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A SPATIAL DECISION SUPPORT SYSTEM FOR THE SUSTAINABLE MANAGEMENT OF FISHING IN MARINE PROTECTED AREAS

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ENVIRONMENTAL IMPACT
EMERGY ANALYSIS
STRONG SUSTAINABILITY
GIS
SPATIAL DISTRIBUTION

ABSTRACT. – Recreational and professional fishing are spread all over the world, generating revenues and opportunities but impacting on limited fish stocks. Even if stocks can recover, over-exploitation and permanent damages to ecosystems must be avoided. The aim of this work is to provide a Spatial Decision Support System (SDSS) to develop sustainable management strategies for fishing in marine protected areas (MPAs). The system, based on a generalized and iterable procedure and tested on the Portofino MPA (Italy), can be applied to any area. Starting from the assessment of the natural capital, the SDSS allows an ecosystem-based evaluation of fishing impact based on information (namely the harvest per species) gathered during the authorization procedure, mandatory for fishermen in MPA. The system assists MPA managers to understand if the MPA is able to support fishing or if there is an over-fishing status, by subtracting the fishing annual catches flow from the fish biomass production flow for each species. Being fishing spatially distributed, the SDSS generates results (*e.g.*, values, maps) at different spatial level: MPA, protection zones and even smaller. The implementation of fishing management procedures through the SDSS allows the quick update of results and the simulation of alternative management scenarios.

INTRODUCTION

Recreational and professional fishing

The marine coastal environment and its natural resources offer goods and services from which humans benefit, both to satisfy their necessities for life (*e.g.*, fishing for fish stocks needed for food) and to improve their well-being (*e.g.*, recreational activities). Fishing is one of the main and traditional activities performed at sea. Along seacoast, we can find small-scale professional fishing, focused on an economic sphere, and recreational fishing, focused on a ludic and social sphere.

In many parts of the world, including the Mediterranean Sea, there is a high level of exploitation of the sea and its resources. The degenerative phenomenon of the system is determined by over-fishing, where the intensity of the catches is greater than the ability to reproduce natural stocks, with a consequent reduction in the stocks themselves. A reduction in natural stocks inevitably leads to the collapse of the fishing activities themselves. In order to obtain a sustainability that is environmental and economic alike, it is therefore necessary to avoid this collapse and to ensure that fishing activities do not damage the coastal marine environment (https://ec.europa.eu/fisheries/; FAO 2018).

The Italian fish production in 2016 saw a reduction of about 60 % compared to catches in the mid-1980s (about from 400,000 to 170,000 tons; ISTAT 2003, Pauly *et al.* 2014, http://dati.istat.it/ precisely in "Pesca serie interotte" folder under "Agricoltura", "Foreste, caccia, pesca").

Recreational fishing is very widespread in the Italian coastal seas and, unlike professional fishing, it involves people of all ages and gives the opportunity to stay in the open area in contact with nature, relax, socialize and, in case of successful fishing trips, consume extremely fresh fish products (Cappanera *et al.* 2010, 2012). Despite its small size, for some time now, environmental associations, scientific community, professional fishermen and part of the political world have considered recreational fishing a real problem. This is because this activity addresses limited, exhaustible and often over-exploited resources and so many stakeholder categories, although driven by different interests, agree that recreational fishing must be properly managed (Cappanera *et al.* 2010, Radford *et al.* 2018). For a correct conservation of the ecosystem it should not be neglected that, often, the stocks from which sport and professional fishermen draw are the same (Campodonico 2010, Prato *et al.* 2016), exerting both a pressure on the marine coastal environment and entering into conflict each other. Moreover, even if the methods employed by recreational fishing are usually considered as having a low environmental impact, the cumulative impacts of recreational fishing, have been assessed as comparable to or even greater than those generated by the professional sector (Cooke & Cowx 2004, West *et al.* 2015, Brown 2016).

To effectively manage these two activities, it is necessary to know their magnitude. This has always been a complex task in Italy for recreational fishing, even if, since December 2010, the Ministry of Agricultural, Food and Forestry Policies issued a decree obliging sport fishermen to register and take part in a census, with the aim of quantifying their number and determining the degree of competition with professional fishing (Campodonico 2010, Cappanera *et al.* 2012). Despite this regulation, there is a lack on qualitative and quantitative data on real fishing days and fishing catches (Cappanera *et al.* 2010, Radford *et al.* 2018). The less rigorous monitoring of recreational fishing, in comparison with professional one, is worldwide spread and there is the need to incorporate recreational fishing data into stock assessments and coastal zone management plans, especially where it is particularly important, as in the Mediterranean Sea (Cooke *et al.* 2006, Lloret *et al.* 2008).

Marine protected areas and fishing management

The fishing management is important everywhere, but it is even more important in Marine Protected Areas (MPAs) where it must be a priority. According to the objectives dictated by the Italian framework law on Protected Areas (Law 394 of 6/12/1991), protection and conservation of environment and its resources must be guaranteed, compatibly with existing traditional activities. Especially in areas where fishermen have a strong sociopolitical weight or where it is a traditional activity.

In the context of ecosystem-based fisheries management, MPAs have often been identified as an appropriate tool to address a variety of fisheries management problems related to the conservation of exploited stocks, biodiversity conservation, exploitation of fishery yields and other social objectives (Dugan & Davis 1992, Costanza *et al.* 1997, Roberts *et al.* 2001, Gerber *et al.* 2003, Halpern 2003, Murawski 2007). MPAs, in fact, can help in the protection of fish stocks and to manage traditional small-scale professional and recreational fisheries. In order to pursue a sustainable development, it is important to adopt a system view, considering the synergistic and conflicting action of professional and recreational fishing. Indeed, even if these are competitive activities, they have interacting ecological effects, which are difficult to understand as the whole (Prato *et al.* 2016).

Natural capital

Costanza & Daly (1992) elaborated the natural capital (NC) concept in relation to human and manufactured capital. NC is defined as the stock of natural resources generating valuable flows of different types of ecosystem goods and services. Human capital comprises individuals' capacities, while manufactured capital includes material goods generated through economic activity and supply chain (UNU-IHDP & UNEP 2012).

