

An integrated approach to valuing the societal costs and benefits of fishing activities in the Pearl River Delta

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Abstract

The paper puts forward a model of the Pearl River Delta (PRD) fishery in the South China Sea that integrates the ecological, social and economic costs and benefits of fisheries activities in a multidisciplinary framework. In particular, an integrated ECOST model is developed by coupling a regional Social Accounting Matrix (SAM) to an ecological model constructed by Ecopath with Ecosim (EwE) software. Then based on the ECOST model, the costs and benefits of five fishing métiers are compared from economic, ecological and social dimensions in monetary terms. Finally, a series of dynamic simulations for a 10-year period are examined under five scenarios to explore the impact of fishing effort reduction on fishing communication. Key results from prediction (2005-2015) and policy simulations illustrate that fisheries of PRE are geared toward short-term economic profits at the expense of ecological gains and the whole group of societal benefits associated with fishing. However, the status quo can be improved to better levels by reducing fishing effort.

Keywords

Integrated ECOST model; Ecopath with Ecosim; costs and benefits analysis; Fishing activities;

1. Introduction

The current trends of over-fishing and biodiversity losses in the Pearl River Estuary (PRE) are causing the collapse of many commercial marine fisheries established in the last century (Duan et al., 2009a). As an unavoidable result of the overcapacities of the PRD's fishing fleets and the overexploitation of its fisheries resources, greater numbers of marine fishing vessels are no longer economically viable (Yu and Yu, 2008). It is therefore necessary to understand the trade-offs between ecological, social and economic objectives. In this paper, an integrated model is applied to analyze the links between a delta socio-economic system and a coastal ecosystem.

Economists and ecologists have traditionally focused exclusively on their own disciplines, leading to an ignorance of connections and feedback among ecological, economic and social systems. Increasingly, scientists and economists from different disciplines have begun to realize the importance of pooling their information and results into multidisciplinary studies (Kittinger et al., 2013; Ommer et al., 2012). The published ecological economic models that focus on marine fisheries can be categorized into three groups, traditional bio-economic models, regional fisheries economic models and ecosystem-based fishery management models.

The traditional bio-economic model is based on the Gordon-Schaefer model (Gordon, 1954; Schaefer, 1957) and has been explored by Clark (1976) and other researchers from the mid-1970s onwards. Bio-economic models try to link biological and economic models and reveal the optimal levels of yield. Traditional fisheries management tools are more suitable for homogeneous fleets targeting one species and it is difficult to analyze large number of species (Worm et al., 2009).

The second group is regional fisheries economic models, which focus on the regional economic impacts of fishing sector. After Andrews and Rossi (1986) reviewed input-output (IO) model studies of

the fisheries, increasing numbers of regional economic studies of fisheries have been published. In the literature, regional economic impacts of fisheries have been studied using a demand-driven input-output model (Steinback, 1999) and a supply-driven input-output model (Leung and Pooley, 2002). Leung and Pooley (2002) suggest that a supply-driven model is more appropriate than a demand-driven model in assessing the economy-wide impact of output reduction (such as landing volume or total allowable catch) of the fisheries sector. The role and linkages of the fishery sector have been examined in Hawaii (Cai et al., 2005) and Korean (Kwaka et al., 2005; Lee and Yoo, 2014). While many of these studies used conventional IO models, a broader range of regional fisheries economic models has also been utilized (Seung and Waters, 2006a, 2006b). The Social Accounting Matrix (SAM) model is an extension of input and output accounts, and the main advantage of a SAM based-analysis over the IO analysis is that the social-economic linkages are taken into account as well as other transactions such as linkages between the production and household sectors. Fernandez-Macho et al. (2008) and Seung and Waters, (2009) developed SAM model to assess the contribution of the fishery sector on employment and income. More recently, Seung and E.C. (2013) apply an adjusted supply-driven SAM model to estimate the economic impact of exogenous output changes to Alaska fisheries management implementation. Vega et al. (2014) examines the potential economic impact of the government strategy for the seafood sector in Ireland and Arita et al. (2014) demonstrate the use of SAM modeling to assess the income distribution linkages of the commercial fishery sector in Hawaii. Other literature applied Computable General Equilibrium (CGE) models to analyze economics effects of fisheries. Houston et al. (1997) use a static CGE model to examine the regional economic effects of fisheries. Seung and Waters (2010), Waters and Seung (2010) evaluate the economic impacts of exogenous shocks on endogenous output, employment, value added and household income for Alaska

fisheries. However, these models are static and don't describe the dynamics interaction in economics and biological system.

Today, widespread acceptance that a more integrated perspective is needed would take marine ecosystem preservation, economics and social objectives into account. Most regional fisheries economic models are stand-alone, and do not consider the role of the ecosystem. In this context, the ecosystem-based fishing management (EBFM) approach has emerged as a promising approach (Pikitch et al., 2004). However, few ecosystem approach based regional fisheries economic models are carried out, because it requires multi-disciplinary research which may increase the complexity of the regional economic analysis. Jin et al. (2003) developed an economic-ecological model by coupling a region input-output model of a coastal economy to a linear ecological model of a marine food web. As one of the first applications of a CGE model in a marine ecosystem-based fishery management, Finnoff and Tschirhart (2003, 2008), Hussain and Tschirhart (2013) developed an integrated regional economic-ecological dynamic CGE model of Alaska fisheries to examine the welfare changes related to regulating commercial fishing quotas. Kaplan and Leonard (2012) combined an Atlantic fishery ecosystem model with an input-output economic model to trace changes in fisheries landings and their impact on the economy. Carvalho et al. (2011) estimated the impact of eliminating fisheries subsidies on economic variables pertaining to the regional economy of the Azores using a dynamic CGE model based on a social accounting matrix. Jin et al. (2012) develop the framework by linking a CGE model to an end-to-end (E2E) model of marine food webs to help assess the implementation of ecosystem-based fisheries management (EBFM) in New England. To our knowledge, no study has so far estimated the societal benefits and costs from social, economic and ecological directions at métier level. Here, métiers are defined as a particular fishing fleet targeting at several particular species with a

particular gear.

This paper presents the integrated ecological-economic-social model-ECOST on the fisheries societal costs and benefits in the PRD. The ECOST model was developed by [Failler and Pan \(2007\)](#) for an international fisheries research project — Ecosystems, Societies, Consilience, Precautionary principle: Development of an assessment method of the societal cost for best fishing practices and efficient public policies (ECOST, short for), of the European commission., The ECOST model was developed by coupling a region Social Accounting Matrix (SAM) to an ecological model constructed by Ecopath with Ecosim (EwE) software. The main goal of this model is to combine social, economic and ecological systems into an integrated assessment, better describing the interaction between socio-economic and ecological systems.

2. Case study

In China, the Pearl River is the second largest river (2200 km) in terms of water discharge, after the Yangtze. Currently, the coastal region of the PRE is a significantly and quickly developing economic zone in China ([Duan, 2009; Duan et al., 2009a](#)). As a result of rapid economic development in recent decades, the whole region has experienced rapid industrialization and urbanization. The high population density and rapid development of industry and agriculture have resulted in severe stress to the aquatic environment. The PRE is also an important fishing ground in the South China Sea, and it provides abundant fishery resources for the PRD. The PRE ecosystem in this study (less than 60 m depth) ranges from 112°30'E to 115°00' E, 21°30'N to 23°30'N. The PRE falls largely within the PRD Economic zone. The study area is associated with six municipal cities, including Guangzhou, Zhuhai, Zhongshan, Dongguan, Shenzhen and Jiangmen, and two special administered regions, namely, Hong Kong and Macau ([Fig.1](#)). According to these boundaries the scope of the research

covers approximately 72490km² (Qiu et al., 2008).

Fig.1 Here

Because of the special hydrological features of the PRE, the interaction among fish species in the Pearl River are quite complex, primarily because of the large variety of species involved, and their habits and diverse mechanisms of biological predation (Li et al., 2000). These factors cause a very complex tropical marine ecosystem to exist in this region. Due to recent large increases in the number of fishing boats and improvements in fishing technology, intensified fishing pressure on commercial fish species has resulted in a decline in the biomass of many large-size and high-quality species and “prey release” of some low-valued species of small fish (Duan et al., 2009b). Chinese fisheries policy has moved in a new direction toward the sustainable utilization of fisheries resources. Regulations have been enacted to reduce fishing effort and conserve fishery resources, including a fishing licenses system, closed seasons and closed areas, minimum mesh sizes and the prohibition of some fishing gear and fishing methods (Xue, 2004; Yu and Yu, 2008). Using the PRE as a case study, the trade-offs between ecological and socio-economic objectives of fisheries management in an estuary ecosystem are explored.

3. Mechanism of ECOST model

ECOST model presents a fisheries assessment method that attempts to assess the social, economic and ecological costs and benefits in a framework coupling the ecosystem to socio-economic systems. As a typical estuary ecosystem, the PRE ecosystem can be described by the interactions of species in a complex food web. Therefore, understanding the biomass stock and ecological relationships of these species is an important part of designing renewable resource policies. In this paper, the PRE ecosystem is simulated by applying an Ecopath model, which has been widely used for constructing food-web

models of marine and other ecosystems (Plagányi, 2007). The species in the food web are represented by predator-prey relationships, and several of these function groups are commercial fishes that provide inputs to economic systems.

An accounting method is applied for economic analysis of the fisheries, and a social accounting matrix (SAM) is constructed for the PRD fishing sector to examine both the linkages between the fishing industry and other industrial sectors, and their relationship with social levels from the household to the global scale. The SAM table provides a consistent database that allows for a detailed analysis of the economic structure of the PRD, and it is a useful tool for assessing the impact of fishing activities on the economy as a whole. Then we try to link the socio-economic model and the ecological model to produce an integrated ECOST model for fisheries management. This integrated ECOST model is adopted to assess the societal benefits and costs for fisheries activities in the PRD. Finally, simulations are developed for a 10-year (2005~2015) period under five scenarios based of the 1998 Ecopath model with each scenario involving reduction of fishing effort of vessels by different métiers at an annual rate of 5% from 1985 to 2015 for 30 years. The heterogeneity of fleets, such as vessel size and fishing gear types, leads to a variety of economic, social and ecological evaluation.

