Sustainability **2013**, *5*, 643-653; doi:10.3390/su5020643

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Valuing the Unmarketable: An Ecological Approach to the Externalities Estimate in Fishing Activities

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Received: 3 December 2012; in revised form: 24 January 2013 / Accepted: 30 January 2013 / Published: 6 February 2013

Abstract: In a rapidly changing world, sustainability, if it can be said to exist at all, is concept that has attained mythic status, often pursued and rarely reached. In order to improve our capability to cope with environmental problems, adopting an Ecosystem Approach has been suggested. One of the major challenges in the implementation of this new paradigm relates to control of externalities. The recognition and quantification of externalities is often cast as valuing the unmarketable, and there are several approaches that have been proposed. Here, we analyze the opportunity to "feed" the economic valuation with ecological concepts. From an ecological perspective, the energy required to sustain a biomass unit at a given trophic level (TL) is the same, whatever the species. We build on this central tenet of ecology to assess the value of a TL unit for each trophic position using fish market data. The results obtained were then used to assign a value to each species living in a given habitat, together with consideration of their ecological role within the community. Estimates of both natural capital and functional value were applied to assess the ecological impacts of mechanical clam harvesting *versus* the multi-species artisanal fishery in the Venice lagoon. Results are discussed in relation to possible contribution to the implementation of a different management strategy.

Keywords: externalities; valuing process; trophic level; fishing activities; Venice lagoon

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1. Introduction

Since its publication in 1968, the metaphor described in essay "The Tragedy of the Commons" [1] has deeply influenced the scientific approach to the analysis of environmental and social challenges, such as the ecosystem degradation, resources depletion and, more generally, anthropogenic impacts.

In spite of continuing progresses in the field of environmental protection, management and planning, however, the crucial point of the externalities management (e.g., their internalization), underpinned by the Hardin's paper, remains greatly unresolved.

Technically, an externality can be defined as an unintended action caused by an economic agent that directly influences the utility of another agent [2,3]. Therefore, negative externalities represent costs imposed upon others (both person or company) where there is no contractual relationship between the two parties. The absence of an agreement means that external costs can be ignored by those who create them.

The externalities issue is particularly evident within the context of the ecosystem goods and services exploitation (e.g., in terms of degradation of ecosystem processes that sustain particular services and/or direct effects due to the same exploitation action—such as in the case of timber or fishing activities).

In order to cope with these issues, within the context of the Agenda 21, the 'precautionary polluter pays principle' (4P) was suggested. The idea was to apply the 4P to potentially damaging activities to incorporate the cost of both the known and possible ecological damages. This would give producers a strong and immediate incentive to improve their environmental performance in order to reduce the size of the environmental bond and tax they would have to pay [4].

The 4P implementation, however, claims that an improvement of scientific knowledge about environmental externalities can be ascribed to three main issues: significance (quantification), recognizing and valuation.

Even if all three issues require efforts in order to fill the gaps of knowledge, the valuation probably represents the biggest challenge, also in terms interdisciplinary exchanges.

The concept of value has been subjected to a wide scientific debate during last decades [5–7], highlighting the limit of economic valuation, due to the fact that the economic value concept is essentially anthropocentric and directly depends on the market rules. All this raises the question on how to value unmarketable goods that have intrinsic value independent of human preferences. In order to cope with this problem, a disaggregation of environment value into use and non-use values has been suggested [8]. The use value approach has been applied since the 90s to produce the first assessment of the ecosystem goods and services value on a global scale [9]. However, although values of environmental services may be used to justify biodiversity protection measures, it must be stressed that value constitutes only a small portion of the total biodiversity value [10,11].

Another opportunity, widely applied in order to value ecological services, is the so called 'willingness to pay' method, that moves from the idea that the market price represents the minimum amount which people who buy the good are willing to pay for, only purchasing the good if their willingness to pay is equal to or greater than the price. By applying this concept to goods and services, it is possible to give an estimate of the value of each particular environmental features, resulting in the maximum amount of other goods (e.g., money) an individual is willing to give up in order to have that good (willingness to pay—WTP); or that an individual requires in order to stop having the good (willingness to accept compensation—WTA).

