An ecosystem dynamic model for the valuation of externalities of fishing activities

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Abstract

There is a growing interest in summarizing, in economic terms all the variables that are referred to as ecological goods and services. The challenge of economic valuation of environmental goods, services and function relies on the understanding of the environmental feedbacks that markets do not account. In this study a mass-balance model and an energy based methodology for economic valuation are applied to the case study of the Venice Lagoon, in order to quantify some of the externalities of fishing activity. Artisanal fishery in the Venice lagoon is a multitarget activity with a long tradition. It was the main fishing activity till the late '80s when, after the introduction and spread of the Manila clam (*Tapes philippinarum*), the mechanical clam harvesting started. A mass-balance model of the lagoon ecosystem was developed using the Ecopath with Ecosim software. 80 scenarios were obtained by changing the fishing effort of the two different types of fishery with the use of Ecosim dinamic model. Those scenarios were used to explore the impact of the fishing activity on the ecosystem. A set of indicators was applied in order to compare the two fishing activities. The results obtained showed that the two activities are strongly interlinked, even if they don't exploit the same resources. The mechanical clam harvesting could reasonably be considered the driving force; it is capable of determining the state of the lagoon ecosystem. The possibility of reporting those eclogical linkages in economic term can represent a step towards a sustainable management of the fishery resources in the Venice Lagoon.

Introduction

From ancient times, fishing has been a major source of food for humanity, and a provider of employment and economic benefits to those engaged in this activity (FAO, 1995). But the exploitation of a common-property, like fish, is revealing to be unsustainable as is shown, on a global scale, by the phenomena of stock depletion (Botsford *et al.*, 1997), reduction of the mean Trophic Levels in the catches (Pauly *et al.*, 1998), and marine habitat disturbances (Hall, 1999).

Notwithstanding all the above, when the correct procedures are not in place, the fishing industry is driven to search for new technologies, thus producing an intensification of the fishing effort. Consequently fishing vessels are becoming larger and faster, are using more expensive types of technology and are catching fish in shorter periods of time, thus enhancing the gap between sustainability and fishing activity (Mathew, 2001). These factors are producing an increasing number of people involved in the exploitation of marine biological resources, who lack training, experience and skills. This gap can result in a lack of 'traditional ecological knowledge' leading to an unsustainable exploitation of the living resources. On the contrary, artisanal fishery requires more experience and is usually based on a strong link between fishermen and the ecosystem, all these drive to a sustainable exploitation activity.

The coexistence of technological and artisanal fisheries can also generate conflicts concerning space and resources, (Allison and Ellis, 2001; Mathew, 2001). In coastal areas, where small-scale and artisanal activities are particularly rooted (FAO, 2000), conflicts between new and old types of fishery can even be bigger. These modifications in fishery structures drive changes at an economic and social level (FAO, 2000; Ruttan *et al.*, 2000; Sumaila *et al.*, 2001) other than at an ecological level; they can result in conflicts between "old" and "new" activities. The artisanal sector is particularly vulnerable, as it often depends on the use of gears, which are incompatible with towed gears, such as those used by industrial trawlers.

The international framework of policy regulations is giving greater interest to coastal resources and fishery conflicts in order to enforce the sustainable development of human activities. Coastal communities and their customary practices are accorded special recognition by the Code of Conduct for Responsible Fisheries (FAO, 1995) where explicit suggestions are also given in order to obtain the protection and rehabilitation, nursery and spawning areas, in so far as it is possible. The importance of artisanal and small-scale fishery to employment, income and food security is also recognised in the above mentioned Code.

Therefore, fishery management has to take into account not only sound research concerning the ecosystem, but also the socio-economic components of the system.

Indicators for the ecological, economic and social effects of fishery are demanded, and a new interest in environmental changes, rather than merely in stock changes, is required (Anonymous, 2000). These indicators could be used as a basis for the evaluation of fishing pressure, and applied in fishery management, in order to create integrated policies, characterised by the combinination of the principles of fisheries and ecosystem management, under the shield of sustainability. The indicators have, therefore, to include a reference direction, allowing for the prediction of whether the indicator will increase or decrease due to exploitation (Rochet and Trenkel, 2003).

In such a complex framework, a potential core set of indicators have been developed within many national and international organisations, with the aim of describing the driving forces, pressures, states, impacts on and responses of the ecosystem to fishing activity (Zenetos *et al.*, 2002). However, the economic and social patterns also have to be clarified, in order to achieve an understanding of all these pressures and for the correct management tools.

Fishery in the Venice Lagoon – case study

The Venice Lagoon is a sensitive area subjected to different kinds of anthropogenical pressures, from industrial activity to resource exploitation. With regard to this last aspect, small scale fisheries have a long tradition also in terms of management (Granzotto *et al.*, 2001) but the introduction, in the middle of the 80s, of the Manila clam (*Tapes philippinarum*) induced major changes concerning ecological, economic, and social dimensions of the lagoon. From the perspective of sustainable exploitation, a greater effort has to be made to define and apply management strategies which can assure the sustainable development of fishing activities, and the coexistence of the two types of fishing activities, in an environment as crucially important as the Venice Lagoon.

