Farm permits and optimal shrimp management in Thailand: an integrated inter-temporal and spatial planning model

Anantha K Duraiappah and Adis Israngkura

Working Paper No 35

October 2000

International Institute for Environment and Development, London, and Institute for Environmental Studies, Amsterdam

Authors
Anantha Kumar Duraiappah is a Senior Research Economist at the Institute for Environmental Studies (IVM). Adis Israngkura is a Research Economist with the Natural Resource Division, Thailand Development Research Institute, Bangkok. They may be contacted at:

IVM
Vrije Universiteit
Boelelaan 1115
1081 HV Amsterdam
The Netherlands

Tel: +31 20 444 9524
Fax: +31 20 444 9553
Email:anantha@ivm.vu.nl

Thailand Development Research Institute
565 Soi Ramkhamhaeng 39 (Thepleela 1)
Ramkhamhaeng Road
Wanggthonglang, Bangkapi District
Bangkok 10310
Thailand

Tel: +66 2 718 5460
Fax: +66 2 718 5461
Email: adis@tdri.or.th

The programme of Collaborative Research in the Economics of Environment and Development (CREED) was established in 1993 as a joint initiative of the International Institute for Environment and Development (IIED), London, and the Institute for Environmental Studies (IVM), Amsterdam. The Secretariat for CREED is based at IIED in London. A Steering Committee is responsible for overall management and coordination of the CREED Programme.

Environmental Economics Programme, IIED

IIED is an independent, non-profit organisation which seeks to promote sustainable patterns of world development through research, training, policy studies, consensus building and public information. The Environmental Economics Programme is one of seven major programmes of IIED; it conducts economic research and policy analysis for improved management of natural resources and sustainable economic growth in the South.

Environmental Economics Programme
IIED, 3 Endsleigh Street
London WC1H 0DD, UK
Tel +44 (0)20 7388 2117; Fax +44 (0)20 7388 2826
e-mail: Jacqueline.Saunders@iied.org

Institute for Environmental Studies, (IVM)

IVM is a non-profit research institute, based at Vrije Universiteit, Amsterdam. The Institute's primary objective is to carry out multi- and interdisciplinary research on environmental issues, based on cross-fertilisation of monodisciplinary sciences. Environment and the Third World is one of eight major IVM research programmes.

IVM, Vrije Universiteit
De Boelelaan 1115
1081 HV Amsterdam
The Netherlands
Tel: +31 20 444 9555; Fax: +31 20 444 9553
e-mail:secr@ivm.vu.nl

CREED Steering Committee members include:

Abstracts of CREED publications and details of all CREED projects are now available on the Internet. Visit the CREED Web site at:

http://www.iied.org/creed

Acknowledgements

We would like to thank Mike Philips and S. Tookwinas for their comments on earlier drafts of the paper. We are also indebted to the three anonymous referees for their suggestions and support in reworking the original manuscript.

Abstract

Shrimp production in Thailand is characterised by boom and bust cycles. The busts are caused by production crashes as a result primarily, of disease outbreaks. A primary factor linked with disease outbreaks is poor water quality, which in turn is a result of management strategies on shrimp farms. The major focus of existing studies has been at the farm level. We suggest that although farm management is a critical variable in determining sustainability for the sector, farm density plays an equally important role. In this paper, we address both factors. We begin by identifying the optimal combination of farm strategies. Once the farm management options have been identified, the optimal farm densities for three principal shrimp farming regions are computed. Spatial variation in the form of soil differences is taken into account in the analysis. Preliminary results suggest that water management and farm density are the two most critical variables determining sector sustainability.

Abrégé

L'astaciculture thaïlandaise se caractérise par des cycles de croissance rapide et effondrement. Les effondrements sont dus à des chutes brutales de production, causées par des épidémies frappant les crevettes. La mauvaise qualité de l'eau, un des premiers facteurs de ces épidémies, est elle-même le produit des stratégies de gestion des exploitations astacicoles. Les études dont on dispose à ce jour ont surtout porté sur des élevages individuels. Nous suggérons que bien que la gestion des exploitations constitue une variable cruciale dans la détermination de la durabilité de ce secteur, leur densité joue un rôle tout aussi important. Dans ce texte, nous traitons ces deux facteurs. Pour commencer, nous identifions la combinaison optimale de stratégies d'exploitation. Ayant identifié les options de gestion d'élevage, nous calculons les densités d'élevage optimales pour trois grandes régions astacicoles de Thaïlande. La variation spatiale, sous forme de différences pédologiques, est prise en compte dans cette analyse. Les résultats préliminaires suggèrent que la gestion de l'eau et la densité des exploitations sont les variables les plus cruciales de la détermination de la durabilité du secteur.

Resumen

La producción de camarones en Tailandia se caracteriza por ciclos de auge y depresión. Las depresiones provienen de crisis en la producción, las cuales son a su vez, causadas por epidemias. Un factor primordial relacionado con las epidemias es la mala calidad del agua, la cual es un resultado de estrategias de gestión en los cultivos de camarones. En los estudios realizados se ha hecho énfasis a nivel de los cultivos. En ellos se sugiere que aunque la gestión de cultivos es una variable crítica en definir su sustentabilidad, la densidad en los cultivos juega un papel igualmente importante. En esta monografía se examinan ambos factores. Se comienza por identificar la combinación óptima de la estrategia de cultivos. Una vez que las opciones de gestión de cultivos se han identificado, se computan las densidades ideales para las tres principales zonas de cultivos en Tailandia. En este análisis se tiene en cuenta la variación espacial bajo la forma de diferencias en la tierra. Los resultados preliminares sugieren que la gestión de agua y densidad de cultivos son las dos variables más críticas en determinar la sustentabilidad de este sector.

Contents

Introduction

The Thai shrimp sector has grown over the last decade to become a major export earner for the Thai economy, accounting for 3.5% of total export revenue in 1996 (Patmasiriwat *et al.,* 1998). It presently accounts for 20% of the world trade in shrimps and Thailand is the world's leading exporter of the Black Tiger prawn (ibid). However, the industry has experienced many economic problems, and the associated socio-economic and environmental impacts of shrimp production give rise for concern.

The economic problems are related to the sustainability of the sector. The shrimp industry in Thailand suffered a series of booms and busts over the last 15 years. The first production crash came in 1990 when disease outbreaks wiped out approximately 90% of farms along the Inner Gulf of Thailand where the majority of farms were located (Patmasiriwat et. al, 1998). However, unlike the 1987 crash in Taiwan, farmers in Thailand were able to migrate and expand from the Gulf to the Southern coasts (Prachuab Khiri Khan, Surat Thani, Nakhon Si Thammarat) and then across to the Andaman Coast, as shown in Figure 1.

But land is a finite commodity and potentially a scarce resource. Indeed there are signs that increasing scarcity of land has already affected production. Production crashes caused by disease outbreaks along the South coast in 1996 resulted in a sharp decline in production (see Figure 2) compared to an earlier crash in 1990 which barely affected production. A continuing decline of production, if not addressed, will inevitably lead to the loss of valuable export revenues for the Thai economy; as well as a loss of livelihood for a large number of people involved in the shrimp sector.

