OVERVIEW[1]

This synthesis, sketched during the course of the workshop proper, was developed in the months thereafter on the basis of written contributions provided by most participants under Sophie Gourguet's coordination. Frédéric Briand edited the entire Monograph and extensively reviewed this introductory chapter. Céline Barrier was responsible for the physical production of the volume.

1. BACKGROUND

For thousands of years the marine realm has been used, shaped and exploited by our species. Examples of the most ancient marine human activities are fishing and shipping. More recently, the marine/coastal domain has been further occupied to accommodate extractive industries in the form of offshore oil platforms, wind farms and wave energy plants, and further developed for the tourism industry. The growing demand for marine resources and utilities by a rising human population is exerting unprecedented pressure on marine ecosystems, from coastal degradation to overfishing, compounded by global climatic change.

Impacts of human activities on marine biodiversity are extensively studied (CIESM 2000). However the opposite, i.e. the impacts of marine biota on human activities, are far less considered. Yet, if biodiversity is widely regarded as favorable for human activities, certain species may also negatively impact human well-being, through direct and indirect effects.

To explore this complex subject, some sixteen experts of various geographic horizons and backgrounds (marine biologists, marine economists, social scientists, fishers, etc.) were invited by the Mediterranean Science Commission (CIESM) at the Oceanographic Institute in Paris, in April 2018, with substantial representation of the CIESM committee on Coastal Systems and Policies.

In welcoming the participants (see list at the end of volume), Drs Frédéric Briand and Sophie Gourguet presented the overall background and objectives of the workshop, emphasizing the need to include a broad marine socio-ecosystem vision when considering the interferences of marine biota and human activities. Obviously, the knowledge and distinct perceptions of the various stakeholders – and in particular fishers – will be given central importance in the workshop discussions.

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[1] to be cited as :

Gourguet S., Briand F., Marçalo A., Ünal V., Liu Y., Kaiser B., Katsanevakis S., Azzurro E., Maccarone V., Hemida F., Pita P., Kafaf O., Brotons J.M., Ramos J., Decugis Ch., Luisetti T. and A. Miliou. 2018. Engaging marine scientists and fishers to share knowledge and perceptions – An overview, pp. 5 - 27 in CIESM Workshop Monograph n°50 [F. Briand, Ed.] CIESM Publisher, Monaco, 218 p.

2. MARINE LIFE / HUMAN INTERACTIONS

2.1. Significant impacts

2.1.1 Marine mammals

By definition, competition between fishers and marine mammals is a mutually disadvantageous situation. It can occur directly when the two groups share a common prey species, or when marine mammals cause damage to fishing gear during depredation (see Marçalo *et al*.; Miliou *et al*.; Brotons; in this volume). It will also occur indirectly when a local cetacean population preys on species that enter the diet of commercial fish species (Plagányi & Butterworth, 2009). Such conflicts between humans and cetaceans are an issue for many fisheries worldwide (Harwood & Croxall, 1988; Trites *et al*., 1997; Yodzis, 1998) and are difficult to handle as they confront two sides of the same coin, often with dramatic connotations. One side amplifies the food demands of a human population on the rise, which would justify increases in fishing effort and overexploitation of resources. As a consequence, conflicts with marine cetaceans multiply, as fishers are tempted to blame them for targeting the same commercial species and overexploiting marine resources. On the other hand, marine mammals are increasingly impacted by incidental bycatch and entanglement in fishing gear (Kaschner and Pauly, 2005), by persistent contaminants (Aguilar *et al*., 1999; Roditi-Elasar *et al*., 2003; Marsili *et al*., 2018; Monteiro *et al*., 2016; Zaccaroni *et al*., 2018) , acoustic pollution (Jepson *et al*., 2003; Rolland *et al*., 2012) and ship strikes (Fujiwara and Caswell, 2001; Akkaya Bas *et al*., 2017), to the point where several populations are locally endangered.

In fact more and more species are now listed as “vulnerable” and even “endangered “in the IUCN Red List. Two sides of the story persist. One concerns the fishing industry where operational interactions between marine mammals and fisheries can take a number of forms and are mostly negative, resulting in injury or death to cetaceans and/or damage to fishing gear and target fish catch to the fishers. The other relates to the expanding economic value of cetacean species not only from an eco-tourism perspective, as flourishing whale-watching businesses provide revenues and jobs to coastal economies (IWC Whale Watching Handbook, 2018), but also as providers of ecosystem services. For example, large whales are known to contribute to the resilience of ecosystems they cross, and to enhance primary productivity of surface waters by concentrating nitrogen near the surface through excretions, a process known as “the whale pump.” The enhancement of primary productivity in ocean waters is an ecosystem service, which will ultimately result in more productive fisheries. Striking the right balance between human and environmental interests through ecosystem-based management practices is a global challenge, essential to the sustainability of our seas.

For fisheries economists, bycatch is considered as a negative externality, and in many analyses, the "cost" of accidental catches is not evaluated in the fishing cost (Lent, 2015). Fishing activities suffering from dolphin depredation do not take sufficient account of the externalities generated. While technologies are developed that will help maintain dolphins away from fishing areas or fishing nets (see Brotons, this volume), one should keep in mind that there exist examples where bottlenose dolphins and fishers are engaged in a form of mutualistic interaction (see Fig. 1).

Figure 1. Complex interaction between fishermen and bottlenose dolphin *Tursiops truncatus*: in this southern Brazil lagoon, some dolphins drive the fish towards the boats and when the fishers throw their nets, they feed on the escaping fish. This behaviour is known since 1850 at least and does not result from training [photo: A. Gandolfi].

The adoption of management measures via policy or subsidies reducing dolphin bycatch or fishing gear depredations could increase the fishing cost of target species, making the seafood product less plentiful and more expensive. Putting a price on dolphin-fisheries interactions could be used to manage bycatch or damages suffered, in order to assign a limited number of bycatch quotas and/or fiscal incentives to buy deterrent equipment. This management approach should be addressed to fisheries that have bought quotas or dolphins deterrent devices. Another possible solution could be to tax the fishing landings and/or evaluate the fishing gear damages through independent observers. The double-dividend taxation could be used to support monitoring and mitigation initiatives for dolphin conservation.

Another useful instrument for mitigating dolphin-fisheries interactions is seafood ecolabelling. Such initiatives are best promoted by both public and private organizations (Ward and Phillips, 2010) to signal sustainable fishing practices and products that support the protection of dolphins. In many cases, fisheries should adopt the eco-labels to achieve a better market position as customers demand sustainable products in line with dolphin protection. In this way, ecolabelling would be used as an additional instrument to reduce marine mammal bycatch and fishing gear damages.

Competition between marine mammals and fisheries is a real problem and there is no easy solution that will be found without a conscious conservation and co-management approach, which will imply the engagement of fishers (see Maccarrone; Brotons, this volume) and will be area, fishery and species specific. As we are approaching a level of exhaustion, some solutions will require the identification and creation of marine protected areas (MPAs), especially if there is a need to limit fishing effort in particular areas or seasons. The definition of these marine protected areas would coincide with the identification of biological hotspots currently under high fishing pressure and/or high levels of cetaceans/fisheries interactions associated with a high bycatch risk.

2.1.2 Invasive species

Maritime traffic, mariculture transfers, aquarium trade and above all entries via the Suez Canal contribute to the introduction of a large number of species to the Mediterranean, most of the time unintentionally, which may displace native species and change local ecosystems (CIESM, 2002; Katsanevakis *et al*., 2013). As evidenced by the forthcoming 2nd edition of the CIESM Fish Atlas, the introduction of fish species, most of them originating from the Indo Pacific realm, has spectacularly accelerated in recent decades.

Some of the new settlers become ecologically and numerically dominant in the new environment with impacts, often negative, on biodiversity, human health, infrastructure, and ecosystem services. Other impacts, such as provision of food, creation of novel habitats or securing ecosystem processes, will be positive. Food provision through fisheries and aquaculture is the marine ecosystem service that seems most affected by alien species (Galil, 2008; Katsanevakis *et al*., 2014). This involves any of the following mechanisms (see Katsanevakis *et al*., in this volume for details):

- Algal blooms: many invasive phytoplanktonic species cause toxic blooms and incur high mortalities or reduced growth in both farmed and wild populations of fish and other invertebrates. During blooms, the production of high amounts of mucilage can also cause extensive clogging of fishing gear and aquaculture equipment.
- Degradation of important habitats: essential fish habitats that provide food, refuge and nursery grounds can be impacted; fish stocks can be substantially affected.

- Direct predation or competition: many invasive species can cause the decline of native fish stocks through intense predation or competition for resources.

- Fouling of shellfish, fishing gear and equipment: alien macroalgae and fouling invertebrates can have negative economic impacts on aquaculture and fisheries by fouling fishing gear, shellfish facilities and shellfish beds, by smothering mussels and scallops, clogging scallop dredges, interfering with harvesting, competing for space with cultured bivalves and so bring additional costs for sorting and cleaning fouled shells before marketing.

- Damage of catch and fishing gear, entanglement in nets: fishing activities can be interrupted due to massive swarms of invasive jellyfish that damage the catch, clog-fishing gear and sting fishers (Luisetti *et al.,* this volume). Certain fish, like the invasive silver-cheeked toadfish *Lagocephalus sceleratus,* attack the catch of nets or longlines and cause extensive damage to the fishing gear (Ünal and Göncüoğlu-Bodur, this volume). Significant damages from the invasive Red King Crab in Norwegian coastal fishing nets instigated the commercial fishing of the crab (Kaiser and Kourantidou, this volume).

- Disease transmission: alien species can transmit new diseases, causing increased mortality in native populations of commercially important species or in holding facilities.

There are also positive impacts. Introduced species may provide:

- New commodities: many alien species are edible, often with high market values and are targeted by fisheries. In the 1930s already, Gruvel (1936) remarked that some Erythraean fish migrants were exploited almost as soon as they entered Levantine waters with a notable economic value for markets in Palestine and Syria. Some alien species have even been introduced on purpose for aquaculture or fisheries.

- New food source for fish: some species enhance native populations of commercially important fish by providing new, important food sources.

- Biological control: some alien species benefit fisheries and aquaculture by controlling the populations of other harmful alien species, as was the case for *Beroe ovata* ultimately controlling the outbreak of *Mnemiopsis leidyi* in the Black Sea in the 1990s.

- New economic development or infrastructure in support of new commodities: instruments in the new Norwegian Red King Crab fishery range from new vessels to onshore processing rejuvenating communities (Kaiser and Kourantidou, in this volume).

Given the complexity of species interactions, the balance between positive and negative impacts is difficult to assess and stakeholders' perceptions may significantly diverge. In view of the large-scale community shifts induced by climate change in the Mediterranean and Black Seas (CIESM 2008, 2009), alien species could be advantageous overall in some area, as the south-eastern Mediterranean, by fulfilling lost ecological roles and providing novel exploitable sources for fisheries (Katsanevakis *et al*., this volume).

Converting the effects of invasive alien species into opportunities

Alien invasive species can severely impact the ecosystems in which they settle. Obviously, preventing their colonization through early detection should be favored as eradication a posteriori always proves very difficult. There might be cases, however, where the establishment of alien species can present opportunities for economic exploitation. For example, invasive jellyfish may be targeted for population control. This may take many forms, starting with the physical removal of the species which could become an opportunity if the species in question can be harvested and exported (in a dry form?) to a region where it is native and accepted as food item (for example Asia). Other opportunities for jellyfish exploitation may soon arise in medical research or cosmetic application.

New markets – A need for caution

Questions regarding how an invasion is likely to change an ecosystem require combined scientific, social scientific and stakeholder knowledge to understand the human welfare implications of the potential paths, risks and opportunities that the invasion presents. The creation of benefits from the ecological change can be expected to create more invested stakeholders and perpetuate the ecological change.

The invasive silver-cheeked toadfish *Lagocephalus sceleratus* is best known amongst the pufferfishes for its direct impacts (mostly negative) on humans. This aggressive predatory pufferfish is the most devastating and dangerous species to fish, mollusks, crustaceans as well as to humans such as commercial fishers, recreational fishers, fish consumers, divers, even people swimming in shallow waters. Since 2003, this species is now part of the Mediterranean marine ecosystem. It has been spreading across the region, posing severe health hazards as it contains tetrodotoxin (TTX), a strong neurotoxin. It causes further socio-economic impacts by damaging fishing nets, requiring extra labour and gear modification costs. For the time being, fishers seem to be the most affected group (Ünal and Göncüoğlu-Bodur, in this volume). On the other hand, there are some noteworthy utilization alternatives, particularly in the pharmaceutical-medical sector. Thus Nader *et al*. (2012) suggest assessing the economic value and potential of TTX as a pharmaceutical agent on the world market. Pufferfishes are also commonly used in aquariums worldwide, regardless of their toxicity (Corsini-Foka *et al*., 2014) Surprisingly this pufferfish also gained a symbolic "iconic" value (tattoo art, souvenir use, animated cartoon, etc.) nearly as soon as it entered the Mediterranean.

