many marine species important for the maintenance of fisheries and biodiversity. In developing countries rural populations depend on mangroves as a source of food and fuel. Mangroves prevent coastal erosion and serve as natural filters maintaining water quality by regulating suspended sediments and nutrients in surrounding waters. Another important service is shoreline protection from storms and high-energy wave events, which has been tragically demonstrated by the tsunami disaster of December 2004. A recent study by Dhadouh-Guebas et al. (2005) compares damage caused by the tsunami in areas with intact mangrove forest with area where mangroves had been cleared or heavily degraded. The authors conclude that mangroves play a crucial role in protection against ocean surges, and strongly make a case for restoration and protection of mangroves.

Mangrove restoration projects undertaken in Thailand and other countries have typically taken the form of publicly funded development projects. Szuster (2003) reports that these projects in Thailand have been implemented on a small scale and have made little progress toward restoring degraded areas. The proposed restoration banking policy is an institutional arrangement that links the environmental resource with economic activities that use the resource, thereby securing a lasting source of funds for restorations.

Problem description: Mangroves and shrimp farming in Thailand

In the mid 1980s the global shrimp aquaculture industry began a period of remarkable growth driven by growing international demand for shrimp and stagnating catches of wild shrimp (Csavas 1995). In Thailand investors seized on the opportunity and rapidly transformed thousands of hectares of coastline into shrimp ponds. By the mid 1990s Thailand had become the world's leading producer and exporter of farmed shrimp generating some US$2 billion in foreign exchange in 2000 (FAO 2002). Shrimp ponds were constructed within mangrove forests as well as on areas above the intertidal zone directly adjacent to mangroves. During this period Thailand lost roughly half of its extensive mangrove forest, and it is estimated by some researchers that half of the loss was caused by clearance for expansion of the shrimp farming industry (Barbier and Cox 2004). Other pressures on mangroves include cutting for timber and charcoal production, and clearance for industrial developments.

The shrimp farming industry is both highly pollutive and strongly dependent on abundant supplies of clean intake water. Mangroves function as natural capital for the industry by assimilating shrimp farm waste, and are a vital constituent of the environmental carrying capacity for coastal shrimp farming. If the industry outstrips the carrying capacity over a region organic wastes accumulate and production crashes can occur due to the effects of pollution and shrimp diseases that become epidemic under polluted conditions. Huitric et al. (2002) have documented sequential production crashes in Thailand in which the industry has migrated from one coastal region to another after depleting mangrove stocks. As the industry has shifted from one region to another large areas of denuded mangroves and abandoned shrimp ponds have accumulated. In 1991 the Thai Fisheries Act enacted a ban on all shrimp farming within mangrove areas and prohibited loans for farms in mangroves. The rate of mangrove clearance now appears to be greatly reduced due to risks of penalties for encroaching on mangrove areas, and to the growing awareness that mangrove soils are poorly suited for shrimp farming. Unfortunately regeneration of depleted mangrove areas has been insignificant to date. Regeneration on former shrimp farm areas usually cannot occur without human intervention because of alternations to coastal hydrology due to shrimp pond dikes and canals (Barbier and Cox 2004); and to date restoration projects have been undertaken only on a small scale with unproven results (Szuster 2004).

Due to the growing difficulty of obtaining clean intake water in coastal areas a large fraction of the shrimp farming industry has relocated to interior regions of central Thailand, relying on seawater brought in by truck and special rearing techniques to acclimate farmed shrimp to lower salt concentrations (Flaherty et al. 1999). The available production figures from Thailand do not distinguish between inland and coastal production, based on figures from Flaterty et al. (1999) and Szuster (2003) it can be roughly estimated that about half of Thai shrimp production occurs in the interior. However, problems with pollution of irrigation canals and inland waters, salinization of surrounding land, and conflicts with neighbouring rice and fruit farmers have prompted the Government of Thailand to place a ban on interior shrimp farming (Szuster 2003). The ban is controversial and thus far enforcement has been lax (Szuster 2003). It appears now that the future success of the Thai shrimp farming industry will depend on the adoption of less environmentally damaging farming practices and on the restoration of coastal ecosystems.

