AN INVESTIGATION INTO THE RELATIONSHIP BETWEEN FISH BIODIVERSITY AND PROFIT MAXIMISATION

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ABSTRACT

This study looks into the loss of fish biodiversity and its effect on profitability of a fishery. Biodiversity may take on different values depending on people's perception of the economic or ecological importance of species diversity to human welfare. In our study following the work by Kasulo and Perrings (2001), biodiversity is expressed in terms of 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. The theoretical aspect is modelled in an extension of the aggregated Gordon-Schaefer standard fisheries model. 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. We have introduced a biodiversity measure 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. This is basically an extension of 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. 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. 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. 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. The indices here have 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. 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. It is found that in Digha fishery, there exists a trade-off between economic biodiversity conservation and profit maximization. Paradoxically it can be seen that greater endeavour 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. 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.

1. INTRODUCTION:

The sustainable use of fish resources is central to fisheries management, given the long-term importance of the fisheries sector in terms of nutrition and employment. However, today's major concern centres around the unsustainable levels of species exploitation with unbridled fish-catch practices leading to the depletion of fish stocks, reduction in diversity and disruption of the ecological equilibrium . A re-analysis of the FAO Catches Statistics (Pauly et al., 1998) reveals progressive 'fishing down' of food chains as fishing effort responds to depletion of original target stocks, where one species is exploited more than another. As a result, their relative abundance changes, as has been witnessed 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 a shift from long-lived ,high tropic level fish towards short-lived, low-trophic level fish species whereas 'fishing down the value chain' a shift from high economically valued species to low economically valued species measured in terms of market prices. [1] Whatever be the fishing sequence 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]

This linkage between fish biodiversity and profitability creates an important entry point of research in this paper. This paper looks into the loss of fish biodiversity due to excessive exploitation of the species and its consequent impact on the profitability of fishery. The study focuses on the Digha fishery in West Bengal on the eastern marine coast of India on the Bay of Bengal. It is pertinent to mention here that the sustainability issue of the fisheries sector, in isolation, 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, et al., 1994, Das et al., 1996;

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[1] For simplicity, in this paper we have not considered non-marketed species .

[2] In the paper we have formally distinguished between ecological and economic biodiversity later. Roughly speaking, ecological fish biodiversity deals with species composition whereas economic fish biodiversity takes into account of not only species composition but also the values of species in terms of their market prices. Actually consequences of 'fishing down the food web' is captured in terms of 'ecological fish biodiversity' whereas consequences of 'fishing down the vale chain' is captured in terms of 'economic fish biodiversity'. Thus 'economic biodiversity conservation' implies conservation of highly valued species. For details see Kasulo and Perrings(2001).

Das et al., 2000; Dhar, 2004, Jana, 2004). The issue of investigating any relationship between biodiversity and profitability has largely been neglected in the literature for this particular location. Further, a void exists in the literature in terms of bio-economic modelling of the fishery in a dynamic profit-maximisation set-up. Also the question of biodiversity needs to be addressed in the light of various reports[3] of the marine fisheries of West Bengal.

In an attempt to bridge these gaps in the literature, this paper reports 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. At a broader academic level, this paper attempts to contribute to the base of literature that has entailed the shift in paradigm in the way research is being conducted at the socio-ecological-economic interface of human endeavour: from a "segmented-specialisation approach" to "collective integration approach". It is a shift from traditional research based on case studies in an isolated way to an integrated wider perspective of case study on both bio-economic aspects along with sustainable regional developmental along with issues relating to environmental governance.

There are two important parts in this paper: the theoretical framework, and an empirical validation. The theoretical aspect has been modelled in an extension of the aggregated Gordon-Schaefer standard fisheries model. A sensitivity analysis has been conducted with respect to small perturbation in discount rate to examine the impact of changes in the value of discount rate on profit under different biodiversity scenarios. In the end, we examine whether economic biodiversity conservation are in conflict with profitability of the fishery.

