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Climate change, poverty and food security: The role of the small-scale fisheries sector

Balbir Singh and Stein Ivar Steinshamn

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Abstract

Coastal small scale fisheries and communities in the developing countries are vulnerable to global climate change. The consequences occur directly due to the impact of rising temperatures on movement of fish resources and indirectly as climate change impacts on other sectors of the economy thereby imposing increased pressure on already overexploited coastal fisheries. A stylistic two-sector dynamic bio-economic model is specified for modelling intra- and inter-sectoral impacts of climate change on fisheries. The approach is useful for design of resource management policies that secure employment, incomes and food security for coastal communities while at the same time avoiding overexploitation of fish resources. A policy and socially relevant implementation of the framework will call for detailed specification and calibrations that have not been attempted in this paper.

1. Introduction

The problem of global warming and its consequences for world climate is high on the political agenda around the world. Since establishment in 1988, the Inter-governmental Panel on Climate Change (IPCC) has consistently updated the scientific evidence. The occurrence of climatic changes[1] observed during the last century [1] and extreme weather events during the last two decades, although not by any means a proof of the change in global climate, are in agreement with the predictions being made by the scientific community. Updated scientific evidence indicates that observations with respect to the changes in climatic conditions will continue into the future with wide ranging consequences on human welfare. There is growing consensus that climate change is occurring, although uncertainties remain with respect to the momentum and dimension of its negative impacts.

While there is reasonable agreement about the physical process of climate change, understanding impacts of climate change on human welfare and designing institutions and policy mechanisms that mitigate the socio-economic consequences of climate change on the welfare of the vulnerable populations is not a trivial exercise. Human interventions in handling the challenge of impending climate change are physical in *content,* socio-economic in *consequence* and political in *implementation*. An important characteristic of all these dimensions is the lack of uniformity; the impacts are not uniform in their geographical distribution either in terms of size or direction, and neither are the socio-economic consequences. That the political will varies across regions and groupings is a reflection of these differences. A common denominator, however, is that, the vulnerability to the impacts is highest on the margin. It is the boundaries of the ecological zones and the populations living

[1] The global average temperature of air at the earth's surface has warmed between 0.3 to 0.6 degrees since the late 19th century . The four warmest years on record since 1860 have occurred after the 1990. Mid to high latitudes in the Northern hemisphere have observed warmer winters and spring temperatures. Other evidence includes observed rise in sea level of 10 to 25 cm, shrinkage of glaciers and reduction of snow cover in the Northern hemisphere.

on the margin with lowest ability to bear and influence human interventions that are most vulnerable to climate change.

Much of the academic and policy attention related to managing climate change has focussed on impacts of climate change on agriculture in semi-arid and arid continental interiors, and communities living in these regions. Analysis of the impacts on coastal small scale fisheries and communities often living under the official poverty line in developing countries has been quite limited. Small scale fisheries provide food security and poverty alleviation for coastal communities. In addition they also provide secondary income generating activities for populations not primarily involved in fishing activities, for example in coastal agriculture activities. Climate change is expected to influence small scale fisheries both directly, and indirectly as non-fisheries households change their effort in the fisheries activities in response to impacts in non fisheries sectors. It is of utmost importance to understand the consequences of both the direct and indirect impacts so as to design efficient and effective strategies to minimise the negative impacts of climate change on the welfare of the coastal communities. The need is urgent as impacts of climate change become more evident and fisheries dependant populations in the developing countries experience the vagaries of weather that correspond with the scientific predictions associated with climate change.

The main focus of this paper is on developing a stylised framework for understanding the direct and indirect impacts of climate change on small scale fisheries and its consequences for the coastal communities. The paper is divided into four sections. Section two gives a brief overview of the issue of climate change and its impacts on coastal small scale fisheries, and welfare of coastal communities. Section three, we review the traditional approaches to management of fisheries resources and outline a conceptual two-sector dynamic bio-economic model that can be used to evaluate the impacts of climate change on coastal fisheries and communities. We provide a preliminary analysis of the model and indicate the kind of scenarios we can expect in the future and how these depend on the parameters. Section four concludes the paper.