The ECOST model is built on Microsoft Excel 2007 and contains several sheets, which are divided into the following three parts: data input, connection between ecological and socio-economic systems, and results output. The data input includes six sheets: macroeconomic, métier, microeconomic, economy, social and efforts. The results output includes the biomass, input and output table, multiplier, society and 10-year dynamic simulation. The connection section is an Ecopath sheet in the ECOST model describing the linkage between the socio-economic and ecological models. The results of the biomass changes which are simulated by the Ecosim model are imported into the ECOST model.

Finally, fishing policy is simulated through time-series of fishing efforts, which are based on the optimal allocation of fleets among different métiers. The theoretical and mathematical backgrounds of the ECOST model are detailed elsewhere (Failler and Pan, 2007; Pan, 2009). We used a flow diagram (Fig.2) displaying the variables and process to illustrate the mechanism of integration of social, economic and ecological systems.

Fig.2 Here

3.1 Ecosystem model

The Ecopath with Ecosim is applied in the ecological model to analyze the structure of trophic interaction in the ecosystem. The method and theory of Ecopath and Ecosim modeling are detailed in the EwE user guide (Christensen and Pauly, 1992; Christensen et al., 2005). Ecopath model is based on the mass and energy balance between the inputs and outputs from the ecosystem. The Ecopath parameterizes models base on two master equations, one to describe the production term and one for the energy balance of each group. The production term for each group into components, can be expressed as

$$B_i \times (P/B)_i \times EE_i = Y_i + \sum_{j=1}^n B_j \times (Q/B)_j \times DC_{ij} + E_i + BA_i \quad (\text{Eq.1})$$

Where B_i is the biomass of group i ; $(P/B)_i$ is the annual production/biomass ratio of i equal to the total mortality coefficient (Z); EE_i is the ecotrophic efficiency representing the proportion of the production that is utilized in the system; Y_i is fishing mortality rate; $(Q/B)_j$ is annual consumption/biomass ratio of predator j ; DC_{ij} is the proportion of the group i in the diet of its predator j ; E_i is net migration rate and BA_i is biomass accumulation rate.

Ecosim is the time dynamic simulation tool that provides description of the ecosystem effects of

fishing effort changes over time. The basic biomass dynamic differential equation in Ecosim is given by

$$dB_i / dt = g_i \sum_{j=1}^n Q_{ji} - \sum_{j=1}^n Q_{ij} + I_i - (M_i + F_i + e_i)B_i \quad (\text{Eq.2})$$

Where dB_i/dt represents the growth rate of group (i) during the time interval dt in terms of its biomass B_i ; g_i is net growth efficiency; Q_{ij} is consumption rates of type i biomass by type j organisms; I_i and e_i is immigration rate and emigration rate; M_i is the non-predation (other) natural mortality rate; F_i is fishing mortality rate.

The vulnerability parameter is one of the most important parameters that determine the form of predator-prey relationship. Here, observed time-series catch rate data of commercial fish and fishing effort data of five fishing métiers from 1981~2005 are used to estimate the vulnerability factors which provided some empirical support to the model. A previous constructed Ecopath model (Wang et al., 2012) for the PRE ecosystem is used as the base for Ecosim prediction of biomass and catch dynamic . The parameters of Ecopath model are presented in [Table 1](#).

Table 1 Here

3.2 Social accounting matrix

Here, a Social Accounting Matrix (SAM) provides a consistent database that allows a detailed analysis of the economic structure of a region. It is also a useful tool for simulating the impact of economic policies on the economy as a whole. A SAM can be represented as a square matrix T whose t_{ij} element shows the transaction value where the income obtained by account i originates from the expenditure by account j . The matrix of direct coefficient in the SAM model, denoted S , is derived as follows

$$S = \begin{bmatrix} A & 0 & C \\ V & 0 & 0 \\ 0 & Y & H \end{bmatrix} \quad (\text{Eq.3})$$

Where S is the matrix of SAM direct coefficients; A is the matrix of intra-industries technical coefficients, includes sales and purchases; V is the matrix of value added coefficients that includes payments from production accounts to factors; Y is the matrix of value added distribution coefficients that includes factor payments to the institution accounts; C is the matrix of the expenditure coefficients that includes household purchases of industry output; and H is the matrix of institutional and household distribution coefficients that includes inter-household/institution transfer payments.

The supply and demand balance equations can then be written as follows

$$\begin{bmatrix} x \\ v \\ y \end{bmatrix} = S \begin{bmatrix} x \\ v \\ y \end{bmatrix} + \begin{bmatrix} ex \\ ey \end{bmatrix} \quad (\text{Eq.4})$$

Where x is the vector of total production output; v is the vector of total value added; y is the vector of total institutional income; ex is vector of exogenous goods and services demand (from exogenous stimulus measures, government expenditure/investment, export demand, or other exogenous resources of demand); and ey is vector of exogenous household transfer payment (primarily government transfer payments).

To estimate the economic linkages of a sector, the multipliers obtained from the SAM's inverse coefficients can be given by the following

$$\begin{bmatrix} x \\ v \\ y \end{bmatrix} = (I - S)^{-1} \begin{bmatrix} ex \\ ey \end{bmatrix} \quad (\text{Eq.5})$$

In this paper the SAM approach is not used to estimate the economics activities (or “impact”) of the marine sector in coastal economics. However, it provides a consistent database that allows for detailed

analysis of the economic structure of the PRD ([Table 2](#)). As detailed in column 2, the total output value of the PRD fishing reached 1512.25 million Euro in 2004, representing 1.42% of the PRD's gross production at current price, an increase of 13.4% from the previous year (unless otherwise specified, increase rates are calculated at the constant price of 1990). The value of fishing processes and rest of the fisheries economy are 175.6 and 1209.49 million Euro, respectively. Row 4 shows that, of the 1643.83 million in fishing industry income, 1591.51 million are sales within the PRD region, and 52.32 million are exported to nearby households and neighborhoods (e.g., Hong Kong and Macao).

A simplified basic fish production table that considers the addition of fisheries harvesting sectors to detail the production of fish is presented ([Table 3](#)). Our model encompasses five métiers from the PRE area: demersal species trawling, shrimps trawling, Japanese scad purse seine, threadfin bream gill net and squids hook and line. The main fishing target species or groups include squids, melon seed, pomfret, upeneus bensasi, chub mackerel, silver croaker, lionhead croaker, greater lizardfish, Japanese jack mackerel, threadfin bream, bigeyes, Japanese scad, hair tail, shrimp, crab, squid, and jellyfish, etc ([Jia et al., 2005](#)).

Table 2 Here

Table 3 Here

3.3 Valuation of Societal cost and benefit

3.3.1 Economic cost and benefit

The economy consists of the PRE fishery sectors, including marine capture and fish processing, and the PRD households, and is linked to the rest of the world through the commodity and factor (labor and capital) markets. The economic model combines macroeconomic structure with microeconomic fishery production, thereby reflecting the production chain of the fisheries.

The economic value of an estuary ecosystem is defined on the basis of its relevant ecological features, and its economic value is equivalent to the net present value of goods and services that flow from uses and “non-uses” of the resource, the sum of consumer and producer surpluses associated with identifiable uses of the ocean, such as recreation, commercial fishing, marine transportation, etc. In the ECOST model, we only estimate the direct economic value from fishing activities, economic costs and benefits of fishing activity include the costs and benefits of three fisheries sectors: harvesting, processing and marketing. These cost and benefit must be forecasted into the future and discounted back to the present. We assume that the annual economic discount rate remains at 4% for all simulations and embodied technical change enhance productivity by approximately 1% per year. It is important to understand the SAM model contains both supply-push and demand-pull input-output mechanism at its core to trace the full impacts of marine fishing on the economy, however, it is not a substitute for the calculation of surpluses. Here the ECOST model provides an approach to estimate the economics cost and benefit. The method and theory of the calculation of economic cost and benefit of fisheries are detailed in the ECOST model user guide (Pan, 2009), from which the brief description of the model and behavior of each fishing sector provided below borrows extensively.

(1) Fishing harvesting sector

The fish harvesting sector consists of a number of producers - the harvesting métier that are defined as a particular fleet equipping with a particular gear and targeted at a particular species as main catch. Therefore, the benefit of a harvesting métier is the total value of a mix of different species including bycatch. In addition, the producer may receive management benefit and subsidy for production from the public sector. Then, the producers’ total benefits can be calculated as follows

$$b^{har} = \sum_{s=1}^n p_s^{raw} \cdot q_s + mb_{har} + sub_{har} \quad (\text{Eq.6-1})$$

Where, b^{har} represents the benefit from the harvesting sector of fisheries; s indicates species of fish, q_s and p_s^{raw} are the catch of species s and the landing price of this fish; mb_{har} and sub_{har} are the management benefit and subsidy for fishing harvesting sectors from the public sector, respectively.

Fish harvesting production requires inputs of intermediate products, services, labor, capital and tax (production tax, environmental or resource tax, etc.). The cost and benefit of the producer by métier can be calculated as follows

$$c^{har} = \sum_{i=1}^n p_i \cdot q_i + w_s \cdot l_s + \gamma_s \cdot k_s + FC_s + T_s \quad (\text{Eq.6-2})$$

Where, c^{har} represents the cost of the fisheries harvesting sector; q_i , l_s and k_s are intermediate products, labor and capital; p_i , w_s and γ_s are their prices, respectively; FC_s and T_s are fixed cost and tax.