Section 2 of this paper relates the reader to the study site. Section 3 focuses on the importance of biodiversity and its ecological and economic aspects. Section 4 presents data analysis and socioeconomic aspects of Digha fishery. This section analyses the economic condition of the fishermen and provides a background for their strive to catch high-valued species. The theoretical framework, modelling and results of model estimation have been presented in Section 5. Optimum values of the variables under profit-maximising regime have been derived in Section 6. Section 7 reports results of sensitivity analysis. Section 8 consists of the concluding remarks.

2. THE STUDY AREA

Our study area is 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

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[3] 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).

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. 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 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[4]. Among them contribution of hilsa 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 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.

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

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

[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.

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[6] 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[7] is a very well known example of the richness index group. An important example of dominance index is the Simpson's index[8].

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[6] The contracted form 'biodiversity' was first coined in the first planning conference of the ' National Forum on Biodiversity' in 1986. Article 2 of the Convention on Biological Diversity (CBD) defined biodiversity as '*the variability among living organisms from all sources including inter alia, terrestrial, marine and other aquatic systems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems'* (UNEP, 1992). Furthermore, the Global Biodiversity Assessment (GBA) defines biodiversity as ' *the total diversity and variability of living things and of systems of which they are a part. This covers the total range of variation in and variability among systems and organisms, at the various bioregional, landscape, ecosystem and habitat levels, at the various organismal levels down to species, populations and individuals, and at the level of the population and genes'* (Heywood, 1995). Ecosystem diversity is the highest level of diversity. It relates to the variety of habitats, biotic communities, and ecological processes in the biosphere as well as the diversity within ecosystems (Pearce and Moran, 1994).

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

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.

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

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.

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[9]. 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. 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

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In some studies, for a measure of diversity, the complement of Simpson's index is used. It is given as:

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

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

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

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 been collected from the Digha Fishermen and Fish Traders' Association[10] 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[11]. 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 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).

The socio-economic impact of loss of fish biodiversity when associated with a shift from high valued to low valued species is generally negative. Most of the fishermen operating

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

[11] 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 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.

We now consider the following notations to specify the our model
Y= fish catch
X = fish stock
E=fishing effort
r = intrinsic growth rate
q = catchability coefficient
K = environmental carrying capacity of fish stock

D = ecological biodiversity index
B = economic biodiversity index
p = average price
c = average cost
δ = discount rate
$\dot{X}$ = net growth in fish stock
U= catch per unit adjusted effort (Y/DE),

In the standard model, we have the expression for time rate of change in the stock of fish biomass as

$\dot{X} = rX(1 - X/K) - qXE$ and at steady state

$\dot{X} = 0 \Rightarrow rX(1 - X/K) = qXE$

or, $X = K(1 - q/rE)$

The Gordon-Schaefer production function is

$Y = qXE$

On substituting the value of X in the above equation, we have

$Y/E = qK - q^2(K/r)E$.

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 Simpson's index with market prices of the species[12].

The growth functions become

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

and

$$\dot{X} = rX(1 - [X/K]) - qBEX \tag{4}$$

The sustainable yield functions become

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

and

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

Therefore,

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

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

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[12] 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[13] 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.

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, in general terms,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

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[13] 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.

$U_t^*= Y_t/(E_t A_t)$, where A is the vector of biodiversity indices where A=D or B as the case may be.

Our analysis uses the Schnute model, first including ecological biodiversity measure in equation (11) and the economic biodiversity measure in equation (12). The regression analysis is based on time series data where the time period is from 1993-94 to 2002-03 (i.e the number of observations is 10). Table 1 shows the results of regression.[14]

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**	**$\overline{R}^2$ 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, level of significance measured at 5%)

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

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

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[14] Though the time period is quite short to conduct any regression analysis based on time series data our purpose in this paper is to estimate the base vales of the parameters instead of calibrating those values.. So we have not considered any detailed economic analysis. Moreover given the purpose of our paper, we have deliberately conducted no time series test of the results.