2. Climate change and impacts on fisheries

Approximately three quarters of the world's fishers can be categorized as small scale fishers [2]. Globally some 150 million people are directly or indirectly dependant on activities that involve exploitation of marine or inland fish resources through labour intensive techniques. A significant share of this population is dependant on small-scale coastal fisheries. Although the actual level of dependence may vary depending on whether fishing is a primary or a secondary occupation, the nature of dependence is such that the fisheries sector often functions as an important buffer that balances variations in household incomes and food entitlements arising from variations in economic and non-economic conditions. Understanding impacts of climate change on fisheries is subject to a number of uncertainties. The main conclusions of recent IPCC studies can be summarised as in table 1.

Table 1: Expected impacts of changes in global climate on world fisheries

IMPACTS	CONFIDENCE LEVEL	
	High	Medium
Global biomass.		No change or possibly increase with better resource management
Trade offs	**Positive Higher latitudes**: Longer growing seasons, lower winter mortality, higher growth rates **Trade off (-):** Changes in reproduction patterns, Migration routes, Eutrification	
Regional biomass.	Shifts in stock location and mix of species	
Abundance and relative location of stocks	Proportional to rate of climate change- Rapid change favours production of smaller, low priced, opportunistic species that discharge large number of eggs over long periods	
Incidence of change	Near major ecosystem boundaries	Small-scale, fishers dependant on specific fisheries EEZ with rigid access regulation that reduce mobility and capacity to adjust to changes in stock location or size
Food security (Household)		Small changes No collapse of major fish stocks No asset fixity

As outlined in table 1, at the global level the impacts may be minimal or possibly even positive, although there would be winners and losers as impacts are not uniform across different regions. Rise in global surface and ocean temperatures due to the increased concentration of green house gasses will vary across the globe. The consequences for the coastal small scale fisheries and communities in the developing countries are expected to be both direct and indirect in nature.

An important *direct impact* of the climate change is a general northwards movement of ecosystems in the Northern hemisphere. In the context of fisheries this implies direct impacts on the production possibilities in the ecological boundary zones in the tropics and subtropics, a region dominated by low income developing countries. Within these zones, small-scale fisheries would be most vulnerable. The vulnerability of the small scale fisheries arises due to the lack of geographic mobility and access to alternative fisheries resulting from asset-fixity in the sector. Fixity of production assets is mainly a consequence of the scarcity of capital resources available to subsistence fishing households and micro-firms involved in the small scale fisheries sector.

The *indirect* consequences arise due to the role of the small-scale fisheries sector as a buffer secondary activity for households primarily dependent on non-fisheries related activities; mainly the agriculture or informal services sector in coastal regions in developing countries. Developing countries have been experiencing a gradual trend in degradation of coastal ecosystems and overexploitation of stocks in coastal fisheries. The trend has been partly a result of the changes in the *structure* of these economies and partly due to the *ineffective resource management* in coastal regions. Among the structural changes that have influenced this process have been the rapid urbanisation, gradual weakening of multi-crop agriculture due to switch over to commercial crops and migration, and development of slum inhabitations and infrastructure often in vulnerable coastal areas. Ineffective resource management has been both due to the general lack of tools and not the least the means to implement the tools to manage resources efficiently and effectively. Traditionally, most of the fisheries stock management techniques and tools have been motivated by the need of the developed countries to manage large-scale exploitation of major specific fish stocks in the temperate regions and there has been a general scarcity of tools that could be used for management of coastal fisheries in developing countries. The other major problem has been that even in cases where tools do exist, lack of resources for monitoring and control have seriously limited the utility of the tools with a result that de facto open access and overexploitation of coastal fisheries has been more a rule than an exception. Under such circumstances, coastal fisheries are quite vulnerable to the type of direct and indirect impacts associated with climate change. In particular, indirect impacts resulting from a large influx of populations from non- fisheries sector would prove to be catastrophic for coastal fisheries.