There are strong linkages between the sector's deteriorating production record and environmental performance. One of the most heavily cited environmental problems attributed to shrimp production is mangrove forest destruction. However, the degree of the sector's contribution to the degradation of the mangroves is debatable. For example, a FAO/NACA report (1995) states that a large portion of mangrove lands used by shrimp farms was actually degraded mangrove lands. Moreover, Portoros (1995) and Paw (1991) found that only about 30 to 38% of mangroves destroyed could be attributed to shrimp farming. In 1996, a joint government study by the Departments of Fisheries, Royal Forests and Land Development, together with the National Research Council of Thailand, used remote sensing images to demonstrate that 30% of the country's mangrove forest has been lost to date; of this area approximately 31% was attributed to shrimp farming (Piamsak, 1996). We shall not focus on the mangrove issue in this paper but allow the possibility of analysing the impacts of mangrove destruction by capturing its benefits through the opportunity cost component we use in the model developed for this study.

Figure 1 here

Figure 2 here

There is less controversy about the problems of coastal pollution (Thongrak *et al.,* 1997; Tookwinas, 1995; Dierberg and Kiattisimkul, 1996; Midas Agronomics, 1995). In a majority of cases, shrimp farms dump their untreated water both during and especially after harvest directly into the common water canals which eventually flow into the coastal waters. The open access nature of the water use and exchange system leads to massive pollution of the coastal waters, and at rates that far exceed the natural systems' regenerative capacity. Both the shrimp sector and others dependent on coastal resources have suffered from this pollution. Ironically, the pollution caused by the shrimp farms has been cited as one of the principal causes of the frequent disease epidemics. Experts stress that if the sector is to be sustainable, then this pressing issue of water quality must be addressed.

Additional problems are caused through land salinisation. Abandoned shrimp farms have very little alternative agricultural use due to the high salinity levels in the soils. It usually takes about five to seven years before the land can be used again for other agricultural purposes. To make matters worse, the salinisation process from the farms is not localised. Intrusion by surface and sub-surface saltwater from the shrimp farms to adjoining lands forces many of the farmers working on these lands to abandon their farms.

Policymakers in Thailand have acknowledged both the importance of the sector as a source of revenue on the one hand, and the associated environmental and socio-economic problems on the other. Many policies have been drawn up to address the issues but to date they have had limited success (Dierberg and Kiattisimkul, 1996; Flaherty and Karnjanakesorn, 1994; Thongrak *et al.*, 1997). The majority of the policy responses have been regulatory in nature with very little attempt to use economic incentives. The main problem has been the inability to monitor and enforce the policies, primarily because of institutional and financial constraints (Flaherty and Karnjanakesorn, 1994). Philips argues that self-regulating mechanisms are needed whereby farmers have a personal interest in improving the sustainability of the sector (Thongrak *et al.*, 1997; Philips, personal communication).

In this paper, we direct our efforts towards finding a sustainable strategy for the sector and identifying some policy tools which will encourage sustainable farming practices. The results and policy recommendations put forward in this paper are undoubtedly dependent on the accuracy of the model. We should like to emphasise here that this model is still in its infancy with scope for improvement especially in the ecological module. Nevertheless, the model demonstrates a number of unique strengths and potential for guiding policymakers.

The paper is structured as follows. In section 2, the main building blocks of the model are presented (the detailed model is provided in appendix 1). In section 3, the dynamics underlying the model are presented. Results from a number of simulation exercises using the model are presented in section 4. In section 5, we discuss some of the policy implications of the results and we end the paper by providing a summary of the main findings together with a number of policy recommendations.

The Shrimp Integrated Assessment Model (SIAM)

The focus of many existing studies on the Thai shrimp sector has been at the farm level, especially on-farm management strategies and options to minimise deteriorating water quality (Funge-Smith and Briggs 1994, Dierberg and Kiattisimkul, 1996). For example, there have been numerous studies examining how various combinations of stocking densities, feeding strategies, water exchange systems and soil types of site locations have impacted on farm shrimp mortality rates (Briggs and Funge Smith, 1994; Dierberg and Kiattisimkul, 1996; Primavera, 1993). A related issue is the economic profitability of different management strategies and the economic consequences of failing to adopt any precautionary measures (Briggs and Funge-Smith, 1994; Funge-Smith and Aeron-Thomas, 1995; Thongrak *et al,* 1997). The information provided by these studies has been instrumental in guiding policymakers to formulate appropriate responses to the growing problems faced by the farms.

However, a unique characteristic of the shrimp sector makes it imperative that a sectoral approach be adopted. As mentioned earlier, the water use and exchange system practiced by the sector effectively operates on an open access basis, and rules governing its use are necessary if degradation is to be avoided. Both Dieberg-Kiattisimkul (1996) and Potaros (1995) emphasise the importance of using an integrated approach to land use and planning for the control and maintenance of water quality for the individual shrimp farms.

In order to fill this gap, we have developed a sectoral land and water use planning model for the shrimp sector. The model aims to answer the following key questions:

- Does the number or density of farms play a crucial role in making the sector sustainable? If yes, what is the optimal number or density within specific geographical boundaries?
- Which factors determine farm density, and which of these factors are dependent on natural properties and limits versus those regulated through management activities?
- What policy options should be used? Regulatory, economic incentives, or a combination of the two?

In the sections below we describe the three main building blocks that make up SIAM: the land use and exchange system; water use and exchange system; and the economic system.

Land use and exchange system

One of the critical elements in shrimp farming is the type of land used. When shrimp farming first started, many farmers sited their farms close to the coast to take advantage of the natural brackish conditions which, it turned out, were frequently mangrove lands. But mangroves normally grow on soils with hydrogen sulphide content which, when used for shrimp cultivation, can reduce growth and survival rates of the shrimps (Poernomo and Singh, 1982). Moreover, the softness of the soil in mangrove swamps makes pond preparation expensive and time consuming. The remedies are costly and have environmental repercussions themselves in the long run (Dierberg and Kiattisimkul, 1996). Soils further inland are normally non-acidic and provide a more appropriate environment for shrimp farming (M. Philips, pers. comm.), but as these sites are further away from the coast, additional costs are incurred for pumping in water from the sea. Clearly, an analysis of the trade-offs in locating ponds on various soil types is necessary before any decision can be made on preferred farm locations.

Abandoned shrimp farms are becoming an important issue. Many are not suitable for other agricultural activities and only seldom can they be used for non-agricultural purposes. Rehabilitating these lands is costly, time consuming and difficult. A cost-benefit analysis of the replacement costs should also be done before a decision to convert land for shrimp farming.

Water exchange

The importance of water quality for the sustainability of the sector is well documented (Tookvinas, 1996; Primavera, 1993; Funge-Smith and M.Briggs, 1994;Thongrak *et al,*, 1997). Although the degree of causality between water quality and shrimp disease and between water quality and farm productivity is debatable, there is unanimous agreement that there is a relationship between declining water quality, disease outbreaks and declining farm productivity.

The degree of control a farmer has over on-farm water quality is largely dependent on the choice of water exchange system used. In the case of a closed system, the farmer can, to a large extent, control the water quality during the grow-out period[1]. No exchange occurs with the common water channels and therefore there is no contamination from pollutants that may have been produced by other farms.