Recently it has been widely accepted the human well-being is tightly linked to NC. From NC stocks ecosystem functions arise, representing the potential to generate services, and ecosystem services arise from functions in turn. Ecosystem services (*e.g.*, harvest of resources, such as fish, for food and recreational purposes) represent benefits that ecosystems directly and indirectly generate for the mankind and from which well-being arises (De Groot *et al.* 2010, De la Fuente *et al.* 2019). Since in this pathway ecosystems generate well-being, it is important to know and to evaluate each step of this so-called "pathway from nature to well-being" (De Groot *et al.* 2010, Paoli *et al.* 2017). Specifically, it is important to being aware and measure NC since in absence of it the pathway cannot start. This means that only if NC is preserved the supply of services in the future and at the actual level can be guaranteed (De Groot *et al.* 2012). With this supply it is also assured the chance to access to the ecosystem services and to the economic benefits generated by their exploitation.

As a consequence, in terms of conservation, the goal of MPAs should be a "very strong" sustainability. The strong sustainability theory, developed in the last decades, claims that natural and human capital are not mutually replaceable, so each of them must be kept constant, since the production of the second depends on the availability of the first (Chiesura & De Groot 2003). The "very strong" sustainability takes a step forward on ecological aspect and implies that every component or subsystem of the natural environment must be preserved (Van den Bergh 2010). In a precautionary approach and in absence of clear evaluation of NC depletion consequences, the "very strong" sustainability theory should be embraced.

Spatial decision support system for fishing management in MPA

For an effective management of an MPA and its activities, policies need to be based on informed decision-making processes. The development and implementation of innovative systems that facilitate this process are increasingly necessary, especially in marine-coastal environments. Furthermore, this responds to national, regional and international request of territorial planning and integrated and sustainable management of the coastal zone (2014/89/EU, 2008/56/CE, 2030 Agenda for Sustainable Development, Strategic Plan for Biological Diversity 2011-2020, Mediterranean Strategy for Sustainable Development 2016-2025, ICZM protocol).

Spatial Decision Support Systems (SDSS) are designed to facilitate the decision process for complex problems, improving the consistency and the quality of these decisions, also taking into account the spatial dimension of the problem (Malczewski 1997, Rizzoli & Young 1997, Cortés *et al*. 2000, Poch *et al*. 2003, Dapueto *et al*. 2015).

A SDSS for the identification of sustainable management strategies in marine-coastal areas, in particular for fishing activities in MPAs, is here proposed. It consists of an information system that supports decision-makers in choosing between alternative solutions, integrating artificial intelligence methods, GIS components, mathematical-statistical techniques and environmental ontologies. Taking advantage of modern information technology and software, the entire system is computerized, both storing alphanumeric and spatial data and implementing the procedures developed, in order to optimize and speed up the decision-making process.

Specifically, the SDSS is a tool that helps to evaluate the impact on the environment due to human activities, namely in this research fishing. In particular, the impact has been considered as the fish harvest that corresponds to the removal of biophysical resources, potentially affecting the NC. It allows to understand if the MPA system is able to support fishing activities or if the system is in an over-fishing condition.

In particular, here the harvest of all fishing activities is considered, in order to understand the overall state of the system. Depending on the management needs, the SDSS, due to its plasticity and adaptability, could be used to evaluate the effect of the individual activities (professional and recreational), which, being very different, could require different management strategies.

MATERIALS AND METHODS

Study area – Portofino MPA: The Portofino MPA (Fig. 1) is an area of great interest for the conservation of Mediterranean biodiversity surrounding the Portofino Promontory (north-western Italy). It achieved the status of SPAMI (Specially Protected Areas of Mediterranean Importance) in 2005. In particular, the area is mainly characterized by two priority habitats, *Posidonia oceanica* (Linnaeus) Delile and coralligenous. The Portofino MPA, as others Italian MPA, is divided in 3 zones with different