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. Here it is found 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 occurred 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 will be used for our subsequent analysis. However, it is to be mentioned in this connection that Digha Estuary has faced over the years increasing problems of water pollution which affects its fish harvest. This is mainly due to the fact that Digha, with its vibrant tourism industry, has attained considerable urbanisation since last twenty years. This has caused large scale discharge of sewage to the estuary. The study by Roy (2004) has shown that Digha daily produces over 3.2 million litres of sewage. The discharge of sewage from hotels drains through canals, which ends in the estuary. Weather here is represented by level of pollutants washed into the estuary. The amount of rainfall in Midnapore district is used as a rough indicator of the level of water pollution. An ideal measure of water quality should have been the concentration of nutrients and suspended particles in the water layer of the estuary. Alternatively, the level of chlorophyll should have been a better indicator of pollution than the amount of rainfall. But such detailed information is not available on a long term basis. However it has been observed that that annual yield of sediments and nutrients deposited in the estuary are dependent on the amount of rainfall in the coastal area.[15]Hence in our estimation of the regression equation (12) in the presence of economic biodiversity we have incorporated an additional environmental quality variable rainfall (W) and we specify it as follows:[16]

$$\ln X_t^* = r - qE_t^* - (r/qK)U_t - reW_t^* \tag{12a}$$

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 and e is the impact of W on net rate of growth of fish stock.
We have re-estimated the modified Schnute equation in the presence of economic biodiversity index and environmental quality variable as shown by equation (12a) and the results are stated in the form of table 2:

Table 2: Regression result of the
Schnute model (with introduction of environmental quality variable and economic biodiversity index)

Equation	**Constant**	**Coefficient of BE or E^***	**Coefficient of U or U^***	**Coefficient of W or W^***	**R^2 statistic**	**$\bar{R}^2$ statistic**
Modified Schnute model	1.527634 (2.00819)	-0.000019 (-3.29691)	-0.0294984 (-2.94028)	-0.0004943 (-1.26947)	0.896241	0.851772

(t-values are given in the parentheses)

One can now estimate the optimum values of the variables in the presence of economic biodiversity. The values of the parameters have been calculated and using these values the optimum value of the variables have been calculated. These estimated optimal values are actually the base vales of or model. From table 2 we find that the weather variable is insignificant at 5% level of significance, though it is significant at the 10% level. So we have used the revised estimates of the parameters when the weather variable is included. However, for the theoretical specification of our dynamic analysis we have ignored the weather variable as its elimination will not significantly hamper our basic conclusion. This is mainly due to the fact that in this paper we want to focus on biodiversity issues rather than on water pollution issues. From our estimates in table 2 we find that the intrinsic growth rate, r = 1.15 (dmnl./year) is the intercept value[17] of the regression of the modified equation (12a). The value of catchability coefficient, q= 0.000019 (1/fishing hours) is the value of the coefficient of the effort function of the regression of the

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[15] See Choudhry et al.(2005) for details.

[16] One can check that equation (12a) follows from the growth equation $\dot{X} = rX(1-X/K-eW)-qEX$

[17] Here dmnl implies dimensionless

modified equation (12a). The environmental carrying capacity of fish stock, K=2725631.8 Kg. is found by using the value of the coefficient of the catch per unit effort function and then plugging in the values of r and q. Average weighted economic biodiversity index B= 0.3946 dmnl is the average of the economic biodiversity indices constructed for the period under study**.** Average price which is the aggregative average of the prices of all fish species under our consideration during the time period of our study is P= Rs. 43.637616 (kg/year). Average cost, c, is the total cost incurred by fishermen calculated on the basis of their wages both for labour in boats and trawlers and its value is Rs. 46.65569 / fishing hour. Discount rate, δ is approximated by the current market rate of interest at 0.11 (dmnl/year). It is only the discount rate that is calibrated and not estimated.