(2) Fish processing sector

The fish processing sector is considered to consist of multiple types of producers which specialize in processing a single species of fish. In addition, the producer may receive management benefits and subsidy for production from the public sector. Therefore, the value output of the processing activities can be calculated as follows

$$b^{pro} = \sum_{sp=1}^n p_{sp}^{pro} \cdot q_{sp} + mb_{pro} + sub_{pro} \quad (\text{Eq.6-3})$$

Where, b^{pro} represents the benefit from the processing sector of fisheries; sp indicates the species of fish processed, and q_{sp} and p_{sp}^{pro} are the quantity and price of the processed fish; mb_{pro} and

sub_{pro} are the management benefit and subsidy for fishing harvesting sectors from public sector, respectively.

The production of each type of fish processing sector requires input of a particular species of raw fish among the species sp , non-fish intermediate products and services, labor and capital. Thus, the cost per unit of processing activity of processing sectors can be calculated as follows

$$c^{pro} = \sum_{sp=1}^n p_{sp} \cdot q_{sp}^{raw} + \sum_{i=1}^n p_{sp,i} \cdot x_{sp,i} + w_{sp} \cdot l_{sp} + \gamma_{sp} \cdot k_{sp} + FC_{sp} + T_{sp} \quad (\text{Eq.6-4})$$

Where, c^{pro} represent the cost of the fisheries processing sector; q_{sp}^{raw} , $x_{sp,i}$, l_{sp} and k_{sp} are input of raw fish, non-fish intermediate products, labor and capital; p_{sp} , $p_{sp,i}$, w_{sp} and γ_{sp} are their prices, respectively; FC_{sp} and T_{sp} are fixed cost and tax of processing sectors.

(3) Fish marketing sector

The fish marketing sector is considered to consist of three types of distributors, including small scale distributors focusing on local markets, large scale distributors focusing on domestic markets, and exporters. Each distributor sells multiple products including both raw and processed fishes and they may receive management benefit and subsidy for activity from public sector. Thus, the distributors' total benefit is

$$b^{mak} = \sum_{s=1}^n p_s^{mak,raw} \cdot q_{d,s}^{raw} + \sum_{sp=1}^n p_{sp}^{mak,pro} \cdot q_{d,sp}^{pro} + mb_d + sub_d \quad (\text{Eq.6-5})$$

Where, b^{mak} represents the benefit from marketing sector of fisheries; $p_s^{mak,raw}$ and $p_{sp}^{mak,pro}$ are the price of the raw and the processed fish; $q_{d,s}^{raw}$ and $q_{d,sp}^{pro}$ are the qualities of the raw and processed fish; mb_d and sub_d are the management benefit and subsidy for fishing harvesting sectors from public sector, respectively.

The marketing sectors production requires inputs of raw fishes, processed fish products, non-fish

intermediate products and services, labor and capital. Thus, the cost of marketing activities can be calculated as follow

$$c^{mak} = \sum_{s=1}^n p_s^{raw} \cdot q_s^{raw} + \sum_{sp=1}^n p_{sp}^{pro} \cdot q_{sp}^{pro} + \sum_{i=1}^n p_{d,i} \cdot x_{d,i} + w_d \cdot l_d + \gamma_d \cdot k_d + FC_d + T_d$$

(Eq.6-6)

Where, c^{mak} represents the cost from the marketing sector of fisheries; q_s^{raw} , q_{sp}^{pro} , $x_{d,i}$, l_d and k_d are input of raw fish, processed fish, non-fish intermediate products, labor and capital; p_s^{raw} , p_{sp}^{pro} , $p_{d,i}$, w_d and γ_d are their prices, respectively; FC_d and T_d are fixed cost and tax of processing sectors.

3.3.2 Ecological cost and benefit

One link between the ecosystem and economic systems involves the supply of ecosystem resources, goods, and services to the economy, such as fish stocks as inputs to the fish harvesting sector. The concept of ecosystem service value can be a useful tool for evaluating ecological costs and benefits. Ecosystem services to human being can often be simply assessed, as in the case of fish harvested from the ocean, but in other cases they may be indirect and difficult to determine, such as gas and climate regulation, leisure and recreation, and nutrient cycling (Farber et al., 2006).

Ideally, we would estimate the ecological impact on the food web and habitat, i.e. benefits from ecosystem services and external costs on biodiversity losses and habitat destruction. Due to limitations on the availability of data, we are unable to estimate all of the cost and benefit of ecosystem impacts. Instead we pursue a simplification of the concept of ecological benefit and cost so we focus on the direct economics value from fisheries and ecological losses from overfished resource stocks. Specifically, the landing value of fish species is defined as the ecological benefit that this fish species

provided to the fishery. The ecological benefit of fisheries activities is defined as the landing value of fish harvested which is equal to the economic benefit. Therefore, the ecological benefits of fishing are calculated as zero to avoid double counting.

Traditional concepts of overfishing include growth overfishing, recruitment overfishing, maximum sustainable yield (MSY), maximum economic yield (MEY) and potential biological removals of marine mammals, etc. (Murawski, 2000; Pauly, 1988). Although classic economic definition of overfishing is relative to maximum economic yield, not maximum sustainable yield, using the MSY benchmark is more realistic than classic MEY (Srinivasan et al., 2010). In our research, we adopt the maximum sustainable yield (MSY), which considers the economic capture of marine fish beyond maximum sustainable yield levels, to calculate the ecological cost of fishing.

The concept of MSY in single-species is criticized for many reasons (Mace, 2001). One of the obvious limitations of single-species fisheries management is that it is not holistic. It generally does not consider species interaction, changes in ecosystem structure or function, biodiversity and ecosystem services, etc. The study by Walters et al., (2005) showed that widespread application of single-species MSY policies would in general cause severe deterioration in ecosystem structure, in particular the loss of top predator species. The difference between the MSY of a species calculated from single-species assessments to those calculated from multi-species assessment is estimated using the already developed routine in Ecosim. Furthermore, ecosystem-based overfishing concepts play a greater role in fishery management (Murawski, 2000). Ecopath and Ecosim model provides an ecosystem-based approach which can be expressed as different equations defining trophic interactions as dynamic relationships varying with biomass and catch changes. However, Ecopath only provides a static picture of ecosystem trophic structure. Ecosim is a dynamic model which simulates changes in ecosystems that are described

under Ecopath. Ecosim model has been fitted to the catch and fishing effort time-series data from 1981 to 2005 of the PRE ecosystem (Duan et al., 2009b; Wang et al., 2012), for which there are long-term data that confirm the ability of the model to reproduce past responses of many species to harvesting, and to predict the biomass and catch dynamics in the simulated years (2005~2015). The dynamic changes in the biomass and catch data of each functional group resulting from the Ecosim simulation are then imported into the ECOST model to calculate the economic benefit and ecological costs changes. Here, ecological cost is measured as foregone losses from overfishing resource stocks. This paper is much more about overfished resource stocks not ecosystem impacts, even if Ecopath is used to capture some of the ecosystem dynamics rather than a single-species population model.

In this study, we want a measure of the total quantity of goods and service the economy and ecosystem is producing that is not affected by changes in the prices of those goods and service. Thus, the nominal value is evaluated by using prices that are fixed at 2004 level. It shows how the production of goods and service changes over time (Gourguet et al., 2013; Liu et al., 2011). The prices of landings which were collected from market survey data in 2004 are assumed to be constant (unpublished data). Catch data for fish species in the PRE are derived from 1981~2005 Fisheries Yearbooks, and biomass data are estimated by the model or obtained from stock assessment reports, field survey data, or other models. The price, biomass stock and catches of commercial fish species in ECOST model are showed in [Table 4](#).

Table 4 Here

For each species, we estimate *MSY* levels based on Ecosim predictions. Let *el* refer to the ecological system, Q_s indicate the total catch of a species *s*, and P_s and MSY_s represent the price and maximum sustainable yield of the species, respectively. The Schaefer model is applied to estimate the

maximum sustainable yield (MSY) for fishes in the delta regions. Therefore, the ecological cost is

$$C^{el} = \sum_{s=1}^n (Q_s - MSY_s) \cdot P_s \quad (\text{Eq.7})$$

If the maximum sustainable yield is below the actual landings, there exists a positive ecological cost.

If the maximum sustainable yield (MSY) exceeds the actual landings Q_s , the ecological cost is negative, presenting an ecological benefit.

3.3.3 Social cost and benefit

The concept of social service is discussed in Millennium Ecosystem Assessment ([Millennium Ecosystem Assessment, 2003, 2005](#)). The services include five categories, namely basic material needs, health, social relations, personal security, and freedom and choices. Clearly, the first two categories are directly related to personal income that is generated from the economy. While there are numerous studies on the economic benefit and cost of fishing activities, literature on social benefit and cost is rare. The Social consideration tends to include benefits for fish communities and fishermen's livelihood ([Teh et al., 2011](#)). Personal income distribution is commonly regarded as one of the main forces determining the social cost and benefit of fishing activity. It is closely related to wellbeing, poverty, and other income-based social issues. After all, some no-income based social issues are also indirectly related to personal income distribution.

The model assumes that the linkages between the social and economic systems are made through income distribution and that personal income distribution is one of the main forces determining social costs and benefits. Fishery household expenses can be classified into basic material needs, health, social relations, personal security, freedom and choice, according to the agriculture statistical yearbook of Guangdong province (2005) ([Table 5](#)). Personal security refers to health care and savings, which account for 8% and 39% of personal expense, respectively. Household savings are thus the major

component of personal expenses in China.