To summarize the problem: expansion of shrimp farming has damaged mangroves over wide areas. The loss of mangroves has in turn significantly undermined the environmental sustainability of the shrimp farming industry in coastal areas. Strong demand for shrimp has prompted relocation of shrimp farms to interior regions; however inland shrimp farming has proven to be fraught with social conflicts and environmental problems of its own. Arquitt et al. (2005) developed a system dynamics model to investigate the dynamics of coastal shrimp farming collapse. The authors proposed a tax and rebate policy for mangrove protection and shrimp farming sustainability. The policy, however, was pre-emptive in nature. Perhaps more pertinent today is the need for policies to regenerate already damaged coastal resources and encourage sustainable production modes. That is the purpose of the proposed restoration banking policy.

Departures from the Saeed model

Saeed's mitigation banking model provided the inspiration and foundation for the current study. There are, however, a number of significant departures from Saeed's model. A discussion of these will shed light on the assumptions and purposes of the current model.

1. The environmental goal of Saeed's model is "no net loss" of ecological resources. This in fact is the goal of mitigation banking as normally practised. The current restoration model seeks to restore extensive areas of depleted resources, and by doing so increase the carrying capacity for economic activity.
2. In Saeed's model there is no direct feedback from the environmental stock to the economic enterprise. In base run mode economic growth continues even as the ecosystem stock decays. This assumption is appropriate for the infrastructural enterprises considered in Saeed's model. The current model focuses on shrimp farming, which is an environmentally sensitive industry; there is, therefore, direct feedback from the environmental to the economic activity.
3. Saeed's model does not consider challenges associated with initial implementation of mitigation banking. Rather, Saeed compares the performances of fully implemented mitigation institutions under a wide range of regulatory and pricing assumptions in order to facilitate design of effective mitigation banking systems. The current model, as a localized practical application of Saeed's generic model, does consider challenges associated with start-up of restoration banking.
4. In Saeed's model the economic enterprises causing environmental damage purchase mitigation credits. This is the case with current real-world mitigation banking practise. In the current model however, this is not the case. It is estimated that there are over 20,000 shrimp farms in Thailand (Barbier and Cox 2004). Many farms operate without permits or outside of zoning regulations. The enforcement of requirements for farmers to purchase restoration credits would be clearly impracticable. In the current model the trading companies who buy shrimp to process and export or sell domestically are required to purchase restoration credits based on volume of shipments. The model assumes that the cost of the credits is then deducted from the prices farmers receive for their produce. There are far fewer shrimp processors than

farmers, potentially making monitoring and enforcement a much more tenable proposition.

Model structure and behaviour

The organization of the model subsystems ("sectors") is presented below along with discussions of key assumptions in each sector. Model behaviour modes are exhibited in simulated time paths of key variables of interest. Model parameters and initial values are based on values obtained from the literature and on consultations with experts. In instances where no values could be obtained from these sources we have relied on intuitive estimates. The fully documented model developed in Vensim Professional Version 5.4 is available upon request from the author.

Base model

The base model offers an explanation of the "business as usual" scenario of coastal shrimp farming in Thailand. Five interacting model sectors have been developed, the Coastal and Inland shrimp production sectors, the Thai shrimp trading sector, the World shrimp market sector, the Mangrove sector, and the Eco-footprint sector, represented by circles in Figure 1. The labelled arrows indicate the key information and material flows operating between the sectors. Key feedback loops operating between the sectors have been labelled and are further indicated by darkened arrows.