According to Mathew (2000), the definition of artisanal fishery can be based on different categories: the social, environmental, and technological features, the boat size, and the fishing ground size. As regards the Venice Lagoon, the small-scale fishery can be defined as artisanal, because of the strong link between the fishermen and the environment, resulting from centuries of traditions rooted in the past. This traditional knowledge led, to the utilization of more than 25 types of fishing technique up to the middle of the 20th century, (Granzotto *et al.*, 2001). At present, only two kinds of static fishing gear are still used. Artisanal fishermen target a wide range of species, including both residents and migrants, depending on the seasons, the fishing grounds and the tide (Mainardi *et al.*, 2002).

On the contrary, mechanical clam harvesting is a monospecific fishing activity, carried out using of small boats with 25HP engines, positioned outboard amidships (Fig. 1). The fishing grounds are shallow water areas, where the propeller can reach the bottom, resuspending the sediment and the clams, which are then collected in the net. This type of boat is also equipped with a 300HP engine, for the purposes of reaching the fishing grounds located in the whole lagoon.

According to Sacchi (2001), the Mediterranean fisheries are described as mainly small-scale type. They are comprised of small enterprises, with little capital, run by artisans who often own the production tools (vessel plus fishing gear) and to a certain extent they also control the commercialisation network regarding this product. Both the fishing techniques considered here can be classified as small-scale. However, the mechanical clam harvesting can also be classified as 'industrial fishery', as this classification is used when other factors, such as the fact that these vessels catch only one target species, the high level of technology used in the process are taken into account.

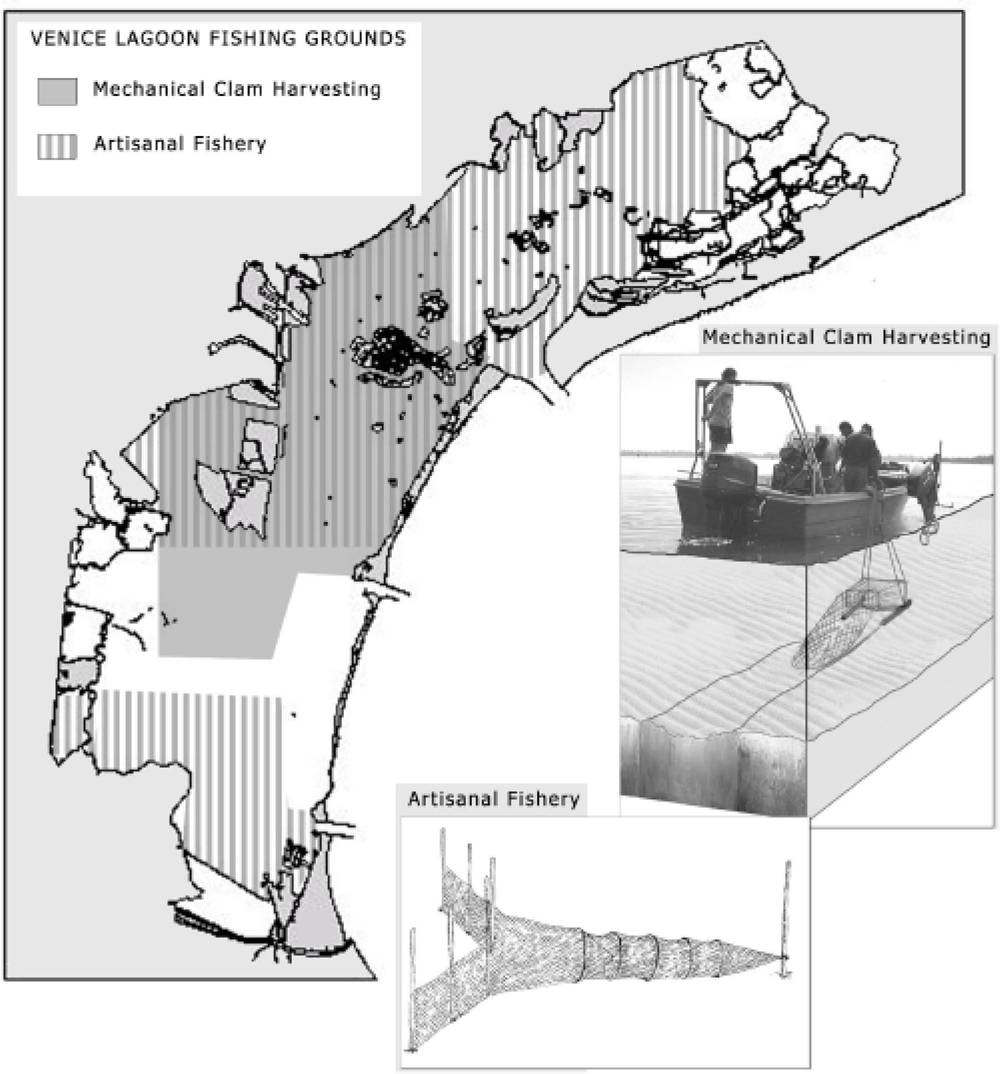


Fig. 1 – The location, distribution and estension of the fishing grouds relatively to artisanal and mechanical clam fisheries in the Venice Lagoon.

