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Internalizing the Cost of Biodiversity Loss due to Aquaculture: A Case Study of the Indian Sundarbans

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Internalizing the Cost of Biodiversity Loss due to Aquaculture: A Case Study of the Indian Sundarbans*

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Abstract

This paper examines the impact of export-driven increases in aquaculture production on biodiversity in the Indian Sundarbans, a UNESCO World Heritage Site. Biodiversity indices for three representative sites for a ten-year period are set up. These indices are integrated into a cost function for aquaculture farming to examine the impact of the 'ecological crop loss' caused by increasing prawn seed collection from the wild on costs of the aquaculturist. Within a translog cost function framework, the results on substitutability between inputs indicate that a land-intensive aquaculture expansion is indicated if biodiversity loss is to be averted. Further, the existence of economies of scale in aquaculture production points towards the economic viability of such an approach. Other policy options such as a hatchery technology for seed production are less cost effective, while requiring at the same time, complementary measures to provide livelihoods to the large numbers of people engaged in prawn seed collection.

JEL Classification: **Q22, Q27, Q56 and Q57**

Key Words: Aquaculture, Indian Sundarbans, Internalizing Social Cost, Biodiversity Loss, Prawn seed collection, Translog Cost Function, Economies of Scale

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Internalizing the Cost of Biodiversity Loss due to Aquaculture: A Case Study of the Indian Sundarbans[1]

1. The Issues

Aquaculture has rapidly developed as a thriving business in many developing countries in response to dramatic increase in the demand for shrimp from United States, Japan and Europe. Shrimp farming and aquacultural activities are mostly carried out in coastal regions as they provide vast tracts of saline lands coupled with an abundant quantity of wild seeds. National governments are supporting this activity in the belief that shrimp farming can generate significant foreign exchange earnings, and enhance the employment opportunities and incomes in poor, coastal communities. As a consequence hundreds of hectares of land have been brought under this venture. But this expansion has several effects on the land and water regimes and is postulated to lead to the degradation of the marine environment. Biodiversity, for instance is impacted by the practice of catching post-larvae shrimp, which has detrimental effects for other species.

Increase in the practice of aquaculture in the Sundarbans region during the last decade or more together with the absence of hatcheries resulted in the seed input (seed of tiger prawn) being collected from the wild, using labour–intensive drag-nets of different kinds. It has been reported in several studies that during the collection of tiger prawn seeds, juveniles of many species of finfish and shellfish are trapped in the net and these non-target species are thrown away and destroyed, as they are not remunerative. This destructive practice causes major damage to the juvenile finfish community of the area. The juvenile stage of the finfish community referred to, as 'icthyoplankton' constitutes an important planktonic component of the marine and estuarine ecosystems and forms an integral part of the fresh-cum-brackish-cum-saline water owing to their migratory behaviour. These planktons in a sense are referred to as the *ecological crop* of the marine

[1] This paper is based on research conducted as part of the " Trade, Environment and Rural Poverty" project supported by the Macro Economics Programme of WWF, and the World Bank, Washington DC. The authors alone are responsible for any shortcomings and the views expressed.

and estuarine systems as they provide nutrition to members of the higher trophic level, which includes larger bony fishes, sharks, turtle, dolphin, etc.

The demand for tiger prawn seeds has risen exponentially, and in the absence of any hatchery, the entrepreneurs have no option but to depend on wild harvest of the tiger prawn seeds, carried out by rural prawn collecting households. Several studies purport to estimate this loss. It is reported, for instance that about 48 species of finfish juveniles are wasted per net per day per haul, which amounts to about 9.834 kg.[2] This constitutes a huge loss of species diversity.

Further, the sustainability of shrimp farming is also threatened by its reliance on the collection of wild shrimp fry. This activity sustains a large number of poor households, using cheap and destructive methods to supply the key seed inputs to shrimp farmers, but these methods may, in the process, be damaging wild stocks of both shrimp and other aquatic species. Although hatcheries are being developed as a potential alternative to the supply of seed from the wild, their development has not been as rapid as desired resulting in growing dependence on wild seed stock. The Sundarbans region in West Bengal is experiencing a loss in fish diversity due to the excessive collection of shrimp fry. Destruction of aquatic resources is considerable due to harmful practices in the discard of by-catch.

Conversion of land to aquaculture is the consequence of market-driven profit-oriented behaviour. Simultaneously, the erosion of biodiversity as a consequence of the mode of seed collection is a social cost of the 'technology' adopted to procure one of the critical inputs. The question then arises: Can this social cost of biodiversity loss, due to prawn seed collection be internalized into the private cost of an entrepreneur? Related questions are:

How significant is the biodiversity use input in the total cost of production? How would it affect his per unit cost and hence profit?

Do the substitution possibilities between inputs get affected by such internalization?

[2] See Mitra (2005), MOEF, Project Report (1996).

Do scale economies exist in aquaculture production and how does inclusion of biodiversity cost affect their magnitude?