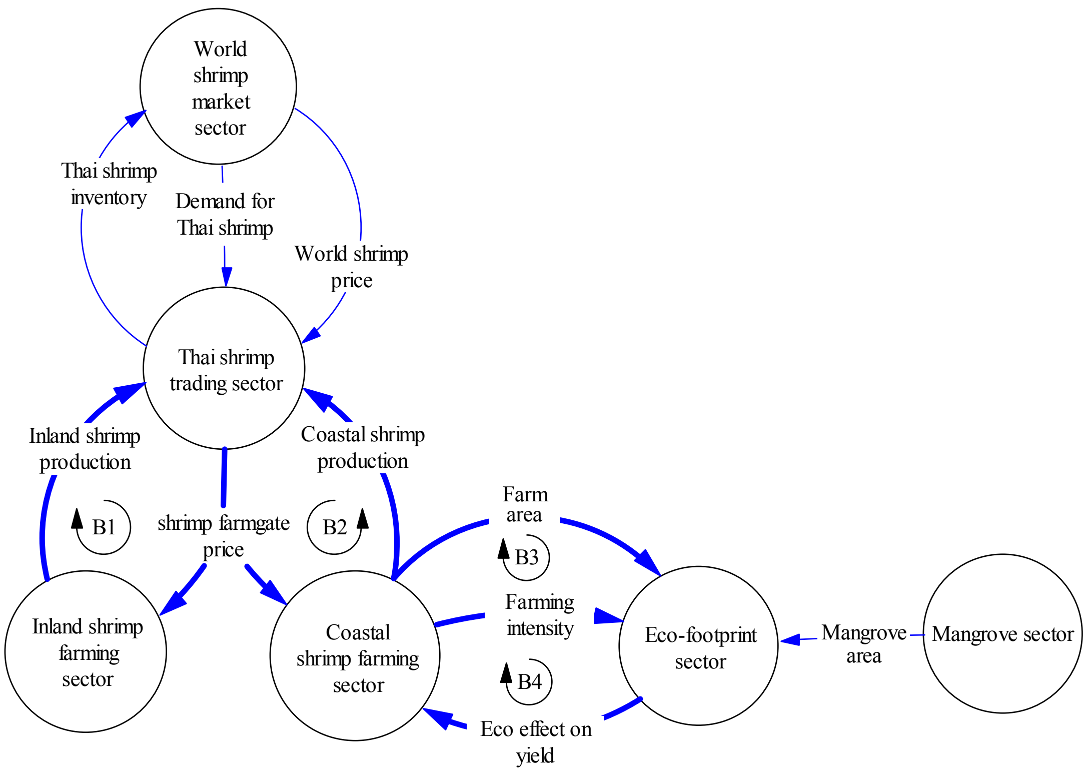


Figure 1. Sector structure of base model.

The *Coastal shrimp production sector* is based on dynamic commodity modelling structures described by Sterman (2000). Shrimp farm area expands or contracts exponentially in response to investors' expectations of future profitability, formulated in this model as expected profit divided by expected revenue. A supply chain structure captures delays associated with planning, farm construction, and decommissioning.

Farming intensity, a measure of the degree of usage of variable inputs such as feed, water treatment chemicals, and shrimp hatchlings, is adjusted on the basis of the mark-up ratio, formulated as expected revenue divided by expected variable costs. Yield is a function of farming intensity and is impacted by ecological effect. It follows that coastal shrimp farmers' decisions to expand or contract farm area and adjust farming intensity are influenced by the ecological effect because it influences yields and, consequently, expected revenues. Parameters such as fixed and variable cost, yield, and price are based on values found in the literature (Rosenberry 2004, Shang et al. 1998). It is assumed that coastal shrimp farms are located in areas adjoining but not directly in mangroves. These are the areas considered ideal for shrimp farm operations.

The *Inland shrimp farming sector* is identical in structure and parameterization to the coastal production sector with two exceptions. First we assume that the yields of interior farms are not impacted by the state of the coastal environment. Second we assume that production costs are higher than for coastal production, in particular related to the need to truck in seawater to inland regions (Szuster 2003).

In the *Shrimp trading sector* the farmgate shrimp price is adjusted to an indicated price that maintains inventory coverage at a desired level. The indicated price is the product of a reference price and the effect of inventory coverage. The reference farmgate price is the world price for shrimp minus traders' desired margin.

The *World shrimp market sector* was put in place to model the world price for shrimp and demand for Thai shrimp. The sector contains stocks representing global shrimp demand, world shrimp production excluding Thailand, and world shrimp inventory excluding Thailand. The world shrimp price is influenced by the effects of Thai inventory coverage and rest of world inventory coverage, each inventory coverage effect weighted by market share which is proxied by the respective fraction of total world inventories. Demands for Thai shrimp and rest of world shrimp are the products of world demand and respective market shares.