Table 5 Here

The ECOST model focuses on the social cost and benefit of basic material needs and health, leaving all other social services to the other categories. Let *BMN*, *HLH* and *OTH* represent basic material needs, health care and other social services, respectively. *PIF* represents personal income for fisheries households, and α indicates the share of each expense in personal income. *PEH* represents the average personal expenses for fishermen in the PRD. The social benefit of social services can be calculated with the formula

$$B^{sc} = PEH = \sum_i^n \alpha_i \cdot PIF, i \in (BMN, HLH, OTH) \quad (\text{Eq.8-1})$$

To address the social cost, at first, we define a society's economic position. We assume that an ideal level of personal income in a society is known. Based on this, ideal levels of spending on basic material needs, health and others can also be derived. Furthermore, based on the current situation, we can calculate the necessary spending on basic material needs, health and others, respectively. If we define the real spending as social benefit, the difference between the ideal and real situation measures the social cost. Since it is difficult to define the value of ideal levels, we assume the local residents' average level is an ideal level for fishermen. Thus, the social cost is the difference between local residents' average expenses and those of fisheries households in the PRD. Let *PEN* represent personal expense at the average level of locate residents, the social cost for the fisheries community is calculated as

$$C^{sc} = PEN - PEH \quad (\text{Eq.8-2})$$

3.3.4 Societal costs and benefits

As previously stated, the societal costs and benefits of fishing activities are accounted for by the sum of their social, economic and ecological costs and benefits. Let *st* indicate the society and *en*, *el* and *sc*

indicate economic, ecological and social factors, respectively. B , C and P indicate benefit, cost and profit, respectively. The societal costs and benefits can be calculated by

$$(B, C)^{st} = (B, C)^{en} + (B, C)^{el} + (B, C)^{sc} \quad (\text{Eq.9})$$

The societal profits are calculated as

$$P^{st} = B^{st} - C^{st} \quad (\text{Eq.10})$$

4. Results

4.1 Cost and benefit valuation

The ECOST model can assess the societal costs and benefits of fishing activities at the métier level and it is applied in this paper to compare and analyze the economic, social and ecological costs and benefits of fisheries activities in the PRD of China. Five métiers are selected for the cost and benefit valuation: demersal species pair and stern trawling (M1), shrimp trawling (M2), Japanese scad purse seine fishery (M3), threadfin bream gill net fishery (M4) and squids hook and line fishery (M5). [Fig.3.1 to Fig.3.4](#) show the cost and benefit analyses of the economic, ecological and social systems as well as for the whole fisheries community. To compare the costs and benefits of métiers in a consistent framework, the unit euro/ton is used in the figures. All values in RMB are converted to Euro€ by assuming the fixed exchange rate of 1 EUR= 10.29CNY. In theory but seldom in practice, a shadow exchange rate should be employed to provide society's accurate valuation of foreign exchange which may be a potential source of bias.

Fig.3 Here

The economics costs, benefits and profits of the fisheries under the different métiers in 2004 are shown in [Fig.3-1](#). In terms of economic revenue, shrimp trawling and demersal species pair and stern trawling are the most profitable métiers, it is therefore clear that trawlers play an important role in the

PRE's marine fishing. Trawlers are one of the least selective gear types, with significant mortality of all fish ages (and particularly high for the younger ones), high by-catch and discard rates (Crilly and Esteban, 2013). The coastal trawlers catch mostly juveniles, small fishes and invertebrates, such as shrimps and crabs, which have high market prices. Squids hook and line and threadfin bream gill net, which generated 718.74 Euro/ton and 663.92 Euro/ton, rank third and fourth respectively. Japanese scad purse seine is the least profitable technique, the use of purse seine gear is discouraged in the PRE, and only a few seiners operate in Shenzhen, Zhongshan and Jiangmen cities, catching a relatively small amount of fish. Because hook and line and gill net métiers are generally practiced by small scale, family-based fisheries, which target their product at high market prices, they generated more economic benefits than the purse seiner fishery.

The ecological cost, benefit and profit of fisheries under different métiers are shown in Fig.3-2. In this analysis, it can be observed that marine resources are overexploited by all five fishing métiers, causing a loss to the ecosystem. The ecological profits are negative, which indicates that fishing effort has exceeded the natural growth of several harvested fish species. Bottom trawling causes a widespread disturbance of sediments in the estuary and has negative impact on both seabed and its organisms. Both pair and stern trawling and shrimp trawling practices caused great ecological costs due to overfishing. The ecosystem structure of the PRE has shifted over time as large predatory species are depleted and smaller fishes gained dominance (Duan et al., 2009b). High demand for small fish and juveniles for the booming mari-culture of predatory fishes, the high market price of invertebrates, and the reduced operational costs of fishing by smaller boats evidently provide the support and incentive for continued resource depletion (Cheung and Sadovy, 2004).

The social costs, benefits and profits of fisheries under different métiers are shown in Fig.3-3. As

observed in the graph, the social benefits of the five métiers follow similar trends to their economic benefits, as do their social costs, which result from personal expenses being closely related to economic revenue. Our social profitability analysis shows that even though small-scale fishing generates positive profits, average fishing income is below the average income of local residents in the PRD, and is barely enough to cover household expenses.

Finally, we combined the economic, ecological and social profits of the PRD into the same graph to determine why these fishing profits are negative. The societal costs, benefits and profits of fisheries under different métiers are shown in [Fig.3-4](#). Although shrimp trawlers have the highest economic and social profits, they also have negative impacts on the estuary ecosystem. Gill net is a métier with the most advantageous trade-offs between ecological and socio-economic objectives. Although economic performance of the gill net is not as good as for trawlers, it is environmentally friendly. The design of gill nets has several favorable characteristics: low energy use, high selectivity and low discard rates. The squid hook and line and Japanese scad purse seine methods both generate low socio-economic benefits while producing relatively huge ecological cost. The ECOST model develops an integrated framework in which the economic, ecological and social systems interact with each other. The societal costs and benefits of fishing activities are accounted for by the sum of their social, economic and ecological costs and benefits. The results reveal that the PRE fisheries are in a loss state in which all of the societal profits were negative. This analysis suggests the currently status of the PRD fisheries appeared to pursue economic benefits at the expense of ecological gains. Therefore, effective conservation policy is critically needed to counter the strong tendency to overfishing.

The ECOST model develops a methodology to assess the societal costs and benefits of fishing activity in the PRE of China at the métier level. However, from a policy maker's perspective, it is more

convenient and desirable to compare all fishery-related costs and benefits in a common unit. The costs and benefits of the social, economic and ecological systems are all analyzed in this paper.

4.2 Cost and benefit prediction

The ECOST model can also be applied in benefit and cost prediction. Changes in the profits of fishing activities for ten years are simulated using historical time-series data of fishing efforts from 1985 to 2005 (Total engine power of boats in the South China Sea, Administration of Ocean and Fisheries, 2005). The economic impact multipliers contain indirect and induced along with direct impacts. Two assumptions are required before a ten year simulation: (1) There is excess capacity in the economy over this entire time period and (2) labor employed due to these secondary impacts is drawn from the ranks of unemployed and under-employed and not from the ranks of the already employed. The simulation results of fishery profits from 2005 to 2015 are presented in [Fig.4](#).

Fig.4 Here

As the first chart indicates, the variation ranges of the total societal profits of shrimp trawler, purse seine, and hook and line fishery are all within $\pm 50\%$ of current level. However, the societal profits of stern and pair trawling and gill net fishery declined sharply from 2006 onward, with the downward trend stabilizing from 2008 onward. As previously explained, ecological cost is composed of landings minus maximum sustainable yield (MSY), and it appears that the ecological profits of all métiers are negative in the simulation years. The curves of ecological profits demonstrate dramatic decreases in the first three years, although the downward trends somewhat stabilized from 2008 to the end of the simulation. It is apparent that ecological losses will only intensify under current exploration levels. In terms of economic objectives, all of the métiers would become less profitable, with the exception of shrimp trawling. The increased dominance of small pelagic fishes and invertebrates is one of the main

reasons for the rising economic profits of shrimp trawlers. Shrimp possess very robust life characteristics of being fast growing, short lived and highly fecund. This result suggests that the economic benefits play a dominant role across whole fisheries communities. Furthermore, the social profit also invariably experienced an increasing trend, although it appears that the value changes of social profit are not as abrupt (within 20% of current levels).

4.3 Policy simulations

To address the issue of excessive capacity, the Chinese government has taken measures to limit (and in some cases reduce) the fishing capacity of the fleets (Zhong Y.G., 1997). Previous study has suggested that the Northern South China Sea ecosystem could be restored by reducing fishing effort at annual rate of 5% for 30 years (Cheung and Pitcher, 2006). In this paper, we simulate the policy of reducing fishing effort by different métiers at an annual rate of 5% from 1985 to 2015 for 30 years. Fishing vessel or license buybacks have been proposed as possible means to reduce fishing capacity and the restructuring of fishing fleets to achieve specific management objectives (Zivin, 2013). Buybacks can be viewed as a second-best policy (A first-best policy is the most economically efficient instrument that addresses the problem in question), although there are first-best exceptions such as the buying back of harmful gear and its replacement with biodiversity friendly gear (Squires, 2010). Due to limitations on the availability of cost data, it is unfeasible to estimate full cost curves of a fishing effort reducing program. Therefore, it should be admitted that the societal profits are overstated, and the economic cost of fishing effort control policy are excluded from the analysis. Fig.5 shows the resultant simulation trends for the following scenarios: S0, status quo; S1, simulation of the reduction of fishing effort for pair and stern trawlers; S2, simulation of the reduction of fishing effort for shrimp trawler; S3, simulation of the reduction of fishing effort for vessels using purse seine gear; S4, simulation of the

reduction of fishing effort for vessels using gill nets; S5, simulation of the reduction of fishing effort for vessels using hook and line gear.

Fig.5 Here

The simulation results suggest that the status quo can be improved to optimal levels by reducing fishing efforts. The policies of reducing the efforts of most fishing métiers create major improvements in societal profits. Reducing the fishing efforts of pair and stern trawlers generates the maximum societal profits gain, while reducing the efforts of shrimp trawling, purse seine fishing and gill net fishing all had similar positive impacts on total profits. Most of the métiers achieve an increase in societal profits under effort reduction policies with the exception of shrimp trawling and hook and line, which experience a decline in profits due to their inherently high profitability.

