VECTORS

VECTORS of Change in Oceans and Seas Marine Life, Impact on Economic Sectors

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VECTORS Overview

'VECTORS seeks to develop integrated, multidisciplinary research-based understanding that will contribute the information and knowledge required for addressing forthcoming requirements, policies and regulations across multiple sectors.'

Marine life makes a substantial contribution to the economy and society of Europe. In reflection of this VECTORS is a substantial integrated EU funded project of 38 partner institutes and a budget of €16.33 million. It aims to elucidate the drivers, pressures and vectors that cause change in marine life, the mechanisms by which they do so, the impacts that they have on ecosystem structures and functioning, and on the economics of associated marine sectors and society. VECTORS will particularly focus on causes and consequences of invasive alien species, outbreak forming species, and changes in fish distribution and productivity. New and existing knowledge and insight will be synthesized and integrated to project changes in marine life, ecosystems and economies under future scenarios for adaptation and mitigation in the light of new technologies, fishing strategies and policy needs. VECTORS will evaluate current forms and mechanisms of marine governance in relation to the vectors of change. Based on its findings, VECTORS will provide solutions and tools for relevant stakeholders and policymakers, to be available for use during the lifetime of the project.

The project will address a complex array of interests comprising areas of concern for marine life, biodiversity, sectoral interests, regional seas, and academic disciplines and especially the interests of stakeholders. VECTORS will ensure that the links and interactions between all these areas of interest are explored, explained, modeled and communicated effectively to the relevant stakeholders. The VECTORS consortium is extremely experienced and genuinely multidisciplinary. It includes a mixture of natural scientists with knowledge of socio-economic aspects, and social scientists (environmental economists, policy and governance analysts and environmental law specialists) with interests in natural system functioning. VECTORS is therefore fully equipped to deliver the integrated interdisciplinary research required to achieve its objectives with maximal impact in the arenas of science, policy, management and society.

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Executive Summary

This report forms D60.4 of the VECTORS project, and builds on information provided by WP1 on resource exploitation - fisheries (D1.1 and D1.2), WP4.1 which focuses on Western Mediterranean research, and WP6 on policy and stakeholders (D6.1). The aim of this deliverable is to assess the efficacy of marine planning in minimising risk in the context of fishery management in a Marine Protected Area of Western Mediterranean Sea. This work is closely linked to D60.3 and D60.5 which provide risk assessments for ballast water and renewable energy respectively, with all three risk assessment deliverables feeding into D60.6 policy and governance synthesis and D60.7 online synthesis of VECTORS for stakeholders and policymakers.

The present report covers, as a case study, the risk assessment and management of an important fishery resource, the sea urchin *Paracentrotus lividus*, in the MPA of “Penisola del Sinis - Isola di Mal di Ventre” (Sinis MPA, Sardinia). This has been identified as a major social and economic issue following the stakeholders’ interviews and the analysis of regional and national legislations conducted in the first part of the VECTORS project, as reported in D6.1. As a tool to determine how risks of over-exploitation of the biological resource can be prevented and if not prevented, how they can be mitigated we used the Bow Tie analysis (Smyth & Elliott 2014, Cormier et al 2013).

Following the identification of potential impacts, the BowTie XP/XL software was used to create a diagram of the factors influencing the management of the sea urchin fishery in the Sinis MPA in order to visualize the hazard and associated causes/effects and to propose preventative and mitigation measures. The BowTie methodology is used for risk assessment, risk management and risk communication. The method is designed to give a better overview of the situation in which certain risks are present. This is particularly useful to help people understand the relationship between the risks and organizational events. The strength of the methodology lies in its simplicity and the adage “less is more” is certainly appropriate. Many risk assessments are done using quantitative instruments. These may be sufficient for certain types of cases but are less valuable for organizational risk assessment. Human beings (as well as biological resources trends) are less easy to predict than machinery (or other simple closed systems) and the operational combination of all factors leads to even more difficulties. Making accurate predictions of the future in an environment that is as complex as the world itself, is simply impossible. In many cases, such as the sustainable fisheries challenge, the stakes of certain consequences are too high to leave unmanaged. Therefore it is wise to think of all possible scenarios and assess how your organization is prepared to deal with them. This is exactly what the bow-tie method and BowTieXP has helped us to accomplish for the management of the sea urchin resource in the Sinis MPA. Risk in bowtie methodology is elaborated by the relationship between hazards, top events, threats and consequences. Barriers are used to display what measures an organization has in place to control the risk. This was the first application of the Bow Tie approach for the risk assessment and management of a marine biological resource. The main benefits of the use of the BowTie approach for the fishery (sea urchin) case study are:

1) it allowed a quick analysis of what has been done in term of management of the biological resource throughout the years;

2) it will support the Sinis MPA managers in the drafting and the adoption of proper management plans that take into account possible repercussions ifsome of the factors involved in the sustainable use of the biological resources are overlooked.

It is concluded that if proper management actions are not taken, the natural equilibrium can be broken by the loss of components of the food web induced by overfishing or variation of environmental conditions as a result of climate change. Adaptive policies are needed to address the complex interaction between human activity and

MPAs safeguarding both ecosystem services and ecological functions supplied by natural resources, as well as the impressive environmental and socio-economic value of MPAs.

Although this exercise has been considered to be successful as a proof of concept and has shown that the Bow Tie scheme is appropriate for mapping out causes, consequences, hazards and risks caused by and to fishery (sea urchin) over-exploitation, further development is needed to determine the overall significance or acceptability of the causes and consequences.

Contents

Introduction

Risk Assessment & Risk Management

The concept of risk reflects our uncertainty as to the outcome of today's actions. Risk is a product of the potential outcomes of a hazard, how likely the adverse events are to occur and the consequence of their occurrence (Kaplan, 1981). A hazard results in a risk only if there is an exposure pathway and susceptible individual(s) that create the possibility of an adverse outcome. The ultimate decision on whether or not to accept a risk is a societal or political choice that involves an understanding of risk perceptions and social values as much as it requires an understanding of science (Stephen 2001). There are two stages in dealing with risk: the first, defined as "risk assessment", is the formulation of advice in a way that conveys the possible consequences of uncertainty. The second is "risk management" which is the way managers take uncertainty into account in making decisions.

Risk assessment allows us to accommodate the precautionary principle and to take account of unintended consequences, for example species where data are limited and/or over-exploited. The aim is to determine what are hazards (e.g. Elliott et al., 2014) and where the risks come from (where risk is the effects of hazards on the things in the natural and human system that we value). For the management of risks it is recognised that we can control causes and manage for effects of endogenic (within the system) pressures such as oil exploration; however, exogenic pressures (those emanating from outside of the system, such as climate change), are more difficult as you can only manage for the consequences rather than the causes at the management scale (e.g. regional seas) (Elliott 2013, 2014). We then need to determine how those risks can be prevented and if not prevented, how they can be mitigated.

Human activities have multiple effects on the natural system. In coastal marine area they include, among many others, removal of biological populations such as fish and shellfish (Elliott et al., 2014). It is therefore important to assess changes to the natural system on the human exploitation (e.g. fisheries) and management. The risk assessment is an integral part of marine management especially where we control human activities and even where we zone areas to prevent harmful changes. Because of this we need Marine Protected Areas (MPAs), which are geographically defined as areas in the marine environment dedicated and managed for the long-term conservation of nature. However, MPA are to be used in sustainable management practices while still allowing society to get benefits, such as from fisheries. Hence the present report covers the risk assessment and management of an important fishery resource, the sea urchin *Paracentrotus lividus*, in the MPA of "Penisola del Sinis - Isola di Mal di Ventre" (Sinis MPA). This has been identified as a major social and economic issue following the stakeholders' interviews and the analysis of regional and national legislations conducted in the first part of the VECTORS project, as reported in D6.1. As a tool to determine how risks of over-exploitation of the biological resource sea urchin can be prevented and if not prevented, how they can be mitigated we used the Bow Tie analysis (Smyth & Elliott 2014, Cormier et al 2013).

Resource Exploitation and Marine Protected Areas (MPAs)

Nowadays the health of marine ecosystems is in serious decline worldwide due to multiple anthropogenic impacts including overfishing, pollution, invasive species introduction, coastal development and climate change (Foley et al., 2010) that can alter ocean ecosystems beyond their natural range of variability (Fig. 1; Halpern et al., 2008).

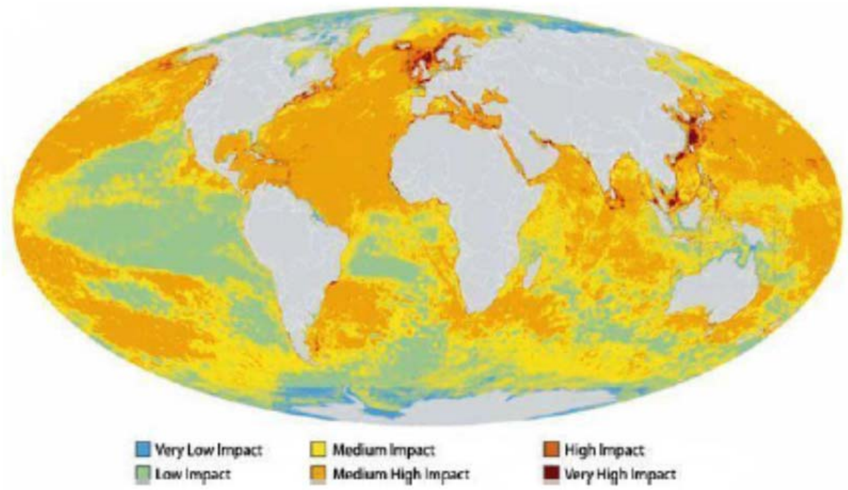

Figure 1. Global map of cumulative human impact across marine ecosystems (Halpern *et al*., 2008)

Human influence on marine ecosystems has accelerated the loss of biodiversity (Fig. 2) directly by exploitation, pollution, and habitat damage, as well as indirectly through climate change and related effects on ocean biogeochemistry (Dulvy et al., 2003), with largely unknown consequences (Worm et al., 2006; Fig. 2). Although at the global scale marine extinctions are gradually known (Dulvy et al., 2003), regional ecosystems such as estuaries (Lotze et al., 2006), coral reefs (Pandolfi et al., 2003), and coastal (Jackson et al., 2001) and oceanic fish communities (Worm et al., 2005) are rapidly losing populations, species, or functional groups.

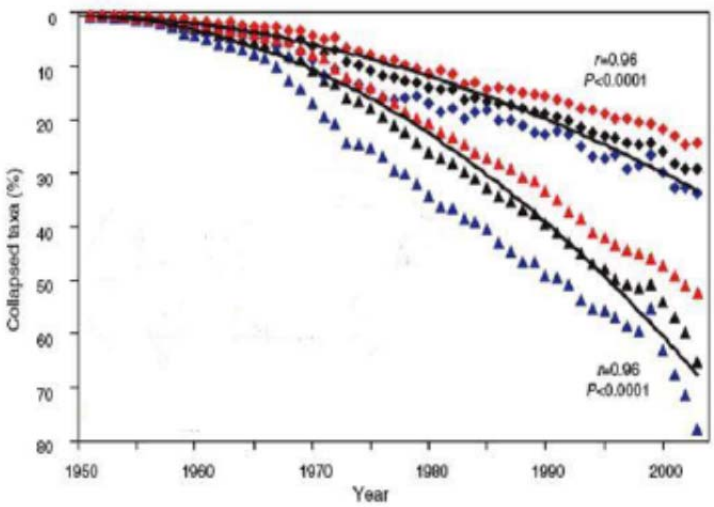

Figure 2. Global loss of species in marine ecosystem. Diamonds = collapses by year; triangles = cumulative collapses. Data are shown for all (black), species-poor (<500 species, blue) and species-rich (>500, red) (Worm *et al*., 2006)

The endangered status of several species may lead to extinction, and extinction results in biodiversity loss (Maczulak, 2010). So in a sense, endangered species also symbolize the success or failure of today's scientific attempts to save biodiversity. The Red List published by the International Union for Conservation of Nature (IUCN) is widely recognised as the most comprehensive, scientifically-based source of information on the global conservation status of plant and animal species. It is subdivided into categories based on species extinction risk that can change as some populations become more threatened or recover. IUCN Red List considers also taxa whose extinction risk cannot be evaluated due to insufficient knowledge, and which have therefore been classified as Data Deficient (DD). Until 2009, marine organisms have been poorly represented on the IUCN Red List, accounting for less than 5% of the 45,000 species it lists. To address this gap, the Global Marine Species Assessment (GMSA), a joint initiative of IUCN and Conservation International, has been formed to complete Red List assessments for approximately 20,000 marine species by the year 2012. The Mediterranean regional assessment is one of the first considered and the categories definition for marine fishes is just completed under the GMSA (Abdul Malak et al., 2011).