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 period of ten years, 1993-94 to 2002-03. A comparative analysis of the unweighted and weighted Simpson’s indices has been carried out by using the data on catch per species for the Digha *Mohona* (Estuary) fishery. The Simpson’s 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. It is seen that 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 an 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 will have higher values than unweighted indices (Kasulo and Perrings, 2001). It suggests a decline in economic biodiversity associated with a shift in fish catch from high-valued to low-valued species. In the context of this empirical validity generated through the data obtained from the Digha Fisheries Association, 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). 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).

The values of the variables in case of the dynamic model have been calculated for the profit-maximising regime. The need for deducing the values of the variables under the dynamic model 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.

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.

Dynamic analysis of the optimal or profit-maximising regime:

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. Here ρ is the discounting factor.

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

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

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

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

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

Equation (18) gives

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

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

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

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

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

Again, equation (21) at steady-state gives

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

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

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

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

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

$$Y^*_{dyn.} = qX^*_{dyn.}\, BE^*_{dyn} \tag{27}$$

Hence, the optimum level of NPV of profit is

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

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. The results are shown in Table 3.

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

	PROFIT-MAXIMISING SOLUTION (Dynamic Framework)			
Alternative scenarios of economic diversity of the fishery	**Stock (kg.)**	**Harvest (kg./year)**	**Effort (fishing hours/year)**	**PV of profit (Rs.)**
Situation 1: High economic biodiversity	14,03,567.7	79,312.17	14,870.40	9,74,557.84
Situation 2: Average economic biodiversity	13,34,194.2	1,26,329.54	12,629.75	17,33,954.10
Situation 3: Low economic biodiversity	12,91,007.7	1,52,923.61	6,234.36	22,47,745.50

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:

Now let us consider the impact of changes in some parameters on the optimal values of the variables under the profit-maximising regime. We consider first, *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 3 are considered as the base values in our sensitivity analysis. Since the discount rate, approximated by the market rate of interest, represents the opportunity cost of investing in the fishery vis-à-vis other allied industries , we have considered a range here from 0.9 to 0.13 between which the market rate of interest has varied over the last 10 years (as reported from Reports of Currency and Finance of the RBI). The results of such perturbations are presented in Table 3.

From Tables 4 and 5, we find that higher discount rates result in lower optimum values for the stock variable and higher optimum values for both catch and effort. So we find that with discount rate fall (increase), there is an increase (decrease) in stock level of fish biomass but a fall (increase) in fish harvest. This result is in accordance with Conrad and Clark (1994). But, even though there is an increase in optimal harvest from 1,26,329.54 kg./year to 1,32,094.55 kg./year and further to 1,37,769.96 kg./year with a rise in δ (for example, a rise in discount rate from 0.11 to 0.12 and further to 0.13), net present value of profit declines. NPV of profit decreases from the base value of Rs. 17,33,954.10/year to Rs. 16,55,341.10 and even further to 15,78,135.60/year as δ increases from 0.12 to 0.13. The reason may be that the cost involved in effort needed for harvest more than offsets the revenue since we observe that this rise in fish harvest is associated only with increasing effort levels. With increase in discount rate, optimum level of effort also

Table 4: Impact of perturbations of the discount rate, δ, on the optimal values

Value of δ	Stock (kg.)	Harvest (kg./year)	Effort (fishing hours/year)	NPV of profit (Rs./year)
0.09	13,52,365.00	1,14,526.31	11,295.37	18,87,813.70
0.10	13,43,234.10	1,20,503.01	11,965.62	18,10,318.90
0.12	13,25,109.00	1,32,094.55	13,296.04	16,55,341.10
0.13	13,16,023.60	1,37,769.11	13,962.96	15,78,135.60

Reference/Base values: Discount rate = 0.11, Stock = 13,34,194.2 kg., Harvest =1,26,329.54 kg./year, Effort = 12,629.752 fishing hours/year and NPV of profit = Rs. 17,33,954.1/year

Table 5: 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	18,87,813.70	+ 8.87%
0.10	18,10,318.90	+ 4.40%
0.12	16,55,341.10	- 4.53%
0.13	15,78,135.60	- 8.98%

increases from 12,629.752 hours (when δ=0.11) to 13,296.049 hours (when δ=0.12) and even further to 13,962.96 hours (when δ=0.13). The positive relation between fish harvest and effort at each level of discount rate when associated with declining values of optimum NPV of profit implies that the rise in revenue from higher level of harvest is here associated with relatively increasing costs due to rising levels of effort.