This paper examines these issues. A methodology based on the translog cost function is developed for the purpose. Section 2 describes the regional context. Section 3 reviews time series estimates of the ecological crop loss and estimates trends in biodiversity loss based on time series indices for representative sites. Section 4 examines different approaches to internalization of the biodiversity loss caused by seed collection technology and uses a cost function approach to estimate it. The database is described in Section 5, while results are analyzed in Section 6. Finally, Section 7 provides suggestions for policy options.

2. The Sundarbans: A Fragile and Changing Ecosystem

The Sundarbans is a region where the biodiversity is rich and valued. The tiger reserve comprising 2,585 sq kms of the Sundarbans National Park and its buffer zone is a part of this region. The national park was declared a UNESCO World Heritage Site in 1989. Two wildlife sanctuaries are also located within the Sundarbans.

The Sundarbans region in West Bengal covers a major portion of the districts of North and South 24 Parganas. The Sundarbans area is located at the apex of the Bay of Bengal (21 degree 32’- 22 degree 40’ N; 88 degree 03’-89 degree 07’ E). Important morphotypes of the area are sandy beaches, mud flats, coastal dunes estuaries, creeks inlets and mangrove swamps. Out of a total of 4,263 sq kms of mangrove forests in the Sundarbans, 1,781 sq km is comprised of water bodies and this waterlogged area is more suitable for shrimp farming in the region. Surface water is generally saline giving the Sundarbans a high comparative advantage for various types of brackish water fish production systems including shrimp farming.

The Forest management divides the area into: (a) core zones, (b) buffer zones, and (c) manipulation zones, which are made up of forestry and agriculture and aquaculture zones.

The different areas support each other and in turn provide ecosystem services to the people of the region. Nutrient supply for instance, comes from the mangrove forests. Salinity of water decreases landward within the rivers so that paddy and other agricultural cultivation is carried on there. The presence of mangroves near the coast provides important storm protecting and other regulating services. In other words, a variety of eco-system services falling within the groups of provisioning, regulating and cultural accrue simultaneously from this eco-system.

The region is also subject to a series of changes from natural causes including sea level rises due to temperature changes in the long run. The temperature is expected to rise at an average of 0.19 degrees Celsius in this region. Sea ingress has been a feature of this area over the past three to four hundred years and the rate may rise in the future.[3] As a consequence land is an extremely scarce resource. A multiplicity of causes makes the region a fragile and vulnerable natural system. Assessing the biophysical impacts of an increase in aquaculture in the region is indeed a major challenge. To add to this, migration of people to areas of increased concentration of aquaculture has added to its vulnerability.[4]

3. Indices of Ecological Crop Loss

Two kinds of factors have operated in the period since 1991 to change the magnitude of loss of biodiversity, otherwise referred to as loss of by-catch or ecological crop loss. The steady increase in land under aquaculture would be expected to have increased it. About 33,000 hectares in North 24 Paraganas and 12,000 hectares in South 24 Paraganas are devoted to shrimp farming. Potential area which could be brought under aquaculture is estimated at 1,80,000 hectares in these two districts.[5] Future expansion could accentuate this ecological crop loss substantially. However, the substitution of improved traditional system of shrimp culture for semi-intensive culture following the Supreme Court of India

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[3] According to a study of the School for Oceanographic Studies, Jadavpur University.
[4] According to the study of Jayshree Roy Chaudhary on migration patterns (personal communication).
[5] Government of West Bengal (2004).

order of 1996 has reduced stocking density per hectare and consequently the loss in by-catch or ecological crop loss per hectare.

While one-time estimates of 'ecological crop loss' exist, it is important to understand changes over time and space underlying this loss. In other words, what was the extent of change in biodiversity indices in the 'by- catch' from tiger prawn seed collection during the decade of the nineties?

The expansion of aquaculture in the Sundarbans region has been accompanied by fast market integration and the rapid movement of raw materials and output across the region. Transport of both raw material and output is well-organised and efficient.[6] We assume therefore that seed collection is spread over the entire region. A representative selection of sites for estimation of biodiversity loss needs therefore to take into account the varying salinity levels and dilution factors which vary in different locations of the coastal zone.

Monthly data for ten years on the number of species lost in the by-catch from three representative sampling stations was used to estimate the indices of biodiversity loss.[7] The sample size for the computation was a 10-gram composite sample of the wasted material obtained by a random mixing of the collection of 15 nets. The three sampling stations were selected for their different salinity profiles and distinct identity. These are: Diamond Harbour (Station1), Sagar South (Station 2) and Junput (Station 3). We give below the characteristics of these three stations.

Diamond Harbour is situated in the low saline upper stretch of Hugli estuary, just outside the northern boundary of the Indian Sundarbans. The station is very near to the Haldia port-cum industrial complex. Salinity of surface water is minimal around the station due to its location away from the Bay of Bengal in the extreme upstream region and also due

[6] This is well-documented. The research team also came across evidence of this efficient transport network during the course of its visits to the region.
[7] This rich data set was made available and analysed as part of the project due to the collaboration of the Department of Marine Science, University of Kolkata. See Mitra (2005).

to huge water discharge from the Hugli river, which is perennial in nature. The station has no mangrove vegetation except for a few mangrove associates and seaweeds.