Despite the fact that protection of endangered species has become an important issue in global conservation activities, through national and international legislation, few effective protection measures are currently in place, either for species or ecosystems, in the Mediterranean region (Bianchi & Morri, 2000). National protection status of a species varies according to country. However, widespread concerns are emerging over declines in abundance of species, especially in the northern Mediterranean (Abdul Malak et al., 2011). There are four Conventions relevant to the conservation and management of the Mediterranean marine endangered species under various regional and international Conventions:

1. the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES);
2. the Bern Convention on the Conservation of European Wildlife and Natural Habitats;
3. the Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean;
4. the Convention on the Conservation of Migratory Species of Wild Animals (CMS or Bonn Convention).

Marine Protected Areas have been set up to protect vulnerable species and ecosystems, to conserve biodiversity and minimize extinction risk, to re-establish ecosystem integrity, to avoid user conflicts and to enhance the productivity of fish and marine invertebrate populations around a reserve (Pauly et al., 2002; Hooker & Gerber, 2004). In particular, protection of populations is generally recognized to be an essential part of endangered species protection and recovery. A focal question that marine researchers attempt to answer is what processes allow populations to recover after overexploitation. It was long assumed that marine populations are able to recover once the main mortality cause (e.g. fishing) is removed. There is now evidence for low recovery rates following severe depletion of marine fish species with varying life histories (Hutchings, 2001; Hutchings & Reynolds, 2004; Micheli et al., 2008). Processes that affect population recovery include: (1) failure in reducing exploitation; (2) allee effects; (3) habitat modification; (4) species interactions and (5) loss of genetic diversity and increased susceptibility to disturbance and disease (Micheli et al., 2008). Therefore, studies on populations of threatened species within MPAs may show evidence of recovery, including increased abundance, changes in size/age structure, and increased recruitment or, conversely, a lack of recovery data due to some of the factors previously described

A Marine Protected Area (MPA) is defined by the World Conservation Union as “any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment” (Kelleher, 1999). The term ‘Marine Protected Area’ or ‘MPA’ is used as a generic term for a multi-use IUCN Category I–VI area which may contain areas with strict reserves. A ‘Marine reserve’ means an area (often within a given MPA and sometimes even identical to an MPA) with strict Category I protection. A national or international ‘sanctuary’, on the other hand, is a very large area designated as a refuge from hunting. This includes national waters where whale and/or dolphin hunting are banned, as well as the large ocean international whale sanctuaries set up through the International Whaling Commission (IWC). The establishment of MPAs represents an important management tool for ecosystem conservation as well as fisheries resource restoration.

MPAs in the Mediterranean Sea

The Mediterranean Sea is considered a fragile oasis of biodiversity, whose conservation is of primary importance from both an economic and ecological point of view. The Mediterranean Sea shows a great number of marine species in a relatively small water volume: between 4 and 18% of the world species can be found in only a volume of about 0.3% of total marine waters (Bianchi & Morri, 2000; Abdul Malak et al., 2011). However, considering its water volume, the Mediterranean Sea also faces enormous human pressure, originated mainly from the industrial revolution and increased by the development of modern technologies and globalization, which could exceed the capacity of natural recovery of this basin. Many calls for attention about the progressive degradation of the Mediterranean Sea have been done during the last decades, but only the development of active protection policies could have practical positive results to reverse this trend (Comeau et al., 2005).

The institution of Marine Protected Areas (MPAs) represents an important management tool for ecosystem conservation as well as fisheries resource restoration. A MPA is defined by the International Union for the Conservation of Nature (IUCN) as "*any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical, and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment*". Currently, MPAs comprise only 3.8% of the Mediterranean Sea. The majority of these MPAs are multiple-use marine areas, with several degrees of protection where certain human activities are still permitted (Harmelin, 2000; Badalamenti et al., 2000; Francour et al., 2001). Fully protected zones (called also "integral zones", "marine reserves", or "no take-no entry areas") cover only 202 km², corresponding to 0.01% of the total surface area of the Mediterranean Sea and 2.2% of the total surface area of the existing MPAs. Marine Protected Areas without integral zones typically provide more limited benefits. For instance, Di Franco et al. (2009) demonstrated that fish assemblages in Tavolara MPA (Sardinia, Italy) benefited only from the no take areas, while partially protected zones, where fishing was allowed, were not effective. It has also been shown that, inside the marine reserves, the abundance, diversity, biomass and size of fishes, invertebrates and seaweeds increase significantly (e.g. Lester et al., 2009). Commercially target species show the biggest changes, sometimes increasing their density by 10 or 20 times in marine reserves (e.g. Guidetti, 2007; Micheli et al., 2004). These outcomes are consistent across different habitats and may spillover to nearby areas receiving less protection (Micheli et al., 2004). Some species and habitats take many years, even decades, to respond, and the benefits can be removed in 1 to 2 years if the area is re-opened to fishing.

Although MPAs can be an effective tool to protect the marine health, they cannot protect against all types of anthropogenic stress such as pollution, climate change or widespread overfishing (Boersma & Parrish, 1999). Other complementary management strategies are needed along with the creation of MPAs, such as marine spatial planning, gear restrictions and biodiversity monitoring for the sustainable management and conservation of the marine ecosystems.

MPAs in Italy

In Italy, the MPAs are established by means of the National Law (no. 979 of 1982 *Finding areas* or 'Aree di reperimento' and no. 394 of 1991) with a ministerial decree which contains the delimitation and boundaries of the areas, the objectives and the main regulations. For the effective establishment of an MPA it is necessary to establish an up-to-date framework of knowledge on the natural environment in addition to obtaining socio-economic data for the respective area. The Ministry of Environment can use scientific institutes, laboratories and research organizations for acquiring such knowledge. The studies are generally divided into two stages: in the first stage, the existing literature is examined, while in the second stage the necessary investigations are conducted. Subsequently, the experts of the Technical Secretariat for MPAs can initiate a general inquiry (in

Italian, “*istruttoria istitutiva*”) (according to art. 2, Law No. co.14. 426 of 1998). In order to draft a proposal for future MPAs, which respect the natural and socio-economic characteristics, the experts of the Technical Secretariat extend their knowledge with specific surveys and consult with local authorities and communities. The perimeter definition, the zoning (zones A, B and C), and the rules for the different degrees of protection, are part of the scheme which is written into the decree at the end of the inquiry. Regional and local authorities are involved in the processes of the decree scheme to obtain a consensus. Finally, as established by Legislative Decree n. 112/98 art.77, the opinion of the Joint Conference on the Ministerial Decree scheme is necessary. The Ministry of Environment (in agreement with the Ministry of Finance) then proceeds to establish an MPA while granting the funding which meets the initial cost resulting from its establishment (Law no. 394/91 art.18 and Law n. 93/01 Article 8). Unless specified otherwise, the Ministerial Decree enters into force on the day after its publication in the Official Gazette.

The management plan for MPAs is the result of a multilevel process where the local authorities (e.g. municipality or the Region) can take decisions in agreement with the Environment Ministry. However, it is of note that in Italy a management plan of MPAs is not yet compulsory. In Italy, there are 27 MPAs five of which are located in Sardinia (see also Deliverable VECTORS 6.1).

The “Penisola del Sinis - Isola di Mal di Ventre”MPA

In 1997, the Sinis MPA was formally established (by MD 12/12/1997, following the ‘Legge Quadro’ 979 of 1982). The coastal and aquatic environments within the MPA are extremely heterogeneous. They include the coastal zone between the cliffs of Su Tingiosu on the north and the Gulf of Oristano on the south together with Mal di Ventre and Catalano Islands. The Sinis Peninsula is characterized by high basaltic or calcareous cliffs alternating with wide beaches of which the most famous, which is located in the area extending from Maimoni to Mari Ermi, are composed of quartz grains. Catalano is a small basaltic outcrop whereas Mal di Ventre is a granitic island of about 5 nm away from the coast, with a surface area less than 1 km2. Generally the seabed profile is slightly tilted and falls below 40m depth only in a few areas. Extensive *Posidonia oceanica* meadows cover most of the seabed surface growing both on hard and soft substrata. The Sinis MPA has been established due to the presence of these significant natural values (Casula, 2010). The Sinis MPA has recently undergone two changes in size and zoning (see MD 22/07/1999, MD 06/09/1999, MD 17/07/2003, MD 20/07/2011). In particular, “no take-no entry” zones and highly protected areas were greatly reduced in number and surface (Fig. 3). Currently, the Sinis MPA covers a surface of about 25,000 ha of which 1.5% is a “no take-no entry” area. These changes were made following pressure from the local population and in particular fishermen. There are approximately 600 fishermen active in both the Cabras lagoon and the open sea.

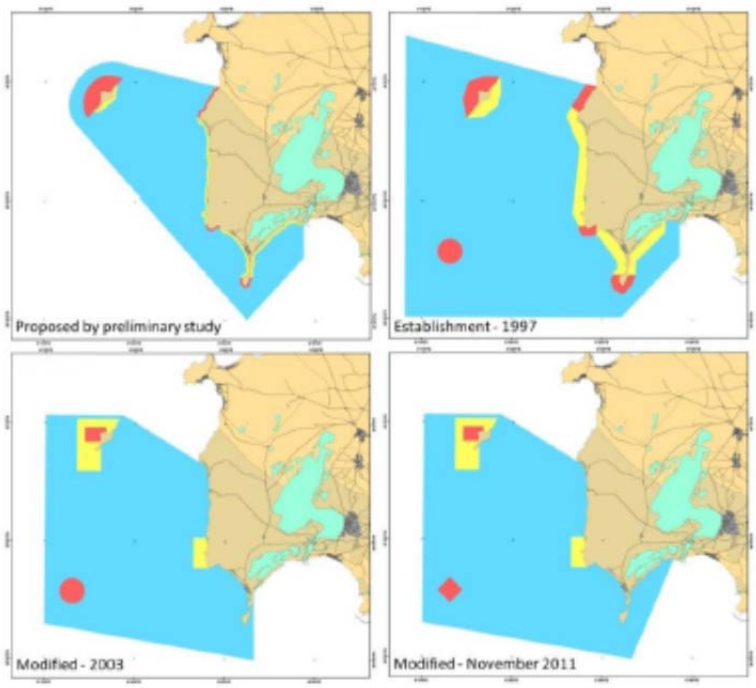

Figure 3. Changes in size and zoning of the 'Penisola del Sinis - Isola di Mal di Ventre' MPA

The Sinis MPA is managed by the Municipality of Cabras whose territory covers a surface of 102.18 km2. 73% of the Sinis MPA is devoted to farming, 13.5% is occupied by wetlands (e.g. the Cabras and Mistras lagoons), about 10% by woodlands and natural areas, while only 2.5% consists of urbanized areas with a resident population of about 9,000 inhabitants. Because of the lack of substantial pollution sources and the low population density, the main threats to marine resources in the Sinis MPA are represented by recreational and professional fishing. The local fishing fleet, which is composed of more than 100 units, is one of the major fishing fleets in Italy (Casola et al., 2008). The Sinis MPA is a destination with low tourist density. Tourists mostly assemble during the summer months, especially in August. The lack of infrastructure and awareness of the use of important environmental and cultural resources are key factors for the potential development of the local area which constitute major barriers to the development of tourism in the Sinis area.

Commercially targetted species, such as the sea urchin *Paracentrotus lividus*, show the biggest changes, sometimes increasing their density by 10 or 20 times in marine reserves (e.g. Guidetti, 2007; Micheli et al., 2004). These outcomes are consistent across different habitats and may spillover to nearby areas receiving less protection (Micheli et al., 2004). Some species and habitats take many years, even decades, to respond, and the benefits can be removed in 1 to 2 years if the area is re-opened to fishing. Although MPAs can be an effective tool to protect the marine health, they cannot protect against all types of anthropogenic stress such as pollution, climate change or widespread overfishing (Boersma & Parrish, 1999). Other complementary management strategies are needed along with the creation of MPAs, such as marine spatial planning, gear restrictions and biodiversity monitoring for the sustainable management and conservation of the marine ecosystems.

The sea urchin *Paracentrotus lividus*

P. lividus fishery "in summary"

The common European sea urchin *Paracentrotus lividus* (Lamarck 1816) is one of the most harvested benthic invertebrates in the Mediterranean and Atlantic coast for the consumption of its roes. *P. lividus* lives on rocky substrates and in seagrass meadows from shallow waters to about 20 m depth. Although a wide literature on biology and ecology of this species is reported, little information is available on the status of the main stocks and on catches for fishery management. Existing data refers only to the large fluctuations on both national and local scale pointing out a negative trend in many European countries, such as France and Ireland.

In Italy, sea urchin fishery is mainly exerted in the Southern regions and in the islands, but there is a knowledge gap on the production as well as on the conservation status of the exploited populations with some exception for some locations in Sardinia and Apulia. In Sardinia sea urchin fishery is carried out from the end of the 1980s with an increased production over the years. This phenomenon is due to two main causes: an increasing demand especially from the tourism market and an increased number of permits allowed by the Region decree (180 up to now). This measure was adopted for the re-allocation of fishermen and for rehabilitation of people with financial and social difficulties. Despite the increase of fishing effort, regulation has remained relatively unvaried (fishery season from November to March or April in some cases, minimum size limit of 50 mm, fixed daily individual quota of 2000 specimens) thus causing early signs of overexploitation and depletion of commercial sizes. One of the main risks is the concession of collecting sea urchin using scuba tanks which allows the catch of all large individuals within the diving area. This unsustainable fishing system is banned in the Sinis MPA where the professional fisherman has a minor daily individual quota and the fishing activity is conducted without breathing apparatus.