Overall, vessel buyback programs can reduce fishing capacity and moderate negative impacts on the fishing communities. In terms of the ecological system, decreasing fishing effort would help to restore the PRE ecosystem and prevent the depletion of several vulnerable species that have already been heavily fished. Economically, many commercially valuable species are heavily over-exploited, which leads to the diminishing of potential economic benefits. However, restoration can increase stock abundance and improve the profitability of fishing activities. Policies that reduce the fishing efforts of those métiers that have large negative impacts on the ecosystem should be implemented while contributing relatively minor economic benefits. For example, reducing pair and stern trawlers can effectively improve total profits. Purse seiners also generate low economic revenues while exerting negative influences on juvenile fish populations.

5. Discussion

5.1 Sensitivity analysis

We conducted a sensitivity analysis to study the effects of changes in the key economic and biological parameters on the optimal policy. The vulnerability factor is a key uncertainty parameter in the Ecopath model. Low vulnerability (close to 1) means that an increase in predator biomass will not cause any noticeable increase in predation mortality; high vulnerability (e.g., of 100) indicates that the predator biomass will create large fluctuations in predation mortality.

The biomass dynamic is sensitive to the vulnerability factor, particularly in a top-down controlled ecosystem (Pauly and Christensen, 1993). As expected, the top-down controlled system varies more considerably than the entire system is assumed to be either bottom-up (Vulnerability factor=1) controlled or estimated “optimal solutions” (Fig. 6). When the ecosystem is assumed to be bottom-up controlled, the profits become closed to a linear relationship. Also, the estimated profits are similar to those from scenario with vulnerability parameters obtained from time-series fitting (base estimation).

The ecological, economics and societal profits predicted from bottom-up controlled scenarios are higher than those from scenarios with vulnerability parameters obtained from time-series fitting, whereas the lower social profits are predicted. Under the top-down controlled assumption, plots of estimated maximum achievable ecological, economic and social benefits are highly scattered at the beginning and finally rebound to original level.

Fig.6 Here

The discount rate is an important parameter to calculate the net present value in economic analysis (Wang et al., 2012). Usually, a lower discount means more weight is placed on future net benefits relative to the higher discount rates (Heymans et al., 2009). In general, the trade-off of relative profits is qualitatively robust at the discount rates (2% and 10%) used in this study. The shapes of profits are similar under different discount rate scenarios while the absolute values varied (Fig.7). As expected, a

higher discount rate (10%) reduces the net present value of profits from the fisheries. The result suggests that high discount rates focus on short term economic benefits at the expense of long term socio-economic and ecological gains.

Fig.7 Here

5.2 Model assumptions and uncertainties

In this paper, we define ecological cost using economic overfishing, in which greater maximum sustained yield (MSY) is obtained from fishing activities. The only factor we consider in this ecological cost assessment is landings, ignoring other environmental impacts. However, the impacts of bottom trawlers on the seabed are a serious environmental concern, because trawling can modify seabed habitats, disrupt food webs and reduce benthic biomass and production (Hall, 1999). Trawlers disturb the seabed and kill a substantial number of benthic organisms in the process of fishing. As benthic organisms are the major food source for many commercially exploited species, trawling directly affects a vital resource for commercial fish stocks and harms the ecosystem functions that the benthic species provide. Increasing the fishing efforts of bottom trawlers therefore results in the depletion of the commercially valuable predators. However, the populations of small prey species may be released from predator pressure and increase, becoming more available for capture. The increase in invertebrate landings might be related to the increase in the economic profits of shrimp trawlers, which target benthic invertebrates. Purse seine fisheries always operate using light. Light-purse seine is one of the main fishing techniques used in the marine capture fisheries of South China Sea. This gear may therefore accidentally capture a high proportion of juveniles from large pelagic species (Yang et al., 2009), which may endanger the sustainable production of these valuable fish. Gill nets can select mesh size, twine strength, and net length and depth, which are all closely regulated to reduce the bycatch of

non-target species. Most gill net fisheries have an extremely low incidence of catching non-target species. Therefore, these fisheries have little negative impact on the environment, as do hook and line fisheries. These impact factors of the different fishing métiers are not considered in this paper. A quantitative analysis of environmental impact is complex to calculate, and the actual ecological cost cannot be accurately reflected.

Both Ecopath-Ecosim and SAM models are considered to have considerable uncertainty. When applied to fishery resources, linking Ecopath with Ecosim and SAM models to capture the endogenous interaction of ecological, economic and social systems in a ECOST model is not only very difficult to implement but also adds more complexity and uncertainty to the modelling work. The ecological, social and economic system is a complex system and it is never possible to include all of the impacts in an analysis. The material and energy changes (e.g. circulation of nutrient matters) may have considerable effects on the PRE ecosystem. In addition, anthropogenic disturbance such as marine pollution may significantly affect the ecosystem, with rapid economic and social development (Zhang et al., 2002). These factors are likely to have negative effect on the benefits from fishery optimization policy. However, the effects of other social, economic and environmental fluctuations are not included in model. The analyses of the effects of these factors are limited by lack of series historical data. Furthermore, the unit cost of fishing and prices of landings are assumed to be constants, which change as the ecosystem and market supply and demand conditions vary.

5.3 Fishing policy optimization

The impacts of fishing policy on the benefits and costs of fishing activities are simulated by the ECOST model. Temporal scales are clearly important for both ecological and socio-economic dynamics. The long-term forecast (10 year) using the ECOST model is to reach a steady state balance,

which allows us to derive the dynamic changes of benefits and costs. The simulations predict fisheries of PRE are geared toward short-term economic profits at the expense of ecological gains under current exploited level and the status quo can be improved to better levels by reducing fishing efforts. According to the observation of fisheries data in Northern South China Sea (Lu and Lee, 2014; Qiu et al., 2010), the result of predictions are in accordance with the actual case.

Conventional economic theory predicts that for an overfished ecosystem, profits from the system will increase if fishing capacity is reduced to a level that produces the maximum economic rent (Gordon, 1954). However, the optimal fishing effort for maximum societal benefits cannot be obtained using the ECOST model. A numerical optimization ecological modelling (Ecopath with Ecosim) has been used to explore the trade-offs between conservation and socio-economic objectives in the management of a tropical marine ecosystem (Cheung and Sumaila, 2008). More recently, a trophic ecosystem model constructed by Ecopath with Ecosim is linked to a value chain approach in which the flows (amounts, revenue, and cost) of fish product are explicitly tracked from the ecosystem level through the consumer level (Christensen et al., 2011).

In this paper, the EwE model is only used in the biomass dynamic of the ECOST model. Further combinations of the ECOST model and the EwE model hold great promise in future fishing policy evaluations especially for optimizing the ecosystem impacts and economic and social benefits of these policies.

6. Conclusion

The PRE is regarded as one of the most important ecosystems in China's coastal sea, as it provides high biological productivity and sustains important commercial fisheries for the Pearl River Delta (PRD). The fishing industry in the PRD was previously the top primary production sector but now

represents only 1.4% of the area's Gross Domestic product (GDP). However, the status of fishery resources and ecosystem structure in the PRD has changed substantially due to overexploitation. As the contradictions between the economy, society, resources and environment become gradually apparent, it is necessary to develop an integrated method to evaluate the total societal costs and benefits of policy decisions. When fishery managers attempt to reduce fishing effort substantially, economic forces often lead participants in the fishery to resist. Decreased fishing levels would lead to reductions in the fishermen's earnings and welfare. This paper provides an ecological-economic model of the fishery for important commercial fishes in the Pearl River that is compatible with the ecosystem models currently used to produce management advice. An integrated ECOST model is developed by merging a Social Accounting Matrix (SAM) of PRD economy with an ecological model of the PRD coastal ecosystem. It thus bridges the gap between economic and biological models. Based on the Pearl River Delta 2004 fisheries SAM table, we have estimated the costs and benefits to economic, ecological and social systems. An accounting framework is developed for evaluating the contribution of environmental assets to the overall economy. The costs and benefits are compared among different métiers, leading to the conclusion that management and conservation can be improved by adjusting fishing efforts.

Our results indicate that total societal net benefits from the fishery could increase by up to 33% through reallocation of the fishery harvest. A possible consequence of restricting the fishery would be that part of the labor and capital currently engaged in the pair and stern trawling and gill net fisheries would move to the coastal shrimp trawling fishery. Furthermore, the substantial increase in the recreational catch would likely create new employment opportunities in providing services for recreational fisheries. Through shifts in the labor force, part of the increased social net benefits generated by the optimal policy could be directed to those currently participating in the trawling

fisheries.

Multi-objective management remains a great challenge for fisheries management and decision making, as conflicts between socioeconomic and ecological goals always exist. We believe that the integrated ECOST model provides a useful approach to quantify the trade-offs between ecological and socioeconomic systems. In addition, the findings in this study are applicable to other marine ecosystems.

