AN INVESTIGATION INTO THE RELATIONSHIP BETWEEN FISH BIODIVERSITY AND PROFIT MAXIMISATION

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1. INTRODUCTION:

The environmentally sustainable use of fish resources is central to fisheries management, given the long-term importance of this sector in terms of nutrition and employment. But today's major concern relates to the unsustainable levels of exploiting fishes with such practices that lead to the depletion of fish stocks, disruption of ecological equilibrium and reduction in diversity. A recent re-analysis of FAO catches statistics (Pauly et al., 1998) documents progressive 'fishing down' of food chains as fishing effort responds to depletion of original target stocks where one species is exploited more than another their relative abundance changes, as in the North Atlantic (Sherman, 1990). This is referred to in the literature as 'fishing down the food web'. Virtually all commercially valuable marine populations are now overexploited. Overexploitation diminishes species population and reduces economic return. As the most valuable species are overfished, they are quickly replaced by catches of less desirable ones. It is seen that a large share of today's global catch consists of previously unused, less valuable species. This type of phenomenon has been identified as 'fishing down the value chain' (Kasulo and Perrings, 2001) in the literature. 'Fishing down the food web' implies that the value of fished stock decreases, but this may not be captured until they make it to the market. Whatever be the fishing sequence, demand or supply driven, it will have an impact on fish biodiversity with a change in composition and relative abundance of harvested species. So a desire to increase profits may hamper economic biodiversity conservation and thereby affect the value of the fishery.

2. CASE STUDY:

Our study uses fish species as indicators of trends in coastal biodiversity. This study looks into the loss of fish biodiversity and its effect on profitability of a fishery. The theoretical aspect is modelled in an extension of the aggregated Gordon-Schaefer standard fisheries model. This study focuses on the Digha fishery in West Bengal on the eastern marine coast of India on the Bay of Bengal as a micro case study in an attempt to analyze the relationship between biodiversity and profitability present there, if any.

Our study area is a part of the coastal area of West Bengal. The total coastal area of West Bengal stretches between the mouths of rivers Herobhanga or Harinbhanga on the Indo-Bangladesh border in the east and Subanarekha in the west, the total length of which is about 220 kms. Quite naturally, fishing activities in this zone provide economic sustenance and a source of livelihood to a cross-section of people who, in turn support the flourishing trade in this lower Ganga deltaic region. The coastline of West Bengal spreads over two maritime districts- 24 Parganas (South) and East Midnapore. There are 13 marine fish landing centers in 24 Parganas and 27 in East Midnapore. The Contai coastal belt under the district of East Midnapore is considered to be highly potential in respect of marine fisheries activities. The coastline stretches from Digha under Ramnagar-I Block to Talpati Ghat under Khesuri-II Block and is about 60 km. in length. Digha is situated close to the Gangetic mouth on the east of India at lat. 21^0 36'N. and long. 87^0 30'E. It is located in the West Midnapore district of the State of West Bengal of Eastern India and lies in the southern most part of the state on the bank of Bay of Bengal. With the introduction of diesel using powerboats, deep-sea fishing and mechanization in fishing is taking an upturn[1]. It has been observed in Digha coastal areas that total marine fish landing mainly consists of sardine, hilsa, coila, pomphret, croakers, Bombay duck, catfish, ribbon fish, shark, shankar, prawn[2] etc. Thus total 37 varieties of fish are found here. These varieties have been divided into five groups considering their importance from the viewpoint of their demand and price[3]. Among them contribution of hilsa

[1] The trawlers are in operation for about 10 to 11 months in a year and generally they are rested in the months of April-May. Usually a fishing trip lasts for about five days in sea and after the catching, the catch is landed in the harbour where from they are sold in the wholesale market at Digha. According to the Digha Fishermen and Fish Traders' Association, the wholesale fish market at Digha accounts for Rs. 70 million a year (Ganguly, 2004). Aso a large portion of the catch is ice packed and sent to the wholesale market in Sealdah of Kolkata and Howrah for auctioning. Besides sending the catch to Kolkata sometimes fishes like pomfret and sea urchins are sent directly to Chennai or Visakhapatnam for marketing.

[2] The biological names of some of the fishes are given in the parantheses: sardine (*Sardinella gibbosa*), hilsa (*Hilsa Tenualosa ilisha)*, coila, silver pomphret (*Pampus argenteus*), black pomfret (*Parastromateus niger*), croakers (*Johnius belangerii*), Bombay duck (*Harpadon nehereus*), catfish (*Arius jella* Day), ribbon fish (*Eupleurogrammus muticus*), shark (C*archarhinus limbatus)*, mackerels (*Rastrelliger kanagurta*), prawn.

[3] See Das, Neogy and Chakraborty (2000).

in total catch per trip was found to be maximum in Digha. It was followed by two types of pomfret: Chinese and Silver pomfret being one variety and the other being Black pomfret. So we see from collected data that mainly four varieties of marine fish dominate the Digha fishing industry in terms of both prices and quantity. They are Hilsa, Chinese and Silver Pomfret, Black Pomfret and Prawn. More than 50% of the total value of catch was contributed by these four species. Individual contributions of other 33 species in terms of value are not very significant. Also these other 33 varieties of fish such as (in local vocabulary) *sardine, mackreal, chela, para* and *American bhetki* have a very low price range in the market. These have been grouped under the heading 'others'. \