Within the context of the externalities valuation improvement, an important role could be played by the ecological point of view. The main idea in this paper is to explore the opportunity to 'feed' the economic valuation with 'more' ecological concepts than the classic methods have done. In order to achieve this goal, it would be necessary to 'translate' them in a language comprehensible to other disciplines (such as economics). To improve the dialogue between different disciplines, such as economy and ecology, other than sharing a common terminology it requires the use of a common unit of measure.

The importance of the application of an energy approach in order to describe the ecosystem functioning (e.g., considering the energy flowing through the different levels of the trophic web) was firstly suggested by Lindemann [12], and reconsidered by Odum [13]. The total amount of energy fixed in chemical products by the photosynthetic process could be considered as an estimate of the ecological work supporting the production of economically valuable products; considering the cost to society necessary to replace this energy, allowed to obtain the equivalent economic value [14].

Moving from these previous experiences, an energy-based method is here proposed for attributing a price to non-marketed species, according to their ecological properties.

2. The Method

From an ecological point of view, each species occupies a precise level in the trophic web (determined by all the trophic interactions with the other species of the community) and this represents its Trophic Level (TL). The TL integer, as defined by Lindeman [12], is the number of passages along the trophic web, from the considered species down to the autotrophic organisms (primary producers), or to the non-living organic matter (detritus). 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 each different prey on its amount in the diet, resulting in a real number, ranging from 2 (detritivores or herbivores) up to 5 or 6 (large top predators).

Based on this description, on one side, it can be assumed that 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 the two species can be considered equivalent, in terms of the Primary Production Required (PPR) [15]. On the other side, the increasing in TL reflects in an increased energy investment by the ecosystem (*i.e.*, an increase in PPR).

Nevertheless, the market price of a good is often influenced by several different factors, such as the personal preferences of customers, local traditions, resource substitutability. As a result it is mainly determined by the product's availability. All this, in relation to natural resources (e.g., ecosystem goods), means that it would be able to take into the account, at least partially, the increase of energy amount increasing TL of species. According to the 10% rule [12], indeed, moving from the base of the trophic pyramid towards the higher TLs, a reduction of resource availability (which results in an increasing scarcity for the market) is expected. Within this context, in the fish market, a positive relationship (even if sometimes weak) for TL *vs*. price has been described, as high TL species showed higher value per kilogram than the low TL species [16,17].

This means that the values of a TL unit depend on the trophic position occupied by the considered species.

Considering this, it would be possible to assign an economic value to non-marketed species, based on the price of the marketed ones. The starting point is represented by the pseudo-market value of the energy embodied in each TL unit.

Two different approaches can be adopted:

the price per unit of weight of each marketed species is divided by its TL, and the average value for a TL unit (VS_{ave}) is then calculated;

parameters of the empirical regression equation calculated for TL (as an independent variable) *vs.* price (as dependent variable) of marketed species are used for calculating the price of the non-marketed species, on the basis of their own TL (VS_{reg}).

Multiplying the obtained values by the species biomass in the environment allows us to estimate the *natural capital value* (NCV_{ave} and NCV_{reg}, depending on the chosen method) [18–20].

Within an ecosystem, however, each species occupies a defined niche and plays a peculiar role, contributing to the functioning of the entire ecosystem. In relation to this, not all species are equal, as some of them could be inserted in a more crucial point than others (e.g., in relation to their capability to structure the habitat—engineering species—or to be an focal energy node of the web—keystone species) [21]. This issue was widely discussed, and different authors suggested different methods to cope with the estimation of the species ecological role [22–25].

Recently, Libralato *et al.* [26] suggested the use of the Mixed Trophic Impact (MTI) index to identify the keystone species. The MTI, originally proposed by Ulanowicz and Puccia [27], given a trophic web and the relationships among its components, allows us to summarize the global effect that each species has on other species, taking into the account all the positive and negative interactions representing a broad description of the ecological role played by each species. The MTI could therefore be used to weigh the non marketed species values, previously obtained (VS_{ave} and VS_{reg}), to estimate a sort of species *functional value* (FV_{ave} and FV_{reg}).