Sagar South is situated on the southwestern tip of Sagar island and falls in the western sector of the Indian Sundarbans. The station has rich mangrove vegetation and extensive mud flats. Although there is no industrial activity around this station, the presence of a large number of shrimp culture farms (carrying on traditional culture with low stocking density) has enriched the surrounding water with nutrient and organic load.

Junput is situated in the Medinipur district of coastal West Bengal and is noted for its high aquatic salinity due to its proximity to the Bay of Bengal. The extremely high salinity has posed an inhibitory effect on the growth and survival of mangroves in the region. Existence of saltpans in the vicinity has made the soil of this region hyper saline in nature. The presence of the Digha tourist center and Shakarpur fishing harbour close to the station is the source of anthropogenic pressure, though there is no industry in the vicinity.

The ecological crop loss was assessed in terms of three alternative indices:

The Shannon Weaver species diversity index: $H = \sum n \sum ni / N \ln ni / N$,

Where ni =total of importance value of each species (number of individuals of each species),

N= total of importance values i.e. total number of individuals of all species in the wasted sample.

Index of dominance given by ($\sum (ni / N)$ **2)

Evenness index given by $H / \ln S$,

where S is the number of species

The results are tabulated in Tables 1 to 3 in the appendix. The 10-year monthly data reveals seasonal oscillation. The values of diversity are highest during the pre-monsoon period (March to June) and lowest during the monsoon (July to October). The seasonal trend is due to the life cycle of most organisms in the ecosystem.

Further, linear regressions using the biodiversity index as the dependent variable on time were run for the three sampling stations namely, Diamond Harbour, Sagar South and Junput. For the two stations, Diamond Harbour and Junput the trend coefficients came out to be negative indicating that there is an increasing trend in biodiversity loss due to prawn seed collection. This is indeed an important result. In one case, the coefficient did not indicate a significant negative trend. This was in Sagar South where there exists extensive mangrove vegetation and very little anthropogenic pressure. It is known that mangroves are nurseries, both for shrimp seed and also harbour a large number of species.

The results from the analysis of the ten-year data can be interpreted thus: biodiversity loss due to prawn seed collection is likely to be far more in regions where it takes place together with other anthropogenic pressure resulting in land conversion away from mangroves. Since rapid transport of prawn seed takes place all over the region, allocating the loss spatially is difficult. The average annual decline (0.03) was taken to arrive at the figure of biodiversity loss over time. To allocate this decline to individual farms, it was assumed that a particular farm's contribution to biodiversity loss was proportional to its demand for seed, which depends on its stocking density and its size. The higher the stocking density, the more is its demand. Similarly, even with the same stocking density, larger farms make a larger dent on loss of biodiversity.

4. Internalizing the Cost of Biodiversity Loss using Translog Cost Function

4.1 The Issue and the Methodology

The erosion of biodiversity as a consequence of the mode of seed collection is a social cost of the ' technology' adopted for provision of one of the critical inputs. The question then arises: Can this social cost of biodiversity loss, due to prawn seed collection be internalized into the private cost of an entrepreneur? Other related questions have been referred to in section 1.[8]

In this section, we address these questions by using a cost function framework. Such a framework for examining the relationship between environmental and other production costs has been used recently by Morgenstern, Pizer and Shih (2001). The analysis follows earlier established methods for studying substitution between natural resources, capital and labour[9] using cost and production functions.

The cost function can be defined as the function specifying the minimum costs of producing an output with a given vector of input prices and a technology. The duality relation between the cost function and the production technology is used to specify the cost function. A translog cost function has been estimated, as it allows scale economies to vary with the level of output and also it does not impose restrictions on substitution possibilities between the factors of production. A recent application in the Indian context to examine the hidden costs of environmental regulation in the textile industry is by Tholkappian (2005).[10]

The following form of translog cost function is chosen for estimation in the present study:

Ln TC=

$$\beta o + \beta y \ln Y + \sum_i \beta i \ln Pi + \frac{1}{2}\beta yy (\ln Y)(\ln Y) + \frac{1}{2}\sum_i \beta ii (\ln Pi)(\ln Pi) + \sum_i \sum_j \beta ij (\ln Pi)(\ln Pj) + \sum_i \beta iy \ln Pi \ln Y$$

Where, $\beta ij = \beta ji$, TC = total cost, βo = constant term, Y=Output, P_i = vector of input prices.

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8 Among these are: the significance of biodiversity loss as an input, possible substitution by other inputs and the nature of scale economies.

9 See the papers by Humprey and Moroney (1975), and Berndt and Wood (1975).

10 For earlier discussions on the methodological issues in the context of water pollution in India, see Goldar, Misra and Mukerji (2001). An early application of the Translog cost function to Indian agriculture is in Chopra (1985).