In the case of a semi-closed or open water exchange system where there is continuous contact with the common water system, the probability of exposure to disease-contaminated water is high. The choice of system is primarily influenced by cost. A closed system requires more land, as more ponds are needed for water storage and cleansing ponds, while an open system does not require this investment. Again, a decision on water systems requires an analysis of the trade-offs, similar to the one made for land use.

We now come to the water quality of the common water system. The deterioration of this water source has significant repercussions for the shrimp sector. Irrespective of the water exchange system used on farm, preventing the deterioration of the common water system is vital for the long-term sustainability of the shrimp sector. This is obvious the case for the semi-open and open water exchange systems, but it also holds for the closed system because sooner or later some form of water exchange needs to occur.

The critical factor which determines the overall loading of the common water system, is the amount of effluents which are disposed into the system. This is turn is dependent on a) the on-farm management strategies; b) the total number of shrimp farms; and c) the total effluent discharge by other users. In this paper, we model the first two and assume the third factor constant. It is beyond the scope of this paper to incorporate the dynamics of other sectors within the single framework developed for this study.

[1] Grow-out period is the time between sowing and harvesting.

Economic aspects

Revenues and costs form important components in the shrimp sector. It is no understatement to say that shrimp farming is a very lucrative business. High and quick returns on initial investments have been the driving forces behind the rapid adoption of shrimp farming (Primavera, 1991; Masae and Rakkheaw, 1992). However, the degree of profitability is closely related to the intensity of farming: the higher the intensity, the higher the profit margins of the newly established farms.

However, Primavera (1993) finds that, although intensive farms have a high rate of return, they have a high cost structure. Therefore, fluctuations in shrimp prices may cause profits to fall drastically and in many instances lead to negative returns. On the other hand, farms practicing extensive and semi-intensive farming strategies are less vulnerable to price fluctuations due to their lower cost structure which inevitably lowers their break-even points.

Because the sector is so sensitive to changes in costs and prices, it is imperative for policy makers to investigate how changes in any one of these two categories impact on the sector and the appropriate responses to cushion the detrimental effects. We do not attempt to find market-clearing prices for the sector. This would require us to model the demand side of the equilibrium equation, which is beyond the scope of this study. Instead we use exogenous prices and undertake a sensitivity analysis to investigate the changes in management strategies that occur in response to price changes.

Model Dynamics

In this study, we compare shrimp farming in three Thai provinces. Within each province, three different types of soil are considered. Next, we have the different farming techniques or processes, which we term management options. We use activity analysis in this study to compare and contrast discrete management strategies, which differ according to site specific and technological properties. An integral component of activity analysis is the 'technology' matrix, which describes the inputs and outputs for a range of management strategies.

In shrimp farming, one of the critical variables which differentiates management strategies is the stocking intensity. In this study we use the following intensity classification: high intensive ($100pl/m^2$)[2]; medium intensive ($75pl/m^2$); low intensive ($50pl/m^2$) high semi-intensive ($15pl/\ m^2$); medium-semi-intensive ($10pl/m^2$); and low semi-intensive ($5pl/m^2$). We exclude extensive farming as it is not used widely in Thailand and, due to its low profitability, is not a likely option. By making the distinction first, between intensive and semi-intensive and, second, within these two broad categories, we capture the differences in the following variables:

- stocking densities
- feeding strategies
- intensity of chemical use
- capital requirements
- labour use
- waste or sludge generation
- potential yield

The final dimension to be explicitly defined, is the water management option. We specify two options - a closed exchange and an open exchange. The different water management strategies allow us to capture three factors: land use and scarcity, the degree of interaction and inter-dependence among farms, and water quality.

The link in the model between management strategy and survival rates is a survival function for shrimps. As the knowledge on shrimp diseases is limited, a detailed disease module is beyond the capacity of this study. Instead, an econometric approach is adopted whereby data from a farm survey are used to estimate a reduced form survival rate function[3]. The survival rate is thus dependent on the variables that form the basis of the various management strategies. In this manner, we capture the trade-offs among management strategies and the respective survival rates. The survival rate is then used to adjust the potential yield to determine the final output level for each one of the farm management strategies used.

The objective of the exercise is to maximise the total discounted net benefits for the sector. The revenue stream comes from final shrimp production net of mortalities caused by diseases. The cost stream has two component: economic costs of production (direct cost), and environmental costs (indirect costs). The former is relatively straightforward and comprises, primarily, raw material input costs, labour costs and capital costs. Effluent disposal cost,

[2] pl stands for post larvae.
[3] The results from the econometric study are available in a forthcoming CREED working paper.

opportunity costs of abandoned land and the opportunity costs of land converted to shrimp farming are the three main items of the environmental cost.

In the optimisation procedure, an analysis of trade-off is carried out in which the cost and benefits of various combinations of farm management strategies and regional farm densities are evaluated. The combination, which produces the highest net benefit over a given time horizon, is then picked as the optimal sector design. The model is programmed in GAMS (General Algebraic Modeling System) and linear programming techniques are used to solve the constrained non-linear optimisation model developed for this study[4].

[4] The GAMS program is available at http://sites.netscape.net/aduraiappah/ The model is in the GAMS Models page.

Results

This paper reports the results from four modeling experiments. A point to keep in mind when interpreting the results is the optimality characteristics of the solution. The model solves for optimal solutions given the constraints specified in the model structure. It is, therefore, highly probable that we may get an optimal solution that may call for high rates of environmental degradation. We must also bear in mind that the results may or may not differ from the present status of the sector. In the case of the latter the challenge is to investigate why the sector is pursing its present unsustainable strategy, and to identify policy initiatives which will encourage a sustainable approach. And if the model produces results different from present practices, then the objective is to find reasons which explain the differences, and then go on to find policy instruments that will promote sustainability[5].

We call the first run Business As Usual (BAU) and will use it as the reference point when comparing subsequent simulations. The second experiment is called IEE for reasons, which will become apparent when we explain the characteristics of the simulation. The third and fourth experiments are sensitivity tests on the price of shrimps; and the opportunity cost of land.

Business As Usual (BAU)

Although there are official regulations governing the disposal of pond effluents, a majority of farmers do not adhere to them (Dierberg and Kiattisimkul, 1996). Moreover, these regulations apply only to farms greater than eight hectares. This in essence rules out 80% of the shrimp farms in Thailand as most of the farms range between 1 - 2 hectares (Tookwinas, 1996). In order to mimic this behaviour, we ran a scenario called BAU, in which environmental costs were excluded from the profit function.

We begin by looking at the farm techniques used and the total number of farms in operation. Figure 3 below clearly illustrates that in all three provinces, the open water system is the preferred. Dierberg and Kiattisimkul (1996) in their study on Thai shrimp farming support the observation that only in very rare instances did farmers use close-water exchange systems. An interesting result which emerges, is the choice of medium high intensive (75pL/m^2) stocking rates for the first seven crops after which the high-high intensive (100pl/m^2) option is also adopted. This particular choice of technique over the five-year period[6] demonstrates and supports the observed myopic behaviour of shrimp farmers (Thongrak *et al,*, 1997).