This analysis was done on the basis of an average level of fish economic biodiversity currently existing in Digha *Mohona* (Estuary) fishery. When economic biodiversity considerations are brought in the fishing process, it is seen that it has a considerable impact on profit maximization of the fishery. In the past years, Digha *Mohona* (Estuary) fishery was composed of a much higher range of economically valued fish species. Our intention is to note how the gradual erosion of fish economic biodiversity affects the optimal values of the fishery under different discount rates. Here, we have first looked at the actual level of economic fish biodiversity currently prevalent in the Digha *Mohona* (Estuary). Next we have contrasted this against two alternative economic biodiversity scenarios- (1) a situation where there are a high number of differentiated priced fish species (past case) and (2) a situation where all fish species have the same marketed value (projected case).

Table 6 shows two alternative scenarios which are distinct from the one currently prevalent in Digha *Mohona* (Estuary) fishery. In the first case, we have a large market for expensive species as previously and so there is an additional pressure of exploitation on them. In the second case, fish species are all of equal value and so here the fishery is mostly of the subsistence type exploited solely for food which may be true in the future considering the current trend of exploitation. As discount rate increases (decreases), fish stock steadily declines (rises) but fish harvest and fishing effort is on the rise (fall) under both the scenarios.

Table 6: Impact of perturbations in the discount rate, δ, (base value: δ = 0.11) on optimal values of stock, harvest, effort and NPV of profit under two alternative scenarios- (1) high economic diversity and (2) low economic diversity in the fishery model

	CASE 1 (high economic biodiversity)			**CASE 2** (low economic biodiversity)		
Value of δ	**Stock (kg.)**	**Harvest (kg./year)**	**Effort (fishing hours/year)**	**Stock (kg.)**	**Harvest (kg./year)**	**Effort (fishing hours/year)**
0.09	14,21,747.30	66,115.30	12,237.59	13,09,187.00	1,41,978.91	5,707.79
0.10	14,12,662.00	72,755.83	13,553.32	13,00,101.70	1,47,494.14	5,970.95
0.11	14,03,567.70	79,312.17	14,870.40	12,91,007.40	1,52,923.61	6,234.36
0.12	13,94,491.60	85,764.57	16,184.84	12,81,931.80	1,58,251.40	6,497.24
0.13	13,85,406.30	92,132.77	17,500.61	12,72,842.10	1,63,496.51	6,760.52

We find that in the first case, as discount rate increases fish harvest increases from 79,312.17kg/year (δ=0.11; the base case), to 85,764.57kg/year (δ=0.12) and further to 92,132.77kg/year (δ=0.13). Correspondingly, the fishing effort also increases from 14,870.40 fishing hours/year (δ=0.11; the base case) to 16,184.84 fishing hours/year (δ=0.12) and further to 17,500.61(δ=0.13) fishing hours/year. Similarly, it can be seen that as discount rate rises from the base value of 0.11 to 0.12 and further to 0.13, fish harvest rises from 79,312.17 kg./year (δ=0.11; the base case) to 72,755.83 kg./year (δ=0.10) and further to 66,115.50 kg./year (δ=0.09) corresponding to falling effort from 6,234.24 fishing hours/year (δ=0.11) to 13,553.32 fishing hours/year (δ=0.10) and further to 12,237.59 fishing hours/year (δ=0.09) in the first situation. But fish stock falls with increasing discount rate (δ=0.11, optimal stock= 14,03,567.70 kg.; δ=0.12, optimal stock=13,94,491.60 kg. and at δ=0.13, optimal stock= 13,85,406.30 kg.).