In order to improve the efficiency of the estimates, the translog total cost function is estimated along with share equations. Differentiating the total cost function with respect to input prices can arrive at the share equations for each factor. The resulting share equation (S_i) takes the following form:

$$\frac{\delta \ln TC}{\delta \ln \mathrm{Pi}} = \beta i + \beta ii \ln Pi + \sum_i \beta ij \ln Pj + \beta iy \ln Y$$

The specified cost function and the share equations are estimated jointly, applying the non-linear maximum likelihood method. To overcome the problem of singularity, one of the share equations (waterfeed equation in the present case) is arbitrarily dropped from the system estimation. The resulting maximum likelihood estimates are invariant to the equation deleted.

From the translog cost function the Allen partial elasticities of substitution, (σij) and (σii), for the ith factor of production are calculated as:

$$\sigma ij = \frac{(\beta ij + \mathrm{Si\,Sj})}{(\mathrm{SiSj})}, \qquad \mathrm{i} \neq \mathrm{j}$$

$$\sigma ii = \frac{\beta ii + (\mathrm{Si} * \mathrm{Si}) - \mathrm{Si}}{\mathrm{Si} * \mathrm{Si}},$$

Price Elasticities of demand for factors of production

Own

$E_{ii} = S_i \, \sigma ii$

Cross

$E_{ij} = S_j \, \sigma ij$

5. The Data Base

The data used is derived from the primary survey conducted by the project team during February 2005. Aquaculture farms located in three blocks of the Sundarbans deemed to be representative of the varying conditions under which aquaculture is carried out in the region were selected.

On the basis of secondary data on water pollution[11] and information gathered from various sources regarding the shrimp business in the Sundarbans, the following areas have been identified for the survey to study the link between shrimp production and water pollution:

Areas were selected on the basis of water pollution parameters exceeding the standards and the presence of a large area under shrimp farming.

1. Minakhan: The analysis of data shows that the Minakhan has a relatively higher compound growth rate (CGR) for DO than other stations but has a low average DO (International Standard of DO for aquatic life is 5 mg/l (minimum)) for many periods in the 1999-2003 period, which is also substantiated by studies done on the Minakhan estuary. In this area, the CGRs for turbidity and nitrate is also the highest along with highest average turbidity for all the periods in the 1999-2003 period. About 3,600 ha of area is under shrimp production.

2. Canning: The area shows relatively higher CGRs for DO and turbidity than other stations for the period 1999-2003. The average levels of DO are marginally below the standard in some years. There are around 150 ponds for shrimp farming at Canning.

Fifty aquaculture farms from 3 blocks, Canning, Minakha, Gosaba, were surveyed. Out of these, two farms are dropped out from the analysis since they are not culture ponds.

[11] Pprovided by Abhijit Mitra, Department of Marine Sciences, Kolkatta University.

For the remaining 48 farms, data was collected on different aspects of production, input costs and technology of production for the year 2004.

Inputs for which use and cost data were collected are: feed, chemicals/fertilizers used in water treatment, land and seed. In addition, information was obtained on stocking density, size of the farm, lease rate, labour employed (permanent and temporary) on the farm, their wage rates, shrimp production, selling price, etc.

For the cost function estimation, the inputs used are: water and feed, seed, land and labour. The cost function and share equations are estimated with a term for the value of production for each farm in order to examine scale economies.

Additionally, the estimation is carried out while taking into account the additional cost of biodiversity loss consequent on the mode of seed collection. Details with respect to the data collected are given below.

Water-feed cost

Price Per Hectare of chemicals/fertilizers used in water treatment and Feed used and Cost Per Farm. A large majority of the farms use lime, bleaching powder, ammonia and urea for treating the water before stocking juveniles. These fertilizers not only improve the quality of water but they also act as feed for shrimp PL. At times, some of the farmers do buy artificial feed from the market over and above this. Even then it was easier to combine the two inputs since the quantity (ha) and price (Rs/ha) were given in the same unit. The corresponding cost of waterfeed is computed by multiplying price (Rs/ha) by pond size.

Rent Per Hectare and Cost of Land Per Farm

The farms are taken on lease, mostly for a three-year lease period, with the lease amount varying for each farm depending on its location. A farm closer to the water source has to pay a larger amount as lease. The data reveals a large variation in the lease rate. The rate per hectare varies from Rs.9,231 per hectare per year to Rs. 76,923 per hectare per year. The corresponding cost of land is computed by multiplying lease rate by the area of the pond.

Wage Rate and the Cost of Permanent Labour Employed

The number of family members working on the farm and the number of hired permanent labour (works through out the year) is recorded separately and the payments made to hired labour are given. A wage rate per person for permanent labour is worked out for each farm and family labour is also valued at this wage rate to yield the cost of labour in aquaculture production.

Stocking density and the Cost of Seed per farm

Stocking density varies from farm to farm depending on the culture system (technique) adopted. At present, the farms mostly follow extensive and improved traditional systems. Stocking density is low, a little bit of management is done through periodical water exchange during high tide, generally twice a month. The farm is fertilized at low dose rates. Sometimes supplementary feed is used. Seed price varies from Rs 210 per thousand to Rs. 1,200 per thousand. Seed cost per farm is estimated by multiplying price by the seed stocked in thousands.