The sustainable management of *P. lividus* represents one of the most important goals for Sardinia's environmental authority both from a socio-economic point of view and for the biodiversity conservation of the coastal ecosystems.

P. lividus ecological and commercial relevance

P. lividus is one of the most important herbivorous of the costal zones in the Mediterranean Sea. Its geographical distribution includes the Atlantic coast (from Ireland to Morocco, including Canarie islands and Azores) and the whole Mediterranean Sea (San Martin, 1995). *P. lividus* is usually abundant on horizontal or slight-slopping rocky substrata (Palacin et al., 1997), but also occurs on vertical cliffs or less stable substrata like the meadows of phanerogams (e.g. *Posidonia oceanica*). Although it is found at a depth of 80 m, the species preferably colonize at shallower depths (with the upper 20 m) with decreasing density at increasing depth (Boudouresque & Verlaque, 2007).

Through its grazing activity, it is an important agent structuring the infralittoral benthic community (McClanahan, 1998; Sala et al., 1998; Fernández et al., 2001) and for this reason it is also called a 'habitat determiner' (Kingsford & Battershill, 2000). On the hard substrate, grazing occurs mostly on erect macroalgae, turf, barren (e.g. *Dictyota* spp., *Padina pavonia*, *Cystoseira* spp.) (Boudouresque & Verlaque, 2007). At high density, P. lividus can modify heterogenous algal communities into a 'barren' habitat characterized by low structural complexity and species diversity, with a dominance of encrusting coralligenous algae (Lawrence, 1975; Harrold & Pearse, 1987; Bulleri et al. 1999; Guidetti, 2006). In the meadows of *P. oceanica* meadows, *P. lividus* feed on the leaves and their epiphytes, whereby over-grazing cases are often reported (Kirkman & Young, 1981; Nédelec & Verlaque, 1984; Tomas et al., 2005; Coppa et al., 2007a).

In the Mediterranean Sea, reproduction occurs on an annual basis (Turon et al., 1995). The gonads start to develop in autumn and reach maturation during the winter months, when the 'gonad-somatic index' is high. The development of the gonads is influenced by abiotic factors, especially temperature. The spawning occurs in spring or at the beginning of summer, when the water temperature reaches about 20°C (Turon et al., 1995). Nevertheless, it has been shown that if conditions are favourable, the gonads can become mature for a second time, with a subsequent release of gametes later in the year (spring and autumn) (Fenaux, 1968; Verlaque, 1984; Pedrotti, 1993).

The consumption of sea urchin gonads is highly appreciated, therefore *P. lividus* represents an important target for fishery and the sea food market (Gianguzza et al., 2006). *P. lividus* is thus subjected to catch in most of its area of distribution. In the last decades, the sea urchin populations have shown a large decline in several European countries (Pais et al., 2007). In Italy, the exploitation of *P. lividus* is conducted especially in the central-southern regions and the islands (Guidetti et al., 2004; Pais et al., 2007). In Sardinia, the catch is regulated by a regional decree limiting the period of fishing and amount which can be collected (Regional Decree N. 0002657/DecA/83 of 31 October 2008. However, stock exploitation is considerable because of an increasing demand from the market. This has led to cases of overfishing partly due to authorized professional fishermen, but also due to illegal fishermen and "recreational activities" (Pais et al., 2007). The uncontrolled catch of this resource mainly affect the size classed > 5 cm. The decline of the population, as a consequence of fishing, can originate numerous effects (cascade effect); As *P. lividus* is interacting with other species, it is involved in multiple ecological processes occurring within the same habitat (Benedetti-Cecchi et al., 1998). To avoid an excessive exploitation of the *P. lividus* population, with possible ecosystem disturbance and biodiversity reduction, it is therefore necessary for the adoption of strategic management measures that allow the stock's recovery and the impact migration on the natural populations (San Martin, 1987; Botsford et al., 1999; Yokota, 2002).

The AMPs, designed worldwide to favour the biological resource intensively exploited by man, are an efficient instrument to promote a sustainable use of the marine resources (Agardy, 1997; Palumbi, 2001). The main objectives, to be achieved by prohibiting or limiting anthropic activities, include the preservation of natural conditions and the marine biodiversity. These are strictly linked to an increase of the coastal fishery and the management of touristic activities (Pomeroy et al., 2004).

Catch management of *P. lividus* in the MPA "Penisola del Sinis – Isola di Mal di Ventre"

Since the implementation of the MPA "Penisola del Sinis – Isola di Mal di Ventre" (hereafter Sinis MPA), special attention has been given to the sea urchin fishery, taking into account the socio-economic importance of the resource in Sardinia. To regulate the catch of *P. lividus* within the Sinis MPA, in the absence of a specific authority, the Management Body ("Ente Gestore") applies the decree issued by the major of Cabras town ("Ordinanza del Sindaco"), an instrument which has subsequently been considered inappropriate. This mechanism is used to allow priority of sea urchin fishery to be allocated to maritime professional fishermen, professional SCUBA fishermen, and not to the recreation fishermen residents in the Oristano province. This decree has been subjected to several modifications through the years that can be summarized as follows:

- sea urchin fishing is allowed as free diving, from a boat or from land
- the catch is allowed if certain periods for the year as indicated by the regional calendar
- the amount of sea urchins should be that established by the regional decree
- fishermen need a special permit from the Management Body ("Ente Gestore").

In 2009, in the light of the forthcoming new Ministerial Decree that refines the perimeter and zonation of the MPA, the Sinis MPA involved the main stakeholders for common understanding and sharing of new roles. In order to ensure the continuity of effective conservation measures and to allow the sustainable catch of sea urchins, the Management Body has also involved the Capitaneria di Porto di Oristano in the process.

Monitoring *P. lividus* in the Sinis MPA

A two year based monitoring plan in the Sinis MPA includes the whole reserve and some adjoining sites as control (Fig. 4). The sampling design takes into account several factors that may affect density and the average size of *P. lividus*:

- depths (2, 5 and 10 meters);

- substrate (sandstone, basalt, granite, Posidonia oceanica);

- level of protection and allowed fishing methods (free-diving within the MPA and scuba-diving outside).

The monitoring design considers a total of 46 sites where, 38 of which are located inside the marine reserve. For every site three random replicates of 5 m^2 (twenty 50 x 50 quadrats) are selected for counting and measuring of all the sea urchin found inside the quadrants.

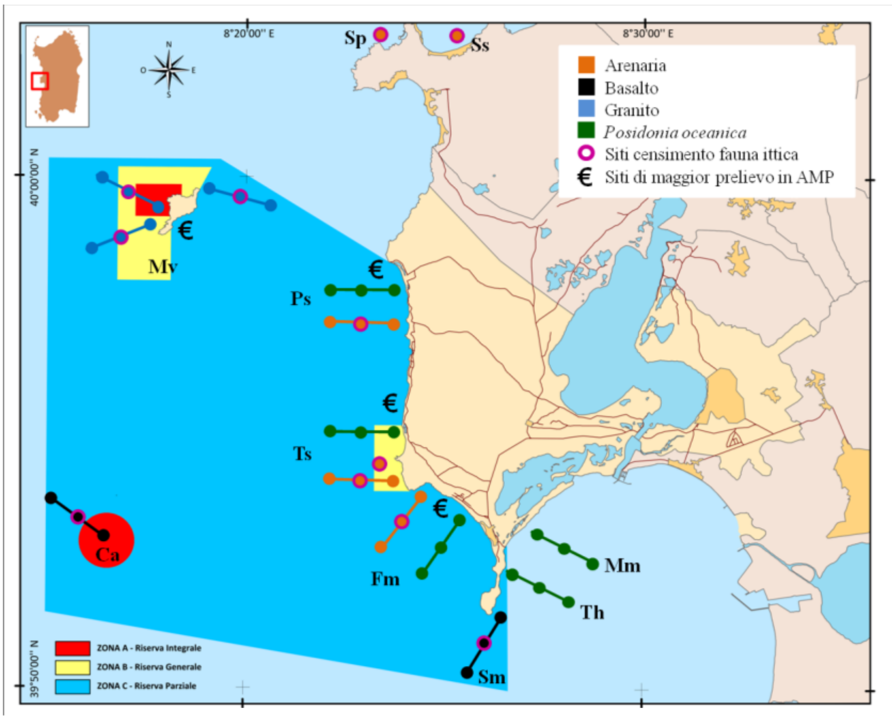

Figure 4. Study area and the monitoring sites

Fig. 5. Example of field work and measurements

The main output resulting from the monitoring activity (Fig. 5) can be summarized as follow: 1) Depth - areas characterized by shallow depth (2-5 m) show higher abundances of *P. lividus* than the others (10 m depth, see Fig. 6).

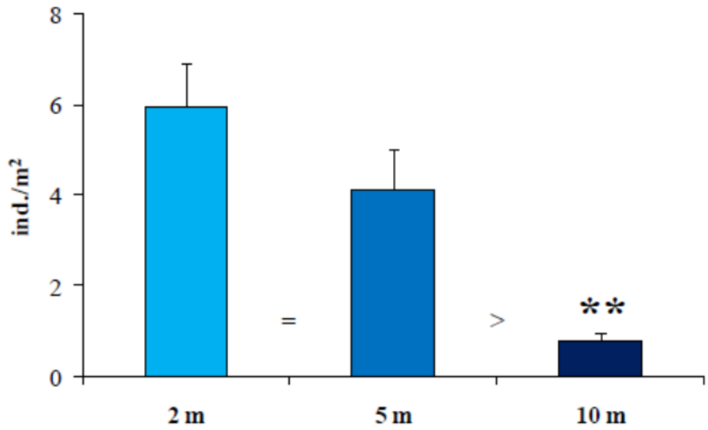

Figure 6. *P. lividus* density according to depth (2, 5, 10 m). Data from Coppa et al. (2010)

2) Substrate - Sandstone is the substrate most colonized by sea urchins probably due to its heterogeneous conformation. Density of *P. lividus* on sandstone shows double values compared to other substrates that characterized the Sinis MPA (granite, basalt, *P. oceanica*) (Fig. 7).

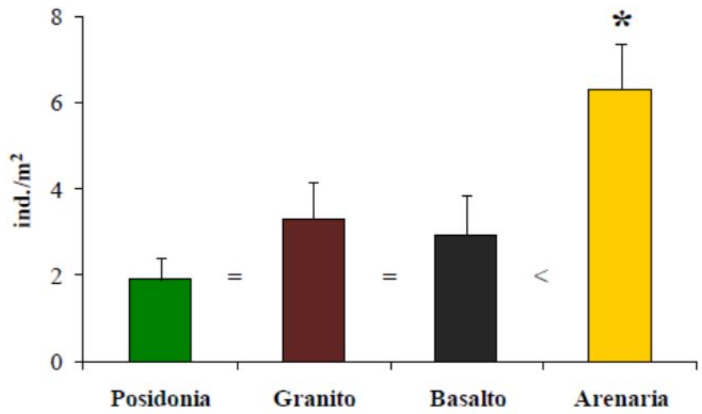

Figure 7. *P. lividus* density according to substrate (*Posidonia oceanica* meadow, granite, basalt, sandstone). Data from Coppa et al. (2010)

3) Resource exploitation - Fishing activities in the Sinis MPA currently does not seem to affect negatively the total stock of *P. lividus* with the exception of the most accessible site of the Zone C (Fig. 8). Significant differences were found in the size classes distribution with a clear dominance of individuals close to commercial size in external sites and the presence of a stable population in good conservation status within the MPA (Fig. 8). Also for size distribution, the most accessible sites of the Zone C are distinguished from the general pattern of the MPA showing a high presence of non commercial size (Fig. 9).