The *Eco-footprint sector* models the interaction between coastal shrimp production and the mangrove stock, which serves as the natural capital base. The sector draws on research by Kautsky et al. (2000) and Rönnbäck (1999) that quantifies the area of functional mangrove required to assimilate shrimp farm waste and sustain shrimp production. This area is considered the shrimp farm's ecological footprint and is directly related to farming intensity. In our model the eco-footprint is an aggregated footprint of the coastal shrimp farming industry and is therefore a function of coastal shrimp farm area and farming intensity. When the footprint increases beyond the mangrove area, the rate of waste production rises above the assimilation rate and organic pollution levels increase. Yields of coastal farms are then adversely impacted by the pollution and by increased incidence of shrimp disease associated with the pollution. It should be noted that coastal shrimp farms are located within or in the vicinity of other eco-types, for example tidal flats. In these cases the eco-footprint is likely to differ, but the principle can still be applied. Mangrove, however is the principal eco-type found in tropical coastal shrimp farming areas.

The *Mangrove sector* contains stocks representing the areas of functional and degraded mangrove. In the base simulation these stocks remain in static equilibrium.

A key assumption is that the mangroves are effectively protected, i.e., no mangrove area is cleared for shrimp farms or other developments.

Base model behaviour

The model is simulated over a time horizon of 50 years. Figure 2 shows time paths representing the area of functional mangrove, and coastal, inland and total shrimp production for Thailand. The model is set in an initial equilibrium. The equilibrium values for shrimp production and mangrove area roughly correspond with available estimates of current amounts.

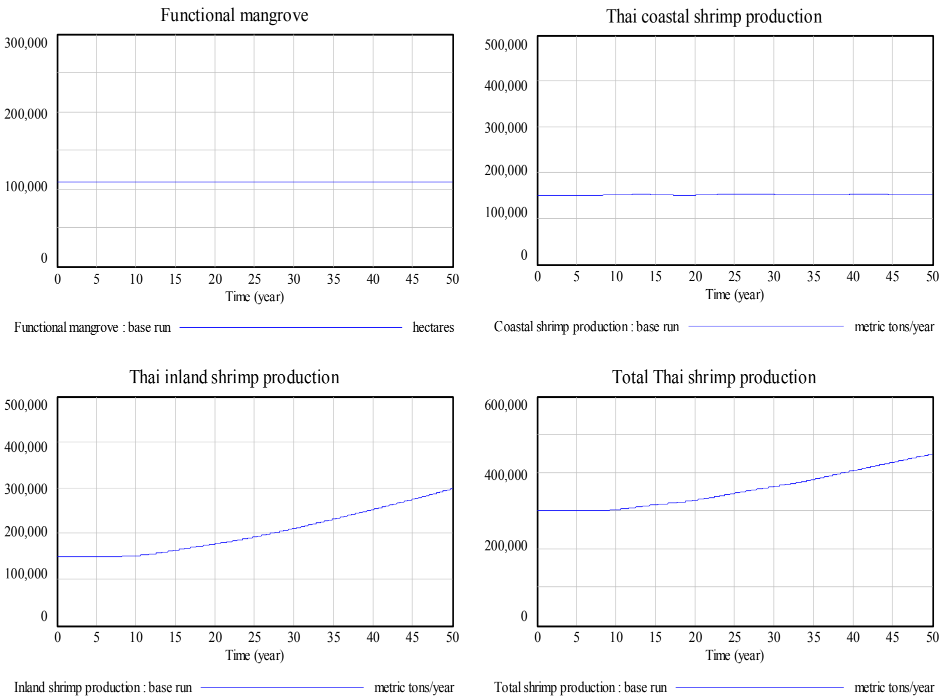


Figure 2. Base simulation. Time paths represent functional mangrove area (hectares); coastal, inland, and total shrimp production for Thailand (metric tons per year).