Cost of Biodiversity Loss per farm

The biodiversity loss cost is estimated using the ecological crop loss assessed in terms of diversity (Shannon Weiner species diversity index, H) to evaluate the quantum of damage both in terms of weight and variability. The average trend decrease in this index is a measure of biodiversity loss in the region. It is attributed to individual farms in proportion to their stocking density and farm size. In our analysis seed cost and biodiversity loss cost have been combined to arrive at one cost. It could easily be done since both depend on stocking density. Also, the seed price is given in Rs/000 similar to what we have estimated for biodiversity loss. In order to arrive at the cost per farm of the biodiversity use, shrimp production per farm is multiplied by the same figure i.e. 0.03. This would give us the per farm cost of biodiversity used in terms of rupees. For a translog cost function the price of the biodiversity loss is required. Using the following formula the same has been arrived at:

$$\text{BDPrice(Rs/000)} = \left(\frac{Valueofshrimpproduction}{stockingdensity}\right) * 0.03$$

Average cost shares for the four inputs are given in Table 1.Labour, land and seed-biodiversity inputs comprise 35, 32, and 27 percent respectively of the total cost of production per hectare. Water-management and feed together contribute only about 5.8 percent.

Table 1: Cost Shares of Inputs

Wf	0.0583
Lab	0.3512
Lease	0.3224
Bdsp	0.2681

6. Results and Analysis

In the present model the social cost of biodiversity loss arising out of the mode of seed collection is internalized in the total cost of aquaculture by including it in the cost of seed collection.

6.1 Model With Biodiversity Loss Cost Internalized in the Input Cost for Seed

The translog cost function and associated system equations for the model with biodiversity cost internalized are given in Tables 2 to 7. We use the following notation:

Wf- Water and feed prices combined together (Rs/ha).

La- wages to permanent labour+ family members working as labourers (Rs/person).

Le- Land lease amount (Rs/ha/year).

Bd- Biodiversity and seed prices combined together (Rs/000).

Table 2: Estimates of Translog Total Cost Function

Variable	Coefficient	T-ratio
A	15.789	1.994
βla	1.039	3.978*
βle	-0.495	-2.522**
βbd	0.405	1.280
βy	-1.207	-0.972
$\beta lala$	0.094	2.449**
$\beta lale$	-0.034	-4.219*
$\beta labd$	-0.054	-1.434
$\beta lele$	0.042	6.431*
$\beta lebd$	0.001	0.061
$\beta bdbd$	0.055	1.347
βlay	-0.060	-2.905*
βley	0.070	4.450*
βbdy	-0.011	-0.432
βyy	0.149	1.542

*Note: * denotes significance at 1 percent*
*** denotes significance at 5 percent*
**** denotes significance at 10 percent.*

The estimated cost function is a well-behaved cost function, as the fitted factor shares are positive at almost all the observations. Labour has the highest share in the total cost followed by lease, biodiversity and waterfeed, in that order.

Table 3: Own Elasticity of Substitution (Allen)

Variable	Coefficient
Wfwf	-11.2871
Lablab	-1.0830
Leaselease	-1.6986
BdSpBdSp	-1.9590

The own elasticities for all the inputs i.e. waterfeed, labour, lease and biodiversity are negative (Table3). However, while labour (wage rate) and lease (lease rate) are significant determinants of cost, the price of seed and biodiversity loss costs are not coming out to be significant at 5 percent and 10 percent as can be seen from Table 2.

Table 4: Own-price Elasticity of Demand

Variable	Coefficient
Wfwf	-0.6575
Lablab	-0.3804
Leaselease	-0.5477
BdSpBdSp	-0.5253

Own-price elasticities are negative for all the inputs. None of the inputs have high price elasticities. This implies that increases in the prices of the inputs shall not impact their demand much. Water-feed having the highest elasticity is not very responsive to its own-price: own-price elasticity being –0.65. Next comes land and seed-biodiversity with own-price elasticities in the range of –0.52 to -0.54. On the other hand, labour has the lowest own-price elasticity-0.3803 indicating that the responsiveness of labour demand to its own-price is very low.

These findings are important with respect to the social cost of biodiversity loss and its delegation to aquaculture farmers. These results indicate that even if a larger biodiversity cost were to be assigned to aquaculture and seed prices were to rise as a consequence, they would be able to absorb it, given the present structure of costs and the present price levels for their output. The overall cross-price elasticities are low meaning demand for inputs is inelastic to change in the price of other inputs (Table 5).

Table 5: Cross- price Elasticities

Variable	Coefficient
Wflab	0.2464
Labwf	0.0408
Wflease	0.1723

Leasewf	0.0311
Wfbdsp	0.2387
Bdspwf	0.0518
Lablease	0.2260
Leaselab	0.2462
Labbdsp	0.1134
Bdsplab	0.1485
leasebdsp	0.2702
bdsplease	0.3249

However, some conclusions can be drawn. These are: waterfeed is responsive, though not very strongly, to the change in the price of labour as can be seen from the above table, wflab 0.246. Labour can be substituted, to a limited extent by water management and feed.