Food security, poverty and the small-scale fisheries sector

Negative consequences of climate change on fish resources have important consequences for poverty and food security among the coastal communities. The concept of food security has to do with the physical and economic access to food that satisfies the dietary requirements necessary for an active and healthy existence. Poverty is a much broader concept and includes food security. It is not only the bare physical existence but also the general economic, political and social conditions that people live under that define poverty. Climate change, through its direct and indirect impacts on the fisheries sector involves worsening of food security and poverty levels of the population dependant on small scale fisheries.

Small scale fisheries provide about half of the world's fisheries production used directly for human consumption, implying that around one billion people rely on this sector as their main source for protein [3]. Fish proteins are a significant source of food security in the coastal regions in developing countries. For example in Small Island States[2] in the tropics fish proteins can account for over 50% of the proteins intake by the local populations. The situation in the coastal regions in other developing countries is also quite similar in a number of cases. The dependence is quite high as compared with situation in OECD region where fish proteins account for around a maximum of 15% of protein intake in countries such as Norway, Iceland and Japan. In developing countries fish proteins are an important supplement to carbohydrate rich diets and have been associated with improvements in maternal health and child nutrition and reductions in child mortality. In addition, small-scale fisheries also provide an important source for income generation for the poor, that has contributed to economic

[2] Small Island States consist over forty countries in Africa, the South Asia, the Pacific, the Caribbean, the Mediterranean, and the Atlantic regions that are particularly vulnerable to global climate change.

stability for the coastal households which, among other factors, has also been associated with higher participation in primary education in the coastal regions.

Despite the importance of the small-scale fisheries, relationship between fisheries management policies and food security and poverty alleviation among coastal communities has attracted minimal attention from both the policy makers and the research community. It is only recently in 2003 at the 25th session of the FAO committee on Fisheries that the importance, of particularly the small-scale fisheries sector to food security and poverty alleviation was placed on the international agenda. The initiative has led to the development of FAO guidelines on the issue. The low recognition of the fisheries sectors role in the context of food security and poverty alleviation can be explained firstly, by the general *lack of reliable information* related to the contributions of the fisheries sector [4] to poverty alleviation and food security. A recent study [5] reviewing 281 national policy papers and 50 poverty reduction strategy papers, indicates that it is only in a small number of countries that fisheries sector was allocated a specific role in poverty reduction and food security despite the fact that fisheries sector provided employment to a significant numbers of households in these countries. Secondly, low priority given to the fisheries sector in this context can also be explained by the difficulties of *monitoring and control* of activities in this sector, particularly in the small scale fisheries most of which is organised in the informal-sector dominated by individual households and micro-firms in developing countries. Whether monitoring difficulties is a cause or an effect of the lack of information is not clear.

Last but not least important is the empirical fact that, with the exception of Small Island States [6] where fisheries is a significant occupation at the national level, the role of the fisheries sector at the national level is less important or even marginal depending on the size and location of the country. In these countries, importance of small scale fisheries is essentially regional or local in character and thus receives low priority at the national level. In cases where it does attract policy attention at the national level, it may result in adoption of institutions and mechanisms that restrict access to fish resources for the coastal communities, thus resulting in further deterioration of the welfare of this group. Policy and research effort in understanding the role of the small-scale fisheries sector in poverty alleviation and food security in general has received much less attention, than what this issue deserves given the number of households whose welfare is directly or indirectly dependant on these fisheries.

3. Management of small-scale coastal fisheries and climate change

Fish resources are referred to as a common pool resource where exclusion is difficult and resource use involves subtractability. There is a long tradition within economic science in studying optimal utilisation of common pool resources.