In the second case, we find that with an increase in discount rate from base case (δ = 0.11) to δ = 0.12 and later to δ = 0.13, optimal harvest rises from 1,52,923.61 kg./year (δ = 0.11) to 1,58,251.40 kg./year (δ = 0.12) and further to 1,63,496.51 kg./year (δ = 0.13). Similarly, optimal effort increases with increase in discount rate (at δ = 0.11, optimal effort = 6,234.36 fishing hours/year; and at $\delta = 0.12$, optimal effort = 6,497.24 fishing hours/year; and at $\delta = 0.13$, optimal effort = 6,760.52 fishing hours/year). But as also in the first case, stock falls with increasing discount rate (at $\delta = 0.11$, optimal stock = 12,91,007.40 kg. and at $\delta = 0.12$, optimal stock = 12,81,931.80 kg. and at $\delta = 0.13$, optimal stock = 12,72,842.10 kg.). With a fall in discount rate from the base level ($\delta = 0.11$), both fish harvest and fishing effort falls (at $\delta = 0.11$, fish harvest = 1,52,923.61 kg., effort = 6,234.36 fishing hours/year; at $\delta = 0.10$, fish harvest = 1,47,494.14 kg., effort = 5,970.95 fishing hours/year and at $\delta = 0.09$, fish harvest = 1,41,978.91 kg./year and effort = 5,707.79 fishing hours/year). But fish stock rises from 12,91,007.40 kg. ($\delta = 0.11$) to 13,00,101.70 kg. and finally to 13,09,187.00 kg. as δ falls to 0.10 and 0.09. This result is in conformity with that obtained in the current state of economic biodiversity existing in Digha *Mohona* (Estuary) fishery. These are the values that are of particular interest to us. On comparing each level of discount rate over both cases, fish harvest in Case 1 and fishing effort in Case 2 becomes much more sharper with falling economic biodiversity. At $\delta = 0.11$, we find that in the first case, 14,870.40 fishing hours/year is needed for 79,312.17 kg/year of fish harvest. In the context of the same discount rate, under Case 2, fishing effort of the level of 6,234.36 fishing hours/year leads to a catch level of At $\delta = 0.11$, we find that in the first case, 14,870.40 fishing hours/year is needed for 79,312.17 kg/year of fish harvest. In the context of the same discount rate, under Case 2, fishing effort of the level of 6,234.36 fishing hours/year leads to a catch level of 1,52,923.61kg/year. So we can see that when the fishery targets for more valued species to increase its profitability, a much larger fishing effort can plough in a relatively smaller catch leading steadily to a situation where no such economic incentives for fishing remains since price differential among species diminishes. This can be observed in each variation of the discount rate that is done under our sensitivity analysis.

Table 6 shows the effect that changes in the discount rate has on the optimal NPV of profit for the three alternative scenarios under our consideration. Also we compare the gains or losses associated with

(1) the profit that is yielded from a much higher economically diverse fishery that includes more highly valued fish species against the case of lesser economically diverse fishery with average biodiversity considerations taken into account,
(2) the profit that is yielded when current average biodiversity considerations are included in the fishing process as against the case of a fishery where all species are equally valued and hence are non-diverse from the economic standpoint.

This has been further highlighted in Table 6 whereby the impact of a change in discount rate on NPV of profit under different biodiversity scenarios has been studied with regard to the base values.

First, let us look at the three situations at a particular discount rate. At each discount rate, NPV of profit when all species have the same economic value (Situation 3) is much higher than when we consider differentiated economic values of different species (Situations 1 and 2). Again, the decline in NPV of profit is sharper the larger is the number of species having different economic values (by comparing between Situations 1 and 3). For $\delta = 0.11$ (base case), we find that NPV of profit is highest in case of Situation 3 (Rs. 22,47,745.50) followed by Situation 2 (Rs. 17,33,954.10) and is the lowest for Situation 1 (Rs. 9,74,557.84). As economic biodiversity decreases and we move from Situation 1 to 2 gives gain in NPV of profit of the amount Rs. 5,13,791.36/year to the fishery, which increases to Rs. 7,59,396.26/year when there is a move from Situation 2 to 3.