The method has been tested in a case study (Venice lagoon), comparing two different fishing activities on the basis of their externalities.

3. The Case Study

The Venice lagoon represents a sensitive area, subjected to different kinds of anthropogenic pressures, such as tourism, industrial activities, pollution, eutrophication, erosion, *etc.* During the last decades, however, a new source of impact was identified in the mechanical clam harvesting (MCH). A fishing activity, started at the beginning of the 90s, exploiting banks of Manila clam—*Ruditapes philippinarum*—an allochthonous species, introduced in 1983 for aquaculture purposes which then spread in the entire lagoon [28]. Several studies [28–30] demonstrated that the mechanical dredging directly affects the bottom morphology and biogeochemical cycles, disrupting benthic habitats and deeply impacting on biological communities.

Moreover, the new activity directly conflicted with the artisanal fishery, producing disruption in the social tissue [31,32] and difficulties in the adoption of management strategies.

The artisanal fishery in the Venice lagoon has a long tradition, being deeply rooted among local people [31,32]. Indeed, it represents an multi-target activity based on a strong link between fishermen and environment and requiring a deep ecological knowledge in order to exploit the different species during the different phases of their life cycles, since it targets a wide range of species (including residents and migrants), depending on season, tide, and fishing ground [32]. In the recent past, this activity used more than 25 different fishing techniques [31]; at present, only one gear remains in use, the fyke net, consisting in a net barrier which drives the fish towards cone-shaped unbaited traps (usually checked every 2–3 days).

In contrast, the mechanical clam harvesting is a very recent single-species fishing activity. It is carried out by means of small boats equipped with a supplementary 25 HP engine positioned outboard amidships. Operating in shallow areas, the propeller can reach the bottom resuspending both sediment and clams, which are then collected by an iron cage positioned immediately after the engine [28]). To quickly move through the lagoon, fishermen use the main engine (300HP).

The two fisheries are therefore quite different. The clam harvesting is classifiable as a semi-industrial activity, based on a single target species, with a high discard/commercial ratio [28]; whereas, the artisanal fishery targets more than 20 different species (both fish and invertebrates), with a strong seasonality and a low discard/commercial catch ratio, showing all small scale activity features [33].

On a classic economic basis, there is no race between the two fisheries, since, in 1999, the MCH produced more than 40,000 tons (about 60 million €), whereas, the artisanal fishery about 1,000 tons (about 2.3 million €). We compare them in terms of discard produced, that is the direct effects of the fishing gear on the whole community, assessed as externalities.

Data about discard composition were obtained by field surveys both for the artisanal fishery (unpublished data) and mechanical harvesting [34]. It showed that, in the MCH, the discard accounted for 195% of the commercial catch biomass (being composed of 10 benthic invertebrate species); while, in the artisanal fishery, it accounted for 14% of the commercial catch (being composed of 22 species, mainly fish). This means that for each kilo of landed clams, almost 2 kilos of invertebrates belonging to non commercial species have been caught, exposed to air, manipulated and finally returned to sea; whereas, in the case of the artisanal fishery, only 140 g of non commercial species are discarded for every kilo of landed species.

The trophic level was assigned to each species on the basis of the food items, as described in wfishbase [35] and using the software package TrophLab [36]; whereas a mass-balance model representing the Venice lagoon food web [29], was used for the evaluation of the MTI.

The basic economic input data were represented by the annual average prices of the 64 species commercialized in the Chioggia fishmarket (the main market in the Northern Adriatic Sea), calculated for the 2007–2010 period.

Being 6.13 (± 4.53) € and 3.33 (± 0.50) TL, respectively (a) the mean price per kilo and (b) the mean trophic level of the commercialized species, a first rough estimation of 1.84 €/TL was obtained by dividing (a) per (b), which combined with the TL of a species allow us to calculate the VS_{ave}.