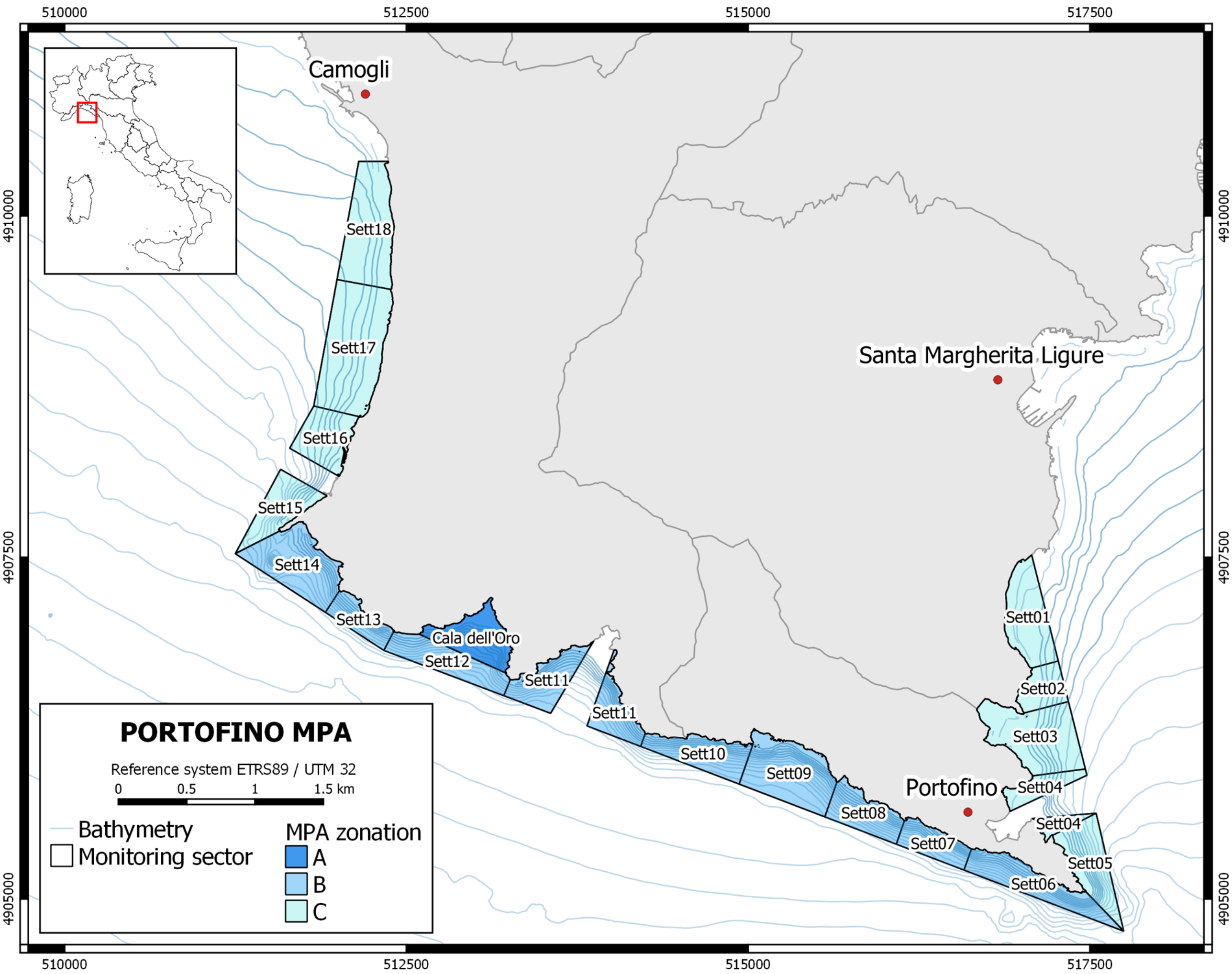

Fig. 1. – Marine Protected Area of Portofino, Italy (realized with QGIS software, version 3.10.1).

level of protection: zone A (integral reserve, "no entry no take zone"), zone B (general reserve) and zone C (partial reserve).

The high environmental relevance of the Portofino MPA is associated with a high human presence and several activities bringing socioeconomic benefits but, at the same time, also logistical and environmental problems (Cappanera *et al*. 2009, 2010).

Recreational and professional (mainly artisanal with small boats, less than 10 meters long) fishing play a relevant role among these activities, also entering into conflict with each other and exercising a synergistic pressure on stocks (Venturini *et al*. 2017, 2019).

As in many MPAs, in Portofino the application of a prohibition rule on recreational and professional fishing is not possible because they are well-established realities: although the consensus process is going on, it's far away to be closed. In particular, professional fishing represents a craft activity rooted in tradition that historically has always been the major source of food, employment and economic benefit for the MPA municipalities (Cappanera *et al*. 2010, 2012).

Therefore, the MPA managing body issued an authorization procedure that allows fishing in the MPA.

Fishing access rules and control: The regulation of the Portofino MPA defines where and how recreational and professional fishing activities are allowed inside the MPA (art. 20 and 21). Specifically, for these activities an authorization is mandatory. Users request the managing body to carry out the activity; the managing body, verified the compliance with the requisites foreseen by the MPA regulation, issues the authorization against a payment.

Recreational fishing is permitted both in zones B and C to residents, only in zone C to not residents. There are some general limitations (*e.g*., species, maximum catch weight, minimum catch size) and some specific ones depending on the area and type of user (*e.g*., fishing gears, shore or boat fishing).

In the Portofino MPA, professional fishing is allowed both in zones B and C only to resident fishermen and to fishing enterprises and cooperatives with registered office in the MPA at the date of entry into force of the MPA regulation. For this type of fishing there are general limitations too.

For monitoring purposes, the managing body provides recreational fishermen with a logbook on which must be noted information about catches: date and time, fishing site, caught fishes (species, biomass and length), fishing technique and tools (Venturini *et al*. 2017, 2019). The authorization renewal can only occur after the fisherman has delivered the compiled logbook of the previous year.

Authorized professional fishermen must communicate annually to the managing body the periods, tools used and fishing methods within the MPA for monitoring purposes. The quantification of fishing effort of professional activity, instead, comes from landings evaluation, carried on by monitoring of the catches with an MPA operator on the quayside at the time of landing. This type of monitoring follows the protocol applied under

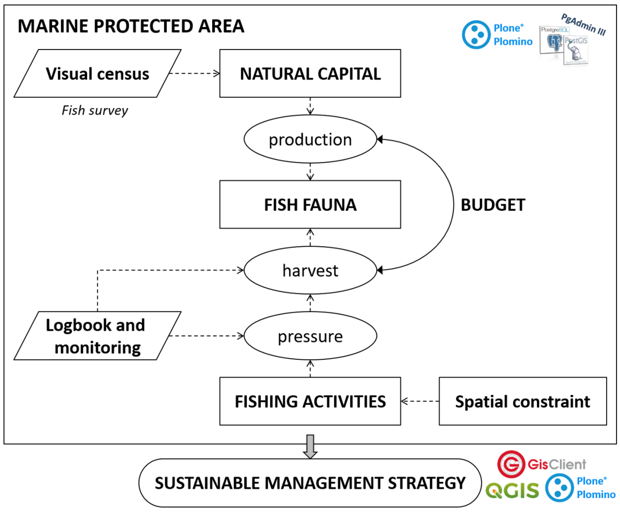

Fig. 2. – Spatial Decision Support System (SDSS) schema.

the EU Interreg MED project FishMPABlue2 (Di Franco *et al*. 2018).

For any violations, the Portofino MPA regulation (art. 32) provides for the application of the Italian Framework Law on Protected Areas (no. 394/1991, art. 29 and 30). If the violation involves a modification in the environment status, the immediate suspension of the harmful activity is ordered to return to the condition before the damage or to reconstitute the species, at the expense of the offender. The violation can lead to suspension or revocation of the authorizations.

In order to improve and focus the monitoring of fishing and other activities, the MPA is divided into 19 sectors (Fig. 1) and the SDSS is designed to reach the spatial resolution of a single monitoring sector.

SDSS architecture: The system procedure (Fig. 2) allows the evaluation of the direct environmental impact of fishing activities (fish catches). Basically, starting from information gathered during the authorization and the monitoring procedure (mandatory for each fisherman in the MPA), and applying an ecosystem approach, the use and production of NC are assessed. Subtracting the annual biomass catches flow from the fish secondary production flow, it is possible to assess the status of the MPA system. The procedure is generalized and iterable, so that it can be applied to any area, but it was tested on the Portofino MPA.