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Tables and Figures

Table 1 Basic parameters of the PRD coastal ecosystem model (1998)

No.	Group name	Trophic level	B(t·km ⁻²)	P/B(year ⁻¹)	Q/B(year ⁻¹)	EE	P/Q
1	Benthic producers	1.0	153	11.885	-	0.01	-
2	Phytoplankton	1.0	13	231	-	0.47	-
3	Zooplankton	2.0	10.4	32	192.00	0.31	0.167
4	Jellyfish	3.1	1.07467	5.011	25.04	0.74	0.200
5	Polychaeta	2.0	0.8	6.75	22.50	0.89	0.300
6	Mollusks	2.2	0.7	3.5	11.70	0.86	0.299
7	Echinoderms	2.3	0.24	1.2	3.58	0.88	0.335
8	Benthic crustaceans	2.2	0.56	5.65	26.90	0.84	0.210
9	Other zoobenthos	2.6	1.69	1	9.00	0.74	0.111
10	Shrimps	2.3		3.08	16.35	0.95	0.188
11	crabs	2.5		3.79	12.50	0.95	0.303
12	Cephalopods	3.2	1.4747	3.1	8.00	0.95	0.388
13	Psenopsis anomala	3.0	0.1006	2.41	24.00	0.97	0.100
14	Stromateids	3.4	0.3930	3.03	15.15	0.93	0.200
15	Upeneus bensasi	3.1		2.0976	10.28	0.95	0.204
16	Pneumatophorus japonicus	2.8	0.0446	2.625	8.80	0.97	0.298
17	Argyrosomus argentatus	3.4	0.0341	3.55	7.71	0.96	0.460
18	Collichthys lucidus	3.3	0.0600	7.36	29.16	0.96	0.252
19	Saurida tumbil	3.3	0.0200	4.26	7.12	0.93	0.598
20	Trachurus japonicus	3.5	0.4120	2.15	7.86	0.90	0.274
21	Nemipterus virgatus	3.1	0.4860	2.07	7.25	0.93	0.286
22	Priacanthids	3.4	0.2160	2.94	8.00	0.92	0.368
23	Decapterus maruadsi	3.1	0.4607	1.87	11.08	0.92	0.169
24	Trichiuridae	3.8	1.1997	3.02	6.21	0.91	0.487
25	Small pelagic fish(30cm-)	2.8	1.772	4.26	17.04	0.97	0.250
26	Large pelagic fish(30cm+)	3.1	0.368	4.26	6.27	0.96	0.679
27	Benthopelagic fish	2.8	0.922	3.08	15.42	0.91	0.200
28	Small demersal fish(30cm-)	2.6		4.7	23.50	0.95	0.200
29	Large demersal fish(30cm+)	3.0	0.1640	3.5	6.21	0.94	0.564
30	Sharks	3.8	0.0050	0.2	4.13	0.10	0.048
31	seabirds	3.4	0.0030	0.06	66.10	0.06	0.001
32	Turtles	2.9	0.0002	0.1	2.50	0.10	0.040
33	Marine Mammals	4.0	0.0090	0.045	14.77	0.05	0.003
34	Detritus	1.0	200	-	0.00	0.16	

B—biomass, P/B—production to biomass ratio, Q/B—consumption to biomass ratio, P/Q—production to consumption ratio, EE — ecotrophic efficiency

Table 2 Social accounting matrix (SAM) for the PRD coastal economy in 2004

			Activities			Commodities			Factors		Institutions				TOTAL
			FISH	PROC	OTHER	FISH	PROC	OTHER	LAB	CAP	HH	GOV	INVENT	ROW/EX	
(million Euro, 1EUR=10.29 CNY)			1	2	3	4	5	6	7	8	9	10	12	14	15
Activities	FISH	1				1512.25									1512.25
	PROC	2					175.65								175.65
	OTHER	3						1209.49							1209.49
Commodities	FISH	4		130.15	210.36						618.31	624.04	8.63	52.32	1643.82
	PROC	5		5.55	33.50						72.06	72.73	1.01	6.08	190.93
	OTHER	6	626.83	29.52	238.72						186.73	188.46	2.61	41.85	1314.72
Factors	LAB	7	783.80	6.82	722.05										1512.67
	CAP	8	101.62	3.61	4.86										110.09
Institutions	HH	9							747.65	54.41			716.08		1518.15
	GOV	10							754.58	54.92	58.33		664.39		1532.21
	SAV	12							10.44	0.76	582.72	646.98	-1219.70		21.20
	ROW/IM	13				131.57	15.28	105.23		.			-151.82		100.25
TOTAL	15	1512.25	175.65	1209.49	1643.82	190.93	1314.72	1512.67	110.09	1518.15	1532.21	21.20	100.25	10841.42	

FISH-fishing, PROC-processing, OTHER-other, LAB-labor input, CAP-capital input, HH-households, GOV-governments, INVENT-investments, SAV-savings, ROW-rest of world, IM-import, EX-export.

Note: Data from the Input-output table of Guangdong Province (2007); Aquatic Products yearbook of Guangdong Province (2004); Statistical yearbook of Guangdong province (2005) and Guangdong finance Yearbook (2005).

Table 3 Fish production make table of the PRD in 2004

Fish production Value (million Euro, 1EUR=10.29 CNY)	Japanese scad	Japanese jack mackerel	Melon seed	Pomfret	Chub mackerel	Silver croaker	Lionhead croaker	Greater lizardfish	Threadfin bream	Bigeyes	Cutlass fishes	Shrimps and Prawns	Crabs	Squids	Other species	Marine fish from the region	Other fishing	Total raw fish
Demersal species trawling	9.438	0.002	0.366	4.260	0.193	0.387	0.039	0.003	6.504	8.785	35.765	5.510	3.732	4.504	0.018	79.506		79.506
Shrimps trawling	0.000	0.000	0.030	0.400	0.000	0.000	0.023	0.003	0.126	0.179	0.707	39.622	9.329	0.715	0.334	51.469		51.469
Japanese scad purse seine	2.072	0.002	0.064	0.811	0.502	0.000	0.087	0.000	0.000	0.000	0.283	0.007	0.000	1.978	0.110	5.917		5.917
Threadfin bream gill net	0.000	0.000	0.062	4.439	0.025	0.269	0.066	0.038	1.409	1.986	9.330	0.000	3.927	0.000	0.466	22.018		22.018
Squid hook and line	0.000	0.000	0.000	1.575	0.000	0.008	0.014	0.000	0.922	1.299	1.187	0.000	0.000	0.954	0.106	6.066		6.066
Other harvesters	0.000	0.000	0.121	1.101	0.023	0.008	0.000	0.009	0.349	0.495	2.403	1.555	1.642	0.026	0.114	7.846		7.846
Harvesting in a region	11.510	0.005	0.642	12.586	0.743	0.674	0.229	0.053	9.310	12.745	49.675	46.693	18.630	8.177	1.149	172.821		172.821
Other fishing																	1339.432	1339.432
Total Fishing	11.510	0.005	0.642	12.586	0.743	0.674	0.229	0.053	9.310	12.745	49.675	46.693	18.630	8.177	1.149	172.821	1339.432	1512.253

Note: Data from Aquatic Products Yearbook of Guangdong Province (2004) and field survey data from Xiangzhou fishing port, Wanshan Island, Guishan Island, Dong'ao Island of Zhuhai City; Nansha fishing port of Guangzhou city.

Table 4 Input ecology data of ECOST model of the PRD in 2004

Species	Price (Euro/tonne)	Biomass stock (million tone/km ²)	Catch (million tone/km ²)
1. Japanese scad	195	0.0262	0.0059
2. Japanese jack mackerel	650	0.0291	0.000
3. Melon seed	400	0.0293	0.002
4. Pomfret	1105	0.0300	0.011
5. Chub mackerel	190	0.0336	0.004
6. Silver croaker	840	0.0381	0.001
7. Lionhead croaker	300	0.0381	0.001
8. Greater lizardfish	115	0.0363	0.000
9. Threadfin bream	1400	0.0358	0.007
10. Bigeyes	2200	0.0361	0.006
11. Cutlassfishes	1100	0.0364	0.045
12. Shrimps	2566	0.0364	0.018
13. Crabs	2900	0.0363	0.006
14. Squids	2100	0.0363	0.004
15. Other species	108	0.3112	0.105

Table 5 Personal expenses of local residents and fishermen of the PRD in 2004

Personal expenses category	Residents in the PRD		Fishermen in the PRD	
	Value	Percentage	Value	Percentage
	(Euro)	(%)	(Euro)	(%)
Basic material consumption	672.56	49.7	392.29	46.7
Health care	70.49	5.2	67.95	8.1
Social relations	75.59	5.6	17.46	2.1
Personal security	444.00	32.8	327.58	39.0
Freedom and choice	91.32	6.7	35.39	4.2
Total	1353.96	100.0	840.67	100.0