The issue of investigating any relationship between biodiversity and profitability has largely been neglected in the literature for this particular location. The sustainability issue has been dealt in some empirical works pertaining to Digha fishery and they are essentially biological and static in nature (Central Marine Fisheries Research Institute, 1984; Guha, Neogi, Das and Chakraborty, 1994, Das, Neogi and Chakraborty, 1996; Das, Neogi and Chakraborty, 2000; Dhar, 2004, Jana, 2004). The Digha Fishermen and Trader's Association regulates fishing activities in that area and acts as a profit-maximising unit within a larger competitive fish market. But a void exists in terms of bioeconomic modeling of the fishery in a dynamic profit-maximisation set-up in the literature. Also the question of biodiversity needs to be addressed in the light of various reports[4] of the marine fisheries of West Bengal. So this paper focuses on the dynamics of the profit-maximising regime and estimates the dynamic maximum economic yield and net present-value of fishery profit that is maximized here. Sensitivity analysis with respect to small perturbation in discount rate examines its impact on profit under different biodiversity scenarios. In the end we examine whether economic biodiversity conservation are in conflict with profitability of the fishery. Section 3 focuses on the importance of biodiversity and its ecological and economic aspect. Section 4 presents data analysis and socioeconomic aspects of Digha fishery. Modelling and results of model estimation have been presented in Section 5. Optimum values of the variables under profit-

[4] The coastal fisheries of West Bengal have seen both freshwater fishes and migratory marine species spawn during the monsoon. In the last three decades (1960-1990), there have been catastrophic changes. Hilsa, an anadromous fish, which used to constitute about 70% to 80% of total fish landings, is disappearing. Instead, marine catfish have become dominant here (Rao, 2000).

maximising regime has been derived in Section 6. Section 7 reports results of sensitivity analysis. Section 8 arrives at some concluding remarks.

3. IMPORTANCE OF BIODIVERSITY:

The importance of biodiversity[5] had long been recognized by ecologists and environmentalists. But the main focus came into being with the initiation of the Convention on Biological Diversity in 1992 (UNCED, 1992). The emphasis was on conserving biodiversity to achieve the sustainable use of its components and therefore to secure the fair and equitable sharing of the resources which that biodiversity represents. Our study relates to that area of the Convention that emphasizes on "… marine and other aquatic ecosystems, and the ecological complexes of which they are part………" and the value that they represent.

Conservation of biodiversity is important in environmental management programs (Turner and Gardner, 1991; Reid and Miller, 1989). Measuring biodiversity is one of the central issues in ecology because of its importance in devising conservation strategies. However, incorporation of biodiversity in a fisheries model is a difficult task. This difficulty arises from the lack of a single practical operational definition and measurement of biodiversity. A simple measure in the literature of ecology used for quantifying fish diversity is to count the number of species in the habitat or community. This measure is considered to be too simplistic and so other indices measuring biodiversity based both on number and abundance of species have been identified. The idea of species diversity has two distinct concepts: species richness and abundance. Species richness is the number of species in a community, while abundance explains the relative proportion of each species in the community. The Shannon index[6] is a very well known example of the richness index group. An important example of dominance index is the Simpson's index[7].

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[5] The term biological diversity has a long history of usage in a variety of contexts (OTA, 1987; Reid and Miller, 1989; McNeely et al., 1990; McAllister, 1991; Wilson, 1992; Johnson, 1993 and Sandlund et al., 1993). Harper and Hawksworth (1994) traces back its rise in the current sense to Lovejoy (1980) and Norse and McManus (1980) and mean essentially the number of species present in a community of organisms.

[6] $H^* = -\sum_{i=1}^{s} (p_i)(\log p_i)$

The main difference between the above two type of indices is that species richness indices are weighted more towards uncommon species while dominance indices are weighted more towards the abundant species. The question now is one of selecting the most appropriate method of measuring diversity[8]. The choice of the index should depend on the component of diversity being measured. If the main concern is on rare species, then richness- based species should be used. But if the major interest lies in the abundance of the commonest species, then dominance indices are preferred. In our case of Digha fishery, data on catch per species will be used to compute the level of biodiversity. Here dominance indices is the most appropriate measure as catch data change shows changes in the abundance of dominant species. In order to apply the Simpson index to the case of fisheries, the unit of measurement must be changed from individuals in a sample population to biomass in the total catch (Goda and Matsuoka, 1986). So the Simpson index (henceforth called the unweighted or ecological Simpson's index) can be expressed as:

$$D_t = \sum_{i=1}^{s} (Y_{it}/Y_t)^2$$

where Y_{it} is the catch of the ith species harvested in period t, Y_t is the total catch in period t and s is the number of species harvested in period t. The use of this estimate enables us to identify an empirical relation between the diversity index and total catch.

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where H* is the Shannon index of species diversity, s is the number of species and p_i is the proportion of total sample belonging to ith species. The larger the value of H*, the greater the diversity.

[7] $D = \sum_{i=1}^{s} p_i^2$

where D is the Simpson's index, and p_i is the proportion of species i in the community. Diversity decreases with increasing D, which ranges from almost zero to one.
In some studies, for a measure of diversity, the complement of Simpson's index is used. It is given as:

$$1\text{-}D = 1 - \sum_{i=1}^{s} p_i^2,$$

where 1 – D is the Simpson index of diversity. The Simpson's index of diversity ranges from zero for low diversity to almost 1.

[8] A study comparing Shannon index and Simpson index has shown that the latter is the least biased between the two (Monillos and Leprêtre, 1999).

These diversity indices are basically ecological in nature as they emphasize on ecological differences among species that comprise a community or habitat.