To facilitate the collection and management of MPA data, coming from both MPA users and managers, and to share information and results of the decision-making system with managers, the SDSS include a user-friendly MPA website (https://www.portofinoamp.it). This website was realized basing on MACISTE (MArine Coastal Information sySTEm), an information system able to manage in an integrated way cartographic and alphanumeric information of the marine environment (Povero *et al*. 2010). In particular, the Portofino MPA website was developed using the content management system Plone (version 4.31.18) and the application Plomino (version 1.19). Collected data are stored into a geodatabase, linked with the website and realized with PostgreSQL/PostGIS (version 9.6).

This structure could facilitate both the users and managers and the relationship between them. Specifically, the authorization system has been implemented. In particular, the website has two sections: one for users and one for the MPA managing body. In the first section, each user, once registered on the website, can access his private area and apply for authorization for different activities (*e.g.*, fishing, diving, boating). Once obtained the authorization, the user can manage his activities performed in the MPA (*e.g.*, communication of daily exits in MPA, compilation of logbooks). In the MPA section the managers can view and administer the activities of all users. Thanks to this system fishermen can apply for recreational or professional fishing and fill in logbooks (when required). Thanks to the responsiveness of the website, fisherman can fill in logbook directly from its mobile phone at the time of capture, thus registering the precise harvest point thanks to GPS, and can upload photos of the caught species.

The modules within these sections have been designed to be, on one hand, general and applicable to the different MPAs and, on the other, adaptable to specific needs. From the authorization system detailed information about fishing activities is collected.

Being fishing spatially distributed, the SDSS generates results, as well as values and maps, at different spatial level (MPA, protection zones and even smaller), based on the MPA management needs. In particular, a WebGIS on GisClient (version 4) was created for displaying maps (Povero *et al.* 2010).

The SDSS procedure, specifically, considers as input: the areas in which fishing is allowed (spatial constraint), the fish species and their distribution in the environment (fish fauna), the distribution of recreational and professional fishing (pressure), and the variety and distribution of catches (harvest). Information about pressure and catches are gathered from fishermen logbooks and monitoring activity. The outputs generated are the estimation of the impact due to each captured species, the overall impact in the MPA (number and biomass) and the loss of associated NC (in ecological terms and in monetary equivalents). Results are generated both as number and spatial distribution (impact maps).

Evaluation of natural capital: To check whether fishing activities in MPA erode NC or not, a comparison between the annual flow of harvest and the annual net flow of NC generated by the MPA is performed, following an ecosystem-based approach. The net flow is obtained from the difference between the biomass secondary production and the mortality rate. This information allows to understand if the MPA is able to sustain the losses or if the NC is eroded.

The fishing activities impact is here accounted as the catches of fish species both in terms of removed biomass and NC decrease.

The assessment of production (*i.e.*, secondary production) and loss (*i.e.*, biomass subtracted by fishing) is carried out in biophysical terms.

The evaluation of secondary production is based on information gathered from visual census campaigns. The visual census is a non-destructive widely adopted technique for the study of the littoral fish communities, particularly in protected habitats, due to its minimal impact (Brock 1954, Harmelin-Vivien *et al.* 1985, Guidetti 2002, Azzurro *et al.* 2007). These field activities allowed to obtain data on species abundances and size distribution then converted into fish biomass by using parameters obtained from FishBase (http://www.fishbase.org/).

The biomass subtracted is extrapolated from logbooks and monitoring reports, where the number and the size or weight of caught species are reported.

The calculation of biomass has been obtained using the Von Bertalanffy equation (Baker *et al.* 1993):

$$W_j = a_j \times L_j b_j$$

where W_j is the weight of the single individual, L_j its length and a_j and b_j are the constants of Von Bertalanffy specific for the species *j*.

Considering the production/biomass ratio and the mortality rates of each species, biomass is converted into net secondary production according to the following equation:

$$NSP_j = \sum_{j=1}^{n} W_j \cdot \left(\frac{P_j}{B_j} - M_j\right)$$

where NSP_j is the net secondary production, W_j the biomass of the single individual, P_j/B_j is the production/biomass ratio and M_j is the mortality rate for the species *j*. The production/biomass ratio for each species is obtained from literature (Pinnegar & Polunin 2004, Coll *et al.* 2007, 2008, Diaz Lopez *et al.* 2008, Barausse *et al.* 2009, Heymans *et al.* 2009, Piroddi *et al.* 2010, Lassalle *et al.* 2011, Bănaru *et al.* 2013, Bayle-Sempere *et al.* 2013, Prado *et al.* 2013, Torres *et al.* 2013, Corrales *et al.* 2015). The mortality is obtained by using the following equation:

$$M_j = 1 - e^{(-k_j \times 1.63)}$$

where M_j is the mortality rate and k_j the Von Bertalanffy growth coefficient for the species *j*.

In order to make comparable fish production and subtraction, only species detectable by visual census are considered in the estimation of harvest (*e.g.*, cryptic species, species hidden because of presence of operators, pelagic species are omitted).

The intrinsic value of the considered good or service (fish) is assessed as both biophysical and monetary value. At this purpose, the methodology proposed by Vassallo *et al.* (2017) for MPAs is applied. This method is based on the emergy analysis, an environmental accounting method introduced by Odum (1988, 1996) that follows an ecocentric approach aimed at assessing the environmental performance and sustainability of processes and systems on the global biosphere scale (Vassallo *et al.* 2017). Emergy is a donor side approach since it measures the nature's investment, in terms of resources used, to create and maintain a good or a service (namely to fish species, produced or subtracted). The investment is evaluated in ecological terms as emergy value. According to emergy, all inputs are accounted as solar equivalent Joules (sej), calculated as the total amount of solar available energy directly or indirectly required to make a given product or flow. The emergy required to generate one unit of input is named Unit Emergy Value (UEV) or emergy intensity (sej/J, sej/g, sej/€). Raw data on mass, energy, labour, and money input flows are converted into emergy units, and then summed into a total amount of emergy used by the investigated system. In this work 15.20E+24 sej emergy baseline (Brown & Ulgiati 2010) was used for emergy calculation.

This value can be converted into monetary equivalents, expressed in emergy-euro (em€), using an emergy-to-money ratio (Brown & Ulgiati 2004a, b) to better convey the importance of NC to policy makers and other stakeholders.