[5] Sustainable path in this study implies that a stable steady state for farm density is achieved.
[6] The time horizon used in the model is 5 years with a total of 10 crops. Farmers are normally able to get two crops a year. The model was limited to 5 years due to non-linearities that make it computationally difficult to find solutions to longer time periods at this point in time.

Figure 3 here

The model results seem to mimic farm behaviour, ie to maximise short-term profits by adopting high intensive stocking densities and allocating the maximum amount of land available for grow-out ponds. The need to allocate the maximum amount of land possible for shrimp cultivation is the primary reason for an open water exchange system, since these systems allow more land to be allocated to shrimp cultivation. The results demonstrate that the higher volume of shrimp produced (high stocking rate coupled with high acreage) compensates for lower survival rates (high stocking rates and open-water systems) (Figure 4.)

Figure 4

Is the BAU sustainable? The decreasing farm density observed in Figure 5 suggests that it is not. The total area under shrimp farming is declining – caused by a rapid increase in land abandonment which in turn is caused by high (low) mortality (survival) rates. The farm density at the beginning of the time period is approximately 65% of total land area in the region but drops to 40 percent by the end of the time period. The high rate of farm abandonment is caused by a succession of low survival rates due to disease outbreaks. At the end of the period, approximately 41 percent of total land area can be classified as abandoned. If the sector is allowed to operate under present conditions, a collapse is inevitable.

figure 5 here

Figure 6 here

Internalisation of environmental externalities (IEE)

In this scenario, environmental costs caused by the shrimp sector are included in the profit function. In other words, the externalities produced by the sector are internalised. We observe a significant change in the techniques as well as in the number of farms across the three regions, compared to the Base solution. First, as Figure 6 illustrates, closed-water systems are used in all sites except in the case of non-acidic clay soil on the Andaman coast.

The primary reason for the switch to closed systems is that the need to minimise the rate of land abandonment becomes critical. There is now a cost for abandoning land and in order to reduce the rate of abandonment, the survival rate has to increase; one way to do this is to use the closed water system. However, because closed water exchange systems require larger tracts of land, the model prescribes a higher stocking rate (75 pl/m^2 to 100 pl/m^2) to compensate for output lost from a lower acreage under production.

In the case of the Andaman coast, an open system was chosen for clay non-acidic lands with a lower stocking density of 75pL/m^2. The main reason for this is the scarcity of land. Total suitable land available for shrimp farming is the lowest in the Andaman region. This forces the sector to choose techniques that maximise the acreage of land under shrimp cultivation. The survival rates shown in Figure 7 attests to the fact that land scarcity plays a more pivotal role than survival rates in the maximisation of profits. Survival rates are about 45% for open systems as compared with 60% to 70% for closed systems.

Figure 7 here

The number of farms observed in IEE is lower than that in BASE – approximately 33% lower for the East, and 25% lower for the South and the Andaman. This tells us that when externalities are internalised, there is a pressure to reduce the total effluent production. The most cost-effective way to do this is to control the number of farms.

We begin to observe a pattern emerging from the two simulation runs above. There is a continuing trade-off between volume production on the one hand and survival rates on the other. For example, if total production under an open system with high intensive stocking rates produces 100 tons of shrimp, but experiences a 40% survival rate, then final yield is only 40 tons. In another alternative, where a closed system is used with a high stocking rate production of 70 tons with a survival rate of 70% yields a final total of 49 tons. The decision in this case would be to choose the latter system. This of course is a simplified explanation of the selection process. In the model, the choice set is much larger and the process of elimination far more complex. We do not make a distinction between size and quality of shrimps produced in this study; however, it is definitely an area for future research.

We next ran a couple of sensitivity tests on two crucial parameters used in the model; price of shrimp and the opportunity cost of abandoned land to investigate if significant changes in management strategies occur.

Sensitivity analysis

We began by reducing the price of shrimp by 20%. The most obvious change observed was the switch from a closed to an open system, and stocking rates of 75pL/m^2 across all three regions – a similar strategy to the BAU run. The primary reason for the switch to an open system is dictated by the economics of the sector. With a 20% reduction in prices, net profit accruing from actual yields is lower in the case of closed water systems and stocking rates of 100pL/m^2 , compared to those using an open-water system and stocking rates of 75pL/m^2. However, the rate of land abandonment was observed to be similar to BAU levels. This tells us that stronger policy measures need to be enforced to control the rate of farm abandonment due to production crashes. We discuss some of these options in the next section.

The next sensitivity test involved increasing the opportunity cost of land. In the IEE strategy, the opportunity cost of land was set at 2000 bath per rai; this was computed based on net profits earned if the land was used for rice farming. It was observed that as this opportunity cost increased, the main behavioural change observed was the switch from a closed to an open water exchange system. As the opportunity cost of land increases, there is a trade-off between using all land for grow-out ponds together with higher mortality rate associated with the open-water system and reduced land allocation for grow-out ponds (close-water system) but with a higher survival rate. The economics of the shrimp sector dictate that farmers opt for the larger volume and low survival rate than the low volume and high survival rate strategy. The opportunity cost at which there is no incentive to convert land to shrimp farming was found to be about 18000 baht per rai.

The high profitability of the shrimp sector makes it difficult for policymakers to discourage shrimp farming. The best strategy would be to ensure that the sector is monitored and encouraged to pursue sustainable farming strategies. We now turn our attention to some policy tools that can be used to achieve this.

Discussion

The policy question that needs to be addressed is how to make farmers accountable for their environmental costs. A number of options are available. One alternative would be to implement an effluent emission tax on farms that pollute above a pre-specified emission limit. Subsidies can of course be given to farms that emit less than the limit. The disadvantage of this is that it does not address two critical issues, namely the environmental costs associated with salinisation on both abandoned and adjourning lands, and the number of farms within specified geographical boundaries.

A second option would be to introduce a system of price differentiated farm permits. Farm permits achieve two objectives: first, by specifying the total number of permits, authorities can control the actual number of farms within specific geographical boundaries. Second, the price of the permit can be set based on farm management practices as well as on soil characteristics, ie, a differentiated permit price system based on spatial and technical properties.

Figure 8 below gives the permit price that needs to be collected from the respective farms based on soil type, stocking density and the water system adopted. These prices were computed by dividing the environmental cost caused by the farms adopting a certain farm technique by the total number of farms using that technique. However, as there was only one difference in site location under the IEE strategy, we have just presented the permit prices based on stocking density and water system in order to simplify the presentation.

Figure 8 here

Farms which adopt the open system pay the highest permit price, while farms adopting lower stocking rates combined with closed water systems pay the lowest permit price. All other combinations fall between these two ends of the spectrum.

The unique characteristic of the pricing system lies in its efficiency improvement properties: high polluting management strategies pay a higher price than those strategies which exert lower pressures on the environment. By imposing a price differentiated permit system based on environmental pressures, it forces, or more appropriately 'motivates', the sector to adopt management strategies which will increase net profits. The profits under IEE were observed to increase by more than a factor of two to those in BAU. This at first glance may seem contradictory, as one would expect that with external costs included, net profits would go down. However, on the contrary, with external costs internalised, efforts are made to adopt techniques which reduce mortality rates. This in turn produces a combination of techniques and farm density which increases the overall profits of the sector.