2.2. Dissemination of good practices

The issue of marine species interfering with human activities is not specific to one country or one region; it is a worldwide phenomenon. It is therefore important for stakeholders at local and international scales to exchange and disseminate their experiences of dealing with such impacts. In the context of accelerating global change, the exchange of good practices appears more and more crucial.

Marine mammals

Good practices to resolve marine mammals fishery interactions are suggested through the course of this volume, with the caveat that what is effective in a given area for certain types of fisheries, interacting with a given marine mammal species, will require adjusting to work in another area. Based on experience acquired elsewhere, modifications to commercial fishing practices should be adopted and implemented, and gear alterations suggested: for example fishers using gill nets in the Mediterranean and South Iberia who report gear or catch damage due to marine mammal interactions, could usefully switch to other fishing gears which suffer far less impacts from marine mammal interactions. Efficient implementation of the mitigation techniques proposed shall further depend on the development of a clear code of good practices that should be widely disseminated, adopted and implemented (Hamer *et al*., 2008; Ward *et al.,* 2018). In the Balearic Islands, a code of good practices minimizing marine mammals-fishery interactions was recently elaborated, but its effectiveness is hampered by the high diversity of the species and interactions involved and by cultural differences observed between sub-populations of the same dolphin species (Brotons, this volume).

While the approaches required will often be fishery specific, all solutions will rely on trustful, positive relationships between scientists, fishers and fishery managers, who should all take an active role in this process. The participation and dynamic engagement of fishermen at all stages of the management process is an essential prerequisite (see section 3 below), in order for cetacean bycatch reduction measures to be implemented successfully.

Invasive species

Early warning systems should be set up with the help of researchers to prevent invasions likely to displace fishes of high economic interest for the fisheries, with special attention to the Sicily-Tunisian biogeographic barrier that appears less and less resistant to crossing. Encouraging the participation of citizens in these initiatives can substantially contribute to early warning systems (Cardoso *et al.,* 2017) while promoting best practices and environmental awareness in the general public.

Priority should be given to the alien species having recently settled in the Mediterranean and considered so far only as a threat. The situation may evolve rapidly, once adaptation and mitigation measures are set in place and if there is evolution of consumers' tastes.

<u>MPA as a possible tool?</u>

Theory predicts that MPAs, owing to their high species richness and complexity, would provide biotic resistance to invasive species. Recent evidence (Giakoumi *et al.,* 2018) indeed illustrates that overfishing alters the ratio native : alien fishes in favour of the latter in the Mediterranean. The establishment of enforced non-fishing zones (NFZ), coupled with species-targeted removals in MPAs, would help protect the indigenous predators/competitors/parasites complex.

For instance, the well-enforced NFZ of Gökova Bay (Turkey) has seen the return of apex predators, while the harmful rabbitfish species *Siganus rivulatus* and *Siganus luridus* seem to be declining (Ünal and Kızılkaya, 2018). Clearly, such areas reduce the impacts of illegal fishing, habitat destruction and overfishing while creating healthy spillover effects in local fisheries. At this time, NFZs account for less than 1% of the total area of the Mediterranean Sea, but examples are growing (See Pita *et al.*, this volume) of fishers engaging in the design of new MPAs. Since many small-scale MPAs, especially in the Mediterranean, have been overwhelmed by invasive species (Galil *et al.*, 2017), enforced non fishing measures are urgently needed.

Law enforcement (illegal practices)

Illegal exploitation of fisheries worldwide (IUU[2]) severely threatens the sustainability of marine living resources, leading to ecological, economic, social and political unbalances in many coastal regions. For the last 50 years and with the upgrade of fleets worldwide, fishermen now harvest far more than is ecologically or socially optimal. Global fish stocks are under pressure: according to the FAO, as of 2013 almost 90% of global fish stocks were being fully or over-exploited, including 31.4% estimated as overfished, 58.1% as fully fished and 10.5% as underfished. In order to address overfishing and over-capacity, management authorities have introduced a wide range of regulations, including gear, effort or area restrictions, landing taxes, harvest quotas, minimum sizes and by-catch regulations, as well as mechanisms for the monitoring and control of fisheries practices. Yet law enforcement in fisheries is often immediately perceived by fishermen as lacking moderation or unfair. This is related to the fact that a fishery is a typical example of a common property resource that must be shared amongst a variety of stakeholders, which in turn requires shared governance.

In many cases, illegal or destructive fishery practices are not conducted by an individual fisherman, but by a collective entity, driven by social, market/ economic demands (e.g. from harvest to processing entities, a supply chain all the way to the consumer level). However, fishermen as primary stakeholders are the first to face regulatory obligations. At the same time, fishermen should be aware that these laws are created to provide recommendations for best resource exploitation and habitat protection based on scientific evidence. Thus co-management including several levels of stakeholders is crucial at this stage (see below).

Limitations to enforce law at sea from responsible authorities arise from the lack of money to monitor and patrol huge fleets over such a vast expanse of water. An optimal solution for this problem could be fishermen endorsing a primary role in protecting the marine resources and environments they exploit, by self-complying and reporting violations to agencies.

Harmonization between countries on management practices

The need for international cooperation in the fisheries sector is urgent and crucial, in order to improve management and provide lasting protection for marine resources. Given that the definition of illegal practices varies from country to country and the widespread variation in how states criminalize the different infractions, neighbouring countries have every interest to participate in summits in order to reach lasting agreements.

[2] Illegal, Unreported and Unregulated fishing

3. MEDITERRANEAN FISHERY COOPERATIVES – A LONG TRADITION

There is a diverse, long history of self-governance by fishers in the Mediterranean Basin, which goes back to the Middle Ages. Fishery cooperatives can be excellent forums to promote sustainable co-management participatory approaches and best practices across comparable regions. Our meeting was informed of, and discussed three specific examples:

3.1. Fishery 'Prud'homies' in the French Mediterranean

Since the 15th century, the management of fisheries in French Mediterranean coastal waters has been left to the responsibility of 33 prud'homies (see Fig. 2). These institutions find their origin in the corporations of the Middle Ages and have shown remarkable resilience.

Prud'homies are communities of artisanal fishermen owners ('patrons pêcheurs'). Born on the French coast of Provence in the Middle Ages, they succeeded in adapting to changes in political regimes – even surviving the French Revolution - under supervision of central authorities.

Figure 2. Localisation of "prud'homies" on the French Mediterranean coast.

The prud'hommes are experienced fishermen, elected by their peers every three years. They have regulatory, judicial and disciplinary power on their respective territory where their mission is to manage the fishing effort and ensure the sustainability of fishery resources.

A guiding prud'homal principle is that every fisher must be able to live by his specialized trade. Therefore prud'homies will prevent a given technique to fully outcompete the others and will keep overfished areas and species off limit to allow them to recover. They will encourage fishermen to diversify via the use of artisanal techniques rather than to intensify their modes of capture.

Today in decline, prud'homies deserve to be revisited and reinforced, as their ancestral mode of negotiated management appears surprisingly modern and may provide local answers to the challenge of global declining resources (Rézenthel, 1983).

3.2. Fishery 'Cofradies' in the Balearic Islands

Fishing is as ancient as man in the Balearic Islands, but it is with Pliny the Elder, under Roman rule, that we find the first references. Archives from the Middle Ages indicate that the College of the Honorable Fishermen of San Pedro was already established in Majorca in the thirteenth century.
Today "cofradíes" in the Balearic Islands are non-profit public corporations, acting as bodies of consultation and collaboration with public administrations in order to represent and promote the economic interests of fishers.

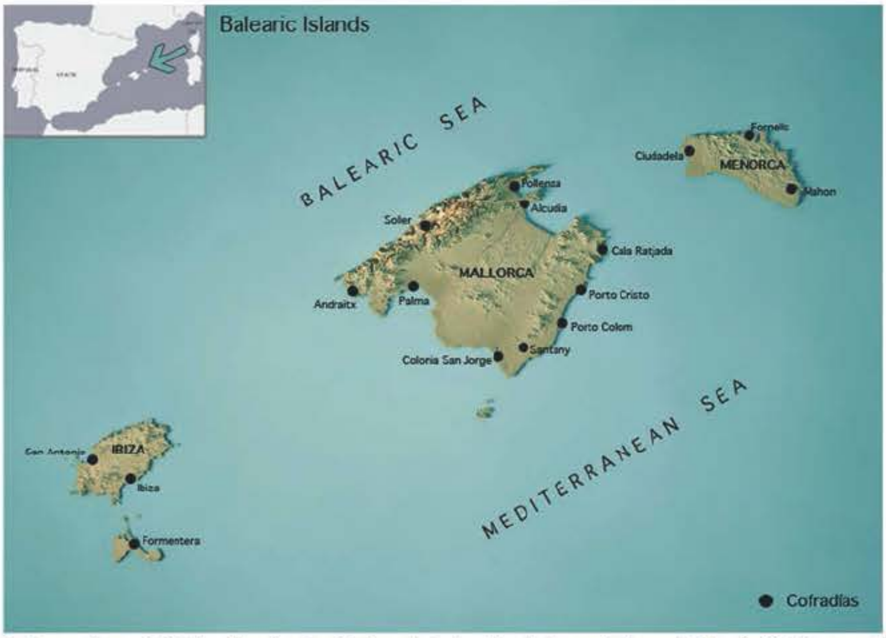

Figure 3. Location of Cofradies in the Balearic Islands. Adapted from Llabrés & Martorell, 1984.

Today we find a total of 16 "cofradies" (see Fig. 3): three in Menorca (Ciutadella, Fornells and Maò), ten in Mallorca (Pollensa, Alcúdia, Cala Rajada, Porto Cristo, Porto Colom, Santany, Colònia de Sant Jordi, Palma, Andratx and Sòller), two in Ibiza (Sant Antoni, Eivissa) and one in Formentera.

Membership in a "Cofradía" is limited to the owners of a fishing boat at a port in the Balearic Islands and to the employees of the extractive sector in the Balearic Islands. Among the main functions of the "Cofradíes" one finds: 1) acting as advisory bodies of the competent public administrations; 2) providing services to its members and representing their interests; 3) managing the inherited resources; 4) representing the fisheries sector to governments and other public or private entities (Llabrés and Martorell, 1984).

All "Cofradíes" of the Balearic Islands are united in a single Federation for a more efficient organization.

3.3. Fishery Cooperatives in Turkey

The roots of cooperative activity in Turkey actually go back to the 12th century *Ahi* movement. The first fishery cooperative, though, was founded much later, in Istanbul, on 11 February 1943, eight decades after the establishment of the first cooperative movement in Turkey by Mithat Paşa (Ünal *et al.*, 2009). The president of the time became the first member of this cooperative in order to encourage organization among fishers. Another noteworthy development was the 1961 Constitution with the provision "The government takes the necessary steps to support and develop cooperative enterprises".

With the implementation of five-year nation-wide development plans, fishery cooperatives started gaining support. In particular the 3rd Development Plan (1973-1977) influenced the foundation and increase of a number of fishery cooperatives, thanks to provisions giving them opportunities to manage or own marketing and canning facilities. In 1965, the number of fishery cooperatives was 36; it had reached 413 in 2005.

After fishery cooperatives were given the rights to hire and run fishing ports, fishery cooperatives further increased and developed into a "three-tier system" of vertical organization : i) 270 primary cooperatives; ii) 15 region-based associations; and iii) one central union.

Despite chronic problems, fishery cooperatives in Turkey are now strong organizations, which embrace thousands of fishers, organize symposiums, panels, workshops, and have the power to influence decisions related to fisheries management. Today, many fishery cooperatives successfully promote their members' products, providing relatively cheaper input, helping with their legal procedures, representing them on related platforms and carry effective lobbying activities. And some of them (e.g. the Akyaka primary fishery cooperative) now play vital roles in the preservation of fishing resources and areas, the establishment of no-fishing zones, fighting illegal fishing or preparing local fishery management plans (as for Gökova Bay small-scale fisheries).