Cross-price elasticities between waterfeed and lease are low. It would be difficult to draw any conclusion. Though one can say that as the lease rate increases, demand for more land under aquaculture production goes down. Without increasing the size of the cultured area, the same output can be produced by improving water quality and increasing the quantity of feed. The relationship is not very strong since the elasticities are low (0.172 and 0.03)

Cross-price elasticities between lease (price of land) and biodiversity (price of seed and biodiversity loss) show that the change in the price of one leads to change in the demand for other. Though here again the elasticities are low.

Table 6 gives the elasticities of substitution between inputs used in aquaculture. A positive value indicates that the inputs are substitutes, a negative then the two inputs are complementary with each other. The production structure reveals interesting possibilities of substitution:

Table 6: Cross Elasticity of Substitution (Allen)

Variable	Coefficient

Wflab	0.7016
Wflease	0.5345
Wfbdsp	0.8903
Lablease	0.7012
Labbdsp	0.4228
leasebdsp	1.0078

Land-lease and biodiversity are strongly substitutable with AES equal to 1.007. This only states the fact that if land were to be in short supply, output can be increased by increasing the stocking density. They are substitutable. This would have implications for biodiversity loss. Conversely, if you use more land and extensive or improved traditional technologies, lower stocking densities and hence less loss of biodiversity is implied. *A land- intensive aquaculture expansion is indicated if biodiversity loss is to be averte*d.

However, since the cross-price elasticities between the price of land and of seed-biodiversity are not high, this effect is likely to be limited in magnitude.

The same is true for water management and feed input (considered as one input in this model). Waterfeed and seed-biodiversity are substitutable: the estimated AES is 0.89. However, the cross-price elasticities, wfbdsp and bdspwf are very low at about 0.238 and 0.051 respectively.

Water-feed and labour display some substitutability: AES is 0.701 and cross-price elasticities, 0.24 and 0.04. Looking at the cross-price elasticities one can say that limited substitutability exists if price is to be its driver.

Labour and land-lease are also found to be substitutes: AES is 0.701 and cross-price elasticities, 0.226 and 0.246, respectively.

6.2. Economies of Scale

The elasticity of total cost, which is a proportional increase in total cost (TC) resulting from a small proportional increase in output (Y), is calculated by differentiating the total cost function with respect to output.

Scale economies (SCE) is defined as:

$$SCE= \frac{\delta \ln TC}{\delta \ln Y}$$

Further, the negative coefficients of βlay and βbdy imply that with the increase in the scale, less of labour is required (Table 7). Similarly, as the scale of operation increases, it leads to less than proportionate increase in seed and biodiversity use, which in turn means less of biodiversity loss. This is a significant finding, implying as it does that if the current technology of aquaculture production were to be used on larger scales, it would provide the advantage of economies of scale without resulting in a proportionate loss in biodiversity.

Table 7: Estimates of Translog Total Cost Function

Variable	Coefficient
βlay	-0.0604
βley	0.0697
βbdy	-0.0110
βwfy	0.0016

There is evidence of strong scale economies in the aquaculture production. The value of 0.54 of the coefficient of economies of scale indicates that a one percent increase in the output would lead to less than one percent (0.54) increase in the total cost. Larger aquaculture farms are therefore indicated.

When this characteristic of the production technology is interpreted together with the finding that land-intensive aquaculture reduces biodiversity loss, the setting up of large aquaculture farms is indicated as the policy direction.

7. Concluding Remarks and Policy Implications

Biodiversity loss can be mitigated through innovative policies. The following policy options exist and may be considered:

Internalize the cost of biodiversity loss in the aquaculture farming cost. This paper illustrates that if more land is used and extensive or improved traditional technologies adopted, lower stocking densities and hence less loss of biodiversity is implied. *A land-intensive aquaculture expansion is indicated if biodiversity loss is to be averte*d. Further, the existence of economies of scale in aquaculture production points towards the economic viability of such an approach.

The above is best implemented by setting up a manner of collecting additional charges on aquaculturists in a 'designated local fund' to be spent on biodiversity conservation. This is economically feasible but administratively difficult to implement. A possible option is to provide prawn seed through the 'hatcheries technology' and supplement it by providing alternative livelihoods to prawn seed collectors. This is important because prawn seed collection is an important livelihood for large numbers of the poor. Such an option also requires extensive preparation by way of setting up of enabling social and legal frameworks.

A market-assisted policy option is to aim at eco-labelling for the acceptance of processed shrimp. The label would require, among other things, that the prawn seed be sustainably harvested. Given the existent cost structure, this is eminently feasible.