In the case of the price drop sensitivity test, an interesting result was observed. The optimal strategy given by the model produces a high rate of farm abandonment – levels similar to the BAU. However, while this is considered optimal, it is not sustainable, and some form of regulatory intervention would be necessary. This could include the imposition of some form of sustainability criteria on the model. The form which we adopted is the imposition of an acceptable upper bound on the total amount of abandoned land[7]. The cost to the sector for this constraint comes in the form of higher farm permit prices; ranging from 12,000 to 25,000[8] Baht. The results in Figure 9 below show that, with the permit system in place, the level of abandoned land can be restricted to below 15 percent of total land within each site.

Figure 9 here

From a policy perspective, the results above suggest that the introduction of a price differentiated permit system could provide an incentive for both higher profits and lower environmental costs. In other words, the permit system motivates cooperative behaviour among the farms towards the use of the common coastal water resource system leading inevitably to the higher profits as highlighted previously. However, we should point out here

[7] We inserted an upper bound of 15 percent of total land.

[8] One management strategy requires a permit price of 25000 Baht. However, the strategies adopted in all other regions and soil types were similar and the permit price was approximately 12000 Baht.

that this study does not investigate the socio-economic repercussions of a farm permit system. This is an area for future research.

Conclusions

This study has highlighted a number of critical issues. The following conclusions about the shrimp sector in Thailand can be drawn:

- The present management strategies are unsustainable.
- It is economically inefficient
- It can increase its economic and environmental sustainability through the use of a farm permit system.
- The farm permit system determines the total number of permits which should be allowed. This number is dependent on the total area under consideration, the soil types in the area, and the farm management techniques.
- The permits should be price differentiated, according to soil type, stocking density and the water exchange system used.
- The farm permit system must be designed to mitigate against farm abandonment, and at a rate which is within acceptable levels determined by both economic and ecological variables.
- The permit system must be continually monitored and adjusted according to prevalent economic conditions in the country.
- An institutional structure needs to be established in order to implement and enforce the permit system. Although the system is self-regulatory to a large extent, some system of checks needs to be put in place to ensure farmers are adopting the management strategies specified in their permits.

The farm permit system we have suggested in this paper is one of many possible alternatives. Whatever system is adopted, the critical issue on farm density must be addressed. The present policy of limiting total area available for shrimp is not sufficient. More important to the equation of sustainability is the number of farms possible within specified geographical boundaries and the management strategies these farms adopt.

Bibliography

Boyd, C.D. and Musig, Y. 1992. Shrimp pond effluent: observations of the nature of the problem on commercial farms. In *Proceedings of the special session on shrimp farming*. World Acquaculture Society Annual Meeting. Baton Rouge. La, USA.

Briggs, M.R.P. and Funge-Smith, S.J. 1994. Unsustainable shrimp culture: a review of causes and potential solutions from experience in Thailand. In M.R.P. Briggs (ed). *Development of strategies for sustainable shrimp farming.* Final report to the Overseas Development Administration. Research Project R4751. Institute of Acquaculture, University of Stirling.

Chiu, Y.N. 1988. Water quality management for intensive prawn ponds. In Y.N. Chiu, L.M. Santos, and R.O. Juliano (eds). *Technical considerations for the management and operation of intensive prawn farms:* pp 102-128. U.P. Aquaculture Society, Iioilo City, Philippines.

Dierberg, F.E and Kiattisimkul, W. 1996. Issues, impacts, and implications of shrimp aquaculture in Thailand. *Environmental Management* Vol 20(5).

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

Flaherty, M and Karnjanakesorn, C. 1994. Marine shrimp aquaculture and natural resource degradation in Thailand. *Environmental Management* 19: 27-37.

Funge-Smith, S.J. and Briggs, M.R.P. 1994. The origins and fate of solids and suspended solids in intensive marine shrimp ponds in Thailand. In M.R.P. Briggs (ed) *Development of srategies for sustainable shrimp farming*. Final Report to the Overseas Development Administration, UK, Research Project R4751. Institute of Aquaculture, University of Stirling, U.K.

Funge-Smith, S.J. and Aeron-Thomas, M. 1995. *The economic factors and risks influencing the sustainability of Thai intensive shrimp farms*. Institute of Aquaculture, University of Stirling, U.K.

Masae, A. and Rakkheaw, S. 1992. *Social aspects of artisanal fisheries and shrimp farming in Pak Phanang Bay*. Asian Fisheries Social Science Research Network: Coastal Resources Institute, Price Songkhla University, hat Yai, Thailand.

Midas Agronomics, 1995. *Pre-investment study for a coastal resources management program in Thailand*. Interim report submitted to the World Bank. World Bank, Washington DC.

Patmasiriwat, D, Kuik, O. and Pednekar, S. 1998. *The shrimp aquaculture sector in Thailand: a review of economic, environmental and trade issues.* CREED Working Paper No 19. International Institute for Environment and Development (IIED), London, and Institute for Environmental Studies (IVM), Amsterdam.

Paw, J.N. and Thia-Eng, C. 1991. An assessment of the ecological and economic impact of mangrove conversion in Southeast Asia. In L.M. Chou, H.W. Khoo, P.E. Lim, J.N. Paw, G.T. Silvestre, M.J. Valencia, A.T. White and P.K. Wong (eds). *Towards an integrated management of tropical coastal resources.* ICLARM Conference Proceedings 22. International Center for Living Aquatic Resources Management, Philippines.

Phillips, M.J. 1994. Shrimp culture and the environment. Unpublished paper prepared for Aquaculture Development in Southeast Asia '94 (ADSEA '94). 26-28th July, Hoilo City, Philippines, Network for Aquaculture Centers in Asia-Pacific, Kasetsart University, Bangkok.

Piamsak, M. 1996. Mangrove destruction and shrimp culture systems. *Asian Shrimp News* 27, 3rd Quarter. Bangkok.

Poernomo, A. and Singh, V.P. 1982. Problems, field identification and practical solutions of acid sulfate soils for brackish water fishponds. Pages 49-61 in Report of consultation/seminar on coastal fishpond engineering, Surabaya, Indonesia, South China Fisheries Development and Coordinating Program, Manila, Philippines.

Potaros, M. 1995. *Thailand.* FAO report on a regional study and workshop on the environmental assessment and management of aquaculture development, Bangkok, Thailand.

Primavera, J.H. 1993. A critical review of shrimp pond culture in the Philippines. *Fisheries Science* 1(2): 151-201.

Primavera, J.H. 1991. Intensive prawn farming in the Philippines: ecological, social and economic implications. *AMBIO* 20(1), 28-33

Simpson, H.J., Ducklow, H.W., Deck, B. and Cook, H.L. 1983. Brackish water aquaculture in pyrite bearing tropical soils. *Aquaculture* 34: 333-350.

Thongrak, S., Prato, T. Chiayvareesajja; S. and Kurtz, W. 1997. Economic and water quality evaluation of intensive shrimp production systems in Thailand. *Agricultural Systems* 53: 121-141.