4. STAKEHOLDERS - ROLES, PERCEPTIONS AND POWER IN A COMPLEX WORLD

To set effective management practices, stakeholders have to be actively included in the decision process. It is therefore very important to take into account their knowledge and perceptions. Indeed, experience has taught us that the best fishing plans were those in which co-management prevailed over the classic top-down strategy (Pinkerton, 2011). Active engagement of fishers in management process will help build relationships between decision makers, other stakeholders and fishers, and yield long-term benefits to fisheries management. However, that is not an easy process, especially considering the following questions: who should be involved, why and how?

4.1. Stakeholders' identification and engagement

The sustainable development of society can be achieved only if we are able to generate "win-win" situations, in which social, economic and environmental needs will be simultaneously satisfied. Citizens and stakeholders' involvement at the local level is crucial. One of the most important drivers of better stakeholder governance is represented by the strengthening of stakeholders' involvement in the decision-making processes. In the past, however, the dialogue with stakeholders was seen more as an obstacle to achieving the goals of the organization. Today in the management activities, the stakeholder involvement plays a crucial role in the processes of strategic organization aimed to achieve the medium and long term objectives. Dialogue with stakeholders also wards off the crises of the parties involved, improving not only the decision-making processes but also the efficiency of the implementation strategy.

The crucial first steps, as detailed in Ramos (this volume), are to properly identify and engage the stakeholders (see Fig. 4). A useful diagram at this stage will combine the influence and the level of interest of each stakeholder, distinguishing between those in favour of the initiative (pro), those opposing it (against) and those not totally involved (ambivalent). It is important to seek different viewpoints, as a crucial part of the stakeholder management process will be to influence stakeholders and try to move them from opposition to support.

The involvement and participation in the management process does not just mean "to inform more" but concerns the collection of opinions and information from different points of view. Obviously, a fisherman does not know more about stock assessment than a fishery biologist. A participatory process always means cooperation and dialogue among persons with different skills. The fisherman will give a valuable and strong contribution to how a management plan works seasonally, while the coastal manager will have a technical vision of the marine ecosystem and legislation. In many cases one will be surprised to find out how fishermen and other actors take seriously the responsibility entrusted to them by a participatory process.

Very often consultations may be opened to the public, as in the case of coastal management plans or in cases where an eco-tourism plan of the area is to be implemented. In other cases, consultations will be limited to specific stakeholders as in the case of mining activities at sea or fisheries management plans. The tools available for stakeholder consultation are multiple, ranging from roundtable discussions, workshops, conferences, interviews to on-line discussion forums. In every case, all interested stakeholders should be invited to participate in the ongoing planning and review process.

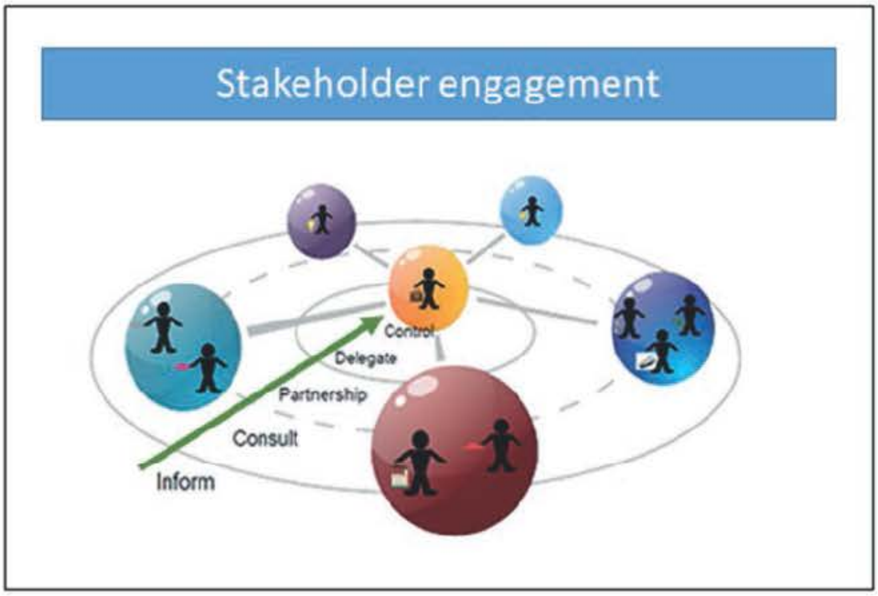

Figure 4. Bottom up engagement of stakeholders during the identification, planning and monitoring stages (Adapted from Meffe *et al.*, 2012).

The effectiveness of environmental policies is partly subordinated to the ability of increasing the stakeholders' awareness. Very often, the resistance encountered is due to poor knowledge of the problem, unawareness of the consequences of the choices and/or to cultural obstacles. For a proactive contribution to environmental management plans from each actor, it is necessary not only to set up an effective communication system, but also to improve and verify the increase in knowledge and awareness of the problem by using participatory tools such as the Fisheries Local Action Group (FLAG) (Linke and Bruckmeier, 2015).

New governance regimes, such as community-based management and co-management that have the potential to address community development as an integral part of fishery resource management and increased use of local fishery knowledge, are recommended.

Experience shows that the development of institutions for self-governance requires time in the order of ten years. In Alanya, on the Mediterranean coast of Turkey, the local coastal fishery developed rules for resource allocation and conflict reduction, which made use of rotating turns at fishing sites. This development took 10 to 15 years, without government support or any other institution-building intervention (Berkes, 1986).

4.2 Perceptions and filters

Whose values should be taken into consideration for environmental decision-making? At the beginning of the new millennium, there was already much debate on what and who determine the value of nature. The anthropocentric value perspective - the one that is used to value the goods and benefits provided by ecosystems - exists when it is a human valuer who assigns a value to nature. Thus natural ecological processes become "services" only if humans utilise them either actively or passively (Fisher *et al.,* 2009). However, different stakeholders can perceive different benefits from the same ecosystem processes, which can also be conflicting benefits. That is the case of the carbon sequestration and storage service by forests, for example, which provide essential climate regulation at the global level. That is hardly perceived by the public, which finds it beneficial to harvest the forest as fuel wood. In fact, Turner *et al*. (2003) warn against the use of economic valuation for nature when there is uncertainty surrounding the natural functions and processes, and therefore ignorance around the welfare consequences of ecosystem degradation or collapse.

In the marine environment, stakeholders, either primary (mostly fishermen), secondary (managers, decision makers, regulators) or external (fish consumers, scientists, media, general public) face complex challenges. The human condition by nature is averse to newness, because it breaks daily routines. Cultural backgrounds (Kafaf, this volume) and geographies (Kaiser and Kourantidou, this volume) may be also averse to changes. Take for example the growing numbers of alien species: stakeholders perception at first is that alien species – particularly if they are invasive – only bring problems and are a burden that offers no opportunities (Katsanevakis and Rilov, this volume). Yet, stakeholder perception may evolve, depending on how the problem has been faced and overcome. For example, since the pufferfish *Lagocephalus sceleratus* was first recorded in the Mediterranean in the early 1930s, a love/hate affair developed between the public in general and this species (see Fig. 5).

Fishers were affected negatively by this species (gear damage, predation of valuable fish, toxicity, low potential as a protein source) whereas the economic value of the species increased in the "souvenir industry" and in the pharmacology sector (Ünal and Göncüoğlu-Bodur, this volume).

Figure 5. Poster illustrating the adverse impacts and associated economic losses linked to the arrival of *Lagocephalus sceleratus*. From Ünal and Göncüoğlu-Bodur, in this volume.

The concept of ecosystem services highlights the connection between science and society (Liu *et al*., 2010). It is a normative concept (i.e., value-laden), also called a 'stakeholder-driven' concept (Jax *et al*., 2013) since the value of ecosystem services is greatly influenced by the uses, needs, views and perceptions of the stakeholders who have an interest in resources and/or depend on ecosystems for their livelihood and well-being. The latter have a better understanding of the resource services and an urgent need of preserving them from anthropogenic pressures, even in the absence of a well-functioning market. Dependent on stakeholders' preferences and involvement, some ecosystem services will be considered as a source of benefits or losses (cost). In the case of jellyfish blooms, some consider that jellyfish can generate incomes for those who exploit it as a valuable resource, while others see jellyfish only as a 'pest' that generates costs for those who suffer from jellyfish blooming, like the *Periphylla* case on the Norwegian coast (see Liu, this volume). It is important therefore to take stakeholders' needs, preferences, views and perceptions into account and to execute management plans with a bottom-up approach. In particular, stakeholder-based approaches are important instruments to achieve multiple objectives and to evaluate different management strategies. The analysis of stakeholders preferences and perceptions will help in increasing the social acceptance and sustainability of the decisions (Paletto *et al*., 2014), and in making management legitimate.

Stakeholders have different social-cultural values that are driven by their tradition, culture and beliefs, knowledge of the resources, attachment to the ecosystem, their interaction with nature, etc. A good example is whale and seal hunting. Hunting whales and seals is a tradition that carries socio-cultural value for Faroe Islanders and Greenlanders, for Arctic First Nations, but for the rest of the world, hunting these animals is considered against nature, even 'criminal' and should be totally forbidden. The values of ecosystem services are based on distinct socio-ecological systems, but social-cultural values have in turn affected resources and ecosystem services.

Consumer perceptions and reactions are widely impacted by diverse factors. In the forefront is culture, but other social aspects (e.g. the consumer' personal characteristics and surrounding environment, lifestyle, views on fashion and healthy food) will be also influential (Can *et al*., 2015). Together, these factors define what consumers perceive as important, shape their gastronomic preferences and define their purchasing behaviour. In the cultures of numerous human populations, seafood occupies a central position, making it not only an essential food component but also something that serves to define social, ceremonial and religious identities. For others, seafood has no part in the food habits, as it is not accepted in their culture. The occurrence of alien/invasive species poses new challenges. On the supply side, fishermen start to catch fish that they were not used to and they have to find an outlet for their catch (Hemida and Capapé, this volume). The initial doubt relates to the eventual acceptability of these new fish species. On the demand side, consumers seek species which they are used to, and if new species do appear, consumers may not be willing to try them out – also due to concerns about their possible toxicity.

4.3. Empowerment of fishers

As primary users of the resource, small-scale fishers are among the first victims of adversities such as climate change, invasive species, overfishing, illegal fishing, mismanagement and marine pollution. Given the circumstance one may expect them to take on a substantial role in combatting the above; but in reality the situation is rarely so. Often held responsible for the predicament fisheries are in, fishers mostly do their job: they fish. They may know the sea, fishing and fish dynamics better than anyone, yet the role they play in fisheries management is either null or insignificant in most countries. In other words, whilst fishers do the fishing, others manage the fisheries. But the concept of co-management is gaining prominence. Fishers spend their days at sea fishing. They have done this every day for years-some, even for generations. There is a growing recognition that they have accumulated an enormous amount of experience and knowledge. In our chaotic environment, it appears unwise to manage the resource and seek solutions to problems - both acute and chronic - without benefiting from their traditional and hands-on ecological knowledge and lore.

4.4. Accessing fishers' knowledge

We need reliable, relevant, accurate and timely data to improve the baseline information supporting decision making. As scientific surveys are often made in summer - the most comfortable period to be in the field – many gaps remain on the marine resources ecology in the other seasons. Most fishers spend many years performing direct continuous observations within small local fishing areas (Fisher, 2000), "sampling" marine resources (García-Quijano, 2009), and discussing the marine "ecosystem" and species on a daily basis (García-Quijano and Pizzini, 2015). They also possess a wealth of knowledge about marine resources which could never be gained in a classroom or by statistical analysis, including migration patterns, spawning behavior and areas, the stock structure, abundance and historical change (Begossi, 2015). From this perspective, the fishers' role has to expand from just providing data on the catch to sharing their knowledge and observations while providing sound advice on fisheries resource and management. Acknowledging each other's knowledge and competence coupled with an effective cooperation is no longer just an option but a necessity. Involving fishers and using their knowledge now appears indispensable to create sustainable fisheries, protect stocks and their habitats. Their collaboration (particularly in the case of "data poor" fisheries) with university and government scientists would allow mapping habitats, producing more robust stock assessments, help improving the survey design, implementation and data analysis as well as swapping vessels and gears (Stanley and Ric, 2003). In return, fishers would increase their knowledge of the oceanographic environment and marine biodiversity, feel empowered and involved.