By applying the GLM method to the fishmarket data, the following empirical equation, describing the relationship between price and TL (see Table 1 for regression details) was obtained:

$$\text{price} = 4.767 * \text{TL} - 9.73$$

On the basis of these results, given the TL of a species, it is possible to estimate its price even if it is an unmarketable one, obtaining the VS_{reg}.

Table 1. Regression summary of price *vs.* trophic level (TL); data from the fishmarket of Chioggia.

	SS	df	MS	F	p
Intercept	131.101	1	131.101	8.672	0.004546
TL	356.145	1	356.145	23.557	0.000009
Error	937.341	62	15.118		

In order to compare the two fishing activities in terms of the natural capital losses produced, VS_{ave} and VS_{reg} were combined with the discard data.

By applying the VS_{ave} and VS_{reg} method to each discarded species, multiplying for the biomass, and finally summing all the values, the loss in terms of natural capital (NCV_{ave} and NCV_{reg}) was estimated. The externalities attributable to the MCH were significantly higher (more than 300% of landed value) than those produced by the artisanal fishery (14%) (Table 2).

Table 2. Discard value (externalities) of the fishing activities in the Venice lagoon reported as percentage on the landings value.

	Natural Capital Value		**Functional Value**	
	VS_{ave}	VS_{reg}	FV_{ave}	FVS_{reg}
artisanal fishery	14%	14%	15%	15%
mechanical clam harvesting	346%	302%	766%	639%

We took into the account not only the quantity but also the ecological role played (synthesized by the MTI), as described by the FV by each species.

Combining the VS_{ave} and VS_{reg} with the MTI estimated by means of a food web model of the lagoon [29], it was possible to estimate the functional value (FV_{ave} and FV_{reg}) of each species. In this case, the externalities values increase significantly for the MCH (more than doubled), whereas remain more or less the same for the artisanal fishery (15%) (Table 2).

Many invertebrates discarded in the MCH, however, being protected by an external hard shell, could survive the sorting operations, whereas specimens involved in the artisanal fishery were more sensitive, and were expected to die. For these reasons, two different mortality scenarios were created for the MCH, the first with 50% of mortality, and the second, extremely conservative, with 15%.

By applying these scenarios, the externalities in terms of Natural Capital loss for the MCH, expressed as € per 1€ of commercial catch, resulted to be 1.51€ and 0.45€ (VS_{reg}), respectively, for the 50% and 15% of mortality scenarios; in terms of functional loss, instead, 3.19€ and 0.95€ (FV_{reg}).

4. Discussions

The exploitation of goods and services from the ecosystems represents a good exemplification of the conceptual model proposed by Hardin [1]. The key issue in the Tragedy of the Commons context is related to the externality concept, since the optimization of short terms maximizes profits and minimizes externalities costs, discharging them on the collectivity and delaying them in time. The availability of goods and services depends of the good status of the ecosystem, but the exploitation activity, directly affecting the structure, could imply a degradation of the status itself, with negative feedbacks [7,11]. This represents one of the major challenges within the context of environmental management.

Fishing activities represent a sort of paradigm. The exploitation of fish stocks produces a lot of different effects that can be roughly summarized as:

effects due to individuals removal from the population:
reduction of the population size with implication on its dynamics;
removal of the all potential future offspring that fish could have generate [37];
reduction of energy availability for TLs upper than that of the caught fish [38];

removal of non target/non commercial species that are extracted from the sea, exposed to air, manipulated and then throw back at sea, with direct effects on populations and indirect effects propagating to entire community through the food web trophic interactions (for the importance of discard at a global level see Alverson *et al.* [39]).

effects due to the interaction of the fishing gear with the marine environment:
some gears can produce heavy impacts on benthic habitats due to their strong interactions with the seabed (scraping, dredging and so on) [40].

Since the objective of renewable resources management is to maximize the profits ensuring the exploitation sustainability, *i.e.*, considering the conservation of resources through the time (*i.e.*, the maintenance of the ecosystem in a good status), the recognition, estimation and valuation of externalities represent a critical issue [4].

During the last 30 years, several efforts have been devoted to demonstrating the economic value of biodiversity and ecosystem services [18,41,42], even if significant controversy regarding its use still remains [43].