At time 5 years the equilibrium is disturbed with a ramp function that increases the reference world demand for shrimp by one percent per year, reflecting a growing population of shrimp consumers and increasing per caput consumption of shrimp. The mangrove stock is assumed to be effectively protected and remains in static equilibrium. The increasing demand draws down Thai inventories and traders raise prices to increase inventories to desired levels (balancing feedbacks B1 and B2 in Figure 1.). Despite the higher farmgate price coastal farmers are unable to increase production because expanding farm area and raising intensity increases the eco-footprint and puts downward pressure on yields (feedbacks B3 and B4 in Figure 1.). Inland farmers, unconstrained by the state of the coastal environment, are able to respond to the higher prices and increase their production through farm area expansion and intensification.

Restoration banking model

The restoration banking policy seeks to restore depleted mangrove resources, and by doing so, rehabilitate an environmentally sustainable coastal shrimp farming industry.

The restoration banking model adds two additional sectors to the base model as shown in Figure 3. Also the structure of the mangrove and shrimp trading sectors is expanded.

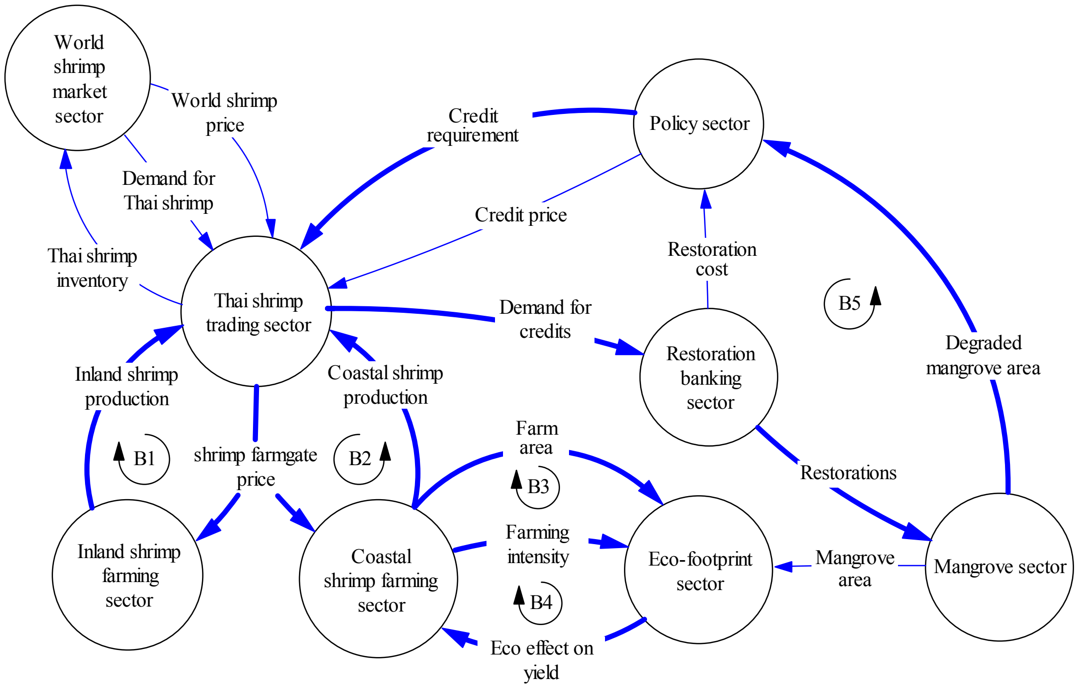


Figure 3. Sector structure of restoration banking model.

The *Policy sector* mimics the perceptions and actions of agents who monitor the stock of degraded mangrove and set yearly restoration credit requirements which shrimp trading companies must purchase. As the stock of degraded mangrove is depleted the credit requirement is gradually reduced. The policy sector also sets the price for restoration credits based on estimated restoration costs. Estimations of degraded mangrove stocks and restoration costs would involve significant updating delays in the real world; these delays are accounted for with exponential smoothing functions.