Fishers' knowledge (FK), Fishers' ecological knowledge (FEK), or, more broadly, the local Ecological Knowledge (LEK) of expert people, can be collected in varied ways and under several formats, from the extractive methods (oral, textual or digital) to collaborative approaches. The sensitivity of the data and the access level to the fishers' knowledge will depend upon the method adopted. For many years, fisheries authorities indirectly extracted basic FK (i.e. on catch, fishing effort and fishing grounds) through the Logbook programs, the catch database, and recently VMS records. Yet, the most recent studies confirm that, globally, the catches are vastly under reported (Pauly & Zeller, 2016), that the data on fishing effort and fishing practices do not reflect what is really caught on the water, and that many fisheries are not-assessed due to a crucial lack of data. The likely cause is mainly a failure of state scientists / managers to establish the necessary trust with the local fishers. Indeed field experiences with fishermen reveal a broad scepticism toward the ulterior motives of the traditional printed questionnaires and a rejection of the traditional (mainly top-down) mode of interaction between the fishers and the interviewers (Kafaf, this volume). As a result, the fishermen respond as briefly and superficially as possible.

Under increasing pressure from environmental change and the high demand for field observations, a growing number of researchers and agencies are promoting the integration of scientific *with* 'local' knowledge. Indeed, accessing the knowledge of people living in intimate relation with the natural environment has become a feature in a number of sectors such as forest conservation (e.g. Charnley *et al*., 2007), wildlife management (Milupi *et al*., 2017) and fisheries (Johannes, 1998; Neis *et al*., 1999; Azzurro in this volume).

Accessing the knowledge of local communities will include different methods such as semi-structured interviews; focus-group discussions; ranking and scoring captures and perceived abundances; participatory mapping; and diagramming techniques (see Azzurro, this volume). Participatory mapping is, for instance, a powerful tool to use in LEK research and is often a good technique to start with, as it involves several people and can stimulate much discussion and enthusiasm (see Pita *et al.,* 2016).

Although time consuming, open-ended interviews and conversations appear as most appropriate to get access to sensitive data such as the fishing grounds, the fishers' incomes and illegal practices (see Fig. 6.). Such questions should never be asked in the beginning but throughout the conversation. The interviewer earns the fishers' confidence when s/he is introduced by one or more local fishers, thus appearing independent from the fishing authority and when the language is not too technical (see Kafaf in this volume). Structured data elicitation techniques are further considered the most suitable to reveal patterns about the way fishers think about their resources and their environment (Orensanz *et al*., 2015). In general, all forms of partnership, based on an effective communication between scientists and fishermen will consolidate trust and provide a channel to exchange knowledge: as soon as scientists concretely acknowledge the fishers' value, they create opportunities for constructive dialogue and discussions, reinforce effective engagement and promote sharing perceptions, information and data. From this perspective, participative and collaborative research, assessment and even management could provide wide access to FEK.

Figure 6. Moroccan official scientist interviewing a fisherman [photo credit INRH].

In the collaborative approach the fishermen are involved in developing the research question and objectives, in designing and executing the research program as well as in the data collection. Their contribution is not passive, which makes them motivated and engaged. In this way, FEK is not only shared and directly applied, but also gets developed (Yochum *et al*., 2011). Moreover, the collaborative research will improve communication and enhance trust between stakeholders (Feeney *et al*., 2010), hence minimizing the suspicions and controversies that too often block access to fishers' knowledge.

Participatory monitoring programs are also a valuable tool in acquiring fishers' knowledge and generating information about fisheries and/or marine resources. This approach is gaining momentum as many case studies show encouraging results (Azzurro *et al.,* 2011; Dias *et al*., 2015). It carries long-term objectives and seeks to provide data on a continuous basis. The data are generally submitted by fishermen voluntarily involved in a partnership program with fishers' associations and scientists (whether national or independent). In certain participatory monitoring programs the fishers are considered as "experts", so they are encouraged to participate to the analysis and discussion of the results, which enhances access to, and use of, fishers' knowledge.

Considering the extreme variability of both social and ecological settings, methods for gathering data should at the same time fit the research circumstances, meet the needs of scientists and respect the attitudes of local communities. In other words, researchers must consider not only their research objectives but also the cultural contexts in which the interactions take place (Briggs, 1986). It is important that they are good listeners and also capable to critically review all the information. The core method of researching FEK is often a semi-structured interview. The interviewer introduces a topic using an open-ended question such as: 'What species have disappeared in the last decades?" This allows the respondents to spontaneously identify species, provide direction to the interview and describe problems in their own terms.

Not all persons within a local setting will have the same knowledge, and so one of the essential aspects in accessing LEK concerns the means by which local experts are identified (Davis and Wagner, 2003). It is therefore vital to design and conduct LEK research with a rigorous thinking and maintain high standards of accountability. Azzurro (this volume) distinguishes three different aspects, which largely contribute to the reliability of LEK exploration regarding marine species: *i*) the characteristics of the target taxa; *ii*) the characteristics of the population interviewed and; *iii*) the questions of researchers. Fishermen are one of the best group of informants on the distribution and abundance of marine resources. It is nonetheless advisable to select people who together form a homogeneous subject, which can prove challenging, as in the case of small-scale Mediterranean fishery which is typically characterized by a great variety of techniques and traditions. Other relevant groups, such as recreational divers, may be considered as a potential target group provided they dedicate much time to their field activities. In any case, it is advisable to ensure that persons considered less knowledgeable are not mistaken as local experts.

Another important rule is to have a respect and a genuine interest in learning from the diverse stakeholders and follow ethical principles in conducting the research, so that community and individual rights are respected. Last but not least, every survey should respect the local legislation on privacy matters. It is therefore suggested to guarantee anonymity and clearly state the objectives of the research at the beginning of the interview. Such interactions are empirical, practical and underscore why LEK has become a significant touchstone in recent years.

4.5 FEK and intellectual property [3]

The valorization of LEK in different sectors, as an alternative to the exclusive use of "Western scientific knowledge", has been favored in recent decades by the recommendations of the UN Rio Summit in 1992, by the Convention on Biodiversity in 1993, and by the efforts of international institutions such as Unesco and FAO (Unesco, 2017). Lately IPBES - the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services - proposed the concept of "nature's contributions to people", which recognizes the fundamental role that culture (and thus LEK) plays in defining the links between people and nature (Pascual *et al*., 2017; Díaz *et al*., 2018).

In fact many national initiatives based in the collection and use of LEK have been lately put into force throughout the world, bringing to light issues concerning intellectual property rights of LEK-based goods (Davis and Wagner, 2003). In this sense, despite growing recognition of the right of local communities to be rewarded by the companies who tapped their knowledge, LEK is difficult to protect under intellectual property rights regulations because in many cases it is a collective knowledge and lacks novelty properties. In addition, the *ex-situ* storing of LEK is meaningless for the proprietary communities because this knowledge only makes sense in a social context as part of a social activity (Agrawal, 1995; Maurstad, 2002). Furthermore, intellectual property regulations promote liberalization of protected goods and services after some time, which poses additional problems for local communities because they will eventually face the loss of their exclusive rights over part of their culture in the future. Under this scenario, the incorporation of FEK into the management of common pool resources - beyond the technical difficulties derived from its collection, systematization and adaptation to the standards of scientific knowledge - raises issues related to confidentiality and ownership of the results. Thus, beyond the need for obtaining informed consent from the fishers, the other parties (researchers, managers and policy-makers), should be aware that their respective positions regarding the publishing and publicizing of the results may greatly differ. For fishers it is often important to keep things confidential; for scientists the value of the results increases as their paper is published in international journals and cited by other scientists, while coastal or fisheries managers can claim the property of the results and develop public policies with sometimes undesired implications for the fishers themselves. Consequently, the lack of

[3] this subsection was enriched by A. Garcia Allut and S. Villasante, who co-authored a chapter in this volume.

attention to the different agendas of the actors involved can negatively affect the fishers who shared their knowledge, time and money (Silver and Campbell, 2005) and damage future collaborative initiatives (Jacobsen *et al*., 2012).

Another question to consider is the ultimate ownership of FEK: is it individual (anecdotal), or collective? And who will benefit, or be negatively affected if it is used in management, or just openly shared? These are critical questions that need attention in the sense that all the interested parties are fully represented in the initiative from the beginning. Scientists and policy-makers must be aware that fishers are more than just information providers: they should be active at the decision table; they should have a voice (and vote) on how to use their knowledge and how to participate in the derived management decisions.

Box 1. Practical Workshop recommendations

- Enhance exchanges between fishers, scientists and decision makers
- Production of a common scientific/stakeholder (e.g. fishers) glossary
- Develop joint fishers/scientific networks
- Encourage/ promote cross-training and good practices of fishers in different locations
- Promote communication (video where fishermen discuss their life, experience, etc.), with back up and advice from scientists
- Favor bottom-up co-governance design in marine spatial planning as a co-governance tool
- Promote good practices through festivals or through workshops for the exchange of experience between different countries
- Engage marine stakeholders more broadly, in particular young generations (Youtube, social media, etc.)
- Develop early warning systems for invasive alien species and promote participation of civil society
- Promote the potential utilization and commercial exploitation of invasive species in collaboration with fishers' associations
- Develop schemes where fishers are able to have an advisory role in the law enforcement process to combat IUU

Concluding remarks: communication gaps

We have reached a point where we really need scientists, fishers and managers to work closely together and develop trusting relations in order to understand each other. Issues, such as preserving of marine biodiversity or combatting global changes and effects of alien species at local, regional and global scales, lay a responsibility on scientists and decision makers to cooperate and understand each other. Yet they seem to live and act in completely separate worlds. They ponder on the same issues but cannot (maybe do not want to) speak the language of the other (see more in Briand, 2012). Sustainable maritime practices will be achieved only through the engagement of all parties.

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Assessing the bio-economic impacts of marine biodiversity on commercial fisheries and aquaculture

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Introduction

Globally, human activities have been shown to negatively impact biodiversity. Consequently, many studies focus on negative impacts of human activities on ecosystems (Figure 1). In the marine realm, studies of the negative impacts of human activities on marine biodiversity have in particular focused on overfishing of species, pollution, eutrophication, and organic waste flows into oceans, as well as on the cumulative impacts of these on the structure and functioning of ecosystems. Studies have also focused on the positive effects of biodiversity for human wellbeing, and the implied losses associated with the degradation of ecosystems due to anthropic pressure. Interactions between biodiversity and human activities are often studied through the ecosystem services approach. To cite to the Millennium Ecosystem Assessment (2003:43): "Biodiversity is the source of many ecosystem goods, such as food and genetic resources, and changes in biodiversity can influence the supply of ecosystem services". Therefore biodiversity is widely considered as presumably good for human activities. However, biodiversity may also negatively impact human well-being, through the direct and indirect impacts of ecosystem functions on human activities and wellbeing. These effects are called ecosystem disservices (Lyytimäki *et al*., 2008; von Döhren and Hasse, 2015). Perceived ecosystem disservices may be observed in both high and low-diversity contexts across different types of socio-ecosystems. Contrary to ecosystem services, these disservices are not always described, studied or even addressed. An implication is that the evaluation of alternative ecosystem states does not always fully address the implied trade-offs for different social groups.

In marine socio-ecosystems, negative interactions between marine biodiversity and human activities are numerous. In this paper, we seek to provide some examples of the current state of bio-economic research regarding these interactions, with a focus on the negative impacts of marine biodiversity on marine capture fisheries and aquaculture, from a bio-economic perspective. The emergence of the ecosystem approach to fisheries has been a step forward to taking into account interactions within marine socio-ecosystems (FAO, 2003; Garcia *et al*., 2003). While the impacts of fisheries and aquaculture on marine biodiversity have been increasingly well studied and assessed (e.g. impacts of trawling; Jennings *et al*., 2001; O'Neill and Ivanović, 2016), the negative impacts of marine biodiversity on fisheries and aquaculture are much less documented and even acknowledged (Fig. 1). Neglecting these interactions in our understanding of the drivers and consequences of change in marine ecosystems can lead to unintended consequences and undermine management objectives (Abbott and Haynie, 2012).