Heywood (1995) reports about the growing perception among both ecologists and economists that the importance of biodiversity lies first and foremost in its role in the production of goods and services that are useful for human welfare i.e., in its social-economic importance. An individual harvested species is valued for specific properties that make it useful in either production or consumption. The biodiversity that supports such species derives its value from this. Any measure of diversity should accordingly reflect this (Perrings, 2000, Heywood, 1995). Ecological and economic values are not necessarily the same. It does not follow that if biodiversity is important to the functioning of some ecological system then it will automatically be valuable for society. Nor does it follow that a species that is rare will be economically scarce and hence valuable. So, there is no necessary correspondence between ecological biodiversity measures and economic value of biodiversity. Systems with a high biodiversity value by any of the standard indices may or may not have high economic value. So, to reflect the socio-economic value of diversity, the ecological diversity measures need to be modified (Kasulo and Perrings, 2001). In fisheries, as most of the species caught are marketed, an economic value of a species can be approximated by using market prices (Hanemann, 1988). The rationale for social-economic valuation of biodiversity lies in the fact that the signals generated by the market system i.e., prices lead to excessive rates of biodiversity loss (Heywood, 1995). Market prices influence the exploitation of a fishery and hence the level and direction of effort. Targeting of effort towards particular species leads to elimination of highly valued species, and to a reduction in biodiversity and productivity (Barbier et al., 1994). To capture the economic value of species, the Simpson's biodiversity index is modified such that it uses market values of species caught rather than the total amount of species caught. Now, the actual amount of the species will be weighted by price. Therefore, the Simpson's index becomes (henceforth called the weighted or economic Simpson's index):

$$B = \sum_{i=1}^{s} (P_i Y_i / TR)^2$$

where B is the economic biodiversity index, P_i is the per unit price of species i, and TR is the total revenue. When all the species have the same market value, the solution for economic biodiversity index is the same as the ecological biodiversity index. When the community is dominated by species of high market value, economic biodiversity index will be greater than an ecological biodiversity index of the same community and vice versa.

Ecologically, it is acknowledged that when the major concern is about the uniqueness of species, then each different type of species should have equal inherent value. However, when economic considerations are taken into account, then different species are assumed to have different values. Biodiversity may take on different values depending on people's perception of the economic or ecological importance of species diversity to human welfare (Barbier et al., 1994). In our study following the work by Kasulo and Perrings (2001) biodiversity is weighted by its economic significance. This is important because it reflects the value of biodiversity to humans. Thus, more weight is given to species with higher market values.

4. DATA ANALYSIS:

Data for this study has has been collected from the Digha Fishermen and Fish Traders' Association[9] in Digha covering the period 1993-94 to 2002-03. Catch is measured as kg.of fish landed and effort is represented by fishing months[10]. Digha fishery, in recent years, has seen a shift in fish species harvested towards catches of fish species of very low local value (ranging between Indian Rs. 4– Rs.35 per kg.) consisting of sardine, chela and kaante which we have clubbed under the heading 'others'. This transition in fish catch from high valued to low valued species points to the role of the market and the effects of economic forces in loss of biodiversity. The decline in the dominance of hilsa

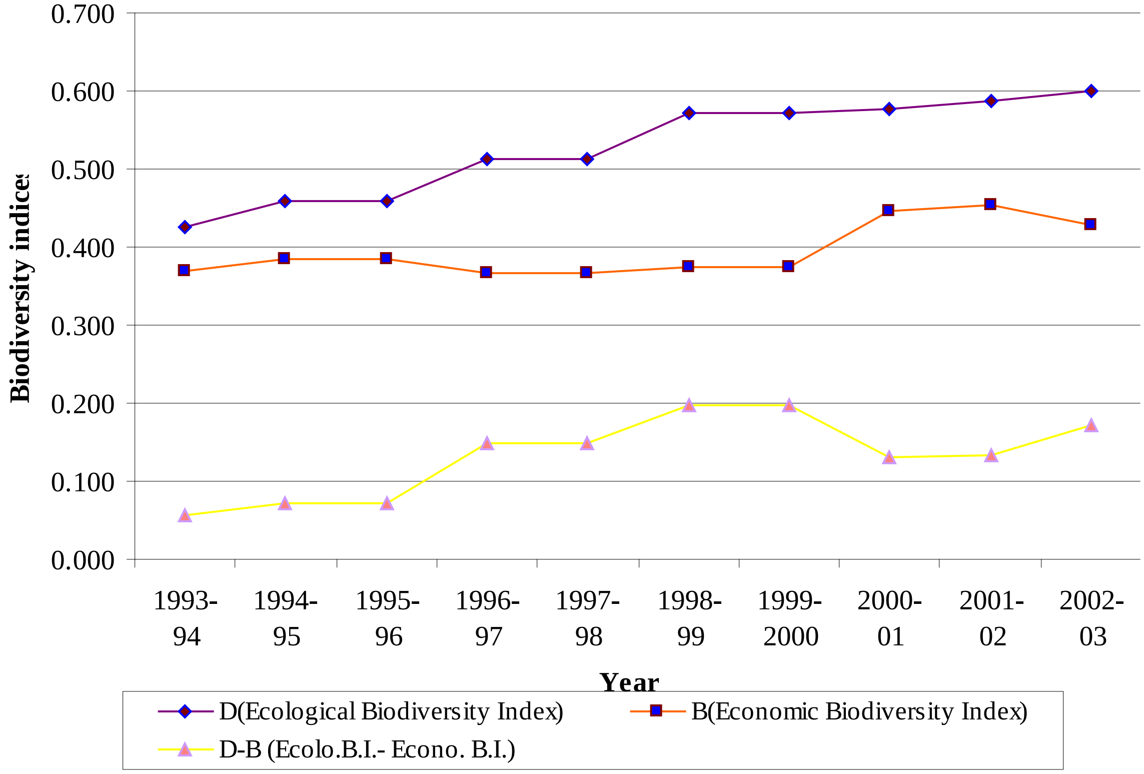
[9] Annual Reports of the Digha Fish Traders' Association, Various issues.