Fisheries management regimes attempt to solve the common resource problem by restricting access to assure efficient resource use that does not result in overexploitation. A *normative approach* to handle the commons problem envisages a central planner who establishes the status of the resource, determines the optimal utilisation levels at which it may be exploited, and implements a command-and-control mechanism to assure that the targets are not exceeded. A number of models and techniques[3] have been developed over the years both to

[3] The literature encompassing so called bio-economic models consist of an economic and a biological sub-model provides the main tools for these excercises. The economic sub-model takes care of costs, revenues and welfare impacts whereas the biological sub-model takes care of the fish stock dynamics and the sustainability aspect. We will briefly go through the main categories here a-d:

a. Surplus growth models. These are aggregated biomass models where the sustainable harvest each period is equal to the surplus growth, which again is a function of the stock biomass. This is a relatively simple type of model with few parameters. The advantage, however, is that due to its simplicity it can be combined with sophisticated methods for dynamic optimization and, as there are few parameters, it may be suitable for circumstances with limited data.

establish the status of the resource and estimate target levels and assure efficient realisation of these targets. The approach is quite data intensive and assumes that the central planner has the necessary competence and resources to monitor and control the achievement of the set targets.

An alternate approach to solve the common resource pool problem is the so called *rights-based approach*, where the emphasis is on defining and allocating property rights to a common resource and creating incentives for property rights holders for self-management of the resource. The theoretical starting point for this approach is the Coase Theorem: as long as property rights are well defined, and may be transferred without transaction costs, market equilibrium will be efficient. The assumption is that rights holders managing their own resource have superior information (local environmental conditions, fish behaviour, migration, spawning areas, seasons etc.) and will undertake efficient resource utilisation. The main function for the central planner in this approach is to define property rights, facilitate contracting and establish a framework for enforcing these rights. The approach is less data intensive and requires minimal monitoring and control as self-regulation substitute regulatory control. Allocation of property-rights in this approach is the main instrument the central planner has to increase pro-poor profile of fisheries management regime and number of approaches has been developed in the recent years in this body of literature[4]. This approach

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b. Stock recruitment models: These models are also aggregated biomass models where the recruitment, that is the stock biomass at the beginning of a new period, is a function of the escapement, that is the biomass after harvesting at the end of the previous period. These models resemble the surplus growth models in many ways but are particularly suited for short-lived species.

c. Year-class models. These are usually fairly large models where the fish stock is divided into age and/or size categories. They usually contain many parameters and require a fairly high degree of biological information, but, if this is in place, they can also provide fairly detailed recommendations. The commonly used yield-per-recruit approach falls within this category.

d. Ecosystem approach. These too are large models that take aims at taking the whole ecosystem into account. Hence this requires a large amount of data and information, but they are very useful if the data requirements are fulfilled.

[4] The relevant approaches to resource management relevant for small scale fisheries that can be analysed using the models are a-e:

generally holds in the presence of other market failures as well as in case of natural monopolies, defined by economies of scale and scope and underlies much of the recent economic literature related to regulation by contracts

A drawback of the normative and rights-based approaches is their partial character, where management of the fisheries resources is assumed to be dependant on effort and stock development in the fisheries sector itself. A major threat to coastal fisheries in the context of climate change is that it has inter-sectoral linkages. It is not only the direct impacts of climate change on the fisheries, but also the indirect-impacts originating in non-fisheries sector that cause the major threat to the coastal fisheries. Satisfactory modelling of these inter-sectoral linkages is crucial to evaluate the impacts of climate change on coastal fisheries and communities. A two-sector dynamic bio-economic model that accounts for both for inter-sectoral impacts and environmental effects on the economy is a useful approach to explicitly account for these inter-sectoral linkages. The term bio-economic refers to the fact that the model consists of both an economic and a biological sub-model. The model is dynamic as the biological sub-model represents the change in the fish stocks from one period to the next. The model is an extension of the earlier similar approaches Chen [7] and Rosser [8] which

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a. Community based approach. This approach is in contrast to the government-based approach. The objective of this approach is to solve the common pool resource problem by restricting access and creating incentives through user rights owned by the communities.

b. Co-management approach. The objective of this is to achieve sustainable management of fisheries through sharing responsibilities and authority between the government and the communities. Emphasis is put on decentralized decisions, delegation of rights and rules to communities and joint decision making.