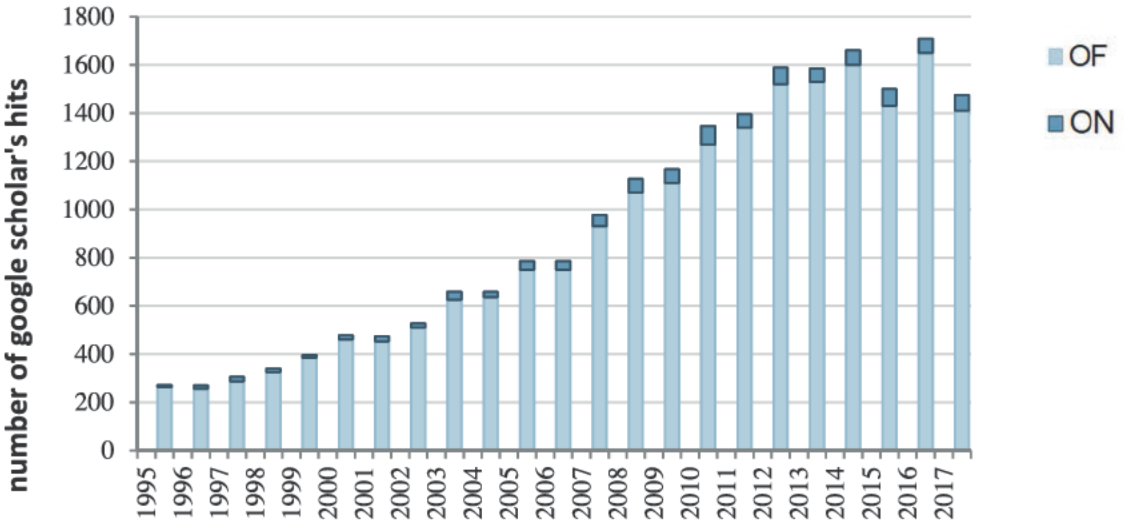

Figure 1. Impacts of human activities versus impacts on human activities in the marine scientific literature. "OF" corresponds to the query: "impacts of human activities" OR "impact of human activities" OR "effects of human activities" OR "effect of human activities"; and "ON" to the query: "impacts on human activities" OR "impact on human activities" OR "effects on human activities" OR "effect on human activities". To focus on marine scientific literature the word "marine" has been added to the queries. Source: Google scholar, on 30/03/2018.

Biodiversity impacts on fisheries and aquaculture: a typology

Various categories of negative impacts of marine biodiversity on marine fisheries and aquaculture can be distinguished. In what follows, we distinguish impacts relating to (i) biological interactions, (ii) operational interactions, (iii) toxicity or (iv) social acceptability.

<u>Biological interactions</u>

Biological interactions relate to the indirect effects of competition between marine biodiversity and human activities. Such competition can be due to either spatial or trophic processes, marine species competing with harvested resources for both habitat (e.g. the invasive species slipper limpet *Crepidula fornicata* competition for space with scallops, Frésard & Ropars-Collet, 2014), or food (e.g. slipper limpet increasing competition for food between benthic species, Stiger-Pouvreau & Thouzeau, 2015; or seabird-fisheries interactions, Doucette *et al*., 2011). Both forms of competition lead to reduced abundance of target resources for fisheries and/or aquaculture activities, and therefore to reduced economic returns with potential social consequences.A particular case in point - marine mammals conservation around the world - has led to the recovery of some marine mammal populations in certain regions of the globe (Magera *et al*., 2013), but it has also generated new challenges for managing marine socio-ecosystems (Marshall *et al*., 2015; Smith *et al*., 2015; Chasco *et al*, 2017). In some instances, the increasing abundances of marine mammals and the associated increasing consumption of fish prey can result in conflicts between marine mammals and fisheries through competitive interactions. The potential impacts of marine mammal predators on other species in the food web include: reduced recovery of forage fish (Surma and Pitcher, 2015), increased competition between marine mammal species that share the same prey (Marshall *et al*., 2015), and increased direct competition between marine mammal populations and fisheries (Gerber *et al*., 2009).

An illustrative example of the complexity of addressing these types of conflicts is that of the competitive interactions between marine mammals and Chinook salmon (*Oncorhynchus tshawytscha*) fisheries in the northeastern Pacific (Chasco *et al*., 2017). The recovery of marine mammal populations in this region has been viewed as a success. However, the increased abundance of protected harbor seals (*Phoca vitulina*) and Steller sea lions (*Eumetopias jubatus*) is now adversely affecting the recovery of endangered Chinook salmon and killer whales (*Orcinus orca*). Populations of harbor seals and sea lions have increased greatly since the 1970s as a result of being protected under the US Marine Mammal Protection Act. Chasco *et al*. (2017) estimate that the annual biomass of Chinook salmon consumed by harbor seals and sea lions has almost been multiplied by ten between 1970 and 2015. While harvest of Chinook salmon has long provided cultural and economic value for tribal, recreational, and commercial fisheries, these fisheries have dramatically shrunk in size over the last three decades. Many populations of wild Chinook salmon in the Northeast of the US have been decimated (Gustafson *et al*., 2007) and most of the remaining populations are at historically low levels and are protected under the US Endangered Species Act (Ford, 2011). As part of a large salmon recovery plan, hundreds of millions of dollars are spent annually on salmon habitat restoration (NPCC, 2017). Despite these efforts, Chinook salmon populations in the region remain in peril. In the meantime, southern resident killer whales, which are iconic animals of great value for wildlife tourism in the region, are also listed as endangered under the US Endandered Species Act and the Canadian Species at Risk Act. These killer whales are highly specialized predators on Chinook salmon, and prey limitation has been identified as one of the biggest threats to their recovery (Ward *et al*., 2009). This killer whale population currently consists of only 76 individuals that are subject to significant nutritional stress, which potentially reduces their ability to reproduce (Wasser *et al*., 2017). Therefore, the issue of recovery of this killer whale population interacts strongly with the issue of Chinook salmon recovery (see Fig. 2). Chasco *et al*. (2017) estimate that by 2015, consumption of Chinook salmon by harbor seals and sea lions was double that of resident killer whales and six times greater than the combined commercial and recreational catches. In this case, a policy aimed at protecting marine biodiversity has not only affected human activities, but it has also caused unintended ecosystem consequences on other protected species through predation and competition.

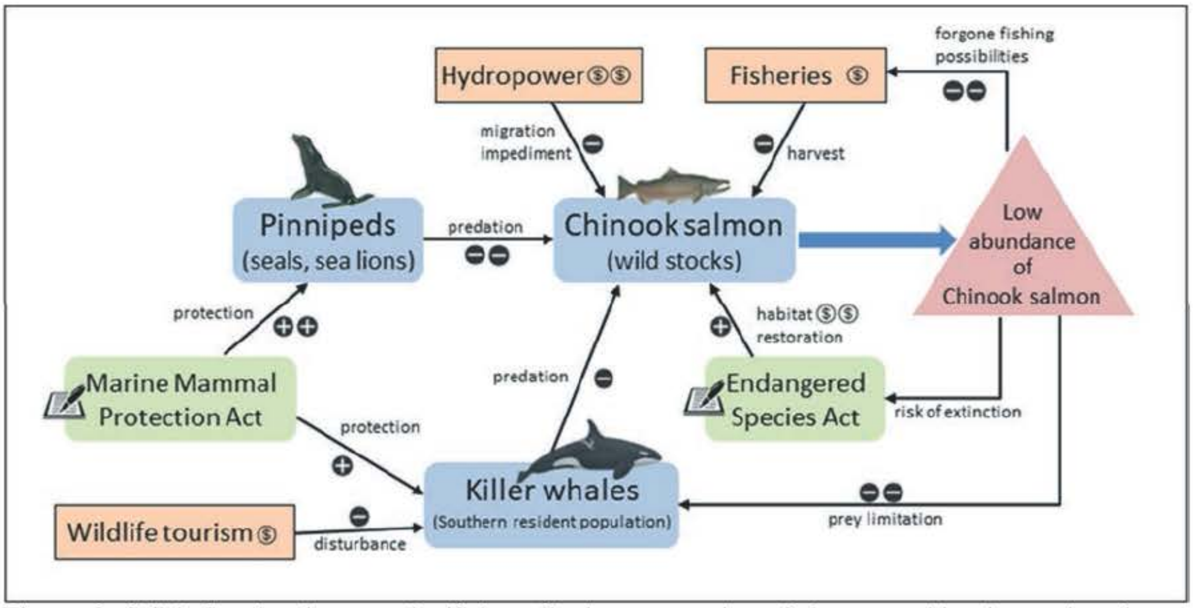

Figure 2. Salish Sea (northeastern Pacific): stylised representation of the competitive interactions between protected marine mammals and Chinook salmon fisheries. Dollar icon indicates significant economic interests.

Operational interactions

Operational interactions are related to direct impacts of marine biodiversity on the production processes of commercial fisheries and aquaculture. They include the degradation of the quality of harvested marine resources due to physical impacts of marine species on the quality of harvested fish and shellfish; and depredation, defined as the act of a predator that steals or damages the bait or prey captured or produced by human activities (Zollett and Read, 2006). The behaviour of depredation is often observed in cetaceans around the world and is likely to lead to considerable economic losses, but also to have important ecological consequences (e.g. additional fishing mortality and / or changes in structure of trophic webs). Operational interactions between fisheries and marine mammals are regularly identified, and may be beneficial or detrimental to one or the other (Northridge and Hofman, 1999). In addition to negative impacts on human activities, incidental catches of protected marine species in fishing gear are also related to these operational interactions. Interactions between marine mammals and fisheries are a worldwide concern and an increasing number of interaction events have been reported over the last five decades (Northridge and Hofman 1999; Gilman *et al*. 2006).

An example of negative interactions between marine mammals and fisheries is that of the French demersal longline fishery targeting Patagonian toothfish (*Dissostichus eleginoides*) within the French Exclusive Economic Zone (EEZ) of Crozet and Kerguelen Islands. This fishery is the second largest fishery in France and the second largest economic sector in Reunion Island with an economic value of more than 100 million euros in 2015. It directly or indirectly generates around 3000 jobs. During the period 2003-2012, Gasco *et al*. (2015) estimated that 5.8 million euros of Patagonian toothfish were lost each year due to depredation by killer whales and sperm whales (*Physeter macrocephalus*), which are the two main species responsible for these losses. In addition to lost catches, fishing companies incur different increased costs due to several factors such as reduced catch per unit of effort (CPUE) and changes in fishing practices to avoid depredating whales (Tixier *et al*., 2015). Indeed, to avoid or reduce depredation, fishermen in the demersal longline fishery adopt a range of mitigation measures such as increased hauling speed, dropping gear, moving to a different location to “outrun and lose the whales”. All these mitigation measures were found to reduce the level of interaction and to increase the mean CPUE. Yet few studies are quantifying the full economic impact of depredation on the fishery sector. Therefore, there is a crucial interest to expand and adapt some of the economic studies on marine depredation such as in Brotons *et al*. (2008), Maccarrone *et al*. (2014; and in this volume), and Peterson *et al*. (2014).

Toxicity

Small organisms can also be detrimental for human activities, such as harmful algal blooms (HABs) which represent a natural phenomenon caused by a mass proliferation of phytoplankton in waters. Not only fisheries and aquaculture are then impacted, but other sectors and social groups such as tourism, residents and human health (Fig. 3). The main groups of organisms generating HABs in seawater are diatoms and dinoflagellates. Algal blooms cause an increase in the turbidity of water and can create taste and odours problems, but can also produce harmful toxins. The consequences of these toxins include fish mortalities, seafood contamination and illness in humans from the consumption of contaminated shellfish or fish (Sanseverino *et al*., 2016). These HABs might lead to shellfish closures which have direct economic impacts through lost revenue. Other direct economic impacts include costs of medical treatments for cases of sickness in humans, expenses to remove algae from the water or dead fish from the beaches and investment costs in preventing and monitoring HABs (Sanseverino *et al*., 2016). Indirect economic effects also exist, such as a decrease in tourists in the areas affected by HABs, a decrease in revenue from businesses related to hotel industry, a decrease in recreation uses and also an increase in residents spending (Sanseverino *et al*., 2016).