Vassallo *et al*. (2017) methodology has already been employed in the Italian national project "The environmental accounting of Italian MPA (EAMPA)" (Franzese *et al*. 2017, Picone *et al*. 2017, Paoli *et al*. 2018) and in the EU Interreg Maritime project "Integrated management of ecological networks through parks and marine areas (GIREPAM)" (Paoli *et al*. 2019).

Very strong sustainability approach: As highlighted above, the management of fishing in MPAs must be addressed with a view to sustainability, *i.e.*, the catches must be controlled so that the environment can counterbalance this loss with an appropriate production of new resources. Therefore, the exhaustion of natural resources must be taken into account and their uncontrolled exploitation must not be encouraged. Otherwise, an unsustainable use of resources could make impossible to use them in the future at the current level or could completely exhaust them (Gowdy & O'Hara 1997). From all these considerations it is clear that a declining NC is an indisputable sign of non-sustainability (Vitousek *et al*. 1997).

The assessment of the environmental impact due to fishing can be approached in different ways: considering the overall species or individual species in a given area.

The SDSS allows to carry out a very strong sustainability analysis producing as results a sustainability map that permits to see the status of the system:

– sustainable: all species are in surplus, *i.e*., the production is greater than the subtraction (green);

– balance: all species are in balance, *i.e*., the production is the same of the subtraction (blue);

– not sustainable: at least one species is in deficit, *i.e*., the subtraction is greater than the production (red).

If only one species is in deficit, all the system is considered in deficit since the very strong sustainability is not maintained.

RESULTS

Evaluation of natural capital: fish production

The total annual net secondary production of fishes in Portofino MPA is 24 645.87 kg/y, corresponding to 1.38E+18 sej/y and 1,432,599.15 em€/y. The species with highest biomass values in MPA are *Diplodus vulgaris* (Saint-Hilaire, 1817; 33.58 %) and *Diplodus sargus* (Linnaeus, 1758; 24.07 %), followed by *Sarpa salpa* (Linnaeus, 1758; 11.62 %). As emergy and monetary value the major production is for *Dentex dentex* (Linnaeus, 1758; 35.23 % *vs* 5.41 % of biomass), *D. vulgaris* (20.27 %) and *Epinephelus marginatus* (Lowe, 1834; 20.22 %).

Considering the comparison among different sectors, the most productive ones, both as biomass and emergy, are Cala Oro corresponding to zone A, 17 and 18 in zone C west (37.42 % of biomass and 46.50 % of emergy overall). Comparing species, the species more representative of the overall MPA are the same that generate the greater production of these sectors (*D. vulgaris*, *D. sargus* and *S. salpa* for biomass; *D. dentex*, *D. vulgaris* and *E. marginatus* for emergy), except for sectors 3 and 5 where *Pagellus erythrinus* (Linnaeus, 1758) is the fish originating the greatest production.

Results by sector are reported in Table I and Fig. 3.

Evaluation of natural capital: fishing harvest

Data on catches are extrapolated from the geodatabase, after they have been put into online logbooks on the web-

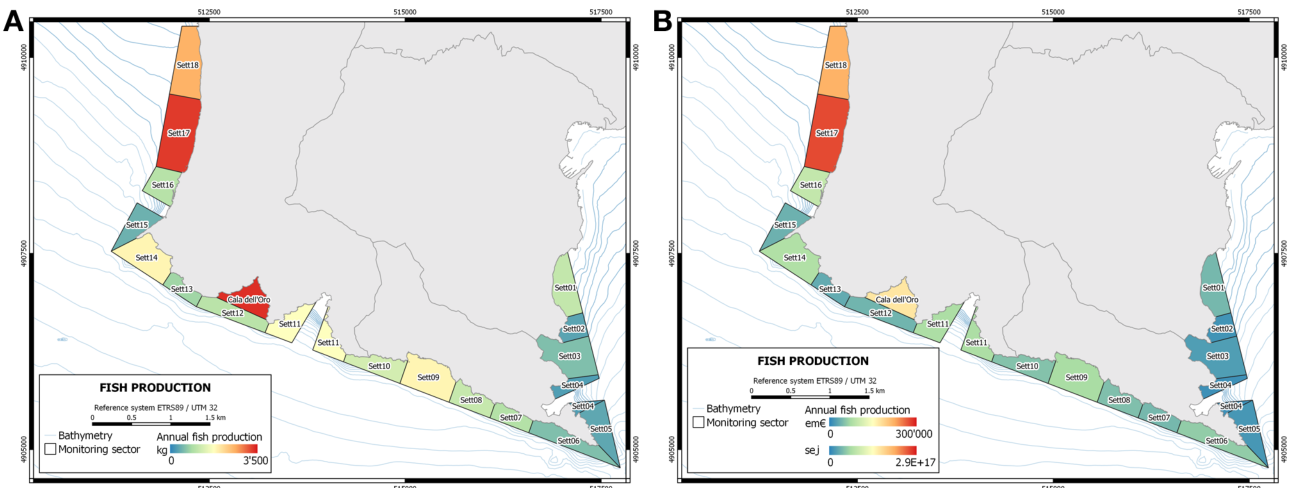

Fig. 3. – Fish production in Portofino MPA at sector level. **A**: Biomass (kg/y); **B**: Emergy (sej/y) and monetary values (em€/y) (realized with QGIS software, version 3.10.1).

Table I. – Annual secondary production, pressure and harvest due to recreational and professional fishing in Portofino MPA.