[10] Fishing effort has been calculated on the basis of a composite index constructed by us. It has been taken to be the weighted average of number of fishing hours involved in catching fish through fishing boats and trawling boats where the weights are the number of trips by fishing boats and trawling boats in an year.

in total catch reflects not only a decline in the trophic level of fishes but can also be associated with its economic value. The total landing of hilsa has declined to 1% in 2002-2003 whereas its contribution was 34% in 1993-1994. In contrast, the total landing of the species such as *sardine*, *chhela* and *kaante* has increased from 43% in 1993-94 to 75% in 2002-2003. It is interesting to note in this context that hilsa, which is a very popular traditional fish, has a high average price of Rs.73.18 per kg. while *chhela*, *sardine* and *kaante* are valued at very low average prices of Rs. 9.77 per kg. The market price in this case reflects people's preference and is one of the reasons for the over-exploitation of hilsa. So, not only is there a shift in relative dominance of fish species in total catch, it also reflects an exploitation from valuable to less valuable species. A comparative analysis of the unweighted and weighted Simpson indices is carried out by using the data on catch per species for the fishery of Digha. The Simpson economic biodiversity is constructed by weighting the simple ecological Simpson's index by average prices so as to capture fluctuations in value. It will capture any shift that may occur in fish value resulting from the over-exploitation of high-valued species. Data shows that a comparison between the Simpson unweighted and weighted indices, we find the value of the weighted index is lower than that of the unweighted index. It is because of the differences in the value of the species caught that the differences in the two indices occur. The lower values of the weighted indices in comparison with the unweighted index reflects that on average catches are dominated by less valuable species. If catches had been dominated by valuable species, price weighting would increase their dominance even further and the weighted indices would have higher values than unweighted indices (Kasulo and Perrings, 2001).

This is seen in figure 1 where it suggests a decline in economic biodiversity associated with a shift in fish catch from high-valued to low-valued species. Curve D reflects the ecological biodiversity index over the years and Curve B the economic biodiversity index over the period 1993-2003. The third curve D-B plots the difference between the ecological and economic biodiversity indices over the same period. The curve D-B takes on the shape of a somewhat inverted U-shape with the difference peaking in the year 1998-1999. In the early years of our study like 1993-1994 we find that the D-B curve is

Fig. 1: Comparison between ecological and economic biodiversity indices in Digha fishery



more or less flat shape at a low level, implying that the difference between the D and the B curves is fixed at a low level.

The implication is simple. At the initial stages of the liberalization regime we find that fishing was not much mechanized in Digha due to which fishermen there used to catch fish by using country boats or non-mechanised fishing boats. Naturally the cost of fishing at that time was not as high as we find in present situation. Due to lack of mechanized trawlers the fishermen at that time were unable to enter deep sea as a result of which they used to sell more or less similar type of fish species in the market. This situation is specific for the local markets near Digha. Apart from this, fish marketing in Digha was not as much developed as we find in present day situation. All these factors led to not much fish price per species variation along with its low price. Hence it can be argued that during the initial years of liberalization the difference between ecological and economic biodiversity indices was not much prominent. The gradual fall-off of the difference in the next few years show the loss of economic biodiversity that the fishery is facing with the more expensive fishes being fished out.

The socio-economic impact of loss of fish biodiversity when associated with a shift from high valued to low valued species are generally negative. Most of the fishermen operating in Digha coastal area are socio-economically backward with average literacy rate, given by census 1991, at only 30.68%. According to Digha Development Authority, there are 600 countryboat owners, 100 motorboat owners and 400 trawler owners operating in the fishery. The average family size in Digha is 4.74 persons/family (census 1991). The marine fishermen in Digha are mostly local people with negligible proportion of migrants, about 4%. With respect to land holding, average land per fisherman is very small. The primary reason behind this is that they find fishing business more profitable than cultivation. They work full time in fishing and do not have practically any other source of income. The shift in fish catch from high-valued to low-valued species means lower profits for the fishing vessel owners and hence crew labourers hired on per trip basis run the risk of losing their jobs. The trawler owners invest large amount of capital on boat and net while the countryboat owners, having non-mechanised boats, invests the least. Since these fishermen have poor economic background, they mostly have to borrow mainly from cooperative banks and private sources such as moneylenders called the Aratdars and Mahajans. A loss in fish diversity (reflected through fall in value of catch) will reduce profits and will mean an additional pressure in repayment and a subsequent debt trap for them. On the other hand, the crew labourers running the risk of unemployment and having no alternative source of income becomes worse off. In a survey conducted on Digha marine fishermen, Guha and Neogy (1996) has found that lower income group of fishermen spend approximately 60% of their monthly expenditure on food while higher income group spends 52% on an average on food items. So it is the crew labourer fishermen who are likely to be hardest hit by the decline in fish diversity.

5. MODELLING BIODIVERSITY:

The most marked effect of biodiversity loss occurs on the productivity of the resource. The effects of changes in fish diversity on fish productivity is observed in terms of the benefits of biodiversity in maintaining the aquatic ecosystems which produce the fish resources that are used for human consumption (Barbier et al., 1994). Fisheries bear the effect of biodiversity loss through declining biological and economic productivity and a diminished range of harvested species. The biodiversity variable can be introduced in the Gordon-Schaefer model through the production function that specifies a relationship between fish biodiversity as an input and fish catch as an output.

The effect of species diversity on fish productivity can be captured through an additional term in the fisheries production function (Kasulo and Perrings, 2001). Thus, we have,

$$Y = qDEX, \tag{1}$$

where D is the ecological biodiversity index constructed on the basis of Simpson's index. Again, we have,

$$Y = qBEX, \tag{2}$$

where B is the economic biodiversity index constructed by weighting the Simpon's index with market prices of the species[11].