These two different fishing activities could be located at the two extremities of more than 45 types of fishing techniques described for the Mediterranean Sea (Sacchi, 2001). Nevertheless, these two methods are those principally used here: i.e. passive (fyke net) and active (clam dredge). However, major differences can be seen regarding potential impact of the gear, e.g. the interaction with the bottom morphology is the highest possible regarding the clam dredge (which produces a 7-10 cm deep track) and is totally absent when using a fyke net.

As stated by Link (2002), it is doubtful whether we are "attempting ecosystem management in a fisheries context or fisheries management in an ecosystem context". At present, in the Venice Lagoon, given the complete absence of a real fishery management (mainly with respect to mechanical clam harvesting), the first hypothesis has been assumed to be realistic. But, as is also highlighted in Pranovi *et al.* (2003a), clam harvesting can be seen to be totally unsustainable, and recent evidence, such as a sharp reduction in clam production (about 40%, Boatto *et al.*, 2001), seems to confirm this hypothesis.

In this context, a change in perspective is needed, which will introduce an ecosystem-based type of management, capable of ensuring the maintenance of the 'ecosystem health and sustainability' (NMFS, 1999) or the 'ecosystem state sustainability' (Link, 2002).

In order to achieve this goal, an estimation of all the effects (both direct and indirect) produced by the fishing activity on the ecosystem becomes essential. Moreover, from a management point of view, it could also be useful to distinguish between the effects induced on the environment by the different types of fishing activity.

The adoption of an ecosystem-based approach to fishery management is now among the principal objectives of policy makers. However, fulfilling this objective is dependent upon a number of factors, including the ability to evaluate the performance, either positive or negative, of these management strategies.

Exploited communities are complex systems and very few indicators are exclusive to the question of fishing impact. Therefore, finding a single indicator which measures the effects of fishing will be difficult. An alternative approach is to examine multiple indicators in order to accumulate evidence (Garcia and Staples, 2000; Rice, 2000).

According to Rochet and Trenkel (2003), there are three ways of assessing whether a community is affected by fishing: (1) examine whether it is currently changing and if so, whether this change can be ascribed to fishing; (2) develop a theory concerning the value of the attribute in an unexploited system and predict the effects of fishing on it; this will allow for an inference, from the observed patterns, as to whether the system is affected by fishing or not; (3) alternatively, an empirical reference system can be developed, by gathering indicator estimates from many communities.

Probably it is possible to locate another way which passes through the simulation obtained by the modelling approach. In this case, the constraints imposed by the trade-off between the complexity imposed by the realism and simplicity necessary for precision (*e.g.* the clustering of species in trophospecies, Yodzis and Winnemiller, 1999), which might bias the results, could be counterbalanced by the possibility of assessing the indicator performances in relation to different fishing scenarios (Walters *et al.*, 1997).

In this framework, starting with a mass-balance model, describing the Venice Lagoon ecosystems, some indicators concerning the impact of fishing activities on the ecosystem state and functioning were calculated, in order to compare artisanal type fisheries with industrial ones. This procedure gave us the opportunity to assess their applicability and to evaluate the resolution power concerning the different kinds of effects.

The aims of this study were:

- to assess the ecosystem impacts and the interactions between the two fishing activities;
- to explore different scenarios obtained in order to optimize individualy the social, economic and ecosystem aspects of fishing impacts.

Materials and Methods

A description of the ecosystem was done by means of a mass-balance model, developed using Ecopath and Ecosim software (EwE, Christensen *et al.*, 2000). The model makes it possible to represent both the biotic and abiotic components of the ecosystem, by means of the flows of matter and energy, including the fishing activities and major features which influence the flows between the ecosystem components (Christensen and Walters, 2000). Thus, the model makes it possible to explore the impact of the fishing activities, described as a part of the ecosystem, on the biological communities through both direct and indirect effects (Pauly *et al.*, 2000).

A published model describing the Venice Lagoon ecosystem in 1998 was used here (Pranovi *et al.*, 2003a). In this model, the biological data are organised in such a way as to estimate the average parameters and biomasses regarding the exploited areas, thus creating a model which represents the "average exploited habitat". The biological components of the ecosystem were aggregated into 25 functional groups, plus the bottom sediment and organic matter present in the water column (Suspend Organic Matter, SOM) which comprised two detritus groups, giving a total of 27 groups (see Pranovi *et al.*, 2003a for a detailed description of the model components). The model also takes the mechanical clam harvesting into account, considering the landings and discards, and the resuspension of the bottom sediments resulting from the fishing activity.

Artisanal fishery is described in terms of the landings, as the discards are irrelevant. The model was built using energetic units; thus the flows are in kJm^{-2} $year^{-1}$ and the biomass in kJm^{-2}.

80 time dynamic simulation were obtained by using Ecosim in order to observe the behaviour of biomasses depending on different fishing effort scenarios.