Sector	Secondary production			Pressure		Recreational fishing harvest			Professional fishing harvest		
	Biomass (kg/y)	Ecological value (sej/y)	Monetary value (em€/y)	Recreational fishing (day/y)	Professional fishing (day/y)	Biomass (kg/y)	Ecological value (sej/y)	Monetary value (em€/y)	Biomass (kg/y)	Ecological value (sej/y)	Monetary value (em€/y)
Cala Oro	3,357.55	1.66E+17	172,505.06								
01	1,117.56	4.21E+16	43,878.48	150	9	20.94	3.82E+14	397.45	0.53	6.69E+13	69.70
02	340.60	1.33E+16	13,893.74	119	24	5.35	5.95E+14	619.61	0.60	7.49E+13	77.98
03	574.91	2.34E+16	24,386.00	173	15	3.96	3.52E+14	366.19	0.05	6.44E+12	6.70
04	272.26	1.19E+16	12,363.04	73	15	1.37	5.83E+13	60.69	0.05	6.44E+12	6.70
05	361.50	1.77E+16	18,485.15	120	15	2.16	2.70E+14	281.57	0.05	6.44E+12	6.70
06	579.16	5.83E+16	60,732.19	130	17	14.82	4.11E+15	4,277.89	0.47	6.81E+13	70.89
07	974.02	4.19E+16	43,668.66	60	24	14.82	4.11E+15	4,277.91	0.73	7.78E+13	81.05
08	1,165.86	4.75E+16	49,463.69	90	24	15.84	3.86E+15	4,017.63	0.73	7.78E+13	81.05
09	1,865.79	7.32E+16	76,249.71	93	24	25.10	2.67E+15	2,780.23	0.73	7.78E+13	81.05
10	1,283.38	5.18E+16	53,930.49	79	24	18.81	1.29E+15	1,346.36	0.73	7.78E+13	81.05
11	1,732.44	7.42E+16	77,287.21	103	27	32.81	2.18E+15	2,271.34	14.95	1.59E+15	1,655.31
12	1,018.42	3.94E+16	41,086.63	42	3	1.68	3.46E+14	359.97	14.22	1.51E+15	1,574.25
13	802.22	3.37E+16	35,099.72	79	3	14.29	2.39E+15	2,491.65	14.22	1.51E+15	1,574.25
14	1,867.66	7.60E+16	79,178.32	242	72	47.97	1.06E+16	11,066.36	269.84	2.87E+16	29,868.91
15	454.32	3.71E+16	38,651.29	165	72	12.95	2.26E+15	2,351.15	172.03	2.51E+16	26,125.02
16	1,012.76	9.40E+16	97,965.71	77	24	2.06	1.70E+14	177.01	95.80	1.40E+16	14,548.27
17	3,305.84	2.64E+17	275,192.27	117	54	13.71	3.15E+15	3,286.29	68.67	1.00E+16	10,427.86
18	2,559.61	2.10E+17	218,581.79	66	54	0.94	1.46E+14	151.96	68.67	1.00E+16	10,427.86
Total	***24,645.87***	***1.38E+18***	***1,432,599.15***	***1,979***	***500***	***249.58***	***3.90E+16***	***40,581.25***	***723.08***	***9.29E+16***	***96,764.63***

site of Portofino MPA.

The fishing pressure (entity and spatial distribution) is here estimated as the number of fishing days in MPA. The average annual total pressure due to recreational fishing is given by 1,979 fishing days, with the greatest pressure exerted on sectors 14, 3 and 15 (Table I). Instead, professional fishing exerts an average annual pressure of 500 fishing days, mostly on sectors 17 and 18.

Fishing direct environmental impact corresponds to a subtraction of 972.66 kg/y, corresponding to 1.32E+17 sej/y and 137,345.87 em€/y: 249.58 kg/y by recreational fishing, corresponding to 3.90E+16 sej/y and 40,581.58 em€/y, and 723.08 kg/y by artisanal fishing, corresponding to 9.29E+16 sej/y and 96,764.63 em€/y.

Overall, the most caught species is *E. marginatus* with 47.98 % of biomass and 55.73 % of emergy, followed by *D. dentex* (12.91 % of biomass and 34.62 % of emergy), *Sparus aurata* (Linnaeus, 1758; 8.87 % of biomass and 2.74 % of emergy) and *D. sargus* (8.38 % of biomass and 1.65 % of emergy). Sectors 14 and 15 are the ones with the greatest harvest (more than 50 % overall), mainly due to *E. marginatus*.

Results are reported by species in Fig. 4 and by sector in Table I and Fig. 5.

Very strong sustainability approach

The overall annual harvest of fishing activities in the Portofino MPA is smaller than the production (3.95 % of the biomass and 9.59 % of the emergy value). The same result is obtained by analyzing each sector and each species in MPA. This would seem to demonstrate that there is no erosion of NC.

Analyzing, instead, the single species within each sector (very strong sustainability) it results that in sectors 4, 14, 15 and 18 there are species for which fishing harvest is greater than what that sector produces. For example, *D. dentex*, *E. marginatus, Ser-*

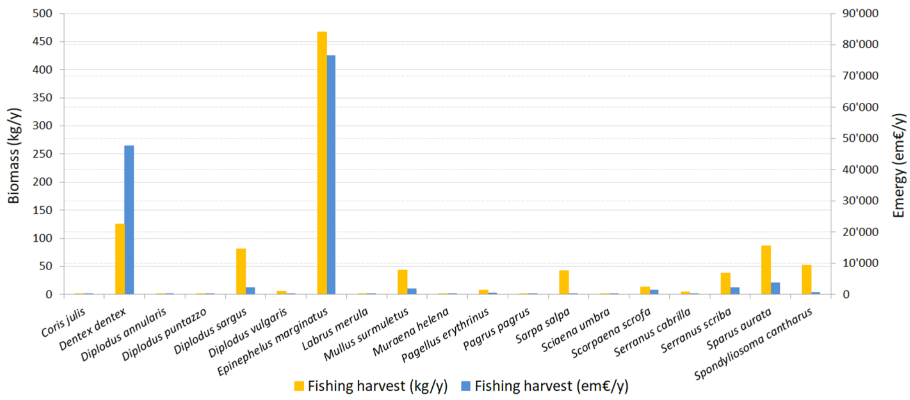

Fig. 4. – Annual direct environmental impact of recreational and professional fishing (only *species of visual census*) in Portofino MPA: biomass (kg/y) and emergy (em€/y).