The growth functions become

$$\dot{X} = rX(1 – [X/K]) – qDEX \tag{3}$$

and

$$X = rX (1- [X/K]) – qBEX \tag{4}$$

The sustainable yield functions become

$$Y = qDEX = qDEK(1 – qDE/r) \tag{5}$$

and

$$Y = qBEX = qBEK(1 – qBE/r) \tag{6}$$

Therefore,

$$(Y/DE) = qK(1 – qDE/r) = qK – q^2K/r.DE \tag{7}$$

$$(Y/BE) = qK(1 – qBE/r) = qK – q^2K/r.BE \tag{8}$$

[11] The case of D = 1 gives us the single-species relationship. The case of B = 1 gives us the case of one valuable species in the fishery i.e., all by-catches and discards are assigned zero value in the fishery. But it is always possible that B = 1 but D ≠ 1.

Equations (7) and (8) relates catch per unit of adjusted effort to adjusted effort[12] where effort is adjusted with ecological biodiversity index, D in the former equation and with economic biodiversity index, B, the latter.

Alternatively, we can write the sustainable yield function as

$(Y/AE) = qK(1 – qAE/r) = qK- q^2 K/r.AE$, and

$Y = qKAE – q^2K/r. (AE)^2$

where AE is the adjusted effort adjusted with the inclusion of biodiversity indices.

Differentiating sustainable yield function with respect to AE and setting that equal to zero, we have

$\partial Y/\partial AE = qK(1-2qAE/r) =0$

or, $AE_{msy} = r/2q$ (9)

For estimation purposes, we have followed the approach of Schnute (1977) where both types of biodiversity indices are introduced. It defines a population growth function in terms of U, i.e., catch per unit adjusted effort (Y/DE), where adjustment of effort is made on the basis of ecological biodiversity index, D. Therefore,

$U = rU(1 – U/qK) – qDEU$ (10)

Equation (10) has been obtained by considering Y/DE = U and by using the Gordon-Schaefer production function so that Y = qDEX implies Y/DE = qX = U or, X=U/q.

Dividing both sides of Equation (10) by U, we have

$(\dot{U} /U) = r – qDE – (r/qK)U$

or, $1/U.(dU/dt) = r – qDE – (r/qK)U$.

The equation can be framed after time averaging and thereby smoothing out the data as

$\ln X_t^* = r – qE_t^* - (r/qK)U_t^*$, (11)

where $X_t^* = U_t^*/U_{t-1}^*$; $E_t^* = (E_{t-1}+ E_t)/2$; $U_t^* = (U_{t-1} + U_t)/2$; $E_t^* = E_t D_t$ and $U_t^* = Y_t/(E_t D_t)$, D_t being the ecological biodiversity index constructed earlier.

[12]The biodiversity measures that are introduced are adjusted to changing fishing effort since efficiency of capture varies. Efficiency varies usually by reducing mesh size or changing fishing grounds. This problem gets accentuated in case of multi-species multi-gear fisheries where the same unselective gear is operated in the fishery. This is exactly why we are using adjusted effort in the context of biodiversity loss.

The modified biodiversity-incorporated Schnute equation, where the effort is adjusted on the basis of the economic biodiversity index, is

$\ln X_t^* = r - qE_t^* - (r/qK)U_t^*$, (12)

where $X_t^* = U_t^*/U_{t-1}^*$; $E_t^* = (E_{t-1} + E_t)/2$; $U_t^* = (U_{t-1} + U_t)/2$; E_t^*=Et Bt and $U_t^* = Y_t/(E_t B_t)$, B_t being the economic biodiversity index constructed earlier.

Alternatively, we can write

$\ln X_t^* = r - qE_t^* - (r/qK)U_t^*$, (13)

where $X_t^* = U_t^*/U_{t-1}^*$; $E_t^* = (E_{t-1} + E_t)/2$; $U_t^* = (U_{t-1} + U_t)/2$; $E_t^* = E_t A_t$ and $U_t^* = Y_t/(E_t A_t)$, where A are the biodiversity indices.

Our analysis uses the Schnute model, first including ecological biodiversity measure in equation (11) and the economic biodiversity measure in equation (12). Table 1 shows the results after regression.

Table 1: Regression results of the Schnute models (equation 13) in its modified forms (1) with introduction of ecological biodiversity index (2) with introduction of economic biodiversity index

Equation of Schnute model	**Constant**	**Coefficient of E_t^***	**Coefficient of U_t^***	**R^2 statistic**	**$\bar{R}^2$ statistic**
with inclusion of ecological biodiversity index	1.10174 (4.52187)	-0.0003181 (-3.56027)	-0.00260084 (-2.6065)	0.643079	0.5538487
with inclusion of economic biodiversity index	1.29711 (5.88448)	-0.0002845 (-4.67727)	-0.0026378 (-3.39413)	0.732351	0.665439

(t-values are given in the parentheses)

Note: (1) $E_t^* = (E'_{t-1} + E'_t)/2$, $E'_t = E_t D_t$ and $U_t^* = (U_{t-1} + U_t)/2$, $U_t = (Y_t/E_t D_t)$

(2) Dependent variable: X_t^* , where $X_t^* = U_t^*/ U_{t-1}^*$

The R^2 and $\bar{R}^2$ statistics indicate an improvement with inclusion of economic biodiversity as against ecological biodiversity index indicating the importance of the role of markets affecting fish harvested via price signals. The difference between the two models basically lies with the presence or absence of the economic forces that are at play. The model with unweighted (ecological) biodiversity index expresses a sort of subsistence fishery, which is harvested for self- consumption and not marketed. With the opening of a market, some species of fish are more in demand due to their high value and there is pressure on these species. So, the model with weighted (economic) biodiversity index acts like a commercial fishery where high-valued fish is harvested for profit making. The incentive to increase profit with the development of a larger market acts as a strong force to reduce biodiversity. In Digha, the fish harvested is not only sold locally but also has a large regional and export market and so fishing gears are adjusted accordingly. We find that market plays a strong role in the harvest from the fishery. The weighted biodiversity index integrates the economic and biological differences of the fish species and therefore reflects more accurately the bioeconomics of the fishery. So the Schnute model incorporated with economic biodiversity index helps sufficiently to explain the effects of economic biodiversity on fish harvest. Therefore, the use of the model with economic biodiversity index is more apt here as a management tool to sustain fisheries and in the process help conserve fish biodiversity.