The *Restoration banking sector* mimics decision making processes of the restoration banking company. The essence of these rules is to maintain balances of cash and restoration credits at desired levels. Cash is accumulated through the sale of restoration credits at the credit price set in the policy sector. The volume of credits sold equals the demand from the Thai shrimp trading sector. Credits may be *earned* credits which the restoration banking company acquires upon completion of restorations, or *advance* credits which must be settled by future restorations. Advance credits are sold only when earned credits are unavailable. The advance credits are necessary because: (1) start-up of restoration banking would otherwise require a large initial subsidy of operating cash and/or restoration credits, and (2) unavailability of credits could lead to non-compliance and abrupt failure of the restoration banking system. To provide incentive to settle advance credits promptly, a fraction of the sales proceeds is deducted at the time of sale which is then credited to the restoration bank when the advance credit is settled by completing restorations. The cash balance is drained by overhead expenditures and restoration expenditures. We assume that scale economies reduce unit restoration costs via a learning curve effect. However, restoration costs are driven upward as the stock of degraded mangrove is nearly depleted, on the assumption that the most difficult areas to restore will be targeted last. The balance of earned credits accrues through completing restorations and is drained through sales of earned credits. The restoration bank's desired rate of credit acquisition is set by the gap between the desired balance of earned credits and the actual balance plus recognized total credit sales and is influenced by cash availability. The desired credit balance is assumed to equal one year of recognized credit sales.

The *Thai shrimp trading sector* in the policy model has been expanded to track the balance of credits held by traders and generates the demand for credits. Traders' credits are acquired through purchase from the restoration bank. Credit usage is the current credit requirement multiplied by the shrimp shipment rate. Traders' demand for credits adjusts to maintain the credit balance at a desired level. The cost of acquiring credits is added to the traders' desired margin and thereby transferred on to shrimp farmers.

The *Mangrove sector* in the restoration banking model closes the loop between degraded mangrove and functional mangrove by adding two stocks which track mangrove under management of the restoration bank and maturing mangrove. Initiation of mangrove restorations simultaneously decreases the degraded mangrove stock and increases the mangrove under management stock. We assume that newly planted mangroves remain under management for a period of five years after which the restoration bank is granted restoration credits. Mangroves then mature for another five years before becoming fully functional.

Behaviour of policy model

Figure 4 shows simulated time paths of functional mangrove and shrimp production when restoration banking is implemented at year five, and provides comparison with the base case. The behaviour is explained with reference to the linkages and feedbacks shown in Figure 3.