Note: Data from the Agriculture statistical yearbook of Guangdong province, 2005

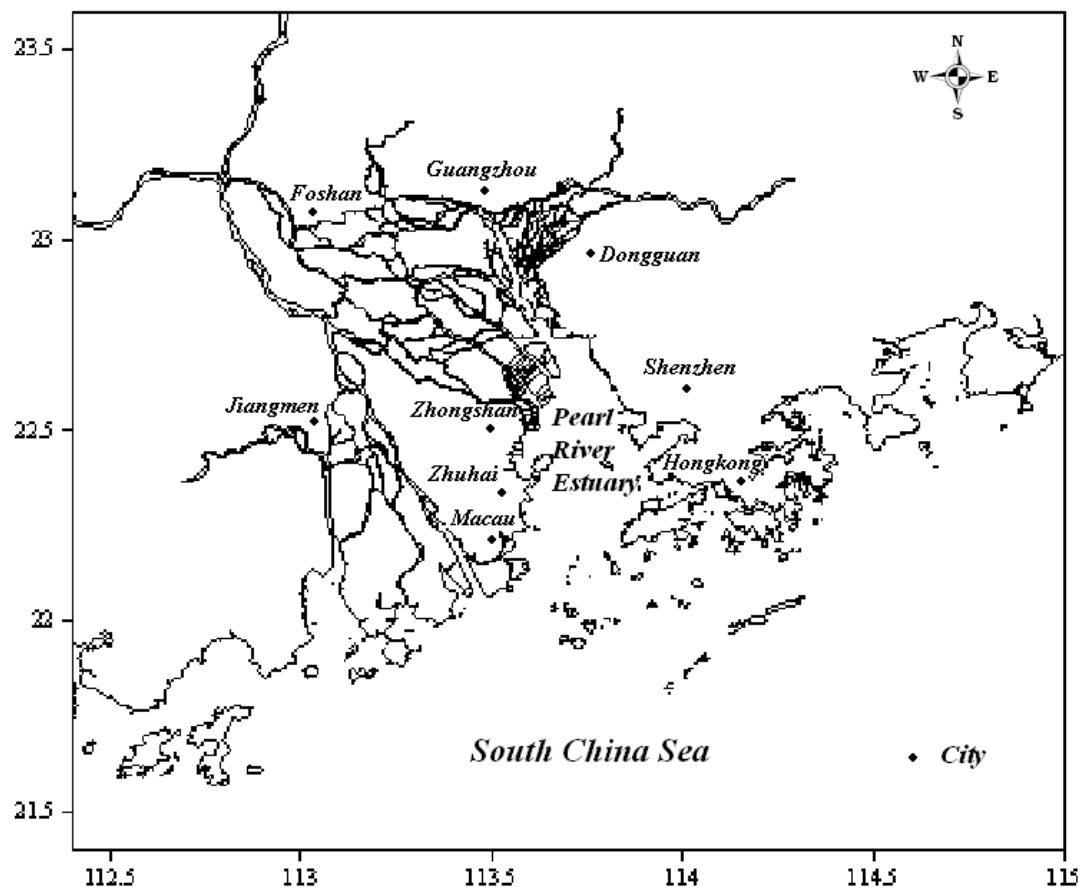


Fig.1 Map of the Pearl River Estuary

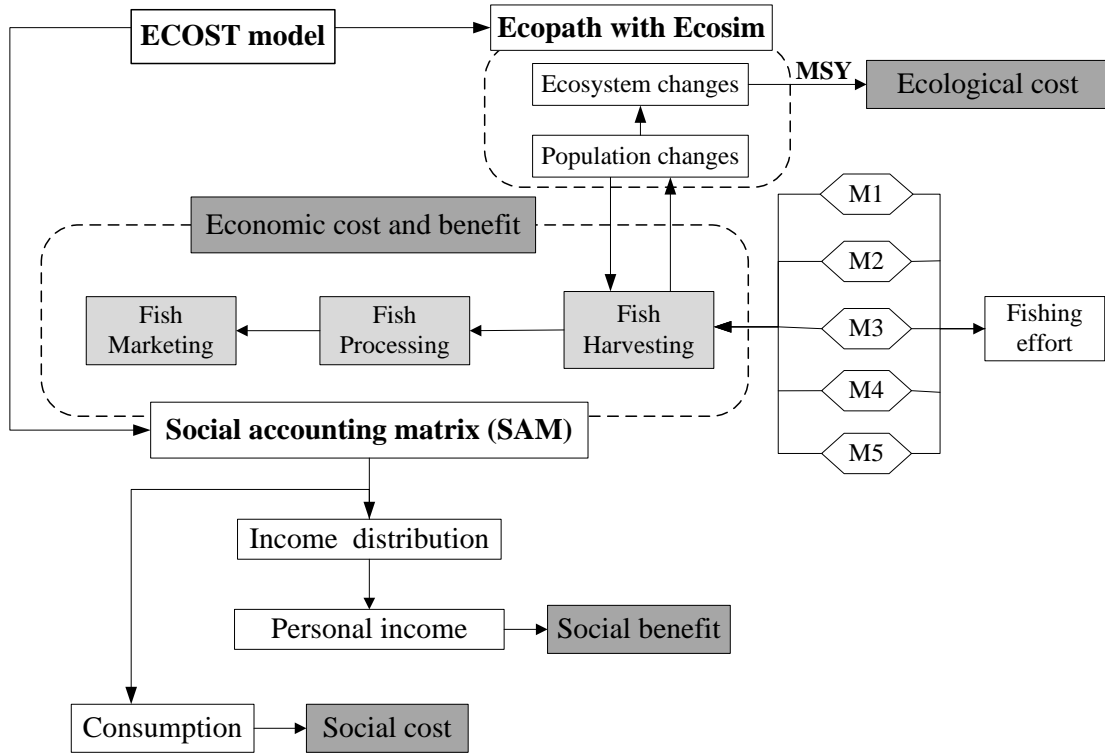


Fig.2 ECOST model with integrated of social, economic and ecological system

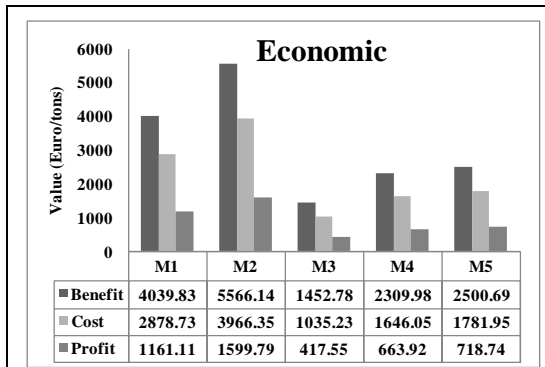


Fig.3-1 Economic cost and benefit of per ton catches the PRD in 2004

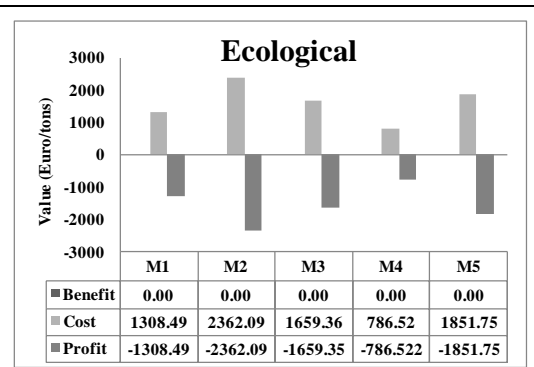


Fig.3-2 Ecological cost and benefit of per ton catches the PRD in 2004

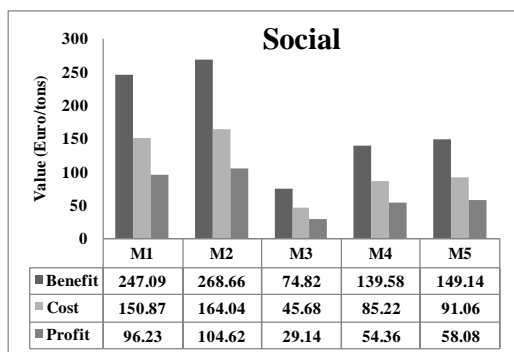


Fig.3-3 Social cost and benefit of per ton catches the PRD in 2004

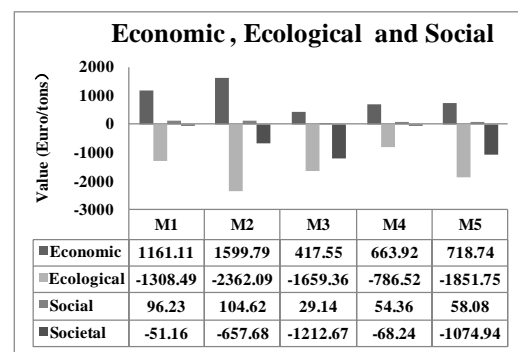


Fig.3-4 Economic, ecological and social profits for per ton catches of the PRD in 2004

Notes: M1- Demersal species trawling, M2-Shrimps trawling, M3-Japanese scad purse seine, M4-Threadfin bream gill net, M5-Squids hook and line

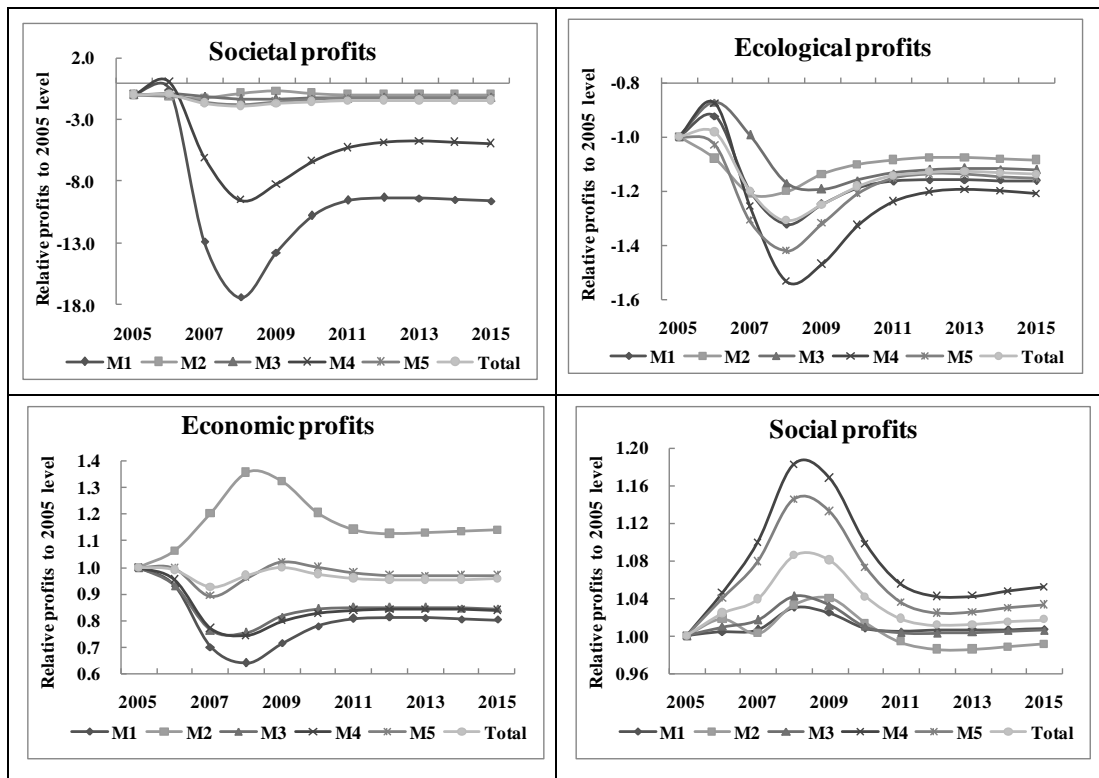


Fig.4 Predicted changes over time in PRE ecosystem from 2005 to 2015 driven by fishing efforts.