Tables

Table A.1: Species Diversity Indices (Diamond Harbour)

Year	Jan-March	April-June	July-Sep	Oct-Dec
1994	8.4308	8.7809	6.3189	8.4474
1995	8.4143	8.8054	6.309	8.4644
1996	8.4283	8.7134	6.2239	8.3684
1997	8.2988	8.6932	6.1192	8.3294
1998	8.5144	8.8117	6.4153	8.5394
1999	8.5143	8.8155	6.4119	8.5052
2000	8.4793	8.7904	6.3472	8.4607
2001	8.4926	8.8137	6.3472	8.4773
2002	8.4793	8.8357	6.3472	8.4607
2003	6.6878	8.9534	0	5.1895

Table A.2: Species Diversity Indices (Sagar South)

Year	Jan-March	April-June	July-Sep	Oct-Dec
1994	9.7019	10.7737	4.7281	7.9539
1995	9.6321	10.7768	4.0187	7.9488
1996	9.6412	10.7825	4.2385	8.0033
1997	9.6717	10.6998	4.1653	8.0504
1998	9.643	10.7726	3.8308	7.9658
1999	9.6559	10.7646	4.2748	8.0727
2000	9.7067	10.7897	4.3052	8.0588
2001	9.6767	10.8059	4.1698	8.054
2002	9.7888	10.2239	7.094	9.1811
2003	9.6675	10.7795	4.2015	8.0339

Table A.3: Species Diversity Indices (Junput)

Year	Jan-March	April-June	July-Sep	Oct-Dec
1994	10.0974	10.4838	6.216	9.3385
1995	10.0715	10.4803	6.2032	9.3573
1996	10.0941	10.4877	6.236	9.3884
1997	10.1032	10.472	6.2255	9.4084
1998	10.1046	10.4725	6.2497	9.4111
1999	10.139	10.3894	6.192	9.4153
2000	9.9996	10.4266	6.2433	9.3655
2001	10.1497	10.4719	6.2693	9.4276
2002	10.1496	10.5223	5.9456	9.4256
2003	9.6326	10.4214	4.7341	8.6465

Table A.4: Indices of Evenness (Diamond Harbour)

Year	Jan-March	April-June	July-Sep	Oct-Nov
1994	2.6536	2.717	2.5952	2.6998
1995	2.6484	2.7131	2.5906	2.7048
1996	2.6527	2.6959	2.5541	2.6745
1997	2.6141	2.6899	2.5124	2.6611
1998	2.6799	2.7265	2.6358	2.7147
1999	2.6799	2.7277	2.6345	2.7186
2000	2.6688	2.7199	2.6076	2.7042
2001	2.6731	2.7271	2.6076	2.7094
2002	2.6688	2.7224	2.6076	2.7042
2003	2.827	2.8176	0	2.7092

Table A.5: Indices of Evenness (Sagar South)

Year	Jan-March	April-June	July-Sep	Oct-Nov
1994	2.7746	2.8492	2.4245	2.7097
1995	2.7713	2.85	2.232	2.6883
1996	2.7739	2.8515	2.3543	2.6987
1997	2.7827	2.8298	2.2772	2.7134
1998	2.7743	2.849	2.1588	2.7117
1999	2.7859	2.8468	2.371	2.7197
2000	2.7928	2.8535	2.3838	2.7267
2001	2.7839	2.8577	2.3801	2.7142
2002	2.8019	2.7858	2.6114	2.8004
2003	2.7815	2.8507	2.3125	2.708

Table A.6: Indices of Evenness (Junput)

Year	Jan-March	April-June	July-Sep	Oct-Nov
1994	2.8108	2.8415	2.766	2.8056
1995	2.8036	2.8405	2.7607	2.7927
1996	2.8099	2.8426	2.7728	2.802
1997	2.8126	2.8382	2.7689	2.8084
1998	2.8129	2.8384	2.7808	2.809
1999	2.815	2.8357	2.7561	2.8104
2000	2.8132	2.8455	2.7768	2.8261
2001	2.8179	2.8446	2.8072	2.8138
2002	2.8253	2.852	2.631	2.8467
2003	2.851	2.9002	2.6445	2.7286

Table A.7: Indices of Dominance (Diamond Harbour)

Year	Jan-March	April-June	July-Sep	Oct-Nov
1994	0.2238	0.2012	0.4623	0.2317
1995	0.2228	0.1999	0.4637	0.2305
1996	0.2235	0.2083	0.4898	0.2425
1997	0.2316	0.2089	0.5041	0.246
1998	0.2146	0.1989	0.4367	0.2209
1999	0.214	0.198	0.4366	0.223
2000	0.2174	0.2002	0.4528	0.2286
2001	0.2158	0.1972	0.4528	0.2264
2002	0.2174	0.1974	0.4528	0.2286
2003	0.3638	0.1786	1	0.6012

Table A.8: Indices of Dominance (Sagar South)