Tookvinas, S. 1996. *Environmental impact assessment in intensive marine shrimp farming in Thailand*. Coastal Aquaculture Division, Department of Fisheries, Bangkok. Mimeograph.

Tookvinas, S. 1995. Quality and quantity of discharge water from intensive marine shrimp farms at Khung Krabaen Bay, Chanthaburi Province, East Thailand. In A. Snidvings, W. Utoomprukporn and M. Hungspreugs. (eds). *Proceedings of the NCRT-JSPS joint seminar on marine science*. Department of Marince Science, Chulalongkorn University.

Wongsaengchan, A. 1990. *Impacts of intensive shrimp cultivation on water quality in the Songkhla Basin, Thailand.* Ph.d dissertation. University of Tennessee, Knoxville.

Appendix

Mathematical Model

Model Nomenclature

Superscripts are used to facilitate the use of variable names longer than just a single alphabet. Subscripts are used to denote the degree of resolution.

Sets

R	Regions
D	Land Type
P	Farm Techniques
W	Water Management Options
C	Commodities
T	Time Periods

Parameters

A	Technology Matrix
L	Land Availability
P	Prices
IC	Initial Conditions
TC	Terminal Conditions

Variables

z	Activity Levels
x	Final Shipment
u	Raw Material Purchases
l^a	land available for shrimp farming
l^u	demand for land by shrimp farming
l^{ug}	land used for the cultivation of shrimps
l^{ur}	land used for shrimp farming in each region
l^b	land abandoned by shrimp farms
l^c	land converted to shrimp farming
l^p	Productivity drop in land caused by drop in survival rates
s	survival rate
f^I	feed intensity
s^I	seed intensity
f^{md}	farm density
x^s	sludge production
π^r	revenue
π^{dc}	direct cost
π^{idc}	indirect cost
n	number of farms

Model Equations

Raw material purchases by respective farms

$$a_{cpdw} z_{rpdwt} + u_{c,r,p,d,w,t} \geq 0 \qquad c \in CFV, p \in P, d \in D, w \in W, t \in T$$

Let us begin by identifying the amount of raw materials used by the sector. The CFV set is the commodity sub-set which consists of only raw materials. These are: (1)energy; (2) feed; (3) seed; and (4) chemicals. The *z* variable tells us the activity level of all in region *r*, using process *p* located in land type *d* and using water management option *w* in time *t*. The coefficients in the A matrix (a_{cpdw}) were computed from data collected from the farm survey carried out in this study. These figures were complimented by data from the NACA database for Thailand.

Total land use

$$a_{"tarea"pdw} z_{rpdwt} = l^{u}_{rpdwt} \quad r \in R, p \in P, w \in W, d \in D, t \in T$$

Land use by shrimp farms is equal to the demand, which is denoted by the purchase level that in turn is determined by the activity or production levels. This area covers ponds plus land used for infrastructure.

Total grow out area

$$l^{ug}_{rpdwt} = a_{"garea"pdw} z_{rpdwt}$$

In this equation we compute the total area covered by ponds used for actual shrimp farming.

Land type covered by shrimp farms in each region

$$l^{ur}_{rdt} = \sum_{p \in P} \sum_{w \in W} l^{u}_{rpdwt} \qquad r \in R, d \in D, t \in T$$

Equation four computes the total land of type d in each of the regions which is covered by shrimp farms.

Land use constraint

$$l^{ur}_{rdt} \leq l^{a}_{rdt} \qquad r \in R, d \in D, t \in T$$

The amount of land used by shrimp farms has to be less than the area under shrimp farming.

Land accumulation

$$l^{a}_{rdt+1} = l^{a}_{rdt} - l^{b}_{rdt+1} + l^{c}_{rdt+1} \qquad r \in R, d \in D, t \in T$$

The land under shrimp farming is accumulative and depends on the level in the previous period minus land abandoned plus land converted.

Land use balance equation

$$la\bar{t}_{rdt} = l^{a}_{rdt} + l^{au}_{rdt} + l^{tb}_{rdt} \quad r \in R, d \in D, t \in T$$

The total amount of land under shrimps, alternative land uses and abandoned land must be equal to total amount of land available. This equation can be interpreted as an identity or balance equation. The data for the total amount of land available for each soil type and in each region were computed based on GIS information.

Land abandoned by shrimp farms

$$l^{b}_{rdt} = \sum_{p \in P} \sum_{w \in W} l^{u}_{rpdwt} l^{p}_{rpdwt}$$

The amount of land abandoned depends on the productivity drop witnessed on the farms.

Productivity drop

$$l^{p}_{rpdwt} = e^{-\frac{s_{rpdwt}}{pconst}} pgrad \qquad r \in R, p \in P, d \in D, w \in W, t \in T$$

The degree of productivity drop is determined primarily by the survival rate. The lower the survival rate, the higher the productivity drops. The pconst and pgrad reflect the rate and magnitude of the impact the survival rate has on the productivity drop experienced by the farms. In many ways, we can use varying figures for pconst and pgrad to capture risk taking behavior on the part of the various shrimp farms. The figures we used were 0.12 and 2.3007 respectively and this gives a productivity drop schedule shown in Figure 10 below. The coefficients used above were derived from a calibration process whereby the underlying premise is that farms get abandoned when the survival rate of shrimps falls below 60 percent.

Figure 10 here

Natural shrimp production level

$$x^{p}_{rpdwt} = a_{"shrimp"pdw} z_{ripdwt} \qquad r \in R, i \in I, p \in P, d \in D, w \in W, t \in T$$

The natural shrimp production level denotes the harvest level, which can be experienced if no diseases occur. The output level used in the technology matrix is net of natural mortality rate.

Actual shrimp production levels

$$x^{o}_{rpdwt} = x^{p}_{rpdwt} s_{rpdwt} \qquad r \in R, p \in P, d \in D, w \in W, t \in T$$

The actual shrimp harvested is net of mortality rates caused by controllable factors that are described in detail in the survival equation below.

Shrimp survival rate

$$s_{rpdwt} = e^{a_1 \ln f^{i}_{rpdwt} + a_2 \ln s^{i}_{rpdwt} + a_3 \ln f^{md}_{rt} + a_4 \frac{\ln f^{i}_{rpdwt}}{\ln s^{i}_{rpdwt}} + a_5 z_{rpd"close"t} + a_6 \left(\ln f^{md}_{rt}\right) + a_7 \left(\ln f^{i}_{rpdwt}\right) + a_8 \left(\ln s^{i}_{rpdwt}\right)} \qquad r \in R, p \in P, d \in D, w \in W, t \in T$$

The shrimp survival rate is a translog function which was econometrically estimated using survey data from a sample size of 350 farms. Various functional forms were used but the above function provided the best fit. We believe that the good fit was primarily provided by the strength of the translog function in capturing second order effects.

Feed intensity

$$f^{i}_{rpdwt} = \frac{u_{"feed"rpdwt}}{l^{ug}_{rpdwt}} \qquad r \in R, p \in P, d \in D, w \in W, t \in T$$

Feed Intensity is primarily computed as the total amount of feed purchased by the farms divided by the grow out area used by the respective farms.