6. OPTIMUM VALUES OF THE VARIABLES:

The model with the economic biodiversity index registered a better performance. It can be seen that an improvement occured after the introduction of a weighted economic biodiversity index and now the model explains about 73% of the variation in fish biomass, which is a good fit for the regression line. Since it helps to explain a large proportion of the variation in fish biomass, this equation is used for using the estimated values of the parameters for the purpose of sensitivity analysis.

One can now estimate the optimum values of the variables under different biodiversity scenarios. The economic biodiversity index that has been considered in our regression procedure is actually the average of the economic biodiversity indices constructed over the time horizon of our study. Generally, the value of B ranges from 1 for the lowest diversity (where the fishery is dominated by species of the same value) to 1/s, where s is the number of species, giving a high level of fish diversity (where fishes have a wide range of differentiated market values). In this context, we have compared three different biodiversity scenarios, reflecting fishing down the value chain that is occurring in the fishery in Digha: one, a scenario where the fishery has a wide range of different valued fish species i.e., high level of economic diversity (past situation), another being the average level of economic biodiversity in the fishery (current situation) and the third, a scenario where the fishery has fish species mostly of similar values i.e., low level of economic diversity (projected future situation).

The dynamic values of the variables have been calculated for the profit-maximising regime. The need for deducing the dynamic values become important since to judge the sustenance of the fishing industry static rent maximization is not optimal if the objective is to maximize present value of profit. The results have been obtained by using the parametric values given in Table 2 and obtained by estimating Schnute's modified equation.

Table 2: Values of the parameters of the Digha fishery model

Parameter	Notation	Value	Unit
Intrinsic growth rate[a]	r	1.10	dmnl./year
Catchability coefficient [b]	q	0.0003181	1/fishing hours
Environmental carrying capacity of fish stock [c]	K	1331685.933	Kg.
Average weighted economic biodiversity index [d]	B	0.3946	dmnl
Average price [e]	p	43.637616	Rs./kg./year
Average cost [f]	c	46.65569	Rs./fishing hour
Discount rate[g]	δ	0.11	dmnl./year

[a] the intercept value of the regression of the modified equation (12)

[b] the value of the coefficient of the effort function of the regression of the modified equation(12)

[c] calculated by using the value of the coefficient of the catch per unit effort function and then plugging in the values of r and q

[d] the average of the economic biodiversity indices constructed for the period under study

[e] it is the aggregative average of the prices of all fish species under our consideration during the time period of our study

[f] it is the total cost incurred by fishermen calculated on the basis of their wages both for labour in boats and trawlers

[g] it is approximated by the current market rate of interest

These values are tabulated under three alternative biodiversity scenarios of the fishery. Since in Digha fishery, the Digha Fishermen and Traders' Association regulates the local fishing activities and acts as a competitive profit-maximising unit in the larger regional fish market, we have ultimately focused on the dynamics of the profit-maximising regime and used it for our sensitivity analysis.

The optimal or profit-maximising regime solution-

Dynamic framework:

In the dynamic framework, fishers seek to maximize the present value of profits over a time horizon 0 to T subject to the constraint of net growth of fish stock. The problem can be stated as

Max. $\pi = \sum_{t=0}^{T} (pY_t - C_t)\,\rho^t$, where $\rho = 1/1+\delta$, and δ is the rate of discount,

subject to

$X_{t+1} - X_t = rX_t(1 - X_t/K) - Y_t$,

where $Y_t = qX_t\,B\,E_t$ and $C_t = cE_t$ (14)

We can rewrite the problem as

Max. $\sum_{t=0}^{T} (pqX_t\,BE_t - cE_t)$

subject to $X_{t+1} - X_t = rX_t(1 - X_t/K) - qX_t\,BE_t$. (15)

The current value Hamiltonian, H_c, for this problem is

$H_c = (pqX_t\,BE_t - cE_t) + \rho\nu_{t+1}(rX_t(1 - X_t/K) - qX_t\,BE_t)$, (16)

where ρ (the co-state variable) is the current value shadow price associated with a change in the fish stock, E_t is the control variable and X_t is the state variable. The first-order necessary conditions for a maximum are

$\partial H_c / \partial E_t = 0$, (17)

$\rho\nu_{t+1} - \nu_t = -\partial H_c / \partial X_t$ (18)

and

$X_{t+1} - X_t = \partial H_c / \partial \rho\nu_{t+1}$. (19)

Equations (17) and (18) give

$(pqX_t\,B - c) - \rho\nu_{t+1} q\,X_t B = 0$

$\rho\nu_{t+1} = p - (c/qX_t)$, and

$\nu_{t+1} = (1+\delta)[\,p - (c/qX_t B)]$. (20)

Equation (18) gives

$\rho \nu_{t+1} - \nu_t = -pqE_t - \rho \nu_{t+1} r\{1 - (2X_t/K)) + \rho \nu_{t+1} qBE_t$ (21)

Steady-state implies that $\nu_{t+1} = \nu_t = \nu^*$ and $X_{t+1} = X_t = X^*$. So, equation (21) becomes

$\nu^*(\rho - 1) = qBE_t\ (\rho\nu^* - p) - \rho\nu^* r\{ 1 - (2X_t/K) \}$. (22)

Putting $\rho = 1/(1 + \delta)$ and using equation (20) (after putting $\nu_{t+1} = \nu^*$), we get

$BE_t = (1/cq)\ (pqBX_t - c)\ [\delta - r\{1 - (Xt/K)\}]$. (23)

Again, equation (21) at steady-state gives

$BE_t = (r/q)\ \{1 - (X_t/K)\}$. (24)