The idea to use an energy approach to obtain a rough valuation of ecosystem services was proposed by Farber and Costanza [41], converting the gross primary production (*i.e.*, the total amount of energy captured by natural ecosystems) into the equivalent in fossil fuel energy, obtaining a "translation" in economically meaningful units.

By applying a similar energy-based approach, a method to quantify, in monetary terms, the value of the non-marketed species was applied to compare two different fishing activities in the Venice lagoon in terms of externalities.

Results of the ecological analyses carried out during the last decades clearly highlighted the negative impacts of the mechanical clam harvesting both on the structure and functioning of the Venice lagoon ecosystem [28,44]. The application of the valuation method allowed us to estimate these externalities in a way directly comparable with the unit used by the economic analyses.

Nunes *et al.* [45], by using the willingness to pay method, valuated in 11.8 millions of euro, the welfare loss due to the implementation of a new management strategy based on the change of clam fishing gear (adopting one with lower environmental impact, which could imply lower catch efficiency). This loss, however, is applicable to a small portion of the local population, the one that directly benefits from the Manila clam exploitation.

Within a sustainable development framework, however, losses in terms of natural capital and ecosystem functioning due to the fishing activities also have to be taken into the account, since they would result in a welfare loss for future generations.

By applying the most conservative scenarios (15% of invertebrate mortality), the MCH externalities value in 1999 (representing the peak of production, about 40,000 tons) resulted in 27 and 57 millions of €, natural capital and functionality loss, respectively. Because ecosystems are characterized by continuous fluxes, which allows for the replacement of the removed energy, these kinds of losses could be considered reversible. As for all renewable resources, however, the ecosystem capacity to cope with these losses depends, among others, on its resilience, which implies the presence of thresholds over which the systems becomes unable to recover even with possible regime shifts [46]. At present, several signs of changes in terms of the structure and functioning of the Venice lagoon ecosystem, directly related to the Manila clam exploitation, have been described [28–30,32,44]. Within this context, it would be reliable to consider the described externalities as real losses, generated by problems in the existing management strategy and possibly impacting upon future generations.

It is worth noting that the economic value reported here does not represent a cost for habitat restoration or a fee, but a price that could to be included in any cost-benefit analysis, as real society loss.

The inclusion of human activities as part of the ecosystem represents a starting point for re-thinking environmental/biodiversity conservation, within an ecosystem approach; however, despite the attention that is paid to the conservation of biodiversity, the management tools are often limited and do not solve the problem at its root. As a result, the ecosystem management goal often failed. Internalizing at least some of the external costs of biodiversity loss, resulting from human activities, is often enough to improve conservation planning [47]. Therefore, a key role of the environmental management is represented by the assessment of human activities and the consequent valuation of the externalities.

The MCH in the Venice lagoon could be considered, in this case, paradigmatic. Since the beginning, this activity, characterized by a 'free access regime', was carried out illegally, because the fishing gears were totally banned in the lagoon, with no real management options. In 2000, local authorities, fishermen and research institutes, were involved in the implementation of a new management strategy, based on a sort of 'culture-based regime', with the allocation of the resources in small portions of the lagoon, and the use of a less impacting gear. At present, however, this approach is not yet fully implemented. Within this context, the MCH externalities estimated herein could be useful in strengthening the management process and offering the opportunity of a monetary assessment (even if partial and rough) of the impact produced the clam exploitation. This represents a further argument for local administrators to really enforce the re-allocation strategy, demonstrating the need to restrict impacts to small portions of the lagoon environment. In this case, indeed, the management decision is not a choice between two alternative fishing activities (MCH and artisanal fishery), but the need to convince fishermen to reduce environmental impacts, limiting the exploited areas and implementing a new regime. For example, in terms of the use of new gear, a direct comparison between the welfare loss (11.8 millions of €) and the diversity/functioning loss (27–57 millions of €) becomes possible. All this allows us to add new tools for solving the quite complex situation for managing the Venice lagoon environment in relation to the many different sources of pressure.

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