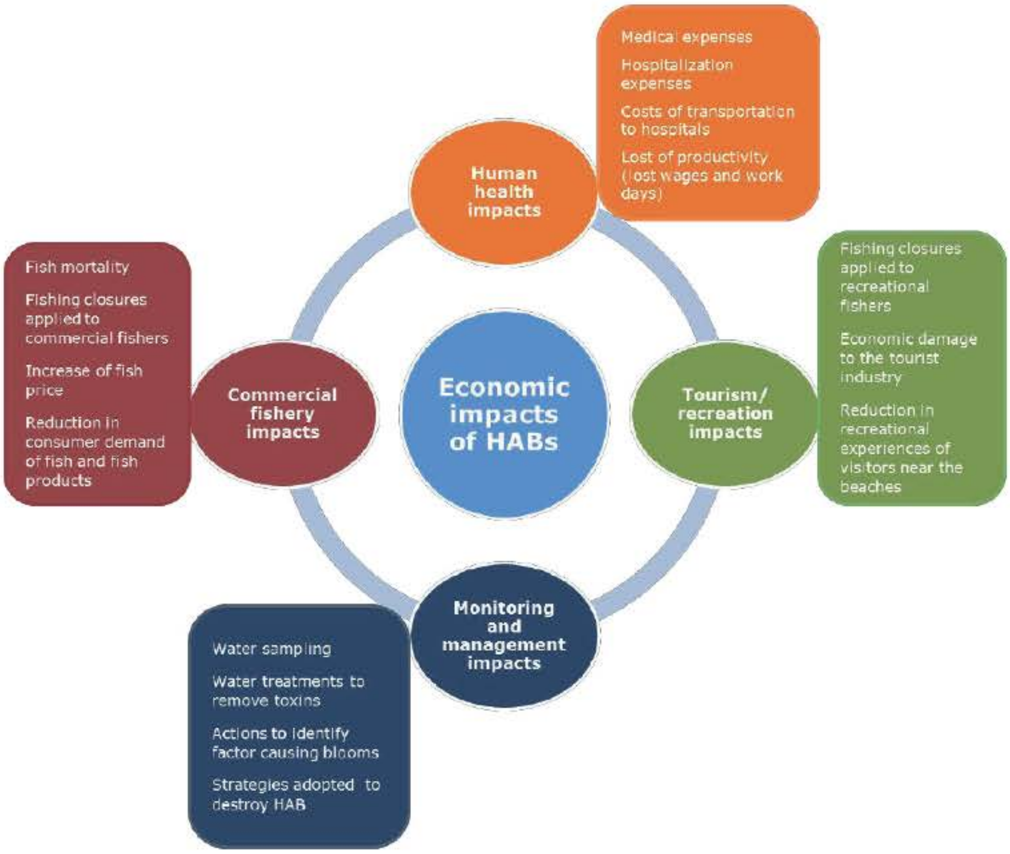

Figure 3. Economic impact of Harmful Algal Blooms (HABs). Figure shows four sectors affected by HABs episodes and lists, for each of them, the main causes of economic losses. Source: Sanseverino *et al.*, 2016

Social acceptability

Beyond the direct and indirect impacts of marine biodiversity on fisheries and aquaculture activities, some of the interactions and the ways in which they are handled may affect the perception of these sectors negatively. In particular, toxic algal blooms may lead consumers to sheer away from certain marine products, with negative economic and social consequences. The way in which depredation and other operational interactions are managed by the industry may also directly compromise the perceived acceptability of fisheries and/or aquaculture, as was illustrated by marine mammal / fisheries interactions (Molony *et al.*, 2015; Jackman *et al.*, 2018).

Towards the identification of bio-economic impacts and scenario evaluation

Ecosystem approach to fisheries requires that the above interactions be fully accounted for to better understand the trade-offs associated with alternative management scenarios for marine socio-ecosystem. This requires the development of adapted methods and tools. An illustration of the approach which can be taken for such an assessment is the evaluation of the potential consequences of alternative strategies regarding the level of protection within marine reserves that are designated for biodiversity protection purposes. It is then important to consider both the impacts on commercial species harvested by a fishery, and the potential development of predation on these resources by protected species in the ecosystem such as marine mammals, which support the development of ecotourism activities. Boncoeur *et al.* (2002) provide a stylized illustration of how such an evaluation can be conducted.

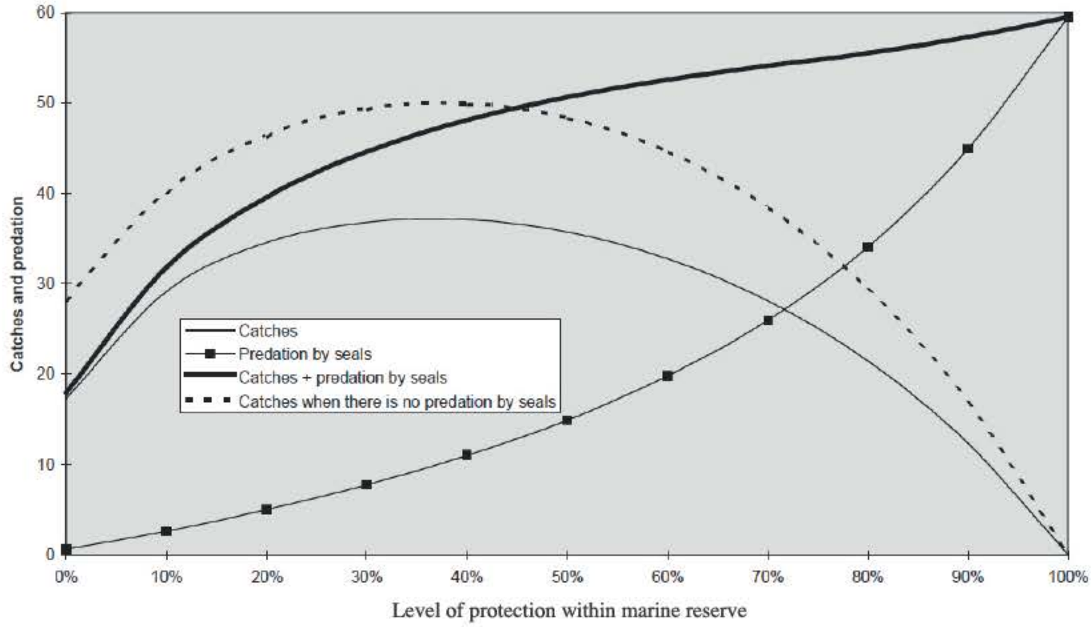

Figure 4. Relation between level of protection within a marine reserve, catches by fishers and predation by seals for a given level of fishing effort. Source: Boncoeur *et al*., 2002

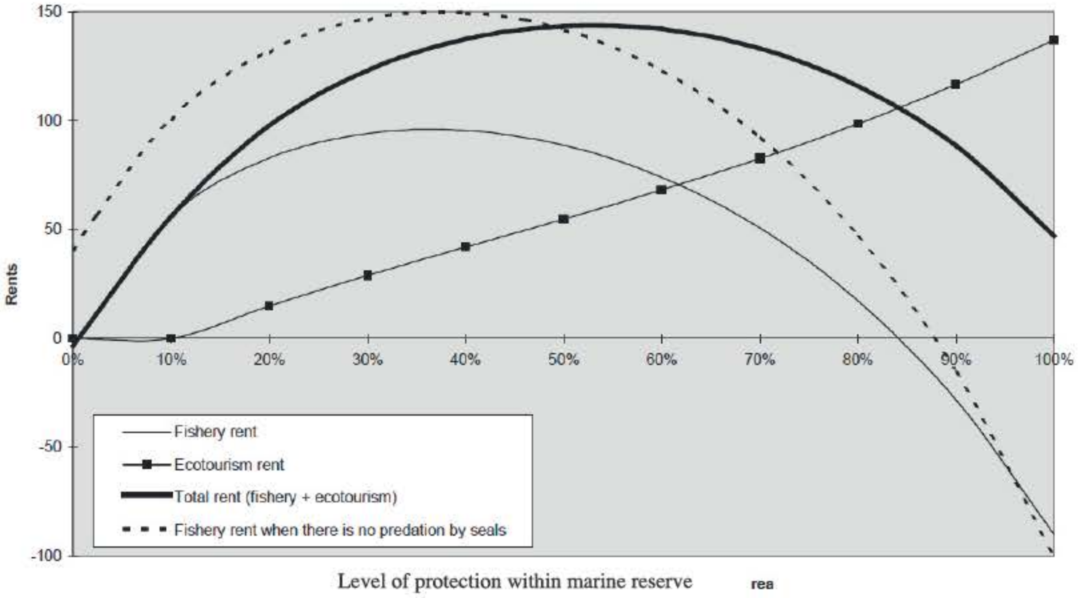

Figure 5. Relation between level of protection within a marine reserve and economic rent for a given level of fishing effort. Source: Boncoeur *et al*., 2002

They found that the competition for fish between seals and fishers results in lowering the benefits of a marine reserve for fishers, as catches will decrease with the level of protection within the reserve (Fig. 4). This affects the steady-state fishery rent for any given level of fishing effort (Fig. 5). However, in the case where the stock of seals may be economically valued by means of a non-extractive use (ecotourism), the implementation of the reserve generates additional incomes through this channel (Figure 5). According to local circumstances, these extra incomes will thus partly or totally offset the negative impact on the fishery rent of the competition interactions between seals and fishers. In this case their model suggested that the optimal level of protection of the marine reserve, from a global cost-benefit analysis point of view, is larger than when only fishery rent is considered.

Regarding operational interactions, Peterson *et al*. (2014) provide a rare illustration of the quantification of the full economic impacts of depredation by marine mammals on fisheries. Their study focused on the demersal longline fisheries operating in the Bering Sea, Aleutian Islands and Western Gulf of Alaska. In addition to the classical evaluation of the reduction of CPUE due to depredation, they estimated the costs of gear damages caused by depredation and additional bait and fuel costs related to the additional time at sea required by each vessel to reach their assigned quota. They also estimated the additional fuel and crew food costs plus opportunity costs in lost time when fishers choose to move to another fishing location (i.e. the costs related to depredation avoidance strategies).
Impacts from direct interactions are often easier to assess compared to those related to social acceptability for instance. Social acceptability is indeed intangible and difficult to apprehend. Consequently, this component is basically represented into assessments and models as a black box linked to other elements of the socio-ecosystem. Biological interactions, such as competition for the resource, are also difficult to assess due to high variability in the diet of marine mammals for instance and hunting areas (Northridge, 1985; Morisette *et al*., 2012).

Conclusion

The ecosystem approach promotes adoption of a "big picture" perspective, taking into account multiple ecological interactions, in order to develop future scenarios for marine socio-ecological systems. Integrated approaches are crucial to achieve this.

This paper aims at providing a preliminary review of the negative impacts of marine biodiversity on fisheries and aquaculture, illustrating these with selected examples. The review shows that these interactions have, to date, been largely under-studied, especially from a bio-economic perspective, and that their integration in Ecosystem-Based Fisheries Management (EBFM) requires further research.
Some public policies aimed at reducing anthropic pressure on ecosystems may lead to controlling these interactions, such as efforts to limit species invasions and perturbations of nutrient inputs into coastal seas. Interactions may however also increase with the development of biodiversity conservation policies and their improved effectiveness, as these enable marine species that generate negative impacts on fisheries and aquaculture to recover. Evaluation of conservation policies will thus benefit from including both ecosystem services and disservices (Dunn, 2010). Categorizing the interactions between marine biodiversity and human activities is the first step towards such an evaluation. Another key dimension relates to the quantification of these interactions, taking into account the ecological and economic processes at play.

A way to learn more about a particular socio-ecosystem is to involve local stakeholders and use their knowledge of the system. Indeed, scientific observations are rarely similar to stakeholders' perceptions, and both should be integrated in analyses to assess interactions in marine socio-ecosystems. There has been a growing interest in involving stakeholders in research on marine socio-ecosystems to increase the amount of information available for assessments (see Azzurro, in this volume; Pita *et al*., in this volume; Ramos, in this volume). Involving stakeholders in scientific studies ensures that their knowledge is included in developing system representations and that the analyses and/or models focus on key issues for stakeholders (Fulton *et al*., 2015; Voinov *et al*., 2016). Co-management approaches, involving stakeholders early on in discussions regarding the management of marine socio-ecosystems and in the ensuing decision processes, can also increase their support towards management systems that include decision-support approaches and tools.

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Local Ecological Knowledge: witness of a changing sea

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Abstract

Drawing on recent experiences on Local Ecological Knowledge (LEK) and on its application in different Mediterranean countries, this work attempts to illustrate several fundamental issues and challenges associated with researching LEK. A growing interest on these methodologies is highlighted in both Mediterranean studies and worldwide. The increasing success of LEK likely reflects a major change of contemporary ecological sciences, which is driven by the highly demand of broad observations and by the LEK value as a mutually beneficial action to social and ecological systems. With several limitations, which should be carefully considered when planning a LEK survey, accessing knowledge of 'sea users' may address a variety of environmental issues in our rapid changing seas. The potentialities of LEK have just started to be explored in the Mediterranean realm and its importance for environmental monitoring and natural resource management is expected to grow, empowering the voices and the observational potential of people living in intimate relationship with the natural environment.