Comparing (23) and (24) and by letting $\Omega = c/Bpq$, we get

$X^*_{dyn.} = \frac{1}{4}\ [\ \{\Omega + K(1 - \delta/r)\} + \sqrt{[\{\Omega + K(1 - \delta/r)\}^2 + 8K\Omega(\delta/r)]}$. (25)

Once $X^*_{dyn.}$ is known, we can determine the optimum levels of effort and catch as

$E^*_{dyn.} = (r/q)\ \{ 1 - (X^*_{dyn.}/K) \}/B$ (26)

$Y^*_{dyn.} = qX^*_{dyn.} BE^*_{dyn}$ (27)

Hence, the optimum level of NPV of profit is

$NPV^*_{dyn} = \sum_{t=0}^{T} (pY^*_{dyn.} - cE^*_{dyn.})(1/1+\delta)^t$ (28)

Here $X^*_{dyn.}$, $Y^*_{dyn.}$, $E^*_{dyn.}$ and $NPV^*_{dyn.}$ are respectively the optimal values of fish stock, harvest, effort and net present value of profit.

The optimal values of the variables in the dynamic framework have been calculated, as before, using the values of the parameters given in Table 2. The results are shown in Table 3.

Table 3: Dynamic profit-maximising values of the variables under three alternative economic biodiversity scenarios

	PROFIT-MAXIMISING SOLUTION (Dynamic Framework)			
Alternative scenarios of economic biodiversity of the fishery	**Stock (kg.)**	**Harvest (kg./year)**	**Effort (fishing hours/year)**	**PV of profit (Rs.)**
Situation 1: High economic biodiversity	3,37,867.74	2,64,913.46	12,903.42	39,91,152.55
Situation 2: Average economic biodiversity	3,25,940.71	2,70,780.52	6,618.47	40,16,415.89
Situation 3: Low economic biodiversity	3,15,648.21	2,77,360.45	2,638.39	41,13,563.35

From Table 3, we find that with progressively lower levels of biodiversity, stock size and effort decrease while fish harvest rises. This is evident when we look at Situation 1(catch: 2,64,913.46 kg./year; effort: 12,903.42 fishing hours/year) and compare it with Situation 2(catch: 2,70,780.52 kg./year; effort: 6,618.47fishing hours/year) and Situation 3 (catch: 2,77,360.45 kg./year; effort: 2,638.39 fishing hours/year). We also observe NPV of profit to increase with lower diversity (an increase from Rs. 39,91,152.55/year in Situation 1 to Rs. 40,16,415.89/year in Situation 2 and a further rise to Rs. 41,13,563.35/year in Situation 3). So economic diversity reduction is associated with a rising level of NPV of profit masking the existence of the potential threat of a loss of the valuable fish species in the fishery.

6. SENSITIVITY ANALYSIS:

Pertubations in discount rate:

We consider, *ceteris paribus*, the impact of perturbations in the discount rate, δ, (base δ= 0.11) on the optimal values of the variables. The optimal values of the variables given in Table 2 and 3 are considered as the base values in our sensitivity analysis. The discount rate here approximated by the market rate of interest represents the opportunity cost of investing in the fishery vis-à-vis other assets or allied industries. We here have considered a range from 0.9 to 0.13 between which the market rate of interest has varied over the last 10 years as obtained from Reports on Currency and Finance of the Reserve Bank of India.

Table 3: Impact of perturbations of the discount rate on NPV of profit

Change of discount rate	**NPV of discounted profit (Rs./year)**	**Change with regard to reference/base value**
0.09	58,87,813.70	+ 46.59%
0.10	48,10,318.90	+ 19.76%
0.12	36,55,341.10	- 8.98%
0.13	25,78,135.60	-35.81 %

***Reference/Base values**: Discount rate = 0.11, Stock =3,25,940.71 kg., Harvest =2,70,780.52kg./year, Effort =6,618.47 fishing hours/year and NPV of profit = Rs. 40,16,415.89 /year*

From Table 3 we find that NPV of discounted profit falls as discount rate rises. The change in NPV of profit with regard to the reference value is relatively much higher at low discount rates than at high ones. In terms of biodiversity considerations, one can infer from Table 4, that NPV of profit $_{\text{situation 3}}$ > NPV of profit $_{\text{situation 2}}$ > NPV of profit $_{\text{situation 1}}$

implying that profitability increases only at the expense of declining economic biodiversity. Another important observation is that the gain in NPV of profit associated with decreasing levels of biodiversity is higher when we contrast between Situations 2 and 3 than between Situations 1 and 2.

Table 4: Impact of perturbations of the discount rate, δ, (reference/base value: δ = 0.11) on optimal value of NPV of profit under three alternative scenarios- (1) high economic diversity (2) average economic diversity and (3) low economic diversity in the fishery model

Value of δ	**SITUATION 1: (NPV of profit)$_{\text{high level of economic biodiversity}}$**	**SITUATION 2: (NPV of profit)$_{\text{average level of economic biodiversity}}$**	**SITUATION 3: (NPV of profit)$_{\text{low level of economic biodiversity}}$**	**Gain in NPV of profit at the expense of fall of economic fish biodiversity from a high level to an average level**	**Gain in NPV of profit at the expense of fall of economic fish biodiversity from an average level to a low level**
	(1)	(2)	(3)	(4) = (1) - (2)	(5) = (2) – (3)
0.09	52,71,870.10	58,87,813.70	67,98,443.26	6,15,943.60	9,10,619.46
0.10	38,31,035.15	48,10,318.90	56,41,354.05	5,61,373.10	8,31,035.15
0.11	35,02,624.53	40,16,415.89	47,75,812.15	5,13,791.36	7,59,396.26
0.12	31,99,265.50	36,55,341.10	43,49,312.29	4,56,075.60	6,93,971.19
0.13	21,48,685.20	25,78,135.60	32,13,018.97	4,29,450.40	6,34,883.37