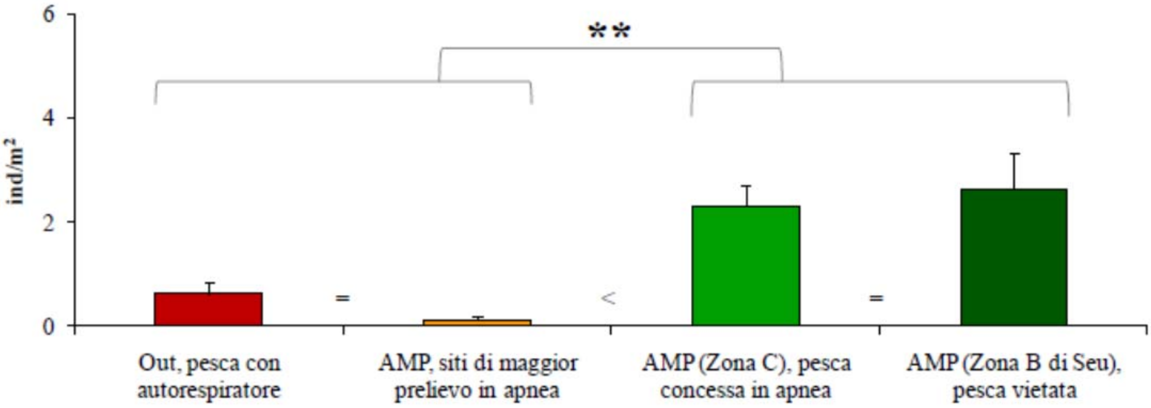

Figure 8. *P. lividus* density according to fishing regulation (Outside with scuba-diving, MPA -most fished site with free-diving due to their easy accessibility, MPA general-only free-diving, MPA fishing prohibited). Data from Coppa et al. (2010)

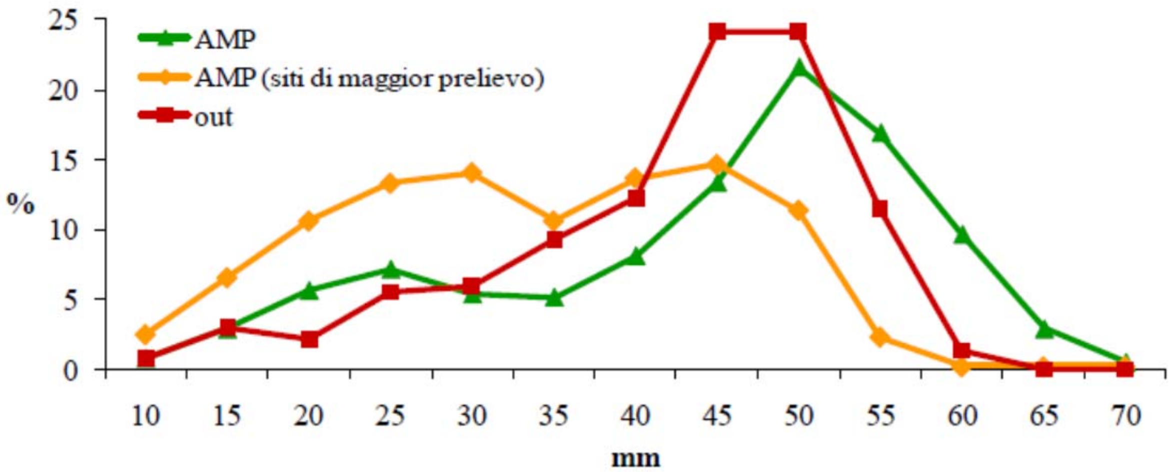

Figure 9. *P. lividus* size frequency (5 mm size classes) according to fishing regulation (Outside with scuba-diving, MPA -most fished site by free-diving due to their easy accessibility, MPA general-only free-diving). Data from Coppa et al. (2010)

Recommendations for management based on the monitoring activities

Based on our results, we propose some recommendations which can be useful for the management of the sea urchin *P. lividus* and to increase our knowledge on the population dynamics of this species, the interactions with the habitat and for the sustainable management of catches:

- The importance of an appropriate control and surveillance should be highlighted. It is well known that surveillance together with awareness is a fundamental aspect in order to see beneficial effects on a MPA, both in term of environmental conservation and in terms of sustainable management of the resources for the benefit of fishermen and the people's community as a whole (Byers & Noonburg, 2007). The low frequency of surveillance and inadequate enforcing laws limit the effectiveness of the MPAs as a main instrument for the conservation of marine resources (es. Agardy, 1994; Allison et al., 1998;. Branch e Odendaal, 2003; Mora et al., 2006; De Lucia et al., 2008; Guidetti et al., 2008; Rodríguez-Martínez, 2008; Chittaro et al., 2009, Espinoza-Tenorio et al., 2010; García-Gómez et al., 2010; Coppa et al., 2011). Some possible solutions to this issue include: joining personnel responsible for the control and surveillance during the monitoring activities; due to the large extension of the Sinis MPA installing check point-type places at the main access areas to the MPA;

- Another important issue is the number and distribution of the access-points to the coast. These are the areas where important resources, such as sea urchins, are most exploited. These areas should be reconsidered in terms of their diversification and utilization;
- Based on ad hoc studies, a kind of "rotation" of some areas of zone C could be considered in relation to the specific needs for the conservation of the sea urchins and the coastal marine ecosystem;
- The importance of no-fishing areas for the conservation of the marine ecosystem is increasingly highlighted worldwide (e.g. Manríquez & Castilla, 2001; Claudet et al., 2008; Chittaro et al., 2009). However, in the specific case of the Sinis MPA the zone B (no fishing zone) does not differ from zone C (fishing allowed by free diving).

Risk analysis and BowTie application

Unplanned incidents/situations in the environment have the potential to result in adverse effects. Environmental risk analysis and management are the processes of systematically identifying environmental hazards, analysing the likelihood of occurrence and the potential consequences, and managing the resulting level of risk. For most natural resource managers, including fisheries management agencies, the level of public scrutiny of decisions and their expectations of performance have increased greatly in recent years (Fletcher, 2005). Indeed management of fisheries around the world is challenged by fishing impacts on habitats, bycatch species, threatened and endangered species, and even associated ecological communities (Hobday *et al*., 2011). This has resulted in a shift to more structured and transparent evaluation techniques to both determine and justify decisions (e.g. disease management; Stephen, 2001). The necessity to have more formal decision-making processes has also been intensified through recent initiatives to implement the principles of sustainable development. Studies on "Risk" related to fisheries management has appeared frequently in the literature only from the nineties (Francis and Shotton 1997; Fletcher, 2005 and literature herein). There are two stages in dealing with risk: the first (defined as "risk assessment") is the formulation of advice for fisheries managers in a way that conveys the possible consequences of uncertainty. This advice is in the form of an evaluation of the expected effects of alternative management options, rather than recommendations. Risk assessment has been undertaken in many fisheries, and there is general agreement as to how it should be done (although technical details differ). Secondly, risk management is the way fishery managers take uncertainty into account in making decisions. Much fisheries risk management is informal (i.e. qualitative, undocumented, and loosely linked if at all with a risk assessment) (Francis and Shotton 1997). The main reason for this is that the objectives of fisheries management are often conflicting and are rarely stated in a way that provides explicit direction to managers or scientists. (Francis and Shotton 1997). Quantitative risk assessments are often employed in stock assessment analyses, allowing advisory/management committees to link their recommended actions to the probability that stock abundance will meet some agreed level of performance. Such quantitative analyses can be highly robust, but they require significant levels of information and can only be applied in a small number of situations; usually in the assessment of a small number of target species. However, the assessment of risk is of great importance also in data-poor situations (Fletcher, 2005).

Marine protected areas (MPAs) are geographically defined areas in the marine environment dedicated and managed for the long-term conservation of nature. The use of marine protected areas has taken on greater importance lately in discussions of how to protect marine ecosystems and reverse the degradation of aquatic habitats. MPAs are commonly described as a tool for biodiversity conservation and therefore as part of the ecosystem approach. Spatial-temporal fishing closures are also used in fisheries management, and MPAs and fisheries are linked through this common avenue of spatial management and through Ecosystem approach to fisheries. There is the need for increased coordination and dialogue among all the stakeholders interested in conservation, use and exploitation of the coastal marine environments. Integration of different interests and viewpoints is required if we are to successfully manage Mediterranean Sea and their resources for future generations. As with all fisheries management, good governance including adequate stakeholder participation is key to successful and equitable management results.

Following the identification of potential impacts, BowTie XP/XL software was used to create a diagram of the factors influencing the management of the sea urchin fishery in the Sinis MPA in order to visualize the hazard and associated causes/effects and to propose preventative and mitigation measures. The BowTie methodology is used for risk assessment, risk management and risk communication. The method is designed to give a better overview of the situation in which certain risks are present. This is particularly useful to help people understand the relationship between the risks and organizational events. The strength of the methodology lies in its simplicity and the adage “less is more” is certainly appropriate. Many risk assessments are done using quantitative instruments. These may be sufficient for certain types of cases but are less valuable for organizational risk assessment. Human beings (as well as biological resources trends) are less easy to predict than machinery (or other simple closed systems) and the operational combination of all factors leads to even more difficulties. Making accurate predictions of the future in an environment that is as complex as the world itself, is simply impossible. In many cases, as the sustainable fisheries challenge, the stakes of certain consequences are too high to leave unmanaged. Therefore it is wise to think of all possible scenarios and assess how your organization is prepared to deal with them. This is exactly what the bow-tie method and BowTieXP has helped us to accomplish for the management of the sea urchin resource in the Sinis MPA. Risk in bowtie methodology is elaborated by the relationship between hazards, top events, threats and consequences. Barriers are used to display what measures an organization has in place to control the risk.

BowTie Results

Overall framework

BowTie focuses on a hazard which is the thing you want or need to make business: in our case the key study resource is the sea urchin population of the Sinis MPA (Fig. 10). Thus as long as this population is controlled it is in its wanted state. But certain events can cause the loss of the good state of your resources. In bowtie methodology such an event is called the top event. The top event (Negative population trend in our case) is not a catastrophe yet, but the dangerous characteristics of the hazard are now in the open.

The use of Bowtie for the sea urchin fishery risk assessment allowed us to indentify 5 main THREATS (blue; Recruitment failure, Bad fishery management, Poaching, Change in Environmental Conditions, Massive Disease) with 13 REACTIVE BARRIERS (gray, left side hand; Maintenance of high density of spawners, Resource Monitoring, No take-No entry areas, Management Monitoring, Regional and local regulations, fishermen cooperation, Surveillance, Sanctions, Environmental Education, Population welfare, Conservation measure and politics, Healthy environment preservation, Disease monitoring), 5 CONSEQUENCES (red; Population collapse, Ecosystem disequilibrium, Reduction in food tourism, Loss of local traditions, Loss of welfare) with 6 PROACTIVE BARRIERS (gray, right side hand; Fishery restrictions, Increase of no take areas, Anthropic pressure reduction, Alternative offers proposal, Enhancement of *pescaturismo*, Enhancement of *ittiturismo*). The escalation factors (yellow) were provided to explain the effectiveness of each barrier. In the present report, we describe the main issues to be considered for the risk management. Those issues are: “Bad fishery management” and “Poaching” for the THREATS and “Population collapse” and “Equilibrium disequilibrium” for the CONSEQUENCES.

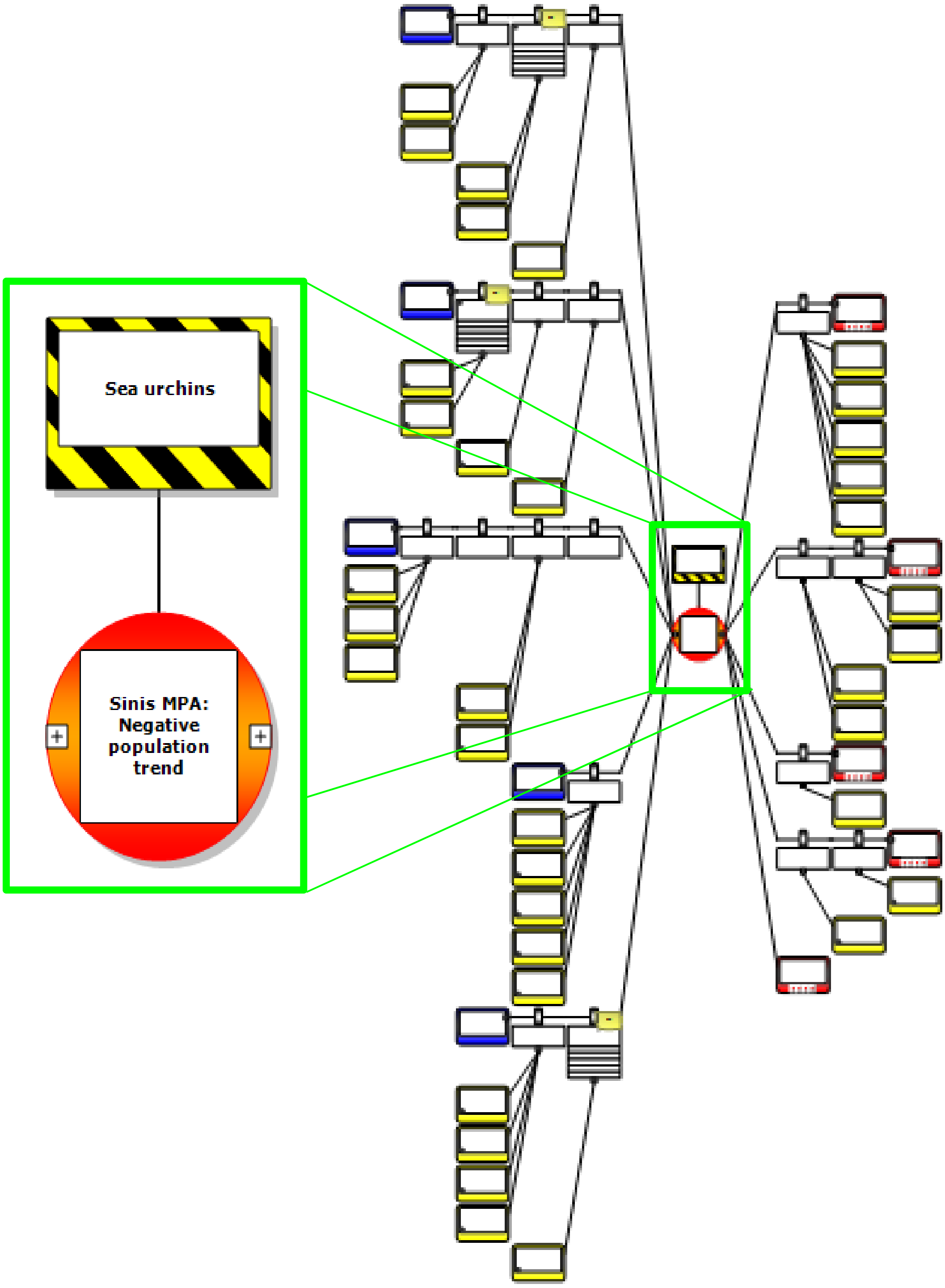

Figure 10. Overall scheme to be used for the management of the resource “sea urchin” in the Sinis MPA with hazard and top event zoomed in the green box