c. Sustainable livelihood approach. Emphasis is here put on eradication of poverty through understanding the livelihood of poor and focusing on both current and future vulnerability to poverty and food security.

d. Ecosystem approach. The aim of this is to manage fisheries such that the whole ecosystem is taken into account with emphasis on sustainability. Management is based on explicit objectives, equity and efficiency indicators, performance measures and decision rules.

e. Global environmental change and human security approach. The objective is to combine sustainable management of natural resources with improvement of livelihood of fishers' communities through better understanding of how climatic variability affects ecological and socioeconomic processes.

however, are purely economic models. The main extension of our model lies in explicit accounting of the feedback from the dynamics of the fish stock biomass within the model. In our specification, we divide the economy into the fisheries sector and other sector where the latter refers to the rest of the economy including the agricultural sector and the manufacturing sectors. The rest of the economy in our specification is both impacted and impacts the climate change. In the rest of the economy, agricultural sector is affected by climate change and environmental disturbances whereas the manufacturing sector accelerates the climate change.

A two-sector model for fisheries

Define a two-sector economy with the regional production possibilities given by

$$\begin{aligned} X_{i,o,t} &= f(L_{i,o,t}, T_t) \\ X_{i,f,t} &= g(L_{i,f,t}, B_{i,t}) \end{aligned}$$

Subscript *i* refers to region *i* and regions are defined according to the mobility of factor inputs. It is assumed that labour is perfectly mobile within each region and perfectly immobile between regions. Subscript *f* refers to the fisheries sector, while *o* refers to other sector that includes all other activities including manufacturing and agriculture. Production in the other sector at time *t* is given by $X_{i,o,t}$ and depends on capital and labour inputs aggregated into the variable $L_{i,o,t}$ and the environment factor T_t as the agricultural sector is included in this sector. In the above specification temperature T, is used as a proxy for environmental factors. Production in the fisheries sector depends on an aggregate of capital and labour inputs $L_{i,f,t}$

in this sector (fishing effort) and fish stock biomass, $B_{i,t}$ whose inter-temporal change is made up of the net growth, $F(\cdot)$, minus the harvest, $X_{i,f,t}$,[5] and environment as follows

$$B_{i,t+1} = B_{i,t} + F(B_{i,t}, T_t) - X_{i,f,t}$$

There are two types of dynamics in this model. In addition to the fish stock dynamics described above, we also have environmental or temperature dynamics

$$T_{t+1} = \tau(T_t, T_n, X_{o,t})$$

where temperature in the next period is assumed to depend on the temperature this period, some average or pre-industrial temperature, T_n, and aggregate production $X_{o,} = \sum_i X_{i,o,}$ in the other sector summed over all the regions.[6] The pre-industrial temperature represents a natural equilibrium that the temperature will tend to if there are no human-made emissions of greenhouse gases. The aggregate production in the other sector summed over all the regions is used as a proxy for the emissions of greenhouse gases. The dynamic relations introduce important intra and inter-sectoral feedbacks in the model.

Additional inter-sectoral linkages occur through the supply relationships for factor inputs that are assumed to be fixed within each region such that a unit of factor inputs allocated to the fisheries sector implies a unit less to the other sector and vice versa. It is assumed that the supply of labour and capital is fixed and constant over time in each region:

[5] The net growth may sometimes be negative under unfavourable environmental conditions or if the stock is above its natural carrying capacity.