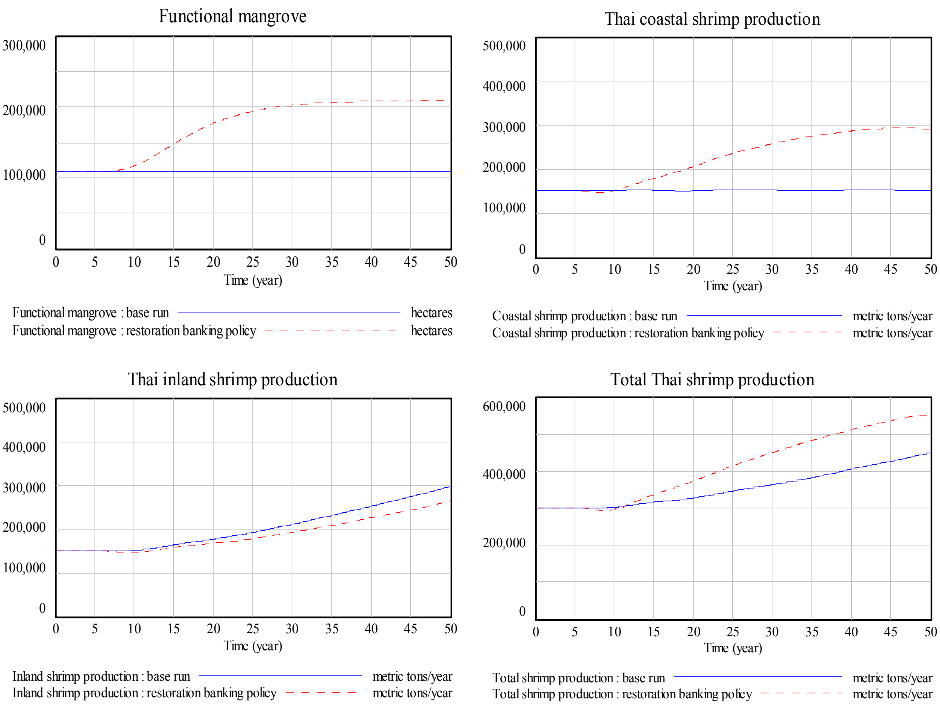
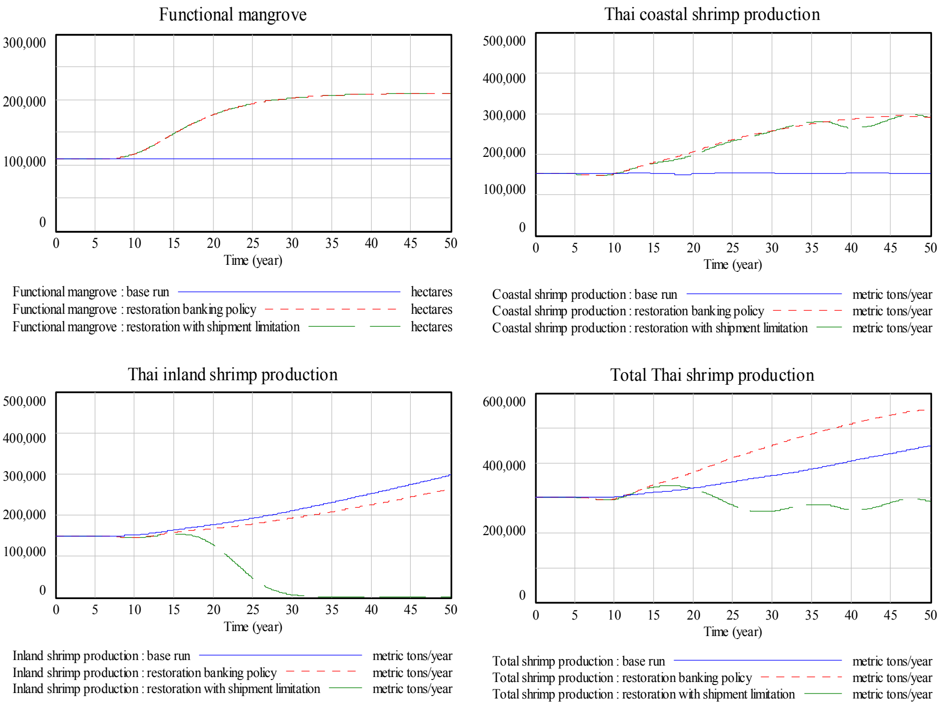


Figure 4. Simulation comparing restoration banking policy with base case. Time paths represent functional mangrove; coastal, inland, and total shrimp production.

At year 5 requirements to purchase credits are imposed on traders, generating demand for credits. The restoration bank responds by selling credits to traders and initiating restorations. Restoration initiations cause the stock of degraded mangrove to erode and the mangrove stock begins to grow exponentially as early stage restorations mature to functional mangrove. The mangrove stock is almost completely regenerated by year 30. Policy agents monitor the stock of degenerated mangrove; as the stock erodes the credit requirements are reduced, putting in place balancing feedback B5 in Figure 3. Shrimp traders pass on the cost of restoration credits to farmers putting downward pressure on farmgate prices. The downward pressure, however, is compensated for by growing demand for shrimp and inland farmers are able to expand production at almost the same rate as in the base case. Coastal farmers are now able to expand their production as well. As the stock of mangrove increases environmental pressure from the eco-footprint effect lessens, meaning that yields and profitability in the coastal shrimp farming sector increase. Coastal production peaks at around 300,000 metric tons at which point environmental limits bring profitability back to zero. The simulated policy is successful in that mangroves are restored and coastal shrimp production rehabilitated. However, the undesirable inland production continues to expand indefinitely.

In an attempt to discourage inland production while still regenerating mangroves and coastal shrimp production, a second round of policy simulations were conducted with a cap on the Thai shipping rate. Such a cap could be instituted through a licensing requirement or by limiting shrimp processing capacity. The cap was placed at 300,000 metric tons, the level of initial total production. Figure 5 shows the results and compares to the previous two simulations.