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Basic scheme with threats and consequences

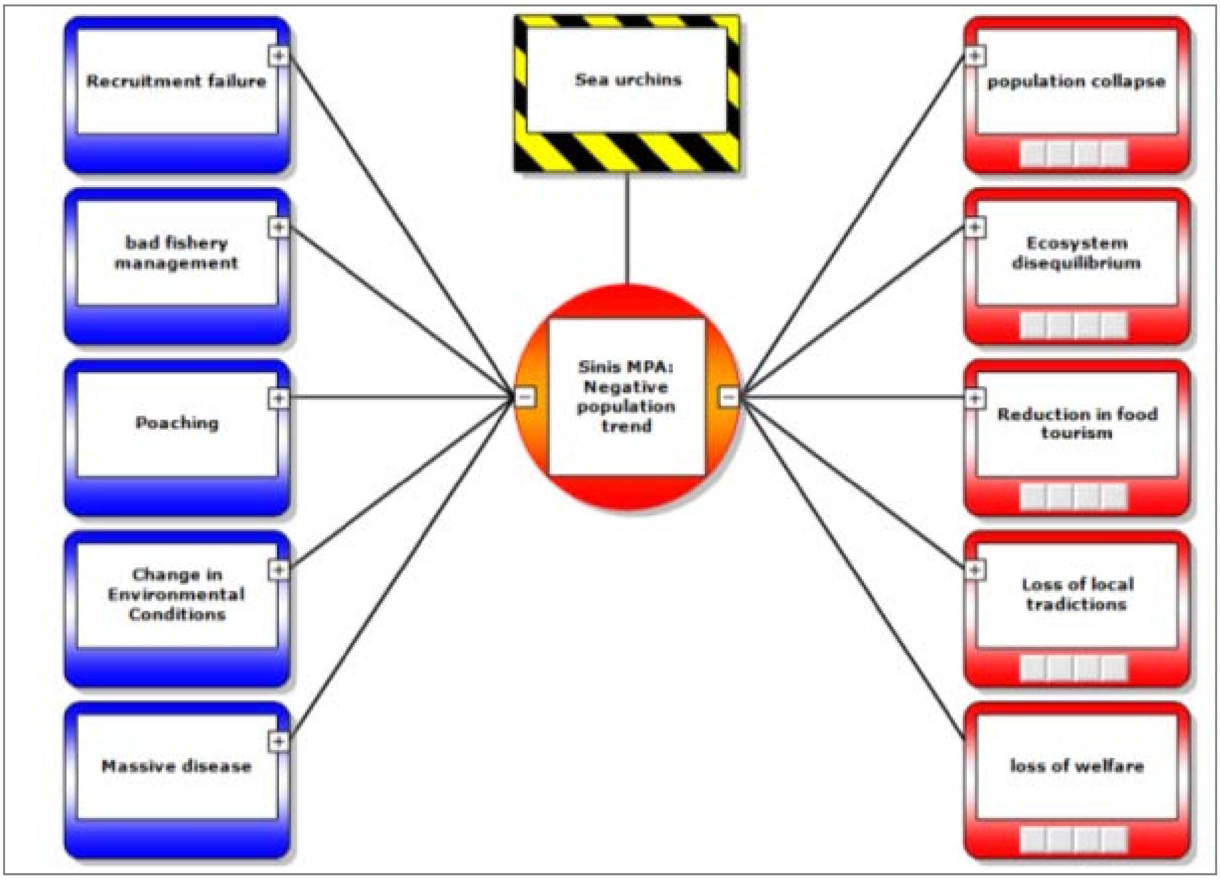

Figure 11. Main boxes used for the management of the resource “sea urchin” in the Sinis MPA (Hazard: black and yellow stripes; Top Event: orange circle, Threats: blue, Consequences: red)

HAZARD: sea urchin = the biological resource to be managed (also in terms of business).

STUDY AREA: the Sinis MPA

TOP EVENT: Negative population trend = a progressive decrease of the biological resource can lead to unwanted events that put at risk the sustainable management of the resource “sea urchin”

THREATS (factors which can cause or contribute to cause the top event):

recruitment failure = the recruitment failure determines the reduction with time of the stock with direct consequences the fishery and the local economy. Subsequent years of scarce recruitment cause the top event.

bad fishery management = a bad fishery management (e.g. quotas, permits, periods of fishing not considering the monitoring results) contributes to the progressive reduction of the stock and limits the possibilities of a long term exploitation of the resource.

poaching = poaching (unauthorized fishermen and authorized fishermen who fish in unauthorized periods and not allowed techniques) is a critical factor in the study area in the determination of the trend of the stock.

change in environmental conditions = important variation in abiotic factors (e.g. temperature) that determine unfavorable environmental conditions for the population growth can cause a decrease with time of the sea urchins’ abundance.

massive disease = a massive disease causes a drastic decrease in the sea urchins' population.

CONSEQUENCES (the occurrence of the top event can lead to consequences. They are unwanted events that are to be avoided by all means):

population collapse = the lack of a sufficient stock of individuals of commercial size that from one hand can sustain the economy related to the selling of gonads and from the other hand can control the growth of macrolgae.

ecosystem disequilibrium = the scarcity of sea urchins creates an ecosystems' disequilibrium with a reduction of biodiversity (and macrolgal dominance)

reduction in food tourism = the loss of the resource "sea urchin" determines a reduction of food (and wine) tourism..

loss of local traditions = the loss of the resource "sea urchin" determines a progressive reduction of local traditions (e.g. fishing techniques, special recipes/dishes, knowledge of the surrounding environment).

loss of welfare = the loss of the resource "sea urchin", is very important for the local economy, and determines a drastic reduction of the quality of life.

"Bad fishery management" and "Poaching" as examples of threats

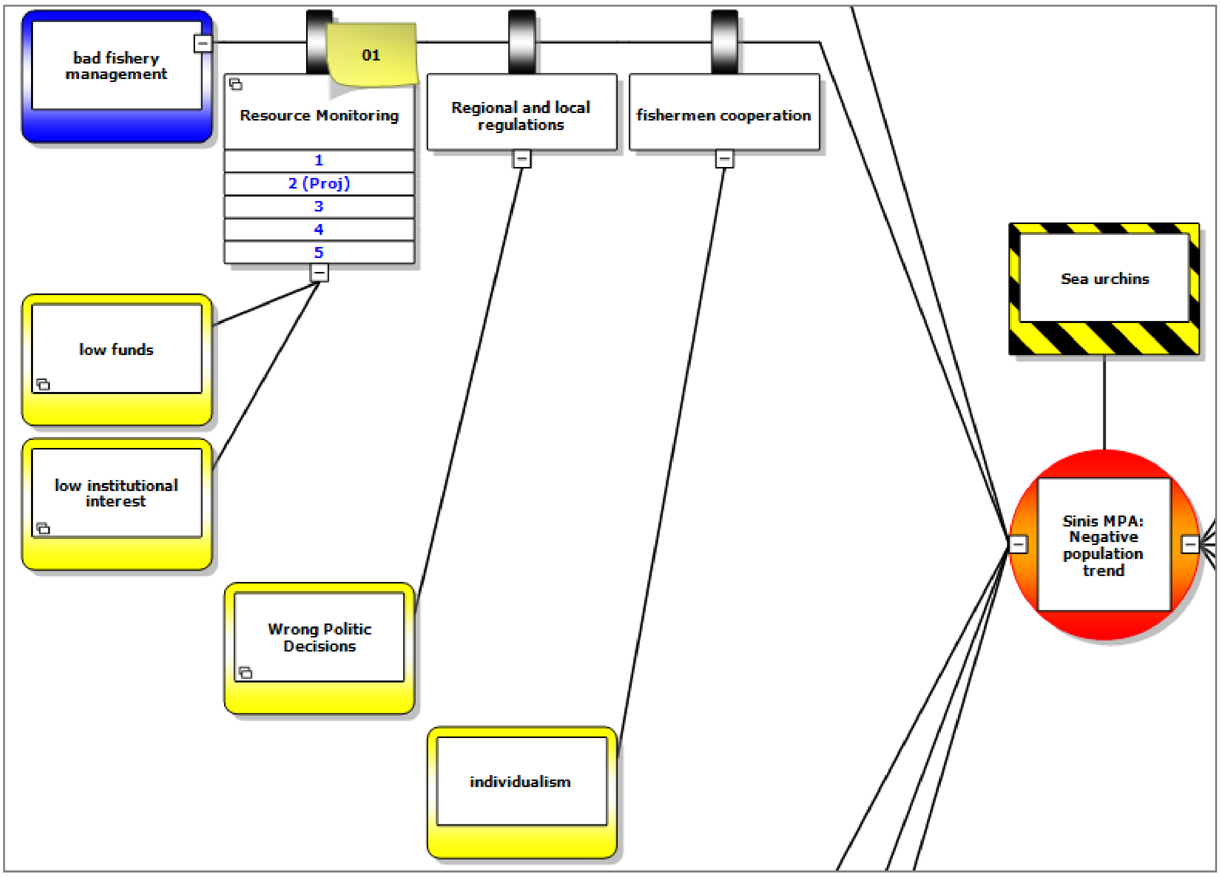

Figure 12. Bowtie scheme relating to the issue of Bad fishery management

Threats, like “Bad fishery management”, have associated some proactive BARRIERS that aim at preventing the top event. In an ideal situation, the barrier should always work. However, there are conditions (defined ESCALATION FACTOR, see yellow boxes) where the barrier can fail. The three barriers evidenced for the threat “Bad fishery management” are:

a. “Resource monitoring" – the monitoring activities have been first defined and standardized with an initial ACTION (indicated as “01” in the above figure; an action is another category of activities that can be used only in the case improving/developing a process). The ACTIVITIES (ordinary phases that ensure the functioning of the monitoring of the resource) of this barrier are 1) planning, 2) sampling, 3) database implementation, 4) data analysis, (5) output production and result dissemination (indicated by numbers below each barrier in the above figure). The results provided should be used by the Management Body to ensure the sustainability of the catches and avoid or amend management mistakes that may occur on a long term. The “escalation factors” that may contrast the effectiveness of this barrier are: the lack of funding for monitoring or a low institutional interest towards long term resource conservation (a short term or more immediate effect is more appreciated by politicians).

b. “Regional and local regulation” – This regulation, being periodically amendable based on the local needs can contribute to the good conservation status of the sea urchin population. The inefficacy of this barrier may occur in relation to the short-sighted approach of politicians that aim to keep the short term consensus and do not consider scientific data when taking their decisions and adopting appropriate regulation.

c. “Fishermen cooperation” – Cooperation and cohesion among fishermen in the management of sea urchin catch is a very important barrier to maintain the resource. However, individualism and lack of sanctions in the case of roles’ infringement may impair this barrier.