Seed intensity

$$s^{i}_{rpdwt} = \frac{u_{"seed"rpdwt}}{l^{ug}_{rpdwt}} \qquad r \in R, p \in P, d \in D, w \in W, t \in T$$

Seed intensity is computed in a similar manner as the feed intensity.

Number of farms

$$n_{rpdwt} = \frac{l^{u}_{rpdwt}}{a_{"tarea"pdw}} \qquad r \in R, p \in P, d \in D, w \in W, t \in T$$

The number of farms is equal to the total land under use by the various farm categories divided by the unit area required by a hypothetical farm. We assume that each category as described by the technology matrix is representative of a farm.

Farm density

$$f^{md}_{rt} = \frac{\sum_{p \in P}\sum_{d \in D}\sum_{w \in W} l^{ug}_{rpdwt}}{\sum_{d \in D} \bar{lat}_{rd}} \qquad r \in R, t \in T$$

The farm density is computed based on the ratio of the number of grow out ponds in operation to total area in the region.

Sludge production

$$x^{s}_{rpdwt} = a_{"sludge"pdw} z_{rpdwt} \qquad r \in R, p \in P, d \in D, w \in W, t \in T$$

Sludge production is dependent on the farm category adopted. The total amount is in turn determined by the actual production levels on each respective farm.

The profit function

$$\pi = \sum_{t \in T} \frac{\left(\pi^{r}_{t} - \pi^{dc}_{t} - \pi^{idc}_{t}\right)}{(1+i)^{t}}$$

The profit function for each farmer is equal to revenues minus costs. The revenues are from the sale of the shrimps while the costs are comprised of the following components: direct and indirect costs. Within the first component, we further clarify between fixed and variable costs. Fixed costs will be land costs and capital costs. Variable cost components will be feed, chemicals, fry, energy. The indirect costs will be off-site environmental costs such as sludge disposal and the opportunity costs incurred from land conversion as well as land abandonment.

Revenues

$$\pi^{r}_{t} = \sum_{p \in P}\sum_{d \in D}\sum_{w \in W}\sum_{r \in R} x^{o}_{rpdwt} p_{"shrimp"}$$

Revenue is equal to actual harvest of shrimps multiplied by the price. Price is a parameter.

Direct costs

$$\pi_t^{dc} = \sum_{p\in P}\sum_{d\in D}\sum_{w\in W}\sum_{c\in CF\cup CV}\sum_{r\in R} u_{ripdwct}\, p_c$$

Direct Cost is equal to fixed costs plus variable costs. CC is a sub-set of commodities which are fixed cost items. These would be capital in this version of the model. The CFV is a sub-set of commodities which depend on the production levels. These would be feed, fry, energy, chemicals etc.

Indirect costs

$$\pi^{idc} = \left(\sum_{p\in P}\sum_{d\in D}\sum_{w\in W}\sum_{r\in R} a_{"sludge"pdw}\, z_{rpdwt}\right) p_{"sludge"} + \sum_{d\in D}\sum_{r\in R} l^{c}_{rdt}\, p_{"opport"} + \sum_{d\in D}\sum_{r\in R} l^{b}_{rdt}\, p_{"opport"}$$

Indirect costs primarily relate to the environmental costs, which are caused by the shrimp sector. We begin by computing the costs of sludge disposal. The next two components are the opportunity costs foregone when land is converted to shrimp farming and when shrimp farms are abandoned.

PUBLICATIONS AND ORDER FORM

The following papers are available from the CREED Programme. Please check the publications you wish to obtain and return the order form to Jacqueline Saunders, Environmental Economics Programme, International Institute for Environment and Development, 3 Endsleigh Street, London WC1H 0DD, or email your requests to Jacqueline.Saunders@iied.org.

Northern-based readers will be charged £12.50 per paper, plus postage and packing. For our southern readers, hard copies are available free of charge, although larger quantities (more than 6) will incur postal costs. All papers may be downloaded free in PDF format from the CREED website, at www.iied.org/creed**.**

CREED Working Paper Series.

- ☐ **No 1. Adjustment policies and the environment: a critical review of the literature.** Carlos E.F. Young and Joshua Bishop. July 1995.

- ☐ **No 2. Environmental regulations as trade barriers for developing countries: eco-labelling and the Dutch cut flower industry.** Harmen Verbruggen, Onno Kuik & Martijn Bennis. July 1995.

- ☐ **No 3. Economic incentives for watershed protection: a report on an ongoing study of Arenal, Costa Rica.** Bruce Aylward, Jaime Echeverría & Edward B. Barbier. September 1995.

- ☐ **No 4. Economic policies for sustainable water use in Thailand.** Ritu Kumar and Carlos Young. June 1996.

- ☐ **No 5. The informal sector and waste paper recovery in Bombay**. Pieter van Beukering, Edwin Schoon and Ajit Mani. June 1996.

- ☐ **No 6. Economic trends in the timber industry of the Brazilian Amazon: evidence from Paragominas.** Steven Stone. July 1996.

- ☐ **No 7. Input substitution in the Indian paper industry: a variable cost function approach**. K.V. Ramaswamy, R.R. Vaidya, M.J. Bennis and J.G.M. Hoogeveen. July 1996.

- ☐ **No 8. Poverty and environmental degradation: a literature review and analysis.** Anantha K. Duraiappah. October 1996.

- ☐ **No 9. Valuation and evaluation of management alternatives for the Pagbilao Mangrove Forest.** Ron Janssen and Jose E Padilla. October 1996.

- ☐ **No 10. The economic and environmental impacts of the waste paper trade and recycling in India: a material balance approach.** Pieter van Beukering and Anantha K. Duraiappah. November 1996.

- ☐ **No 11. Incentives for eco-efficiency: lessons from an evaluation of policy alternatives; a case study of the steel sector in India.** Ritu Kumar, Nick Robins, A.K. Chaturvedi, R. Srinivasan and J. Gupta. December 1996.