Background

Members of the public participate in scientific research in many different contexts and from a variety of social and academic fields. In conservation and natural resource management contexts, efforts may deal with different ecological questions and issues regarding how people relate to their environments (reviewed by Shirk *et al*., 2012). A first approach is often reported under the name of *citizen science*. By 2009, Jonathan Silvertown was defining citizen scientists as 'volunteers who collect and/or process data as part of a scientific enquiry' and observations are collected in a voluntary way from enthusiasts and amateurs, following a guide or precise instructions given by professional scientists. By mapping, integrating and coordinating citizen-based observations, scientists can capture information that otherwise would be unaccessible via professional surveys alone. Such projects have become very popular today, providing new opportunities for marine research while achieving broader goals such as increased awareness and environmental literacy. Nevertheless, it can be acknowledged that in some cases these initiatives may follow a top-down approach, especially when participants lack ecological understanding. Such an approach can have limits (Lehr *et al*., 2007) that are avoided in projects in which there is a mutual exchange of knowledge (Jordan *et al*., 2011; Newman *et al*., 2012).

In the past two decades, another kind of approach has emerged, one that takes advantage of knowledge, which is already in the possession of community members living in close contact with nature. This knowledge, often reported as *Local Ecological Knowledge* (LEK), is receiving considerable research and policy interest, especially in relation to the need of monitoring, assessing and managing natural resources. Local Ecological Knowledge can be defined as the 'information that a group of people have about local ecosystems' (see Davies *et al*., 2010 for more definitions). Investigating LEK capitalizes the daily ecological experiences of people and their intimate relation with the environment, and natural resources (Davis *et al*., 2003). Practices commonly used by oral history (Fogerty *et al*., 2001) can be employed to access information from individuals' memory. Noteworthy, the concept and definition of LEK used in the present paper strictly refer to the on knowledge gained by individuals over their lifetimes, and not on information, which has been handed down through the generations by cultural transmission. The latter, often indicated as *Traditional Ecological Knowledge* (TEK), can be defined as a cumulative body of knowledge and beliefs of societies with historical continuity in resource use (see Berkes *et al*., 2000 for a complete list of definitions and concepts).

Until the last three decades, no one had really settled on a name or a concept for *Local Ecological Knowledge*, but in the mid '90s, the term started to be used with a rapid exponential increase in the scientific literature (Fig. 1).

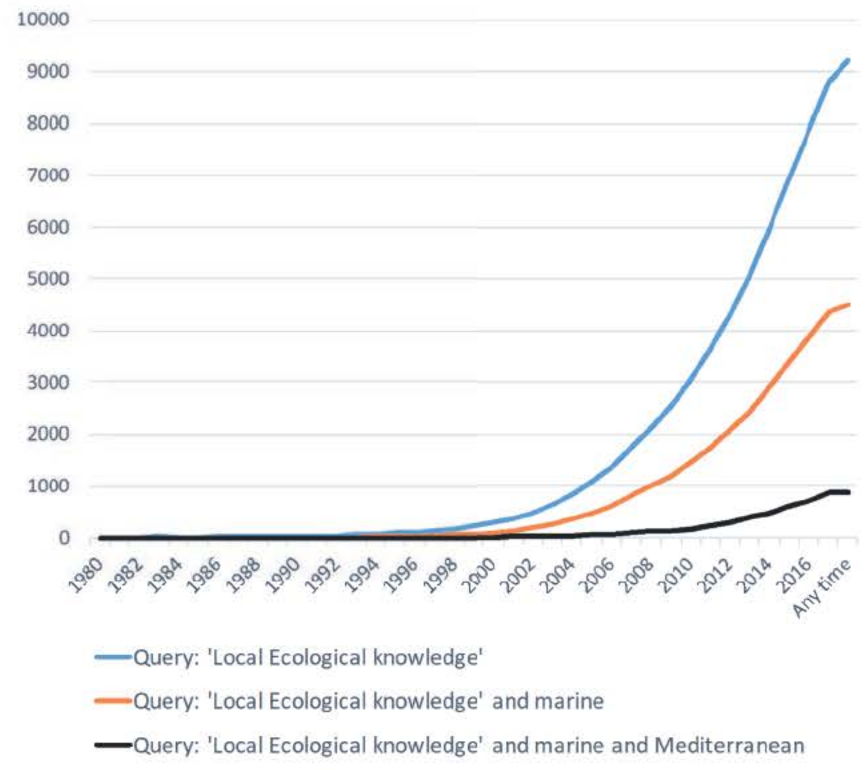

Figure 1. *Local Ecological Knowledge* (LEK) – Usage of the term in the scientific literature through time (source Google scholar).

It is also true that LEK surveys may embody perceptions, concerns and attitudes of local communities, which are key information for the science-management knowledge interface (e.g. Olsson and Folke, 2001, Roux *et al*. 2006). Drawing on these aspects empowers the voices of local communities, thereby providing people with a much greater capacity to understand core factors in their lives and livelihoods. Therefore, the active participation of stakeholder groups in a dialogue may not only be informative, but could aid in exploring management options, helping people to self-manage environmental issues in a sustainable manner. Such interactions are practical and underscore the other reason why LEK has become a significant cornerstone in recent years. As a matter of facts, a growing number of researchers and agencies (such as UNESCO, FAO, CIESM, IUCN) are promoting the integration of scientific with 'local' knowledge in a number of resource areas, such as forest conservation (e.g. Charnley *et al.*, 2007), wildlife management (Milupi *et al.*, 2017) and fisheries (Johannes, 1998; Neis *et al.*, 1999). Certainly, public attitude toward environmental issues may vary according to a diversity of values, perceptions and cultural perspectives, which needs to be explored to support appropriate management and adaptation. For example, if we want to involve local fishermen in the removal of invasive species, we need to know the willingness of these people to take personal actions and if they believe their actions matter (Carballo-Cárdenas, 2015; Azzurro and Bariche 2017). Such information is likely to improve the operability of future actions, considering the cultural environment.

A focus on Mediterranean experiences in researching LEK

The Mediterranean, a semi enclosed sea characterized by a high level of social, economic, and political complexity (Coll *et al.*, 2012; Micheli *et al.*, 2013), provides an interesting field of research for LEK. By reviewing the available literature (Table 1) we may note that so far this approach has been mainly used with fishermen, who have a comprehensive knowledge of the exploited species and can provide valuable information in data-less management scenarios. Specifically, Mediterranean LEK has been explored to describe trends in fish diversity and abundances (Azzurro *et al.*, 2011; Coll *et al.*, 2014; Mavruk *et al.*, 2018), to investigate historical abundances of long-lived marine species such as dolphins and sharks (Damalas *et al.*, 2015a) and to assess discarding of commercially important fish species in the bottom trawl fishery (Damalas *et al.*, 2015b). Fishermen and other well-informed people, can also provide simple observations such as presence records (Elbarassi *et al.* 2014; Crocetta *et al.*, 2017; Azzurro *et al.*, 2018) including historical records (e.g. Bariche *et al.*, 2013), or even abundance estimates (Boughedir *et al.* 2015;). This information can be particularly useful in poorly studied areas and it helps filling gaps in knowledge and assessment of the spatial distribution of both indigenous and non-indigenous species. Recently LEK has been employed to examine Jellyfish blooms occurrence and perception in Mediterranean finfish aquaculture (Bosch-Belmar *et al.*, 2017) and to reconstruct the temporal change of habitat-forming invertebrates in the Adriatic Sea (Bastari *et al.*, 2017).

Table 1. Main scientific studies, incorporating a LEK approach in the Mediterranean Sea. Both Indigenous (IS) and non-indigenous species (NIS) are considered.

					Perceptions on			*Interviewed*		
Main taxonomic subjects	**IS**	**NIS**	**Reference**	**Spatial coverage**	**Historical trends**	**Distrib. (presence records)**	**Env. impacts**	**Fishery**	**Divings**	**Aquaculture**
	x	x	Azzurro et al., 2011	Italy	x	x		x	x	
		x	Bariche et al., 2013	Lebanon		x		x		
		x	Azzurro et al., 2017	Italy	x			x		
fish	x		Mavruk et al., 2018	Turkey	x	x	x	x		
	x		Damalas et al., 2015a	Spain, Italy, greece	x	x		x		
		x	Boughedir et al., 2015	Tunisia, Libya	x	x		x		
		x	Azzurro and Bariche, 20	Lebanon	x	x	x	x		
fish and invertebrates	x		Coll et al., 2014.	Spain	x			x		
Fisheries discard	x		Damalas et al., 2015b	Spain, Italy, greece	x			x		
Dolphins and sharks	x		Maynou et al., 2011	Italy, Spain, Greece	x			x		
Invertebrates	x		Bastari et al., 2017	Italy	x			x		
Jellifish	x	x	Bosh-Belmar et al., 2017	Spain, Tunisia, Italy, Malta	x					x

One of the first and largest efforts for Mediterranean LEK was initiated within the framework of the international basin-wide monitoring program "CIESM Tropical Signals" http://www.ciesm.org/marine/programs). During this programme, we conceived a specific LEK methodology to reconstruct drastical changes in distribution and abundance of Mediterranean species. This specifically applied to both the decline of cold water species and to the geographical expansion of thermophilic taxa (reviewed by Azzurro *et al.*, 2008). A semi-structured standard questionnaire was developed around the following central questions - *What species showed the greatest variation in abundance in the last decades*? including species that 'appeared' or 'disappeared' in the fishing areas. Semi-quantitative data on species abundances were reconstructed by year, discriminating species that have increased, decreased or fluctuated over the respondent experience period. This protocol, which was initially tested between 2009 and 2010 in Italy (Azzurro *et al.*, 2001), was later adopted by researchers of 11 Mediterranean countries and applied in 79 Mediterranean locations (Fig. 2).

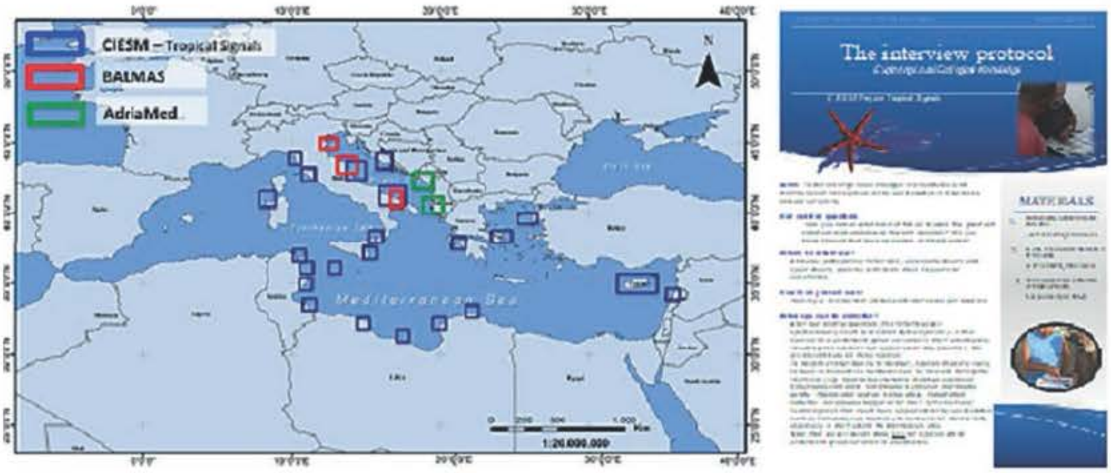

Figure 2. LEK pilote project: study areas (left), cover of the original LEK protocol (right).

This large effort, initially coordinated by the CIESM was later adopted by other international projects, such as the Interreg 'BALMAS' - Adriatic IPA and the FAO projects AdriaMed, MedSudMed and the Interreg project MPA-ADAPT, which allowed us to establish an informal but large network of LEK-interested researchers, well connected with local communities. This experience also allowed to develop a large dataset filled with historical data on occurrences and qualitative abundances of species (mainly fish). Currently the dataset brings the information provided by 506 fishermen for a total of 4352 perceptions on 102 species, accounting for a total of 15,954 yrs of experience at sea. Extending our goals from focused, local investigations to regional surveillance was a new challenge for researching LEK and some hitches were encountered. Pitfalls were mainly related to the difficulties (and requested energies) to coordinate such a large group of people. Moreover, the variable motivation of participants was reflected in a variable quality of data, which emerged after a cross validation process. Notwithstanding these practical drawbacks, the LEK was robust enough to provide significant ecological information at the regional level, opening new grounds for using LEK as a novel standard methodology in large scale monitoring.