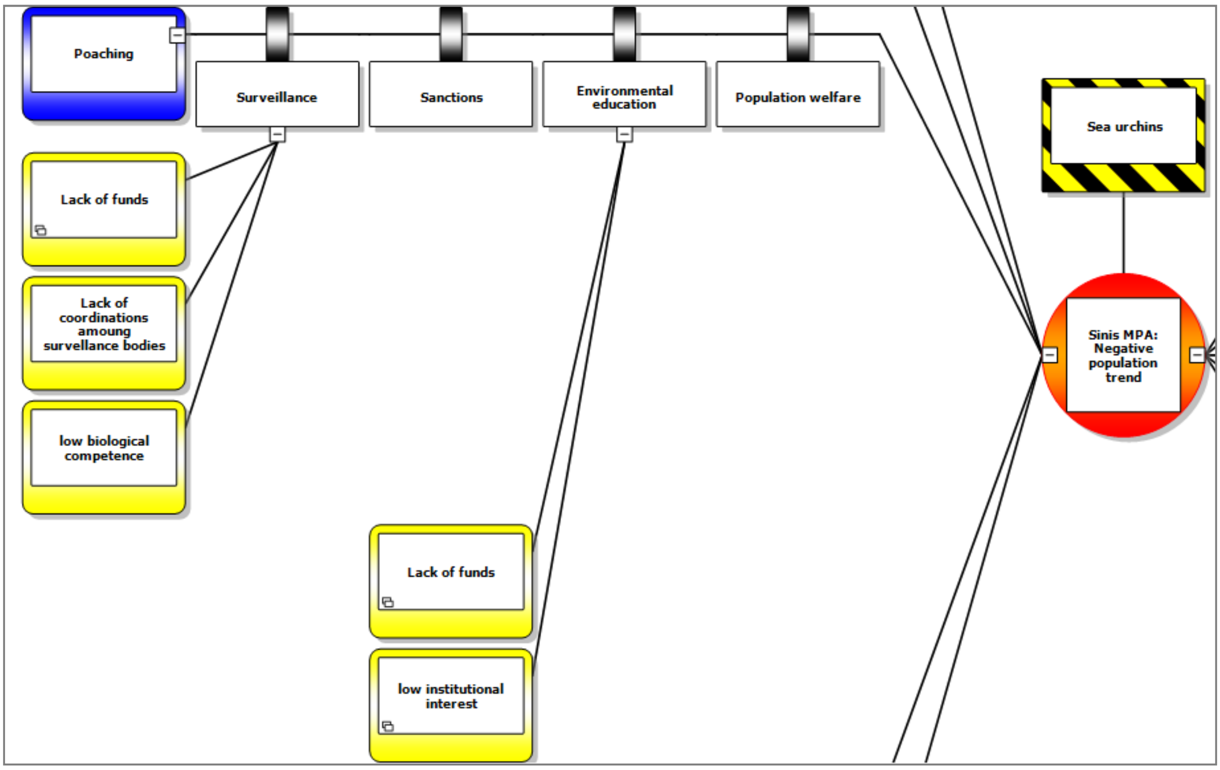

Figure 13. Bowtie scheme relating to the issue of poaching

The following barriers have been identified as potentially limiting Poaching:

a. “Surveillance” – Effective surveillance ensures the least impact of poaching. The lack/scarcity of funding, of coordination among different national and regional bodies (e.g. police, port authority, environmental agency) that control the marine environment and of scientific knowledge (e.g. species identification) may render this barrier completely ineffective.

b. “Sanctions” – Penal and administrative sanctions represent a deterrent to poaching.

c. “Environmental education” – Education to the respect of the environment and the dissemination of scientific results contribute to the progressive reduction of poaching because of increased awareness of local stakeholders (e.g. people visiting the Sinis MPA). Also in this case, the “escalation factors”) The “escalation factors” that may contrast the effectiveness of this barrier are: the lack of funding for monitoring or a low institutional interest towards long term resource conservation

d. “Population welfare” – The welfare of the local community should be considered to reduce/remove or render ineffective poaching.

“Population collapse” and “Ecosystem disequilibrium” as examples of consequences

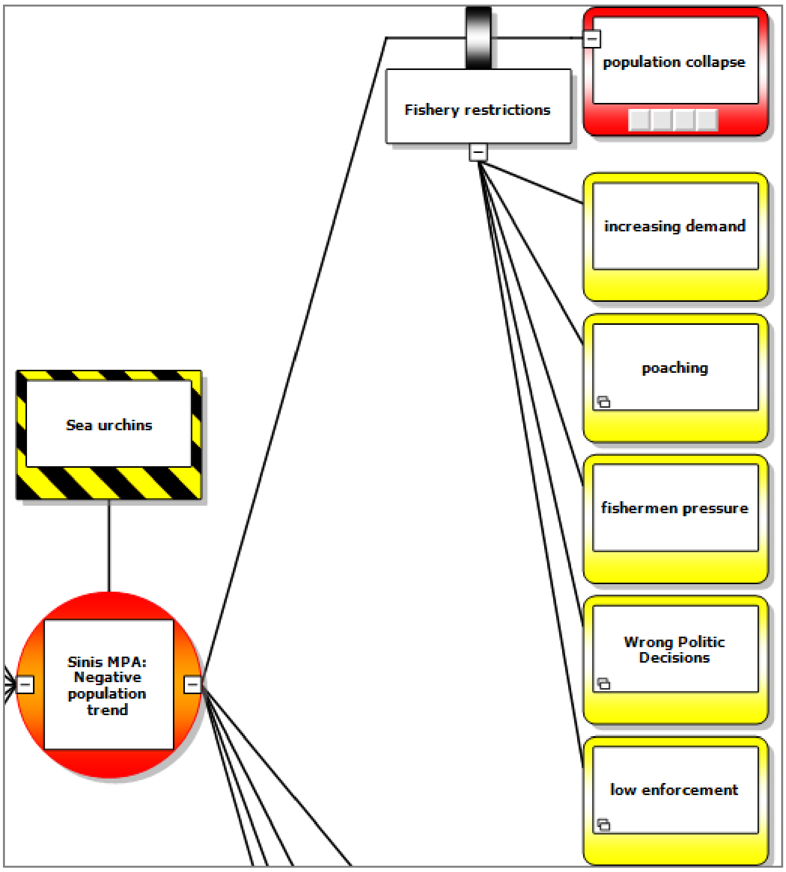

Figure 14. Scheme of the factors to be considered to avoid the collapse of the sea urchin population

In the case that the “top event” would occur, the collapse of the sea urchin population could be avoided by applying restrictions to fisheries (the BARRIERS on the right side hand of the top event are defined as “reactive” and have the aim to limit damages and the occurrence of the “consequences”). Changes in the fishery management (“fishery restrictions”) may relate to the number of permits, the period of fishing, fishing techniques, the number of individuals that can be caught, the areas of catch (“rotational fishing”). The increasing market demand, the illegal catch, fishermen pressure on the politicians, wrong political decisions and ineffective surveillance represent the “escalation factors” of this barrier.

A continuous decrease of the sea urchin density determines an ecosystem disequilibrium, as described above. The barriers that have been identified to avoid these consequences in the study area are:

a. increase of the no-take no-entry area in order to contribute to the previous environmental conditions. Poaching and low-enforcement can contribute to make this barrier ineffective.

b. reduce the antrophic pressure in the MPA even though the touristic demand and request for the renewal of fishery permits can limit the power of this barrier.

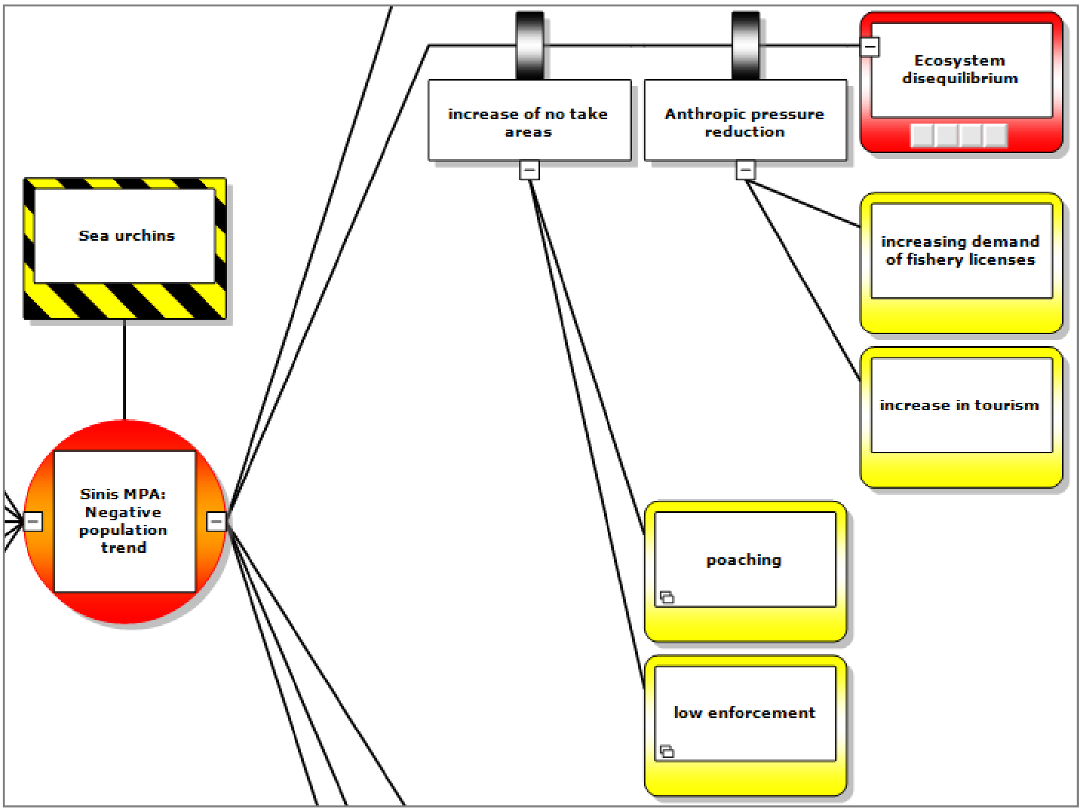

Figure 15. Scheme of the factors to be considered to avoid the ecosystem disequilibrium

Conclusions

Responses of coastal ecosystems to climate change (CC) take place across different spatial and temporal scales, involve multiple levels of biological organization, —genome to, populations, communities, ecosystems, and biomes— and of course include humans (Tagliapietra et al., 2011). In the western Mediterranean, climate change has been demonstrated to affect the boundaries of biogeographic regions, with some warm-water species extending their ranges and colonizing new areas where they were previously absent (VECTORS D1.1). The northward migration of species with an affinity for warmer waters has been demonstrated in several regions (Morri and Bianchi, 2001). As an example, the alien crab *Percnon gibbesi* established in most Mediterranean coast twelve years after its introduction, while it is absent from the Northern Adriatic Sea, as well as the Ligurian Sea, the Corsica Island, and the Aegean Sea, possibly because of the low winter temperatures (Katsanevakis et al., 2011). Changes in the composition of ichthyofauna also have had a considerable impact on local fishing industries (Francour et al., 1994).

CC effects propagate through food webs with cascading reactions with sudden and non-linear changes thresholds, and regime shifts (Conley et al., 2009). Species of commercial interest are highly sensitive to CC, displaying phenological changes, lag time in life cycles, asynchrony between prey-predators, and other complex interactions that significantly alter ecosystem structure and processes (Michner et al., 2001). If proper management actions are not taken, the natural equilibrium can be broken by the loss of components of the food web induced by overfishing or variation of environmental conditions as a result of climate change.

Marine Protected Areas (MPAs), which are geographically defined as areas in the marine environment dedicated and managed for the long-term conservation of nature, can serve to this scope. However, MPAs are to be used in sustainable management practices while still allowing society to get benefits, such as from fisheries. Adaptive policies are thus needed to face the complex interaction between human activity and MPAs safeguarding both ecosystem services and ecological functions supplied by natural and the impressive environmental and socio-economic value of MPAs.

The present report covers the risk assessment and management of an important fishery resource, the sea urchin *Paracentrotus* lividus, in the MPA of "Penisola del Sinis - Isola di Mal di Ventre" (Sinis MPA). This has been identified as a major social and economic issue following the stakeholders' interviews and the analysis of regional and national legislations conducted in the first part of the VECTORS project, as reported in D6.1. Following the identification of potential impacts, the BowTie XP/XL software was used to create a diagram of the factors influencing the management of the sea urchin fishery in the Sinis MPA in order to visualize the hazard and associated causes/effects and to propose preventative and mitigation measures.

The sea urchin, *P. lividus*, fishery in the Sinis MPA has been shown to be a complex issue involving several managerial and legislative issues as well as several stakeholders and sectors. The sustainable use of *P. lividus* fishery is in line with the criteria defined for the establishment of the Sinis MPA and its implementation. It has several social and economic consequences for the local population that uses this resource. Not only fishermen, but all different sectors involved in this activity can benefit from the correct management of the sea urchin fishery. The analysis of such a complex system cannot be tackled with classic methodologies alone. The use of the BowTie approach for the first time has enabled an innovative analysis for the correct management of a biological resource under pressure from excessive human exploitation. The multidisciplinary approach used for this case study has allowed us to disentangle and categorize the different factors involved in the analysis according to a qualitative and, where possible semi-quantitative, approach. The interpretation of the relationships among the numerous factors identified enables generation of different scenarios, which can all be plausible. At the same time, it allows the evaluation of the weight of each factor in relation to the environmental, economic and social factors driving management decisions. In fact, the management aspects mostly benefit from such a multidisciplinary approach. The availability of environmental and biological datasets derived from monitoring activities carried out in the Sinis MPA has a double function: providing science-based recommendations for the sustainable use of the biological resources and validating the management decisions once they are implemented. The main benefit of the use of the BowTie approach for the sea urchin fishery case study is two-fold: 1) it allowed us a quick analysis of what has been done throughout the years and 2) it will support the Sinis MPA managers in the drafting and the adoption of proper management plans that take into account possible repercussions when overlooking some of the factors involved in the sustainable use of the biological resources.