20 of the simulated scenarios had a final "artisanal fishing effort" (F_A) ranging from $F_A = 0$ to $F_A = 2$ relative to the baseline, with increments of 0.1; these 20 scenarios were then repeated three times with relative "mechanical clam harvesting fishing effort" (F_{mch}): $F_{mch} = 0.0$, 0.5 and 1.0 obtaining a total of 60 scenarios. Other 20 scenarios were simulated with F_{mch} ranging between 0 and 2 and $F_A = 1$.

Methodology for attribution of economic value to non marketed species

Only the commercial species are brought to the fish market and are priced; the non-commercial species, which are directly or indirectly involved in the fishing activity, do not have a market value. Therefore in order to measure the economic externalities of the fishery, we need to attribute an hypothetical value to them.

The methodology here applied for economic valuation of non marketed species can be summarised in 2 main steps: a first evaluation, based on the species energy required and a second evaluation, based on the functional role of the species in the considered ecosystem.

Required energy analysis

From an ecosystem point of view, each species occupies a precise level in the trophic web and this represents its Trophic Level (TL). The TL integer, as defined by Lindeman (1942), is the number of passages along the trophic web, from the considered species down to the autotrophy organisms, or the non-living organic matter. Since the living species usually feed on more than one food item, it is possible to obtain their effective TL by weighing the TL of the different preys in terms of the amount of the latter in the diet, which results in a real number, ranging from 2 (detritivores or herbivores) up to 5 or 6 (large top predators).

Based on this simplified description of the energy dynamic in an ecosystem, we can assume that, in a first approximation, two different species, sharing the same TL, require the same primary production, in order to be sustained by the system. In a first approximation, this means that these two species can be considered as equivalent, in terms of the primary production required (PPR).

From an economic point of view, the price of a good is determined by a lot of factors, which vary between personal preferences, resource scarcity, substitutability, etc. Nevertheless, a relationship has been recognized between the TL and fish prices per unit of weight of species landed (Sumaila, 1998; Pinnegar *et al.*, 2002), as the high TL species have a higher value per kilogram than the low TL species. When considering this relationship, a unit of TL has a different monetary value, depending on the TL of the species considered. Therefore, the value of a unit of stocked energy seems to depend on the quantity of energy required to produce and maintain it, that is the "Embodied Energy", Emergy.

By combining these two introductory statements, it is possible to give an economic value to non-marketed species, based on the price of the marketed species; a pseudo-market value of the energy required by the species can be obtained in two different ways: firstly based on the average value of a unit of TL, and secondly based on the relationship between the TL and the price per unit of weight.

The price per unit of weight of each marketed species is divided by its TL, and the average value for a TL unit (average emergy value = *Ve*) is then calculated.

This values, when it is multiplied by the biomass of the considered species, give an estimate of the *natural capital value* (*NCV*) as was intended by Daly (1994).

Functional analysis

In a first approximation, in order to roughly estimate the role each species plays in determining the functioning of the ecosystem, the trophic interactions between the species upon each other in the system can be used.

In this context, Ulanowicz and Puccia (1990) proposed an index, called the Mixed Trophic Impact (MTI) index, which synthesizes all the positive and negative interactions of each species in the system. This index, given a trophic web and the trophic relationship among its components, summarizes the effect of the species on the whole ecosystem. It is of interest to note here that a similar index was used for the first time by economists when Leontief (1951) demonstrated how the knowledge of all the direct exchanges (input-output) occurring in an economic community could be used to infer the level of *activity* necessary within any economic sector to discover the final demand by any other sector. This *activity* can be considered as a kind of value which refers to the *functionality* of that sector.

With reference to the direct and indirect influences of each species on other species, the MTI can represent a broad description of the functionality of the species in the system. The MTI is therefore used to weight the value previously obtained by multiplying it by the *Ve*, thus obtaining the value *Vf*, which could be reported as estimate of the *functional value* of the species.

The output biomasses resulting from the 80 time dynamic simulations were multiplied by the economic values obtained by the previously described methodology.

Results

The total catches, landings and discards of the two fishing activity of the Venice Lagoon are here reported as resulting from the 80 dynamic simulation obtained by the Ecopath with Ecosim model.

In figure 2 the total landing quantities (a) and the discard quantities (b) of the fishing activities are reported. The landing depending on the mechanical clam harvesting resulted to be so high that the variation of the artisanal fishery catch is not clearly visible.

Discard quantities reported are 3/2 of the landing and they depend only on the mechanical clam harvesting.