Year	Jan-March	April-June	July-Sep	Oct-Nov
1994	0.1438	0.0938	0.8193	0.2658
1995	0.147	0.0932	1.0589	0.274
1996	0.1464	0.093	0.9932	0.2693
1997	0.1455	0.0981	1.0293	0.2654
1998	0.1473	0.0937	1.1701	0.2731
1999	0.1464	0.094	0.9853	0.2626
2000	0.1414	0.0933	0.961	0.2585
2001	0.1437	0.0922	0.9901	0.2645
2002	0.1325	0.1131	0.3844	0.1648
2003	0.1451	0.0931	1.016	0.2668

Table A.9: Indices of Dominance (Junput)

Year	Jan-March	April-June	July-Sep	Oct-Nov
1994	0.1189	0.1021	0.463	0.1573
1995	0.1203	0.1025	0.4656	0.1576
1996	0.1193	0.1021	0.4639	0.1562
1997	0.1194	0.1031	0.4637	0.155
1998	0.1195	0.1031	0.4594	0.155
1999	0.1182	0.1064	0.4721	0.1556
2000	0.1227	0.1043	0.4586	0.1542
2001	0.1169	0.1025	0.4524	0.1521
2002	0.1165	0.1003	0.537	0.1511
2003	0.1353	0.1011	0.7849	0.2106

B.1 Model Without Internalizing the Biodiversity Loss Cost in the Total Cost of Production

The results for the translog cost function estimates without biodiversity loss attributed as a cost turn out to be similar in many respects to the ones discussed above.

Table B.1: Estimates of Translog Total Cost Function

Variable	Coefficient	T-ratio
A	14.992	1.926
βla	1.013	4.095*
βle	-0.519	-2.578**
βsd	0.456	1.519
βy	-1.087	-0.89
$\beta lala$	0.149	3.77*
$\beta lale$	-0.031	-4.008*
$\beta lasd$	-0.116	-2.973*
$\beta lele$	0.046	6.835*
$\beta lesd$	-0.006	-0.604
$\beta sdsd$	0.130	3.108*
βlay	-0.060	-3.047*
βley	0.072	4.492*
βsdy	-0.015	-0.603
βyy	0.141	1.474

*Note: * denotes significance at 1 percent*
*** denotes significance at 5 percent*
**** denotes significance at 10 percent.*

Table B.2: Own Elasticity of Substitution (Allen)

Wfwf	-10.771
Lablab	-0.6257
Seedseed	-0.9239
leaselease	-1.6372

Table B.3: Own-price Elasticity of Demand

Variable	Coefficient
Wfwf	-0.6357
Lablab	-0.2231
Seedseed	-0.2394
leaselease	-0.5327

Own-price elasticities are negative for all the inputs (as expected). However, the own-price elasticity of seed is lower than earlier at –0.24 (compared to –0.53 when biodiversity loss was included as a cost). *In other words, including biodiversity cost made this input relatively more responsive to changes in its own-price.*

From the results of own-price elasticities it can be said that waterfeed to some degree is responsive to its own- price –0.63. Other inputs are not responsive as the elasticities are very low. This means that even if the price of labour, seed and land-lease increases, for carrying out production, their demand would not decrease by the same proportion. The results of the cross- price elasticities show that waterfeed input, basically the price of chemicals, organic fertilizers and feed, is an important input in the aquaculture production.

Table B.4: Cross- price Elasticities

Variable	Coefficient
Wflab	0.3151
Labwf	0.0521
Wfseed	0.1354
Seedwf	0.0308
Wflease	0.1852
Leasewf	0.0335

Labseed	-0.0665
Seedlab	-0.0915
Lablease	0.2374
Leaselab	0.2601
Seedlease	0.3001
Leaseseed	0.2390

The cross-price elasticities are low for all the inputs. There is a negative relationship between labour and seed exhibiting *weak complementarity*.

Table B.5: Cross Elasticity of Substitution (Allen)

Variable	**Coefficient**
Wflab	0.8839
Wfseed	0.5225
Wflease	0.5691
labseed	-0.2567
Lablease	0.7296
Seedlease	0.9223

Important observations that can be made:

1. Waterfeed and labour are substitutes of one another, as the elasticities are positive for them, AES 0.883.
2. Seed and lease are also substitutes of one another- AES around 0.922 with corresponding cross- price elasticities of 0.30 and 0.24.
3. Slight complementarity exists between labour and seed as is suggested by AES –0.25 and cross-price elasticities-0.06 and –0.09.

There is evidence of strong scale economies in aquaculture production in this model as well. The value of 0.45 of the coefficient of economies of scale indicates that a one percent increase in the output would lead to less than one percent (0.45) increase in the total cost.

Table B.6: Estimates of Translog Total Cost Function

Variable	Coefficient
βlay	-0.060
βley	0.072
βsdy	-0.015
βyy	0.141
βwfy	0.002

The negative coefficients of βlay and βsdy imply that there is scale bias against the use of labour and seed, whereas the positive coefficients of lease βley and waterfeed βwfy indicate scale bias in favour of the two. In other words, scale is labour and seed saving. An increase in output would lead to less than proportionate increase in labour and seed. Which is not the case with lease and waterfeed. This also means waterfeed, quality of water and feed for the shrimp, are important inputs in the aquaculture.

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