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Annex 1

Fishery risk assessment (list of the main papers and documents)

INTRODUCTION

- Astles KL, Gibbs PJ, Steffe AS, Green M (2009) A qualitative risk-based assessment of impacts on marine habitats and harvested species for a data deficient wild capture fisher. Biological Conservation 142: 2759-2773.

  - Mechanics of a qualitative ecological risk assessment applied to a currently operating data deficient commercial fishery -

- Campbell ML, Gallagher C (2007) Assessing the relative effects of fishing on the New Zealand marine environment through risk analysis. ICES Journal of Marine Science 64: 256–270.

  - Using catch-effort and observer data, the likelihood that a certain fishery will impact upon five effects of fishing (EoF) issues (non-target species, biodiversity, habitat, trophic interactions, and legislated protected species) is determined -

- de Juan S, Demestre M (2012) A Trawl Disturbance Indicator to quantify large scale fishing impact on benthic ecosystems. Ecological Indicators 18: 183-190.

  - TDI was proposed as a tool for fisheries managers to assess the ecosystem health

- Freire J, García-Allut A (2000) Socioeconomic and biological causes of management failures in European artisanal "sheries: the case of Galicia (NW Spain) Marine Policy 24 375-384.

  - The present state of the artisanal coastal "sheries in Galicia (NW Spain) is analyzed, presenting different symptoms of a general state of overexploitation derived from the mismatch between management (derived from models designed for industrial "n"sheries) and the biological and socioeconomic context. We propose to modify the strategies of research to use inexpensive and rapid methodologies and introduce the "shers' ecological knowledge. A new management policy is outlined based in the establishment of territorial users' rights, the involvement of "shers in the assessment and management process, and the use of protected areas and minimum sizes as key regulation tools -

- Katsanevakis S, Stelzenmüller V, South A, Sørensen TK, Jones PJS, Kerr S, Badalamenti F, Anagnostou C, Breen P, Chust G, D'Anna G, Duijn M, Filatova T, Fiorentino F, Hulsman H, Johnson K, Karageorgis AP, Kröncke I, Mirto S, Pipitone C, Portelli S, Qiu W, Reiss H, Sakellariou D, Salomidi M, van Hoof L, Vassilopoulou V, Vega Fernández T, Vöge S, Weber A, Zenetos A, ter Hofstede R (2011) Ecosystem-based marine spatial management: Review of concepts, policies, tools, and critical issues. Ocean & Coastal Management 54: 807-820.

  - Strategies to take into account climate change effects and geohazard risks in Ecosystem based marine spatial management have been applied or proposed worldwide. EB-MSM regimes must be alert to such risks and flexible to account for changes -

- Lane DE, Stephenson RL (1998) A framework for risk analysis in fisheries decision-making. ICES Journal of Marine Science 55: 1-13.

  - On herring fishery-

- Lleonart J, Maynou F, Salat J (2013) An analysis of fishing gear competition. Catalan fisheries as case studies. Scientia Marina.

  - Asymmetric indices is to assist fisheries managers in the decision-making process to optimize the allocation of fishing effort, including energy efficiency, and to reduce environmental impact -

- Muntadas A, Demestre M, de Juan S, Frid CLJ (in press) Benthic functional changes induced by chronic trawling. ICES Journal of Marine Science.

  - Trawling and ecological functionality of benthic communities -

- Sethi SA (2010) Risk management for fisheries. Fish and Fisheriess 11: 341–365.

  - decision analysis (including multicriteria decision-making tools, and the related concept of risk assessment) & Precautionary Approach, portfolio management, financial contracts to manage price risk and horizontal integration-

- Stelzenmüller V, Ellis JR, Rogers SI (2010) Towards a spatially explicit risk assessment for marine management: Assessing the vulnerability of fish to aggregate extraction. Biological Conservation 143: 230–238.

  - Marine spatial risk assessment framework for the UK continental shelf -

- Sumner J, Ross T, Ababouch L (2004) Application of risk assessment in the fish industry. Fao Fisheries Technical paper, 22 pp.

  - "How to" package on risk assessment for seafood technologists, regulators and health professionals –

SEA URCHIN FISHERY AND MANAGEMENT

- Addis P, Secci M, Manunza A, Corrias S, Niffoi A, Cau A (2009) A geostatistical approach for the stock assessment of the edible sea urchin, *Paracentrotus lividus*, in four coastal zones of Southern and West Sardinia (SW Italy, Mediterranean Sea) Fisheries Research 100: 215-221.

  - The geostatistical approach seems to be a good estimator of P. lividus density and biomass and for the assessment of its harvestable stocks, and thus provides an initial step towards a scientific approach to the management of local sea urchin fisheries -

- Barnes DKA, Crook AC (2001) Implications of temporal and spatial variability in *Paracentrotus lividus* populations to the associated commercial coastal fishery. Hydrobiologia 465: 95-102.

  - There is a strong 'natural' and possibly predictable element to the variability in P. lividus population size and structure. For the restoration and sustainable harvest of Irish P. lividus aspects of its behavioural ecology need to be taken more closely into consideration -

- Bayed A, Quiniou F, Benrha A, Guillou M (2005) The *Paracentrotus lividus* populations from the northern Moroccan Atlantic coast: growth, reproduction and health condition Journal of Marine Biological Association of United Kingdom 85: 999-1007.

  - The growth rate of the juvenile sea urchins in this intertidal zone was low compared with more sheltered populations. A sharp increase in the gonad index was observed between January and March at the beginning of a period of algal production, and was concomitant with increases in seawater temperature and food consumption rate. This gonad index increase was followed by a single spawning period occurring between March and June, probably triggered by the phytoplankton bloom induced by upwelling conditions. Larval development in all three populations was severely inhibited and could be explained, in part, by high and generalized Cu contamination throughout the region. Specific contamination of particular populations by Pb or Hg was attributed to local industries and the incomplete dispersion of pollutants in spite of the high hydrodynamics along the Moroccan Atlantic coast. One of the three populations studied showed strong indications of abnormal development; the degradation of its condition appeared to be due to the presence of a wadi (temporary river) which can seasonally reduce the salinity, directly affecting the sea urchin physiology and indirectly enhancing the metal toxicity -

- Botsford LW, Morgan LE, Lockwood DR, Wilen JE (1999) Marine reserves and management of the northern California red sea urchin fishery. CalCOFI Rep. 40: 87-93.

  -The answer to the question of whether reserves would benefit this fishery depends on an essential uncertainty in recruitment, which we model as a parameter in a Beverton-Holt relationship between number of larvae produced and successfully settling juveniles-

- Carter SK, VanBlaricom GR (2002) Effects of experimental harvest on red sea urchins (*Strongylocentrotus franciscanus*) in northern Washington. Fishery Bulletin 100: 662-673.

  - Size-selective harvest significantly decreased sea urchin densities by 67% in the first year and by 47% in the second year. We recommend that managers consider the potential efficacy of marine harvest refuges and reevaluate the existing upper and lower size limits for commercial harvest to improve long-term management of the sea urchin fishery in Washington -

- Ceccherelli G, Pais A, Pinna S, Sechi N, Chessa LA (2011)·Human impact on *Paracentrotus lividus*: the result of harvest restrictions and accessibility of locations. Marine Biology 158:845-852.

  - There is an effect of harvest restrictions in relation to accessibility that emphasizes the need to carefully address the enforcement of the MPA toward easily accessible sites. Thus, surveillance and investment in enforcement of marine reserves seem crucial points that may provide the greatest return on maintaining the ecological benefits to the fishery activities -

- Chen Y, Hunter M (2003) Assessing the green sea urchin (*Strongylocentrotus drobachiensis*) stock in Maine, USA. Fisheries Research 60: 527-537.

  - Using the data collected from the fishery and urchin life history parameters derived from scientific studies, we conducted a formal stock assessment for the urchin stock. This study shows that the current stock is only 10% of the virgin stock biomass and that the exploitation rate is close to 40% suggesting that a large reduction in exploitation rate is necessary -

- Garmendia JM, I Menchaca, MJ Belzunce, J Franco, M Revilla (2010) Seasonal variability in gonad development in the sea urchin (*Paracentrotus lividus*) on the Basque coast (Southeastern Bay of Biscay) Marine Pollution Bulletin 61: 259–266.

  - Generally high gonad indices and a single yearly main spawning period, between April and May. Further, females show a shorter spawning period than males, becoming the limiting organisms for the availability of larvae -

- Gianguzza P, Chiantore M, Bonaviri C, Cattaneo-Vietti R, Vielmini I, Riggio S (2006) The effects of recreational *Paracentrotus lividus* fishing on distribution patterns of sea urchins at Ustica Island MPA (Western Mediterranean, Italy). Fisheries Research 81: 37-44.

  - This study evaluated the effects of recreational Paracentrotus lividus fishing on average density and size of this edible sea urchin, and itsindirect effects on Arbacia lixula on barren substrates of Ustica Island MPA -

- Grabowski RC, Windholz T, Chen Y Grabowski, R. C., & Chen, Y. (2001) Estimating exploitable stock biomass for the Maine green sea urchin (Strongylocentrotus droebachiensis) fishery using a spatial statistics approach, Fishery Bulletiin 103: 320-320–330.

  - Exploitable biomass was estimated by using two different sea urchin density threshold values, which made different assumptions about the fishing industry. We observed considerable spatial variability on both small and large scales, including large-scale patterns in sea urchin density related to depth and fishing pressure. We conclude that the TIN method provides a reasonable spatial approach for generating bio- mass estimates for a fishery unsuited to geostatistics, but we suggest further studies into uncertainty estimation and the selection of threshold density values -

- Guettaf M, San Martin GA, Francour P (2000) Interpopulation variability of the reproductive cycle of Paracentrotus lividus (Echinodermata: Echinoidea) in the south-western Mediterranean. Journal of Marine Biological Association of the United Kingdom 80: 899-907.

  - Spawning: April-June and October-December -

- Guidetti P (2004) Effects of the edible sea urchin, *Paracentrotus lividus*, fishery along the Apulian rocky coast (SE Italy, Mediterranean Sea). Fishery Research 66: 287-297.

  - P. lividus harvesting may cause reduction in average size and biomass of this echinoid because of the selective harvesting of largest specimens. Densities of P. lividus at fished and control areas, instead, did not change, which suggests that P. lividus populations subject to fishing could have the potential to recover by appropriate management policies (e.g., catch quotas)-

- Jurado-Molina J, Palleiro-Nayar JS, Gutiérrez NL (2009) Developing a Bayesian framework for stock assessment and decision analysis of the red sea urchin fishery in Baja California, Mexico. Ciencias Marinas, 35: 183-193.

  - CPUE and catch data were used to conduct a stock assessment and decision analysis for the red sea urchin stock. This study suggests that the current stock is only 17% of the virgin stock biomass and that, for a constant catch policy, a 10% increase in the current catch rate could potentially cause the collapse of the fishery in 20 years. Simulation results suggested that a constant harvest rate between 15% and 25% would cause the population to recover and maximize the catch in 2024. Higher harvest rate levels would increase the probability of the biomass being less than 40% of the population carrying capacity -

- Kanaiwaa M, Chena Y, Hunter M (2005) Assessing a stock assessment framework for the green sea urchin Strongylocentrotus drobachiensis fishery in Maine, USA.Fisheries Research 74: 96-115.

  - A Bayesian stock assessment framework with a size-structured population dynamics model used to assess the green sea urchin fishery in Maine, USA was evaluated, using a simulation approach, for its performance in describing sea urchin population dynamics under different recruitment dynamics and data quality. This study suggests that the current stock assessment model performs well in estimating key sea urchin fishery parameters such as exploitable stock biomass, total stock biomass, natural mortality, and fishing mortality under different simulation scenarios, and can capture the dynamics of the Maine sea urchin population. The recruitment dynamics of the sea urchin are likely to vary greatly with large changes occurring in its ecosystem. The finding that the current assessment framework is able to capture different patterns of recruitment dynamics implies that the current assessment framework will remain effective in future stock assessments of the Maine sea urchin fishery -

- Mahon R, Almerigi S, McConney P, Parker C, Brewster L () Participatory methodology used for sea urchin co-management in Barbados. Ocean & Coastal Management 46: 1-25.