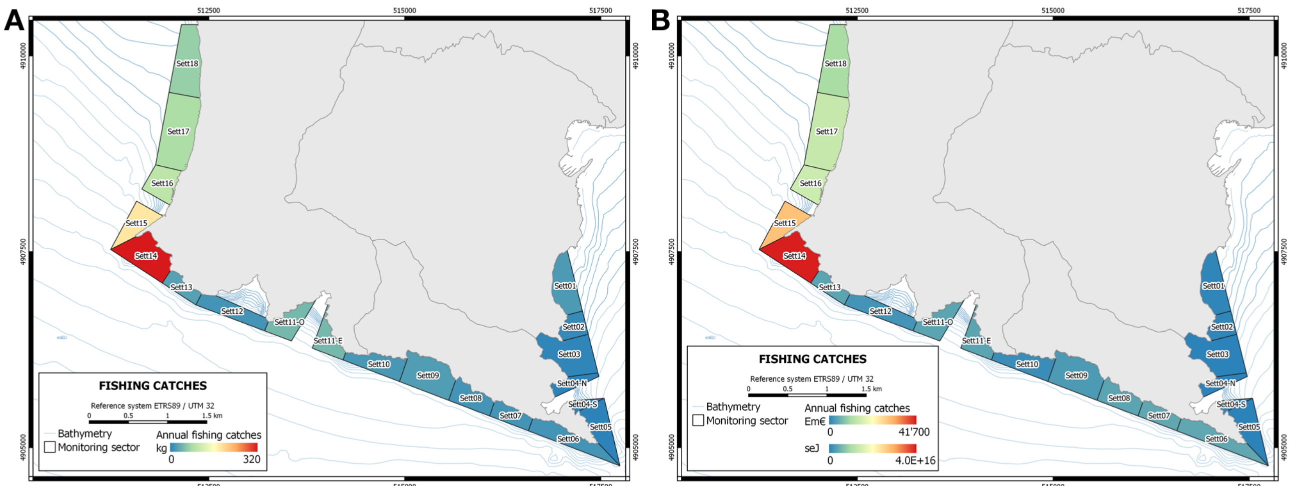

Fig. 5. – Distribution map of fishing catches in Portofino MPA at sector level. **A**: Biomass (kg/y); **B**: Emergy (sej/y) and monetary values (em€/y) (realized with QGIS software, version 3.10.1).

ranus scriba (Linnaeus, 1758), are overfished in sector 14. Basing on this latter budget, the SDSS produces the very strong sustainability map shown in Fig. 6.

DISCUSSION

Fishing is a worldwide activity impacting on limited stocks. Stocks can recover but it is necessary to avoid over-exploitation and permanent damages to ecosystems. MPAs have a fundamental role in the protection of the marine environment and, at the same time, in promoting the enhancement of a sustainable socioeconomic development of local community.

Here the SDSS proposed is a tool to assist MPA managing body in planning a sustainable management of fishing activities, starting from the assessment of the NC supporting the fish stocks and its production. The SDSS provides an environmentally focused accounting model in order to keep the NC at least intact in the framework of a strong or very strong sustainability.

The estimation of fish stock is based on information gathered from visual census campaigns, the most non-destructive widespread and used one. Nevertheless, this technique does not allow to detect the stock as a whole (*e.g.*, cryptic species, species not detected because they hide in the presence of operators, pelagic species; Brock 1982). In particular, many harvested species reported in logbooks are not detected by visual census. For this reason, for the sake of this analysis, only species identifiable by visual census are considered in the estimation of fishing harvest. This inevitably leads to an underestimate of the real impact generated by fishing on NC. With a view of further improvement, a sampling method that allows to evaluate the entire fish stock of the MPA or an integration of visual census with other techniques is therefore needed to get to a more consistent assessment of the sustainability of the MPA.

In order to fine-tune the system, the case of the Ligurian MPA of Portofino was examined, located in the context of a highly anthropic coast and lobbied by strong social pressures from local communities. The analysis is carried out at sector level in order to meet MPA managers needs and to better identify the areas where there is greater pressure and, in turn greater environmental costs. This punctual analysis allows to highlight any critical issues

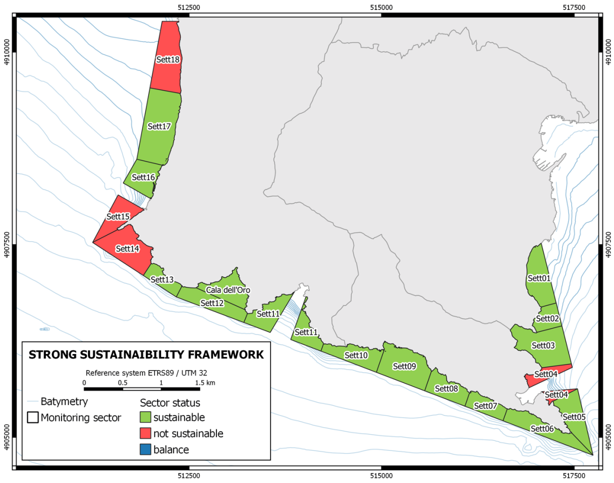

Fig. 6. – Very strong sustainability map for Portofino MPA fishing (realized with QGIS software, version 3.10.1).

not necessarily noticeable at overall level (MPA level) and is expected to better address protection and conservation strategies.

If a very strong sustainability approach is followed, according to each species must be preserved as it is, and the analysis is conducted at sector and species level, it appears that some species are being caught more than produced. Indeed, the overall budgets at MPA, sector or species level proved that, apparently, the NC is not eroded. This happens because, in the first two levels, the loss of one or more species is compensated by the surplus of other species or, in the third one, the loss of a specific species is compensated by other sectors in which it is less caught. For example, an overall analysis of sector 14 shows that it is in a good condition with a production surplus of almost 1 thousand of kilograms per year (4.18E+16 sej/y, 4.36E+04 em€/y). Analyzing instead single species in this sector, 3 species (*Dentex dentex*, *Epinephelus marginatus* and *Serranus scriba*) appear to be in a suffering condition with a production deficit.

According to Prato *et al.* (2016), the data reliability and availability are important for an accurate account. In this context, an in-deep analysis about the truthfulness of data declared by the fishermen in the logbooks, which often fill in hastily and incompletely, should be done. The consequence is a further underestimation of pressure exerted, subtraction and impact on NC. Measurements in MPA can be biased due to catches limitations (*e.g.*, species, maximum catch weight, minimum catch size). For this reason, even if fishermen caught more than they could, they wouldn't declare these catches in order not to incur in penalty provided by Portofino MPA regulation (art. 32). However, logbooks represent most of the data on fishing in MPAs. To deal with this underestimation, monitoring at sea is necessary in order to compare data declared with the actual catch.