So paradoxically it can be seen that greater endeavor to capture the most expensive species leads to greater losses associated with the fishery. This occurs as demand in the markets triggers off greater exploitation of the expensive species and in this process large amounts of cheaper by-catches are discarded. So the current trend towards the exploitation of only valuable fish species raises doubts about the profitability and hence sustainability of the fishery. One can hence conclude that maximization of profit and economic biodiversity considerations are ultimately in conflict with each other in the context of sustenance of a fishery. This underlines the importance of economic scarcity and the role of market demand for fishes in a fishery. Changes in the discount rate have been found to affect fish catch and NPV of profit and hence loss of economic biodiversity. The higher the discount rate or rate of interest on a project the smaller the present value of a given payment in the future. It is important to consider the factors that lead to changes in the discount rate such as excess demand for money or decrease in government spending. Policies that lead to reduction in interest and discount rates will also lead to losses in biodiversity. So economic biodiversity conservation is at stake in a high profit-maximising regime.

8. CONCLUDING REMARKS:

A biodiversity variable has been introduced in the Gordon-Schaefer model through the production function that specifies a relationship between fish biodiversity as an input and fish catch as an output. One biodiversity measure is introduced based on the observed pattern of sequential exploitation that fisheries go through as they develop. A fishing-up process has been observed whereby fish stocks are gradually depleted from large to small fishes, abundant to less abundant species and from easily caught to less easily caught species (Pauly et al., 1998). This is basically the Simpson's ecological biodiversity index that has been used here. One other index has been used here-the economic biodiversity index- based on the observation that in the development of a fishery the sequence of exploitation is from high-valued to low valued fish species (Boechlert, 1996). The Simpson's biodiversity index has been modified here by weighting the former with market prices of the fish species. The Simpson index following Kasulo and Perrings (2001) has been used as the basis for developing a modified index because it is more sensitive to changes in dominant species. To incorporate the economic value of biodiversity, the index used has been the weighted market price of fish species. The indices here been calculated on the basis of the catch data of the Digha fishery. It has been found that the economic (weighted) biodiversity index has lower values than the ecological (unweighted) biodiversity index. This suggests that fish catch in Digha fishery are dominated by less valuable species. Our work started with the standard Gordon-

Schaefer model which has been modified to include the biodiversity variable. The parameters of the model are estimated using Schnute's (1977) method, as it reduces the bias in the estimates resulting from errors in the measurement of variables. The model fit and the parameter significance improved with the introduction of the economic biodiversity index as against the ecological biodiversity index. This clearly shows that biodiversity plays an important role in the value of the fishery. This is specially true if the fishery is subjected to market forces where the market value of the species is taken into account. The ecological biodiversity index can be thought of as representing a subsistence fishery in which the species are not marketed but are solely exploited for food. But when a market for the fish opens up, some species are likely to be in more demand than others and this would create pressure on the valuable species. The economic biodiversity index therefore represents the commercial exploitation of the fishery. Loss of biodiversity is linked to the development of the market in that it leads to over-exploitation of valuable species, which results in a reduction in aggregate fish biomass. Since fish biodiversity plays a significant role it is imperative that its conservation be a priority. As a public good, fish biodiversity can best be conserved not only by the application of traditional management strategies, but also by using economic instruments. In particular, economic incentives that lead to loss of diversity should be replaced by those that encourage biodiversity conservation. In fact, the Convention on Biological Diversity has called for developing and adopting economically and socially sound measures that act as for the conservation and sustainable use of components of biological diversity incentives.

We have also done sensitivity exercises by pertubating the discount rate and examined its impact on net present value of profit under alternative biodiversity scenarios. Interestingly it has been found that biodiversity conservation and profit maximization are in conflict with each other. The conflict between profit maximization and biodiversity conservation underlines the importance of economic scarcity. The fishery is exploited to meet market demand and any signals of scarcity as reflected by market prices induces further exploitation of the fishery. So a reduction in the over-exploitation of the fishery will increase not only biodiversity but also the value of the fish catch. Traditional fishery management strategies mostly involve gear restrictions, closed season and licensing. Gear restrictions involve prohibition of certain methods of fishing like mesh size restrictions. Enforcement of mesh size regulation is very difficult. Closed seasons aim at protecting fish stocks during critical stages like breeding. These policies have not been very effective in the case of Digha fishery. Licensing is aimed at limiting entry into the fisheries. It seeks to control the amount of effort by directly regulating the number of fishermen. This method has been partially effective in Digha fishery.

The traditional fishery management strategies have largely focused on the biological aspect of the resource. Biological analysis relates sustainable catch with the amount of fishing effort but importantly this effort level is itself driven by economic forces. If this aspect is not considered, it has a negative impact on the biodiversity of the resource. Economic incentives and disincentives through price and tax policies can help stakeholders to conserve biodiversity. If fishing costs are sufficiently high relative to the price of fish, the fishery will not be exploited [13]. A user tax may help to reduce fishing effort as the fishery owners will try to control the costs to maintain their level of profit. Costs also include the opportunity cost of fishing. Low opportunity cost in the fishing industry means overexploitation of the fishery. The opportunity cost of fishing may be enhanced by creating better employment alternatives, raising the minimum wage and improving the availability of credit for small scale business. Employment opportunities outside the fishing industry has to be created because controlling of fishing effort without creating alternative employment opportunities will mean increasing poverty. It is also essential that an enabling environment with a greater emphasis on institutional support involving stakeholders be developed. For proper development of the fishery the possibility of stakeholder participation and community-based participatory approach needs be explored and considered.

[13]It is quite reasonable to assume that the fishermen are not able to influence the fish price. Fishery in Digha and in the surrounding region suggests that the fishermen there are mainly price takers.

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