  - Fishers involvement was developed in stages: identification of groups of fishers in communities and a contact person for the group; dialogue with individuals and the small groups; discussion in larger groups to derive approaches to management; and full group participation to reach consensus regarding the most appropriate approach to management. Key persons identified in communities helped organize meetings to discuss the sea urchin fishery. From these community meetings, individuals were selected to take part in the strategic planning. Two vision meetings with separate groups of fishers, produced similar results. These groups were combined at a planning meeting, where fishers examined the blocks to achieving the vision, developed strategies to overcome the blocks, and an action plan to implement the strategies. Fishers and government officials concluded that the methodology had

successfully facilitated the input of both parties and produced a workable, consensual approach -

- McClanahan TR, Muthiga NA, Kamukuru AT, Machano H, Kiambo RW (1999) The effects of marine parks and fishing on coral reefs of northern Tanzania. Biological Conservation 89:161-182.

  -Reduced fishing effort, elimination of destructive gear, protection of vulnerable species and i some cases sea urchin reduction could rectify the problems of overfishing-

- Ouréns R, Flores L, Fernández L, Freire J (2013) Habitat and density-dependent growth of the sea urchin *Paracentrotus lividus* in Galicia (NW Spain) Journal of Sea Research 76: 50-60.

  - The Tanaka function obtained the best fit to the data. Recruitment seems to occur mainly in shallow waters (≤4 m) and when the sea urchins reach 50 mm (approximately 4 years old) they migrate to deeper areas. The population density also influenced the growth -

- Palacín C, Turon X, Ballesteros M, Giribert G, López S (1998) Stock evaluation of three littoral echinoid species on the Catalan coast (North-Western Mediterranean). PSZN: Marine Ecology 19: 163-177

  - Useful tool for management resource -

- Pais A, Chessa LA, Serra S, Ruiu A, Meloni G, Donno Y (2007) The impact of commercial and recreational harvesting for *Paracentrotus lividus* on shallow rocky reef sea urchin communities in North-western Sardinia, Italy. Estuarine, Coastal and Shelf Science 73: 589-597.

  - The results reveal the existence of a heavy fishing impact on P. lividus in North-western Sardinia and the need for regulation of its harvesting to prevent severe direct effects on its populations -

- Perry RI, Zhanga Z, Harbo R (2002) Development of the green sea urchin (*Strongylocentrotus droebachiensis*) fishery in British Columbia, Canada — back from the brink using a precautionary framework. Fisheries Research 55: 253-266.

  - Example of how a precautionary approach was applied to avert collapse of a developing invertebrate fishery and to rebuild towards a sustainable fisher -

- Pinnegar JK, Polunin NVC, Francour P, Badalamenti F, Chemello R, Harmelin-Vivien ML, Hereu B, Milazzo M, Zabala M, D'Anna G, Pipitone C (2000) Trophic cascades in benthic marine ecosystems: lessons for fisheries and protected-area management. Environmental Conservation 27: 179-200.

  - Expansion of coralline barrens in the Mediterranean rocky-sublittoral will not be readily reversed in MPAs -

- Pinnegar JK, Polunin NVC (2004) Predicting indirect effects of fishing in Mediterranean rocky littoral communities using a dynamic simulation model. Ecological Modelling 172: 249-267.

  - The Mediterranean infralittoral rocky-bottom ecosystem was predicted to be relatively resilient to pulses of increased fishing and exhibited a high degree of detritus recycling. However, the speed and magnitude of ecosystem responses was shown to depend greatly on the extent of 'top-down' or 'bottom-up' control assumed for components within the system -

- Sánchez-España AI, Martínez-Pita I, García FJ (2004) Gonadal growth and reproduction in the commercial sea urchin *Paracentrotus lividus* (Lamarck, 1816) (Echinodermata: Echinoidea) from southern Spain. Hydrobiologia 519: 61-72.

  - The six populations exhibited similar reproductive patterns, having mature gonads during almost all months while reconstitution and spent were present mainly in autumn -

- Sellem F, Guillou M (2007) Reproductive biology of Paracentrotus lividus (Echinodermata: Echinoidea) in two contrasting habitats of northern Tunisia (south-east Mediterranean). Journal of Marine Biological Association of the United Kingdom 87: 763-767.

- Breeding period occurring between April and June. Hydro- dynamic conditions might play a key role in diverting energy to the maintenance in an exposed environment at the expense of reproduction -

- Smith MD, Wilen JE (2003) Economic impacts of marine reserves: the importance of spatial behavior. Journal of Environmental Economics and Management 46: 183-206.

  - Marine biologists have shown virtually unqualified support for managing fisheries with marine reserves, signifying a new resource management paradigm that recognizes the importance of spatial processes in exploited systems. Most modeling of reserves employs simplifying assumptions about the behavior of fishermen in response to spatial closures. We show that a realistic depiction of fishermen behavior dramatically alters the conclusions about reserves. We develop, estimate, and calibrate an integrated bioeconomic model of the sea urchin fishery in northern California and use it to simulate reserve policies. Our behavioral model shows how economic incentives determine both participation and location choices of fishermen. We compare simulations with behavioral response to biological modeling that presumes that effort is spatially uniform and unresponsive to economic incentives. We demonstrate that optimistic conclusions about reserves may be an artifact of simplifying assumptions that ignore economic behavior -

- Tomšić S, Conides A, Dupčić Radić I, Glamuzina B (2010) Growth, size class frequency and reproduction of purple sea urchin, *Paracentrotus lividus* (Lamarck, 1816) in Bistrina Bay (Adriatic Sea, Croatia). ACTA ADRIATica 51: 67 - 77.

  - Longevity:15.06 years. The gonad somatic index: peak in April -

- Turon X, Giribet G, Lopez S, Palacin C (1995) Growth and population structure of Paracentrotus lividus (Echinodermata: Echinoidea) in two contrasting habitats. Marine Ecology Progress Series 122: 193-124.

  - Different dynamics underlie both populations, the one at the unstable site being driven primarily by episodic storms, which cause high mortalities but carry new individuals to the site. The stable community relies instead on an annual settlement and features a lower and more predictable mortality which allows for the development of a well-structured population -

- Turon X, Palacin C, Ballesteros, M, Dantart L (1995) A case study of stock evaluation on littoral hard substrata: Echinoid populations on the north-east coast of Spain. Biology and ecology of shallow coastal waters, book series: Olsen & Olsen international symposium series, 333-340 pp.

  - Stock evaluation up to 10 m depth, fractal proprieties of the shore were considered

- Warner G (1997) Participatory management, popular knowledge, and community empowerment: the case of sea urchin harvesting in the Vieux-Fort Area of St. Lucia. Human ecology 25: 29-46

  - Devolution of authority lo locally based sea urchin harvesters -

- Watson M, Ormond RFG (1994) Effect of an artisanal fishery on the fish and urchin populations of a Kenyan coral reef. Marine ecology progress series 109:115-129.

  -Effectiveness of a marine park-

- Williams H (2002) Sea Urchin Fisheries of the World: A Review of Their Status, Management Strategies and Biology of the Principal Species. Report 29 pp.

NATIONAL/REGIONAL LEGISLATION (in Italian)

- Legge regionale del 7/03/1956 n. 37 recante disposizioni relative all'esercizio delle funzioni in materia di pesca
- D. Lgs. n. 154 del 26/04/2004 "Modernizzazione del setore pesca e dell'acquacoltura" e, in particolare il comma 4 dell'art. 12

- D. Lgs. n. 4 del 09/01/2012 concernente misure per il riassetto della normativa in materia di pesca e acquacoltura, a norma dell'art. 28 della legge 4 giugno 2010, n. 96 (pubblicato nella gazzetta uff. 1/02/2012 n. 26)
- D. Lgs. 26 maggio 2004 n. 153 in materia di pesca marittima;
- D. Lgs n. 193/2007 relativo al rispetto dei requisiti generali e speciali in materia d'igiene dei prodotti raccolti e/o allevati, per l'immissione sul mercato, ai fini del consumo umano, di molluschi bivalvi vivi, echinodermi, tunicati e gasteropodi marini vivi provenienti da zone di produzione classificate;
- Decreto ministeriale del 10 novembre 2011 finalizzato a dare attuazione alle disposizioni di cui al Titolo V del Reg. (CE) 1224/2009 ed al Titolo IV del Reg. (UE) 404/2011 inerenti gli adempimenti connessi agli obblighi di tracciabilità e di registrazione, nonché, gli adempimenti previsti a carico degli operatori responsabili dell'acquisto, della vendita, del magazzinaggio o del trasporto di partite di prodotti della pesca;
- Decreto del Direttore Generale della pesca marittima e dell'acquacoltura del Ministero delle Politiche Agricole Alimentari e Forestali del 28 dicembre 2011 e ss.mm.ii. relativo alle procedure e le modalità attuative degli obblighi previsti dal DM 10.11.2011 (art. 4, comma 2 e art. 5, comma 2) al fine di assicurarne la rintracciabilità dei prodotti della pesca e dell'acquacoltura;
- Decreto del Direttore Generale della pesca marittima e dell'acquacoltura del Ministero delle Politiche Agricole Alimentari e Forestali n. 174 del 29.05.2012 concernente modifiche e integrazioni al sopracitato Decreto direttoriale n. 155 del 28 dicembre 2011;
- Determinazione del Direttore del Servizio pesca del 31 ottobre 2008, n. 21573/797 che ha specificamente classificato zone di classe A, ai fini della raccolta dei ricci di mare (Paracentrotus lividus), tutte le acque marino-costiere della Sardegna ad esclusione delle aree portuali e delle zone dove sono presenti fonti di contaminazione quali foci dei fiumi, scarichi di altri corsi d'acqua, scarichi industriali, scarichi di fogne urbane, entro un raggio di 500 metri dalla foce o dal punto di immissione dello scarico;
- Legge regionale 14 aprile 2006 n. 3, concernente disposizioni in materia di pesca e, in particolare, l'art. 6 che prevede interventi per la protezione e la gestione delle risorse acquatiche;
- Decreto n. 2524/DecA/102 del 07/10/2009 "disciplina della pesca professionale subacquea nel mare territoriale prospiciente la Regione Sardegna";
- Decreto n. 2764/DecA/118 del 29.10.2009 "modifiche e integrazioni Decreto n. 2524/DecA/102 del 07/10/2009 "disciplina della pesca professionale subacquea nel mare territoriale prospiciente la Regione Sardegna";
- Decreto n. 1525/DecA/102 del 25 ottobre 2012 recante "calendario della pesca del riccio di mare (Paracentrotus lividus) per la stagione 2012/2013";
- Legge 31/12/1982 n. 979 recante disposizioni per la difesa del mare
- Legge quadro sulle aree protette 6/12/1991 n. 394 e successive modifiche e integrazioni
- Decreto del Ministero dell'Ambiente e della Tutela del Territorio e del Mare del 20/07/2011 n. 188 Regolamento recante la disciplina delle attività consentite nelle divers zone dell'AMP Penisola del Sinis - Isola di Mal di Ventre
- Proposta di Regolamento di esecuzione ed organizzazione dell'AMP Penisola del Sinis - Isola di Mal di Ventre

EUROPEAN DIRECTIVE ON CONSERVATION

- Reg. (CE) n. 2371/2002 del 20 dicembre 2002 relativo alla conservazione e allo sfruttamento sostenibile delle risorse della pesca nell'ambito della politica comune della pesca;
- Regolamento (CE) n. 852/2004, il Regolamento (CE) n. 853/2004, il Regolamento (CE) n. 854/2004 relativi al rispetto dei requisiti generali e speciali in materia d'igiene dei prodotti raccolti e/o allevati, per l'immissione sul mercato, ai fini del consumo umano, di molluschi bivalvi vivi, echinodermi, tunicati e gasteropodi marini vivi provenienti da zone di produzione classificate;
- Regolamento (CE) n. 1967/2006 del Consiglio del 21 dicembre 2006 relativo alle misure di gestione per lo sfruttamento sostenibile delle risorse della pesca nel Mar Mediterraneo e recante modifica del regolamento (CEE) n. 2847/93 e che abroga il regolamento (CE) n. 1626/94;
- Regolamento (CE) n. 1224/2009 del Consiglio del 20 novembre 2009 che istituisce un regime di controllo comunitario per garantire il rispetto delle norme della politica comune della pesca, che modifica i

regolamenti (CE) n. 847/96, (CE) n. 2371/2002, (CE) n. 811/2004, (CE) n. 768/2005, (CE) n. 2115/2005, (CE) n. 2166/2005, (CE) n. 388/2006, (CE) n. 509/2007, (CE) n. 676/2007, (CE) n. 1098/2007, (CE) n. 1300/2008, (CE) n. 1342/2008 e che abroga i regolamenti (CEE) n. 2847/93, (CE) n. 1627/94 e (CE) n. 1966/2006;

- Regolamento di esecuzione (UE) n. 404/2011 della Commissione dell'8 aprile 2011 recante modalità di applicazione del regolamento (CE) n. 1224/2009 del Consiglio che istituisce un regime di controllo comunitario per garantire il rispetto delle norme della politica comune della pesca;
- Habitat Directive (92/43/CEE)
- Regolamento UE 338/97(Convenzione di Washington del 1973)
- Barcelona Convention, 1978
- Bern Convention, 1979
- Bonn Convention, 1983
- Convention on Biological diversity, 1992