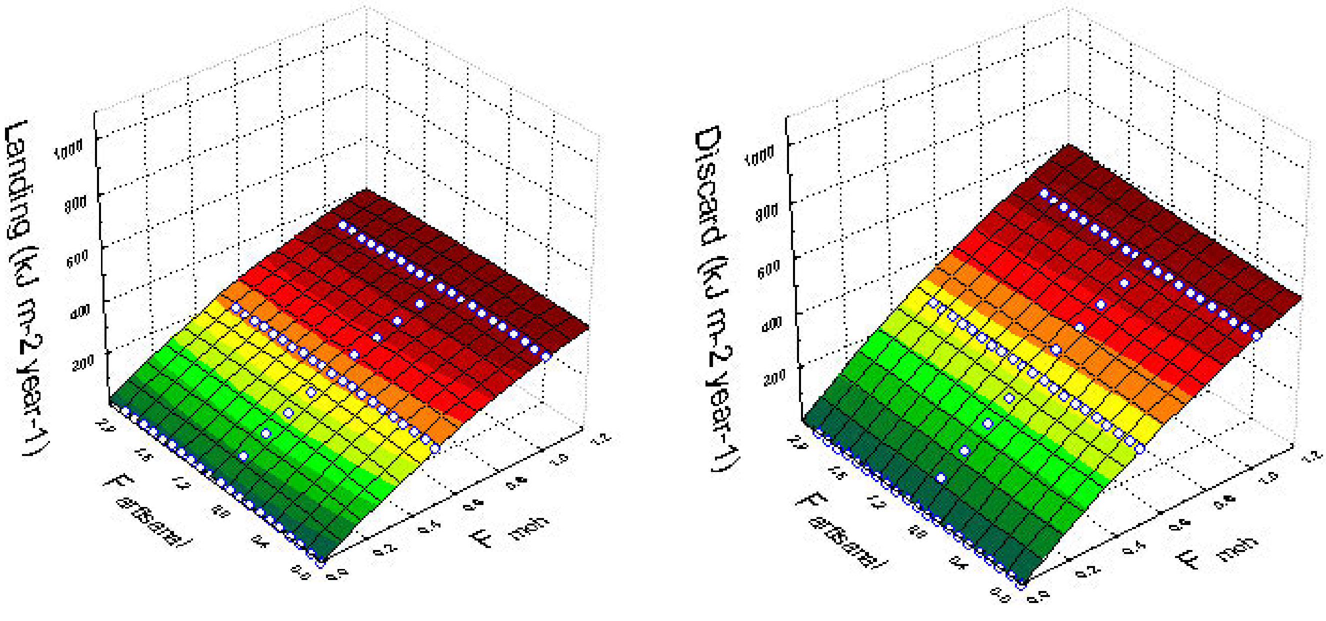


Figure 2 – (a) Total landing and (b) discard related to the two fishing activities considered.

In figure 3 the artisanal fishery total catches in relation to three different level of mechanical clam harvesting effort are reported. It is possible to note that higher mechanical clam harvesting fishing effort (F_{mch}) are related with lower commercial catch of artisanal fishery.

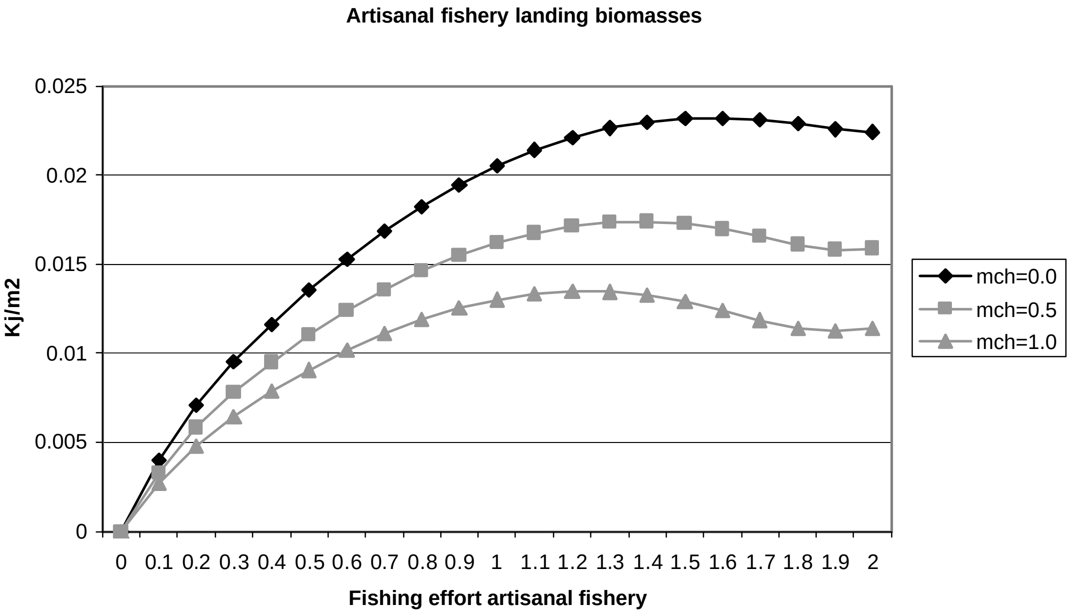


Figure 3 – Arisanal fishery landing biomasses depending on mechanical clam harvesting (mch) fishing effort.

Biomasses in the environment depending on the scenarios are reported in figure 4. Higher fishing efforts for both the activities are related to lower biomass quantities in the environment. The decreasing of biomasses depending on mechanical clam harvesting is steeper than that one depending on the artisanal fishing effort.