Again, at $\delta = 0.13$, NPV of profit is highest at Rs. 20,07,586.00/year under the third situation. It is Rs. 15,78,135.60 /year in case of second situation which is lower than the third and it is Rs. 9,43,252.23/year for the first situation which is the lowest. A move from situation 1 to 2 shows a gain in NPV of profit of Rs. 4,29,450.40/year. This gain increases when we compare between situations 2 and 3 (Rs. 6,34,883.37/year). At $\delta = 0.10$, the gain from moving from Situation 1 to 2 is Rs. 5,61,373.10/year which further increases to Rs. 8, 31,035.15/ year while moving from Situation 2 to 3. Also at $\delta = 0.09$, the gain in NPV of profit is Rs. 6,15, 943.60/year as we move from Situation 1 to 2 and later Rs. 9,10,619.46/year on moving from Situation 2 to 3.

The above analysis has been illustrated in Figures 1 and 2. So one can infer that, at any particular discount rate, NPV of profit $_{\text{situation 3}}$ > NPV of profit $_{\text{situation 2}}$ > NPV of profit $_{\text{situation 1}}$. Another important observation is that the gain in NPV of profit associated with decreasing levels of economic biodiversity is highest when we contrast between Situations 1 and 3 than between Situations 1 and 2. So, paradoxically, it can be seen that greater the targeting of the capture of the most expensive species and greater the loss in economic biodiversity the greater are the 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.

Table 7: **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	**<u>SITUATION 1:</u>** **NPV of profit when a high level of economic biodiversity in the fishery is present**	**<u>SITUATION 2:</u>** **NPV of profit when current average level of economic biodiversity in the fishery is present**	**<u>SITUATION 3:</u>** **NPV of profit when there does not exist any economic biodiversity in the fishery**	**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	9,77,194.24	18,87,813.70	25,03,757.30	6,15,943.60	9,10,619.46
0.10	9,79,283.75	18,10,318.90	23,71,692.00	5,61,373.10	8,31,035.15
0.11	9,74,557.84	17,33,954.10	22,47,745.50	5,13,791.36	7,59,396.26
0.12	9,61,369.91	16,55,341.10	21,11,416.70	4,56,075.60	6,93,971.19
0.13	9,43,252.23	15,78,135.60	20,07,586.00	4,29,450.40	6,34,883.37

Table 8: Impact of a change in discount rate, δ, on NPV of profit under different biodiversity scenarios with regard to the reference/base values

Change in discount rate	NPV of discounted profit in Situation 1 (Rs./year)	Change with regard to reference/base values for Situation 1	NPV of discounted profit in Situation 2 (Rs./year)	Change with regard to reference/base values for Situation 2	NPV of discounted profit in Situation 3 (Rs./year)	Change with regard to reference/base values for Situation 3
0.09	9,77,194.24	+ 0.27%	**18,87,813.70**	+ 8.87%	25,03,757.30	+ 11.38%
0.10	9,79,283.75	+ 0.48%	**18,10,318.90**	+ 4.40%	23,71,692.00	+ 5.51%
0.12	9,61,369.91	- 1.35%	**16,55,341.10**	- 4.53%	21,11,416.70	- 6.06%
0.13	9,43,252.23	- 3.21%	**15,78,135.60**	- 8.98%	20,07,586.00	- 10.68%

[redacted]