Changes are shown relative to the ecological, economic, social and societal profits in 2004, respectively.

Notes: M1- Demersal species trawling, M2-Shrimps trawling, M3-Japanese scad purse seine fishery, M4-Threadfin bream gill net fishery, M5-Squids hook and line fishery

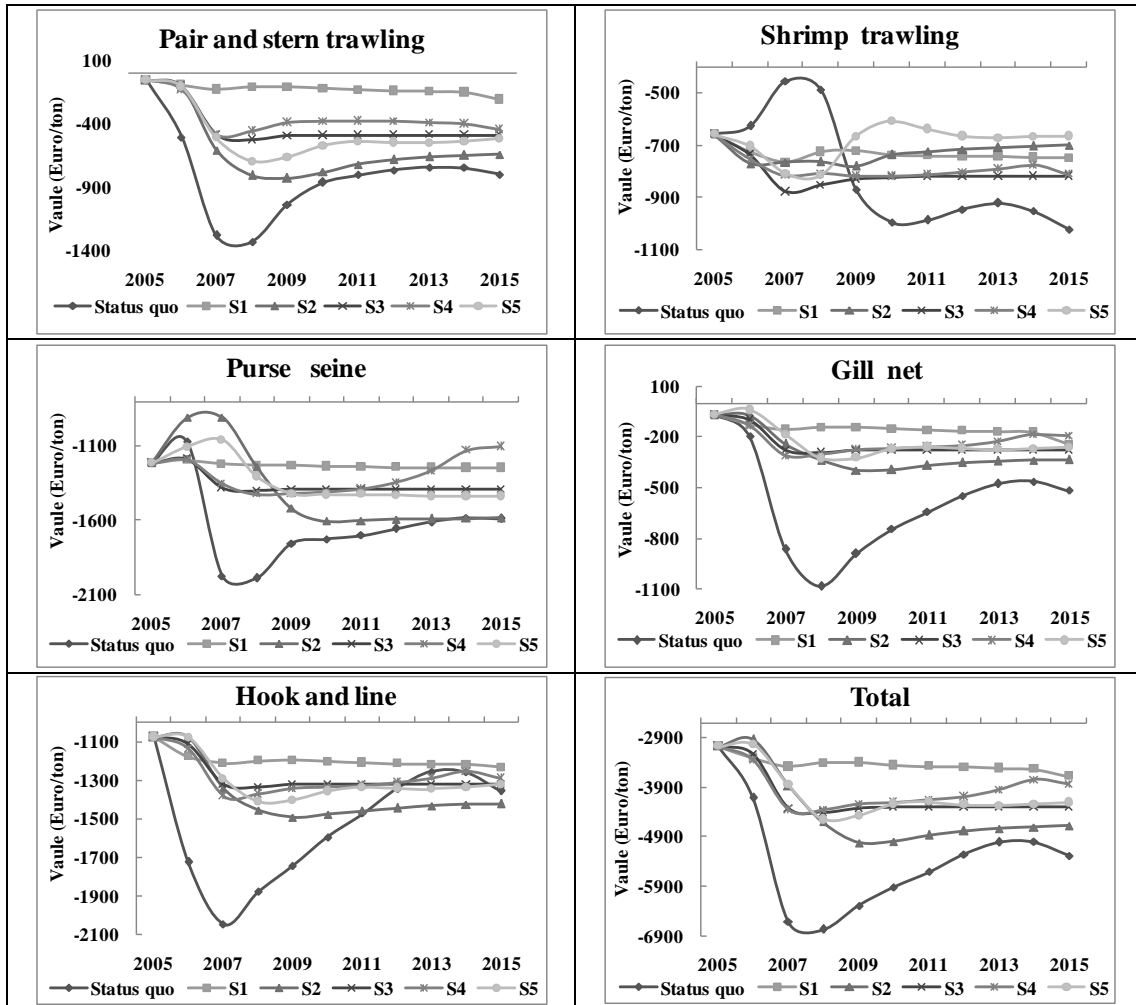


Fig.5 Predicted changes in societal profits of five métiers compared to the status quo after a 10 years period of simulation

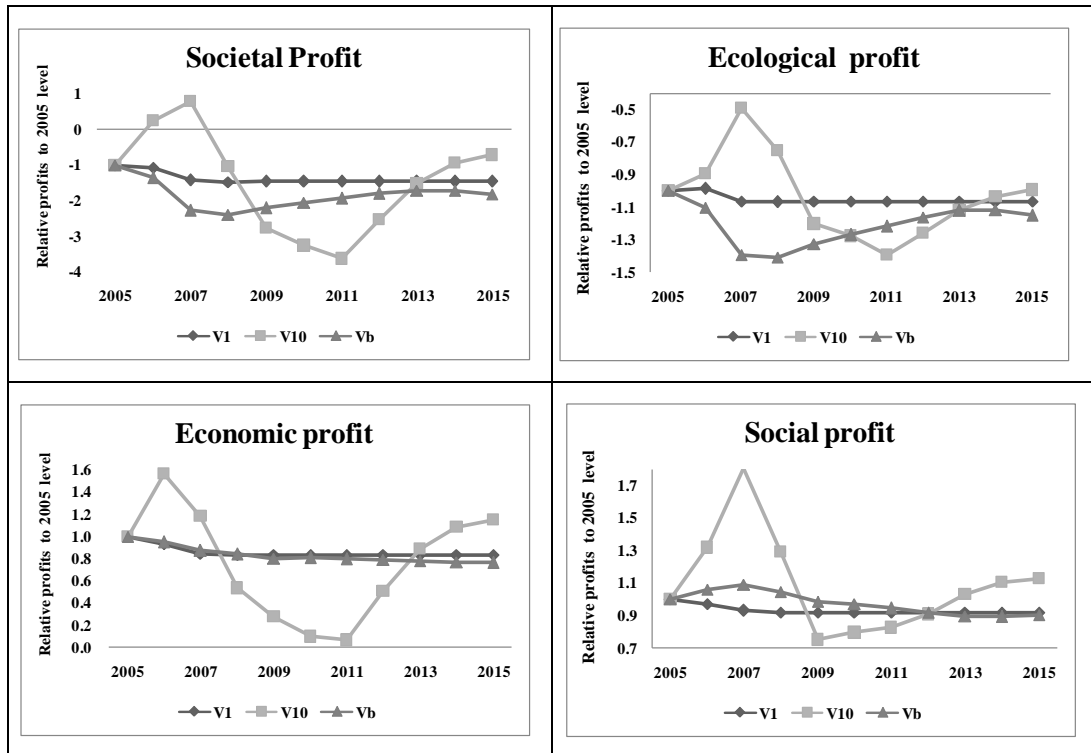


Fig.6 Predicted changes in ecological, Economic, social and societal profits under (1) V1- bottom-up controlled (vulnerability parameters=1), (2) V10- top-down controlled (vulnerability parameters=10) and (3) Vb –base estimation (vulnerability parameters estimated from fitting with time series data) were included in the figures for comparisons

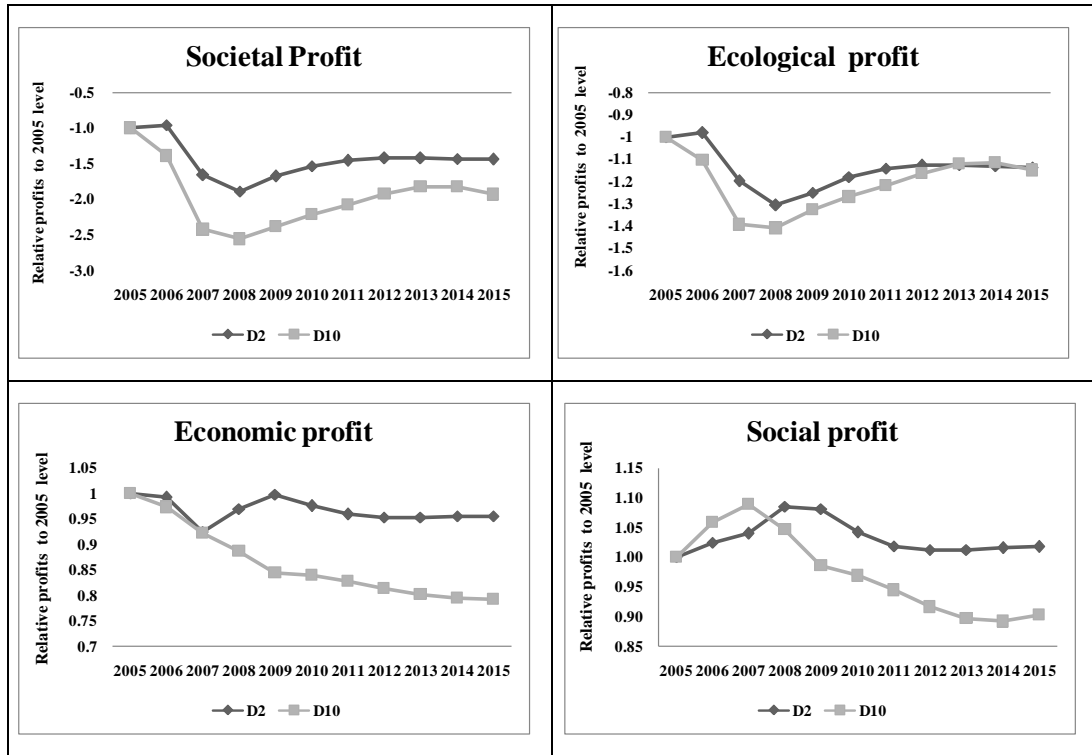


Fig.7 Predicted changes in ecological, Economic, social and societal profits under (1) D2- annual discount rates 2%, (2) D10- annual discount rates 10% were included in the figures for comparisons