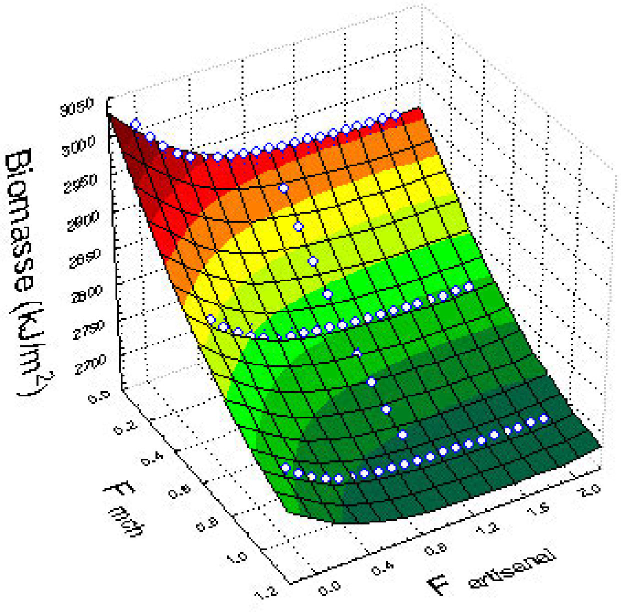


Figure 4 – Biomasses variation of the ecosystem depending on the variation of the fishing effort of the fishing activity.

The price obtained for marketed and non marketed species are applied to the landings and discard biomasses of the two fishing activities.

After valuing ecosystem interactions in terms of biological quantities, a price is attributed to each species considered in the model. The price attribution were done basing on the energy content of the species, as explained in the material and method session, therefore a trophic level value to each species was attributed. The average price of the 65 commercial species was 4.95 (± 3.84) €/Kg, and the average Trophic Level was 3.55 (± 0.71). Therefore, the average price of a "unit of TL" (Ve) was: 1.39 (± 0.93) €.

In figure 5 artisanal fishery landings values results from three series of dynamic simulations are reported. The three curves represent the fishery landing values of the artisanal activity depending on three intensities of mechanical clam harvesting fishing effort (F_{mch}=0, F_{mch}=0.5, F_{mch}=1.0).

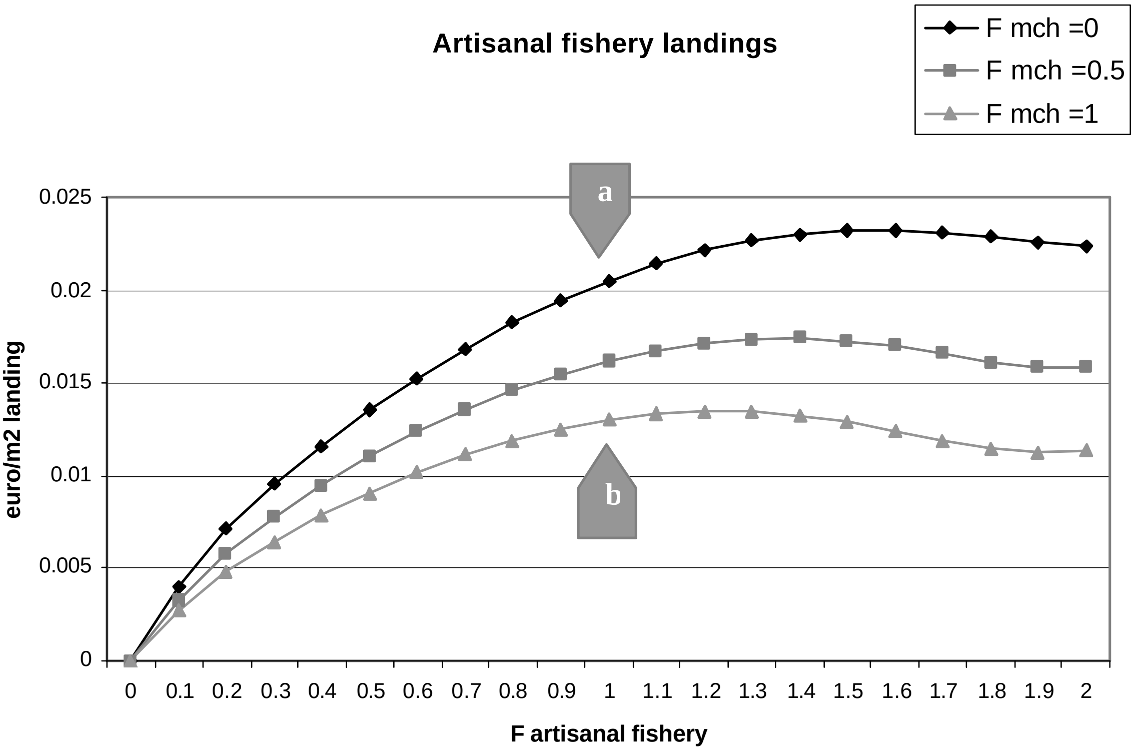


Fig. 5 – Variation of artisanal fishery landings maintaning fishing effort of mechanical clam harvesting constant at three different levels.