Now we would like to compare of the NPV of profit between the different scenarios of economic biodiversity in the presence of perturbations in the discount rate. The presence of a large number of economically valuable species in the fishery depresses the NPV of profit. Increasing δ leads to increased fish catch and the economically valuable fishes are overfished leading to a fall in NPV of profit. As δ increases from 0.11 to 0.13, a decrease in NPV of profit takes place from Rs. 9,74,557.84/year to Rs. 9,43,252.23/year (Situation 1) from Rs. 17,33,954.10/year to Rs. 15,78,135.60/year (Situation 2) and from Rs. 22,47,745.50/ year to Rs. 20,07,586.00/year (Situation 3). Similarly, as δ falls from 0.11 to 0.09, NPV of profit rises to Rs. 9,77,194.24/year from Rs. 9,74,557.84/year in Situation 1; Rs. 18,87,813.70/year from Rs. 17,33,954.10/year in Situation 2 and Rs. 25,03,757.30/year from Rs. 22,47,745.50/year in Situation 3. The fundamental equation of renewable resources equates the internal rate of return with the discount rate. So, as the discount rate increases, it implies more exploitation of fish stock (i.e., increase in fish catch) until the internal rate of return is again equal to the rate of discount. The impact of increase in discount rate leading to increase in fish harvest is shown in Table 8.9. Again, for a given fish price, increase in fish catch leads to an increase in revenue from fisheries. Again, there is a simultaneous increase in associated fishing effort leading to an increase in cost of fishery. The fall in the NPV of profit can be explained through a larger cost that offsets the higher revenue. The fall in the NPV of profit due to increase in discount rate is shown in Table 6. The utilization of the fishing effort changes with the interest rate. At low interest rates, the average fishing effort is lower than at higher interest rates. Thus assigning a smaller value to the future leads to an increase in the present effort to exploit the resource. Table 7 shows that change in NPV of profit with regard to reference/base values is sharpest for Situation 3 with respect to fall in δ (from 0.11 to 0.09) and lowest for Situation 1 for fall in δ (from 0.11 to 0.09). The change in NPV of profit with regard to reference/base values is more or less the same for Situations 2 and 3 and low for Situation 1 for increase in δ (from 0.11 to 0.13). This has been graphically illustrated in Figure 1.

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 in a fishery.

Changes in the discount rate have been found to have effect on fish catch and NPV of profit and hence on 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. These include the following: an excess demand for money, expansionary fiscal policies including income tax cuts and/or increases in government spending. Conversely, a decrease in government spending would lead to a reduction in interest rate and discount rate. In summary, policies that lead to a reduction in interest and discount rates will also lead to a loss of biodiversity. Such policies may include changes in government expenditure, income tax, money supply and improvements in financial markets.

8. CONCLUDING REMARKS:

Any fishery model needs at the aggregated level to incorporate important factors that affect fish harvest. One such component biodiversity occurs through the depletion of a number of fish species. Incorporation of biodiversity into a fisheries model is a difficult task. The main difficulty lies in choosing the relevant biodiversity measure to be used for our study. Simple biodiversity measures based on species number are widely used but even they have been criticized for ignoring the relative abundance of species. On the other hand, heterogeneity measures that combine species numbers and abundances have also been criticized for treating all species as equal. Following the work of Kasulo and Perrings (2001), we have used the economic biodiversity index which has been formulated on the basis of Simpson's biodiversity index.

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. 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.

We have also done sensitivity analysis by perturbating the discount rate and examined its impact on net present value of profit under alternative biodiversity scenarios. The economic impacts on the fishery in Digha that is brought about by an increase in the discount rate leads to reduction in the levels of fish stock and NPV of profit and to increase in the levels of fish harvest and fishing effort. At low interest rates, the average fishing effort is lower than at higher interest rates. Also, we observe the existence of a negative relation between fish harvest and effort at each level of discount rate. This is associated with steadily declining NPV of profit as we move from higher discount rate to a lower discount rate. Thus it has been found that biodiversity conservation and profit maximization are in conflict with each other. To resolve this conflict the government may impose landing tax where the tax rate is positively related to the price of the species. Apart from this a part of the tax collected can be used for benefit of the fishermen and this tax-transfer process can be governed locally through the *panchayats* (local government).

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