[6] The fisheries sector is assumed to be small relative to the other sector such that emissions from this sector can be ignored.

$$L_{i,o,t} + L_{i,f,t} = \overline{L}_i \, .$$

The utility to be maximized is a function of consumption of fish products and other products:

$$U_{i,t} = u_i(C_{i,o,t}, C_{i,f,t}) \, .$$

This function is homothetic and has constant elasticity of substitution less than one. Assuming market clearance at all points in time implies

$$\begin{aligned} C_{o,t} &= X_{o,t} \\ C_{f,t} &= X_{f,t} \, . \end{aligned}$$

The individual consumer's problem, with identical consumers within each region, is then to

$$\max \sum_{t=0}^{\infty} \beta^t U(C_{o,t}, C_{f,t})$$

subject to:

$$p_{o,t} C_{o,t} + p_{f,t} C_{f,t} = w$$

where β is the discount factor, p are the prices and w denotes the wage. Assuming constant prices over time, and defining the relative price as $\frac{p_o}{p_f} \equiv p$, we have from the first-order condition

$$\frac{U_o}{U_f} = p$$

where subscripts on U denote partial derivatives. With the homotheticity assumption on $U(\cdot)$, this implies that in equilibrium the consumption ratio of the two goods is a function of the relative prices:

$$\frac{C_o}{C_f} = \xi(p)$$

with $\xi'(p) < 0$; see Chen (1997). Combined with the market clearing conditions this implies that output from the other sector can be written as a function of the relative price, $X_o = \psi(p)$.

If we specify the temperature dynamics as follows:

$$T_{t+1} = (1-c)(T_t - T_n) + T_n + h(X_{o,t}),$$

where $0 < c < 1$ is a parameter, this can be rewritten

$$T_{t+1} = (1-c)(T_t - T_n) + T_n + h(\psi(p)).$$

Intertemporal optimization requires:

$$\frac{U_{f,t}}{U_{f,t+1}} = \frac{U_{o,t}}{U_{o,t+1}} = \beta$$

The model can be used both as an optimization model and as a simulation model. As an optimisation model it will consist of equations representing the standard conditions for individual utility maximization given the income constraint and market clearing conditions. The optimisation specification can be used to find optimal harvest and optimal use of inputs, especially labour in the fisheries sector. The results would assist in identifying what the best actions are in order to secure employment and increase incomes and food security of the coastal communities while at the same time avoiding overexploitation of fish resources.

The simulation model may be more complex depending on the details included in the model. As a simulation model it can be used to analyse time-paths of variables such as status of the marine resources in question, consumption and employment in the fisheries sector, production in the other sectors and development of temperature. There are three possibilities in this context: 1) steady state equilibrium, 2) cyclically repeating behaviour or 3) chaotic behaviour. Which of these outcomes prevail depends on the parameters in the model and is therefore an empirical question that has to be investigated. In particular the dynamic development depends on the parameter c affecting temperature dynamics. Depending on the initial conditions, a high c is most likely to result in steady state, a medium c is likely to result in cyclical behaviour and a low c may very well lead to chaos. The model can also be used to predict catastrophes and irreversible events such that appropriate action can be taken against this.

4. Conclusions

There is growing consensus that climate change is occurring, although uncertainties remain with respect to the momentum and dimension of its negative impacts. Much of the academic and policy attention related to managing climate change has focussed on impacts of climate change on agriculture in semi-arid and arid continental interiors, and communities living in these regions. Analysis of the impacts on coastal small scale fisheries and communities often living under the official poverty line in developing countries has been quite limited. Coastal small scale fisheries and communities in the developing countries are expected to be affected directly due to the impact of rising temperatures on movement of fish resources. Equally important are the indirect impacts of climate change in the economy that impose increased pressure on already overexploited coastal fisheries. Understanding these intra and inter-sectoral impacts is crucial to designing efficient and effective resource management strategies to minimise the negative consequences of climate change on the welfare of the coastal communities. A two-sector dynamic bio-economic model provides a useful approach to understanding the intra and inter-sectoral impacts of climate change on the economy. Such an approach can be used both for design of resource management policies that secure employment, incomes and food security for coastal communities while at the same time avoiding overexploitation of fish resources. The modelling approach can also be used to analyse future time-paths of variables relevant for welfare of coastal fisheries and communities. Needless to say; the two sector formulation developed in this paper is a simplification that is made to illustrate the nature of inter- and intra-sectoral origins of the impacts of climate change on fisheries. A policy and socially relevant implementation of the framework will call for detailed specification and calibrations that have not been attempted in this paper.

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