Despite these, results confirm previous researches realized in the area, that highlighted how, although the Portofino MPA was able to recover fish biomass (Guidetti *et al.* 2008), the overlap of catches among artisanal and recreational fisheries, causes strong fishing losses on high trophic level predators (Prato *et al.* 2016). Moreover, according to Prato *et al.* (2016), results show that at the current exploitation level, the ecosystem is far away from its carrying capacity and fishing within the MPA borders should be reduced to pursue the MPA conservation objectives.

The SDSS is a tool that can be exported and applied to wider realities than the national and local context. In fact, the European Union, within the EU Biodiversity Strategy to 2020 (COM/2011/0244), called Member States to map and assess the state of ecosystems and their services while promoting the integration of these values into national accounting systems by 2020. Moreover, according to the strategy, the ecosystem services and its NC should be protected, valued and appropriately restored by 2050, also taking into account their essential contribution to human well-being and in order to avoid catastrophic changes. This highlights how much urgent is to define and apply methodologies able to assess NC and changes that our activities impose to it with the aim of its preservation or restoration (UN *et al.* 2014).

This is more and more important in those areas where a protection regime is established (such as in the case of MPAs) to assess the efficacy of undertaken conservation strategies (Vassallo *et al.* 2017). Fishing activities are an ecosystem service that must properly managed within MPA borders providing managers with operational decision-making tools which allow to make informed and aware decisions (Cortés *et al.* 2000, Poch *et al.* 2003, Pérez *et al.* 2005), mostly where the consensus process struggles to well-end.

The proposed SDSS hits this target since it plays an important role supporting the MPA in reducing the risks arising from the interaction of human societies with natural environments (Cortés *et al.* 2000). Indeed, SDSSs are widely used in environmental field (Latteman 2010, Stewart & Purucker 2011, Garrido-Baserba *et al.* 2015, Zhang *et al.* 2015) and in particular for protected areas management (*e.g.*, MARXAN, see Stewart *et al.* 2003). The SDSS allows, through the production of a map of very strong sustainability, to identify where fishing activities affect the NC. In such cases, it may be necessary for the managing body to review accessibility to individual sectors or to change the species that can be caught, giving the environment the opportunity to recover the depleted NC.

The iterability and implementation of the SDSS procedures in a computerized system allows 1) to quickly insert a large amount of data that is stored in a geodatabase, 2) to update the results fast and easily and 3) to produce different management scenarios, responding to manager need of having information in real time. At this purpose, the development of new technologies such as apps and responsive websites easily usable with a mobile phone can help more and more (Papenfuss *et al*. 2015, Venturelli *et al*. 2017, Joly *et al*. 2018). For this purpose, a responsive website linked to geodatabase is integrated in the SDSS in order to collect data on authorizations of fishing activities and logbooks and to overcome problems of excessive time and inefficiency related to handwriting. Moreover, filling logbook directly on the boat it is possible to register the precise harvest point thanks to GPS and to upload photos of the caught species.

An additional advantage of the SDSS is the ability to visualize spatial results within a WebGIS reserved for MPA managers. WebGIS are currently the most advanced and used systems for the visualization and diffusion of geographical information and represent a fundamental aid for activities in the field of environmental management. By accessing the WebGIS, the cartographic and/or alphanumeric data can be viewed, consulted and downloaded. This WebGIS fully responds to the problems of integration, dissemination and use of data, as it is an easy-to-use tool, which allows a quick update and easy access to data, without having to install any software on computer.

The SDSS potentially also would allow to spread the results to a large audience at reduced costs. At the moment results are accessible to MPA managers. Moreover, user-friendly interface for data sharing and information spreading (*e.g*., diagrams and pictures) to fishermen and other MPA users, with respect for privacy, are under discussion and development, thanks to potentialities and applications of used software (Plone/Plomino and PostgreSQL/PostGIS).

A constant relationship between MPA and users and a better management of activities, *e.g*., through a dedicated website, is expected to increase the level of loyalty with respect to the MPA by the users themselves. Fishing activities in MPAs, if properly managed, can constitute a sustainable activity to maintain the sociocultural and economic structure of the regions (UNIMAR 2001). Moreover, in recent years in some Italian MPAs fishermen seem to be able to change their relationship with sea and to be available to operate in harmony with the rules of environmental protection, even if it is a very slow and difficult process (Cattaneo-Vietti & Tunesi 2007).

Inadequate public and stakeholder involvement and communication/education about the MPA decision-making process undoubtedly lead to conflicts and disapproval by locals about the establishment of marine reserves, do not increase the perceived legitimacy of decisions, and lowers compliance with restrictions (Guidetti *et al*. 2008).

The SDSS is a step towards solving this problem and can be a useful tool for the citizen science. In the last decades, citizen science is increasingly used in biology, conservation and ecology. Concerning marine environment, citizen science projects rely on fishermen and target nearshore habitats (Changeux *et al*. 2020). The SDSS not only allow to collect mandatory data for carrying out the activities, but also further volunteer data (*e.g*., in logbooks and monitoring reports there is the possibility to write down any information that may be useful for the MPA management).

A system for MPA managers to insert updated data for the calculation of the value of NC has also been developed, through the implementation of the methodology. Thanks to a specific interface on the website, managers will be able to enter new input data, such as fish fauna.

To make the SDSS even more efficient and supportive to the MPA managing body, a simulation system for developing real-time forecasting scenarios is under construction. It will allow to see the changes that would occur following management strategies alternatives to those currently in place. Managers, again through the website, will be able to perform simulations by changing the pressure exerted by users on the various sectors and see how the direct environmental cost and the reduction of NC associated would change.

From the management point of view, the availability of data, results and impact maps, together with the possibility to design different scenarios allows for the planning of multiple management interventions aimed at regulating human activities, such as those involving marine areas at risk and to implement appropriate policies for the conservation of biocenosis.

In conclusion, the described SDSS procedures allow to obtain a reliable result, both in numerical and spatial form opening up new potential perspectives. In particular, the maps generated by the SDSS allow both experts and managers to identify and characterize MPA areas at different levels of detail and to provide the results needed to operationalise a strong sustainable management.

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