Comparing two scenario (a, b) characterised by the folowing fishing efforts: (a) F_{mch}=0.0, $F_{artisanal}$=1.0, and (b) F_{mch}=1.0, $F_{artisanal}$=1.0, it resulted that the economic loss of artisanal fishermen is 37.8%. Comparing other scenario with a higer value of $F_{artisanal}$ this difference can be even higher reaching the 50%.

In Fig. 6 the effects of fishing effort of mechanical clam harvesting (F_{mch}) on the environment (discard loss) and on the artisanal fishery landings are reported. The discard value of mechanical clam harvesting is here reported as social loss.

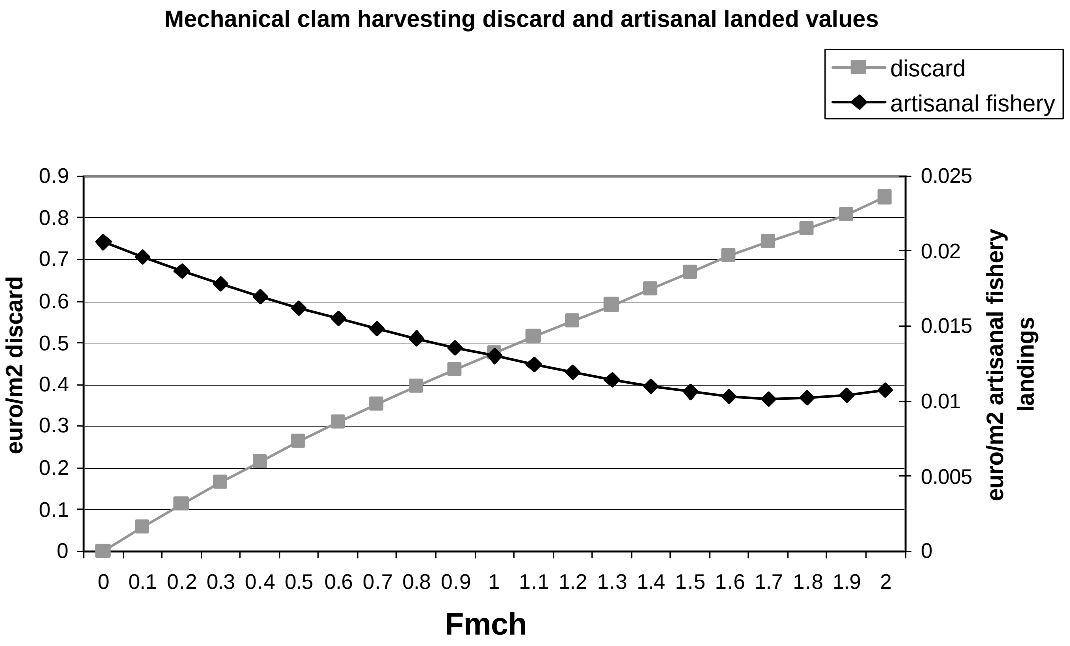
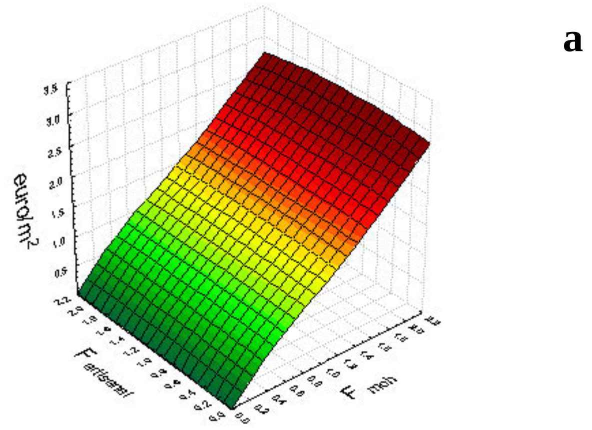


Fig 6 – Variation of social loss and artisanal fishery landing values depending on mechanical clam harvesting fishing effort (ranging 0-2.0) and maintaining constant fishing effort of artisanal fishery ($F_{artisanal}$=1.0).

The 80 dynamic model are analysed in terms of economic value of landings (figure 7 a) and value of discard (figure 7 b,c). Summing the natural capital and functional value of discard it results that the discard value is almost half of the landing values.