- ☐ **No 12. Poverty and environment linkages in mountains and uplands: reflections on the 'poverty trap' thesis.** Sanjeev Prakash. February 1997.
- ☐ **No 13. The economic importance of wild resources in the Hadejia-Nguru Wetlands, Nigeria.** Derek Eaton and Marie-Thérèse Sarch. May 1997.
- ☐ **No 14. Economic valuation of mangrove ecosystems: potential and limitations.** Frank Spaninks and Pieter van Beukering. July 1997.
- ☐ **No 15. The use of environmental functions to evaluate management strategies for the Pagbilao Mangrove Forest.** Alison J. Gilbert and Ron Janssen. August 1997.
- ☐ **No 16 Trends and issues in the plastics cycle in China, with special emphasis on trade and recycling.** Pieter van Beukering, Li Yongjiang, Zhao Yumin & Zhou Xin. December 1997.
- ☐ **No 17. Economic valuation of communal rangelands in Botswana: a case study**. Jaap Arntzen. February 1998.
- ☐ **No 18. Environmental product measures: barriers for South-North trade?** Harmen Verbruggen, Onno Kuik, Martijn Bennis, Hans Hoogeveen, Roland Mollerus. March 1998.
- ☐ **No 19. The shrimp aquaculture sector in Thailand: a review of economic, environmental and trade issues.** Direk Patmasiriwat, Onno Kuik and Sunil Pednekar. October 1998**.**
- ☐ **No 20. An analysis of private and social discount rates in Costa Rica**. Bruce Aylward and Ina Porras. December 1998.
- ☐ **No 21. Institutional arrangements for watershed management: a case study of Arenal, Costa Rica.** Bruce Aylward and Alvaro Fernandez Gonzalez. December 1998.
- ☐ **No 22. Farmers' perceptions and sustainable land use in the Atacora, Benin.** A. Adegbidi, K. Burger, E. Gandonou and I. Mulder. February 1999.
- ☐ **No 23. Sustainable livestock management in the Kalahari: an Optimal Livestock Rangeland Model (OLRM).** Anantha K. Duraiappah and Jeremy S. Perkins. March 1999.
- ☐ **No 24. Analysing urban solid waste in developing countries: a perspective on Bangalore, India.** Pieter van Beukering, Madhushree Sekher, Reyer Gerlagh and Vijay Kumar. March 1999.
- ☐ **No 25. Market and policy incentives for livestock production and watershed protection in Arenal, Costa Rica.** Bruce Aylward, Jaime Echeverría, Katherine Allen, Ronald Mejías and Ina T. Porras. March 1999.
- ☐ **No 26. Integrated modelling of solid waste in India.** Reyer Gerlagh, Pieter van Beukering, Madhu Verma, P.P. Yadav and Preety Pandey. March 1999.
- ☐ **No 27. The plastics sector in China: issues in production, recycling and international trade**. Anantha K. Duraiappah, Zhou Xin and Pieter van Beukering. March 1999.
- ☐ **No 28. Farmers' perceptions of soil fertility in Benin** Ingrid Mulder. February 2000.
- ☐ **No 29. Automobile pollution control in Brazil**. Claudio Ferraz and Ronaldo Seroa da Motta. June 2000.

☐ **No 30. Soil fertility: QUEFTS and farmers' perceptions**. Ingrid Mulder. July 2000.

☐ **No 31. Sustainable shrimp farming: estimations of a survival function** . Anantha K. Duraiappah, Adis Israngkura and Sombat Sae-Hae. July 2000.

☐ **No 32. Traditional Chinese medicine and species endangerment: an economic research agenda**. Konrad von Moltke and Frank Spaninks. August 2000.

☐ **No 33. Land tenure, land use, environmental degradation and conflict resolution: a PASIR analysis for the Narok District, Kenya.** Anantha K. Duraiappah, Gerrishon Ikiara, Mutsembi Manundu, Wilfred Nyangena and Rueben Sinange. August 2000.

☐ **No 34. The environmental effects of tax differentiation by vehicle characteristics: results from Costa Rica.** Jaime Echeverría, Nick Johnstone, Ronald Mejías and Ina Porras. September 2000.

☐ **No 35. Farm permits and optimal shrimp management in Thailand: an integrated inter-temporal and spatial planning model**. Anantha Kumar Duraiappah and Adis Israngkura. October 2000.

CREED Final Reports

The following reports are available from recently completed CREED projects. A charge is levied for all readers as indicated**.**

☐ **International Trade and Recycling in Developing Countries: The Case of Waste Paper Trade in India**. P. van Beukering and V. Sharma (eds). November 1996. 155 pages. £20

The importance of international trade in the global economy is expanding, not only for primary products but also for recyclable waste. The main objectives of this study were to determine the economic, social and environmental impacts of international trade of waste paper for recycling purposes in India. The report addresses three main sectors: (i) the world market for waste paper, (ii) the local waste paper market and (iii) the Indian paper industry. It also makes recommendations for policy makers at an international, national and local level: international agreements should distinguish between hazardous and non-hazardous waste; national trade barriers to waste imports should be eliminated; and existing local informal recovery sectors should be favoured over formal Western-style recycling systems.

☐ **Mangroves or Fishponds? Valuation and Evaluation of Alternative Uses of a Mangrove Forest in the Philippines.** Ron Janssen & Jose Padilla. September 1997. 258 pages. £25.

One of the major threats to mangroves in the Philippines is the rapidly increasing aquaculture industry. This study includes a review of valuation methodologies and their application to the case study area of the Pagbilao experimental mangrove forest in the Philippines. Valuations of goods and services and environmental functions of the forest are employed to assess alternative management regimes using both cost-benefit analysis as well as a multi-criteria approach. Much depends on the management objectives: conversion to aquaculture is the most economically efficient management option. However, if equity and sustainability objectives are included, commercial forestry is the preferred alternative.

☐ **Incentives for Eco-Efficiency. Market Based Instruments for Pollution Prevention: A Case Study of the Steel Sector**. Ritu Kumar, Nick Robins, A.K. Chaturvedi, R. Srinivasan and J. Gupta. December 1997. 96 pages. £20.

Mounting pressures on industry to reduce pollution, to remain globally competitive and to meet the requirements of international standards, require fundamental changes in government policy and corporate approaches to environmental management. This report presents the results of an international study assessing the potential for market-based instruments for pollution prevention in the steel sector in India. It recommends a set of policy measures to reduce discharge levels in the most cost effective manner, to induce firms to adopt cleaner technologies and to encourage firms to economise on energy and water resources. In this regard, the importance of achieving coherence with existing policies, building trust among key stakeholders and gradually phasing in market-based instruments is emphasised.

☐ **Economic Incentives for Watershed Protection: A Case Study of Lake Arenal, Costa Rica**. Bruce Aylward, Jaime Echeverria, Alvaro Fernandez Gonzalez, Ina Porras, Katherine Allen, Ronald Mejias. February 1998. 323 pages. £30.

Conventional wisdom holds that cutting down tropical forests for livestock production is not only bad business but bad for the environment. In particular, it is thought that conversion of natural forest to pasture leads to a rise in the sedimentation of waterways and resevoirs, increased risk of flooding and loss of dry season water supply. In the case of Lake Arenal, Costa Rica, this conventional view is stood on its head by research showing that ranching, dairy farming and associated downstream hydrological effects represent important positive values to the Costa Rican economy, values that significantly outweigh expected returns from reforestation

☐ **Plastics Recycling in China. An International Life Cycle Approach.** Edited by Pieter van Beukering. April 1999. 148 pages. £20.

Please check the papers you wish to obtain and use this form for delivery, to indicate a change of address, or to be added to the mailing list to receive information about future CREED Working Papers (please tick).

Name ....
Organisation ....
Address ....
....
I enclose a cheque for *£.....................made payable to **IIED**/I authorise you to debit my credit card for £............. My Access/Visa/Mastercard number (please tick as applicable) is:

Expiry date.................................. . Name of cardholder..
Cardholder address...

* For postage within the UK please add 20%, minimum £1 (first class or equivalent)
For postage to Europe please add 25%, minimum £2 (printed matter airmail or equivalent)
For postage to the rest of the world, please add 40% (printed matter airmail or equivalent) or 25% (surface)