The pattern of mangrove regeneration is identical with the pattern under restoration banking alone. Coastal production exhibits a very similar pattern, however some oscillation is apparent when coastal production nears the cap. Inland production, however, declines and is near zero by year 30. The cap effectively insolates the Thai production system from the growing world demand for shrimp. When coastal production expands owing to mangrove restoration and improved yields, downward pressure is put on the farmgate price. Inland farmers are forced out of business due to their higher production costs and coastal production is able to quickly fill the void.

The restoration-banking and cap policy appears, in the virtual setting, to solve three interrelated problems: depleted mangroves are restored, stagnant coastal shrimp production is expanded, and undesirable inland shrimp production is greatly reduced and eventually eliminated. However, on closer inspection problems may still be present. In the simulations described above coastal shrimp production is limited by environmental feedback. It is reasonable to suspect that this environmental feedback may also adversely impact other coastal industries and resources. To reduce adverse environmental feedback in the present model the shrimp eco-footprint must be reduced relevant to the mangrove stock. This could be done by lowering the cap on shrimp shipments below the initial level of total shrimp production, a move that would probably not be acceptable to the shrimp industry. Even with restoration of mangroves and control of shrimp production through a cap on shipments technological improvements, in particular on-farm wastewater treatment, may be necessary for high levels of sustainable shrimp production.

Limitations

The model has additional limitations which in turn present opportunities for further investigations:

1. The model does not take into account costs to establish and maintain regulatory institutions. These institutions are necessary to monitor the status of environmental assets, mitigation banking activities, user compliance, and restoration costs; and to impose credit requirements on users. Future work could incorporate estimates of these costs into the model to more fully assess the practicability of restoration banking in particular settings.
2. Only the shrimp farming sector is assessed for mangrove restoration in the present model. In fact, other industries potentially benefit from mangrove restoration, for example, other forms of aquaculture, fisheries, and tourism, and could be included in future models.
3. The model assumes that credit prices are set by a policy-executing agency on the basis of perceived restoration cost. Delays associated with updating perceived costs are likely to be lengthy (Saeed 2004). Experiments with the model showed market determined prices to be extremely instable in the early stages of mitigation banking development. More study is needed to assess price-setting strategies, in particular during the transitional start-up phase of restoration bank development.
4. Successful policy for restoration of mangroves and rehabilitation of coastal shrimp farming is likely to involve a policy mix, perhaps including restoration banking, limitation of shrimp farm numbers through licensing and zoning, and promotion of improved production technology. Models examining the efficacy of policy mixes should be investigated for more realistic solutions.
5. Available estimates of shrimp yields and production volumes, production costs, etc. are scant and of questionable accuracy (Rosenberry 2004). Estimates of degraded mangrove lands available for restoration are largely anecdotal but obviously very influential on the success of the policies investigated here. If the policies investigated in this modeling study are to be seriously considered by policy makers these knowledge gaps must be addressed.

Summary and concluding comments

Simulation results in this study suggest that a variant of environmental mitigation banking, termed "restoration banking," may be an effective policy for restoring large areas of degraded ecological resources in the case study considered here. The model described here differs significantly from mitigation banking as currently practised in that the cost of restoration is passed indirectly down to the users of the environmental resources. Initiation of restoration banking presents serious challenges because of long lead times required to complete restorations and earn credits. In our modelling study we have found that sale of advance credits could be a viable means of initiating restoration banking, and that the system can gradually shift to exclusive sales of earned credits if requirements to settle advance credits quickly are in place.

Mangrove depletion and shrimp farming collapse are not unique to Thailand. Very similar scenarios have been witnessed in other shrimp production countries, for example in Indonesia, The Philippines, and Ecuador. A form of restoration banking similar to what is proposed in this study may have the potential to help rehabilitate coastal resources and aquaculture industries in these areas as well. However, mitigation and restoration banking are still in early stages of development and there are many unanswered questions regarding institutional and regulatory design.

Requirements for successful implementation are likely to vary case by case depending on the nature of the ecological resources and resource users. The mitigation banking model developed by Saeed (2004) and the work described in this paper demonstrate the value of experimental simulation in design considerations for mitigation banking-type institutions. We strongly advocate the use of systems modelling and simulation to inform design, and to encourage focused debate, before investments are made in real world mitigation or restoration institutions.

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