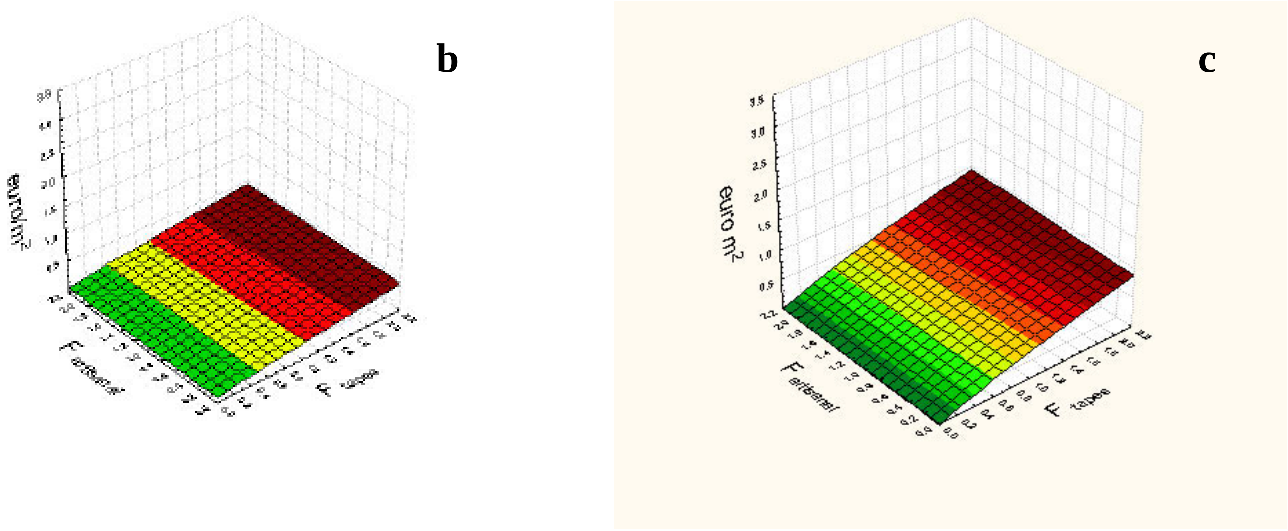


Figure 7 – The landing values (a), discard value in terms of natural capital (b), and discard value in terms of functionality of the species (c).

Finally, an Ecosim module for policy exploration is applied. The goal function for policy optimization is based on an evaluation of three weighted policy objectives alternatively maximized: fisheries rent (economic optimization); social benefits (social optimization); ecosystem structure or ‘health’ (ecosystem optimization).

	Fishing effort	
Goal function for policy optimization	Mechanical Clam Harvesting	Artisianal Fishery
Economic	1.6	0.3
Social	0.0	1.0
Ecosystem	0.0	0.0

Tab. 1 – The fishing effort values of the two fishing activities obtained simulating the maximization of, alternatively, the three goal functions (Economic, Social and Ecosystem) by means of an Ecosim module.

Discussion

At present we are faced with the challenge of assessing the effects of human activities on the environments which have long been exploited, without any knowledge of their original 'pristine' state (Jackson *et al.*, 2001). Therefore, the problem of restoring the ecosystem to its original state besides being economically unaffordable, might also be impossible, as its original state remains unknown, and a method which would allow us to measure the "marginal" impacts of human activities would be needed.

In general, the value of the marketed products of an ecosystem is easier to measure than the value of the non-commercial and subsistence direct uses. This is one reason why policy makers often fail to consider either a subsistence or informal use of the ecosystems when making many development decisions (see Barbier, 1993).

This dynamic model allowed us to consider, besides the direct impacts, also some of the indirect impacts of the fishing activity on the ecosystem. This is done by taking into account the trophic interactions between the species in the ecosystem and the interactions between the two fishing activities.

Also, the utilization of the model outputs, allowed us to quantify, in monetary terms, the value of the discard, the loss of which is usually not considered as an externality in an economic assessment of human activities, because of the absence of the discarded species in the market.

The dynamic model was here applied to a case study where the two fishing activities considered have strongly different features. The artisanal fishery targets a wide variety of species with static gears, the mechanical clam harvesting exploit an alloctonous species recently introduced by means of a gear deeply interacting with the sediment.

The biomasses in the environment are strongly affected by mechanical clam harvesting, while the effects of artisanal fishery have proved to be very small. Based on this, and considering that reducing the biomasses to low levels also generates effects in terms of commercial stocks by inducing greater variability in the yields and recruitment (Murawski, 2000), the importance of reducing the F_{mch} rather than the $F_{artisanal}$ can be seen. The mechanical clam harvesting resulted also to strongly affect other indicators (Granzotto *et al.*, 2004) because it produces a lot of indirect effects in all parts of the ecosystem - *e.g.* a high discard incidence, many feedback loops (either positive or negative), the exploitation of key species (Pranovi *et al.*, 2003a,b).

Also the mechanical clam harvesting affects the landings of artisanal fishery, this interaction can be seen only by using an analysis that allows us to consider the indirect relationship between the activities. In this situation, a conflict between the two kinds of fisheries becomes inevitable, even if there is no direct competition regarding gear or resources, but merely a sharing of the exploited ecosystem.

When 80 dynamic scenarios are analysed in terms of total economic value of landings and total economic society losses, it results that, even if using the most conservative analysis of discard mortality (15%), almost half of the landing values has to be subtracted as society loss.

At present the only cost that is considered in the cost-benefit analysis related to the mechanical clam harvesting is the direct costs of the fishing activity, that means the boat and the fuel. But the costs to be taken into account for a sustainable management of the resource exploitation are also those related to the environment. Mechanical clam fishery economic performances have to be evaluated considering inputs and outputs. A cost-benefit analysis of fishing activity need to take into account all those externalities that will be paied by the future generations; what is reported in the results as negative impact of mechanical clam fishing activity can be referred as a society loss.

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