Methods and methodological advices, including critical aspects

Researching LEK may include different methods such as semi-structured interviews; focus-group discussions; ranking and scoring captures and perceived abundances; participatory mapping; and diagramming techniques (e.g. seasonal calendars and historical timelines). Interestingly these approaches, recently adopted in marine research, have been largely employed by other distant disciplines, such as participatory epidemiology (Jost *et al*., 2007). Participatory mapping is, for instance, a powerful tool in LEK research and is often a good technique to start with, as it involves several people and can stimulate much discussion and enthusiasm. In epidemiological research, participatory mapping has been widely used to map disease outbreaks, both spatially and temporally, within rural and urban communities (Jost *et al*., 2007) and similar approaches can be transferred to the marine realm for a variety of research questions. Respondents indicate the locations or areas, and dates of events highlighting important ecological information. This information, properly collected, validated and spatially elaborated (i.e. GIS tools), may significantly contribute to understand and manage changes at the level of populations, communities and ecosystems. A common assumption of these approaches is that investigators cannot fully anticipate the ecological problems they study. This assumption helps to avoid many biases associated with LEK, empowering the knowledge of stakeholders, since they are the ones who identify and describe the problems. This tactic also ensures flexibility of field approaches, allowing time for the 'discovery' of new information. Another important rule is that practitioners of LEK must have a respect and a genuine interest in learning from the diverse stakeholders. It is therefore important to be good listeners but also to critically review all the information. Therefore, the core method of researching LEK is often a semi-structured interview. The interviewer introduces a topic using an open-ended question. An example of an open question would be: 'What species have disappeared in the last decades? This allows the respondents to spontaneously identify species, provide direction to the interview and describe problems in their own terms.

Certainly, to rely with man-based observation has both advantages and pitfalls. The latter are related to intrinsic limitation of these approaches but also to the variety of cultural aspects and perceptions, whose variability may represent a limit but also another interesting field to be explored in our research. LEK can be criticized when observations of local people do not provide hard evidences on ecological questions. It will be therefore vital to design and conduct LEK research with a scientific thinking and maintain high standards of accountability. As in other studies, appropriate research designs and clear methodologies are needed to enable assessment of the reliability and representativeness of findings, to facilitate comparison, generalization, and evidence-based conclusions (Davis *et al*., 2010). Specifically, we can distinguish among three different aspects, which largely contribute to the reliability of LEK exploration: *i*) the characteristics of the target taxa; *ii*) the characteristics of the interviewed population and; *iii*) our questions and research design (Table 2). Considering the target taxa, these should be conspicuous and easily recognizable. It is thus preferable to select unmistakable taxa with a strong cultural and/or emotional dimension in local communities (see Anadon *et al*., 2009). We should however consider that some questions may be uncomfortable and generate conflicts of interest, reluctance to share knowledge or untrue answers. This may happen when people can feel that the information may be used against them e.g., declaring protected areas or regulating fishery activities (see Grant & Berkes 2007 for fishermen). Concerning the interviewed population, groups like fishermen may constitute the best group of informants about distribution and abundance of marine resources. It is nonetheless advisable to select people who together form as homogeneous subject, and this can be sometimes challenging, such as in the small-scale Mediterranean fishery, which is typically characterized by a great variability of different techniques and traditions. Some relevant groups, such as recreational divers or fishers may vary much in the time dedicated to their environmental-based activities and deeply involved people should be preferred with respect to salutary users. It is therefore advisable to assure that persons considered less knowledgeable will not be mistaken as local experts, reducing the confidence with LEK-based documentation processes.

If we are interested in quantitative estimates, we might reason on how to quantify and to standardize the "sampling" activity of the respondents. Standardization may be particularly challenging when local activities vary much in both space and time. It is therefore advisable to select a priori the objective of our investigation, which must be realistic in consideration of the socio-cultural characteristics of our sampling units. It is also true that the interviewees' memories, and thus the accuracy of the information, are expected to decline with time (Bernard *et al*. 1984), we therefore need to understand precisely what information can be obtained at what historical times and on what group of respondents.
Last but not least, we should remember that every survey must respect the local legislation on privacy matters. It is therefore suggested to guarantee anonymity and clearly state the objectives of the research at the beginning of the interview.

Table 2. Some practical suggestions for investigating LEK.

	Methods in LEK	
	To avoid	**Desired**
Target taxa	Difficult to identify species, possible confusion with other Taxa	Unmistakable taxa, easy to identify
	Low cultural/emotional dimension, not important for people	Strong cultural/emotional dimension (e.g. large, dangerous, 'totemic', odd or new species)
	Low interaction with human activities	High interaction with human activities (e.g. fish species for fishermen)
Intervieweee population	Heterogenous groups, with different uses and attitudes toward the natural environment	Homogeneous groups with similar uses and attitudes toward the natural environment
	Not experienced, only superficially involved in environmentally-based activities	Experienced, deeply involved in their environmentally-based activities (e.g. artisanal fishermen, profesional divers)
	Variable activities in terms of time and space	Regular activities in terms of time and space
Questions and objectives	Vague objectives, not clearly stated a priori	Clear objectives are stated a priori
	Distant happenings are more difficult to remember	Recent happenings are easier to remember, especially those related to an emotion
	Sampling activity difficult to quantify (and standardize), too detailed scales	Sampling activity easy to quantify (and standardize), simple scales
	Unconfortable or too complicated questions may generate untrue answers	Simple and clearly understandable questions ; leave the option 'I don't know', 'I do not remember'

Conclusions, with a personal lesson gained from field applications

Exploring LEK can be a formidable experience for researchers interested in understanding, describing and taking actions in the real world. This can be done at the local level but also at much larger scale, when we establish collaboration with other LEK- interested researchers. Such a network of LEK-interested researchers allows bringing together the voices of people from different countries, reporting direct observations and perceptions on common environmental problems, such as climate change, pollution or invasive species. Nevertheless, to guarantee LEK as a legitimate source of scientific ecological understanding, we must be very careful in planning our research under a scientific thinking as in every scientific study every time. With some notable exceptions, Mediterranean fishermen demonstrated a great interest and wide availability to share information on specific subjects, especially when these raised their curiosities and were related to their personal or collective emotions. They were also pleased to be considered as experts and be listened by the interviewers. What most of the participants remarked in their narratives is their witnessing of rapid and dramatical changes in the ecological systems. Many felt their actions would simply be ineffectual but reasonably, the scientific and social valorisation of their knowledge, might contribute to reinforce the participants' belief that their knowledge matters and their attitudes can contribute to the conservation. Clearly, LEK has just started to enter into the field of ecological research and a further integration of sociological tools is needed to support this process. Moving science in this direction is likely to open new grounds to fulfill both scientific and managing needs in a variety of social and environmental settings.

Acknowledgments

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Stakeholders' vision on landing obligation: transformation of the Mediterranean social ecological system?

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Article 15 of the last reform of the Common Fisheries Policy (reg. 1380/2013 of EU Parliament and Council) banned the practice of discards in all EU fishing fleets by establishing a landing obligation for all species caught under the TAC system, and in the Mediterranean for all species under Minimum Legal Size defined in Annex III of Regulation (EC) No 1967/2006. This new rule is not only applicable to the fleet operating within the EU territorial waters but also to EU fleets operating outside Union waters not subject to third countries sovereignty or jurisdiction. All catches should be brought in and retained on board the fishing vessels, recorded and counted against the quotas, where applicable, except when used as live bait.

The Landing Obligation (LO) was to be implemented gradually, within a four-year period, and the first to start were the Baltic Sea and the pelagic species in 2015. Both cases were considered easier for its application. Then LO was implemented for the demersal species and the Mediterranean in 2017; and it should be really enforced by 2019 in all EU areas and for all species. Article 15 provides also the possibility of exemptions which can be interpreted as follows: species and fisheries can be exempted on the basis of evidence of high survival rates for discarded fish. Further, up to 5% of the total catch of a species may be discarded if it is shown that selectivity increases are difficult to achieve or that handling of unwanted catches is overly costly (*de minimis* exemptions). The last type of exemptions that can be granted is for "high additional cost". The implementation of a such rule requires its acceptance from fishers and all other actors involved in fisheries management within EU. According to the European Union governance principle, participation of stakeholders in the decision-making process contributes to legitimate the decisions and make them more applicable. The main objective of our research was to ascertain whether LO is considered as a legitimate decision by the different stakeholders involved in fisheries, and also what can be the impact of such an implementation in the Mediterranean fisheries. The paper starts with a general presentation of Mediterranean fisheries and management issues, including the issue of discards. Then, the vision of the EU main stakeholders, collected through interviews, is developed.

The Mediterranean Sea and Fisheries

In the Mediterranean Sea, nine out of twenty-three countries are members of the EU (France, Italy, Greece, Spain, Cyprus, Malta, Slovenia, Croatia, UK), four others are candidates or potential MS (Albania, Montenegro, Turkey, Bosnia-Herzegovina) and ten are non-EU countries (Algeria, Egypt, Israel, Jordan, Lebanon, Libya, Morocco, Palestine, Syria, Tunisia). So, the Mediterranean fisheries resources are shared between different fleets operating under the management system of their respective country. Normally, each national fleet operates within the Economic Exclusive Zone of its country, but often EU and non-EU fleets compete for the resources within the same space. In addition to this spatial competition, EU MS fleets are subject to a common regulatory framework under the Common Fisheries Policy (CFP), which is not the case for all other fleets operating under their own national laws. The rules applied in the Mediterranean Sea for the EU fleet are perceived by fishers as very restrictive compared to those applied by other countries. So, EU fishers feel they put much more efforts in the matter than other Mediterranean fishers. The implementation of Article 15 of the CFP will make even more complex the rules that they must already obey; and fishers would tend to avoid this implementation as much as they can.

The Mediterranean fisheries fleet numbers 91,425 vessels which are divided in different segments (Table 1). 80% of it includes vessels of less than 12 m Length Overall (LOA, Machias *et al.,* 2016). So, small-scale fisheries (SSF) vessels are the main characteristic of the Mediterranean fisheries industry. The majority of SSF vessels are found in non-EU countries; but their number is also important in some EU countries like Greece. In addition, it is the only fishing fleet in Cyprus, for instance. EU members States fleets include a great number of large vessels using trawls or purse seines. These vessels are more powerful than the SSF vessels with which they often compete.

Table 1. The Mediterranean Fishing Fleet sectors

Fleet	**Main gears**	**Target Species**
Polyvalent small scale (<12m)	Set nets, traps, hooks & lines	Coastal demersal & pelagic fish, molluscs, crustaceans
Trawlers (6 to >24m)	Trawls & entangling or surrounding nets	Misc. coastal shelf & slope demersal fish, crustaceans
Purse seiners (6 to >24m)	Seine nets, surrounding nets	Misc. pelagic, coastal & demersal fish
Long Liners (>6m)	Hooks and lines, surrounding nets	Demersal shelf & slope species, large pelagics
Pelagic trawlers (>6m)	>50% effort with pelagic trawl	Misc. small pelagics, tuna, bonito, billfish, misc. demersal fish.
Tuna seiners	Surrounding nets	Tuna, bonito, billfish
Dredgers (>6m)	Dredges, surrounding nets	Molluscs, crustaceans

(Source: GFCM/33/2009/3http://151.1.154.86/gfcmwebsite/docs/RecRes/Rec_GFCM_33_2009_3.pdf).

In 2013, 787,000 t of fish, crustaceans and mollusk were landed. Landings have decreased since 1994 when they amounted to 1,087,000 t (FAO, 2016). Thirteen fish species account for about 65% of landings, small pelagic (anchovy 393,500 t, sardine 186,100 t) being the most important. According to different scientific sources, this decline can be explained by the overexploitation of the stocks.

There is significant interaction between EU and non-EU fleets in many fisheries across the MED; and the fact that only EU fleets are subject to strict management rules and controls generates contestation, against LO for example. Despite the larger size of EU countries vessels and the better technology they use, non-EU fleets are the larger catchers, with the Turkish fleet producing a yearly average of 459,400 t between 2000-2013 (equal to the catches of Spain, Italy, Greece and France combined). And Algeria, with 115,400 t, produces the combined quantities of Greece, France, Malta and Cyprus.

Discards in the Mediterranean

A defining characteristic of the Mediterranean is its species diversity, with approximately 714 fish (Dimarchopoulou *et al.,* 2016) 2,239 crustacean and 2,113 mollusk species (Coll *et al.,* 2010) occurring there. From 300 species regularly caught in the Mediterranean, only around 10% are consistently marketed, 30% are occasionally retained (depending on the sizes and market demands), whereas up to 60% are always discarded (Bellido *et al.,* 2014). Discard rates differ from one country to another.

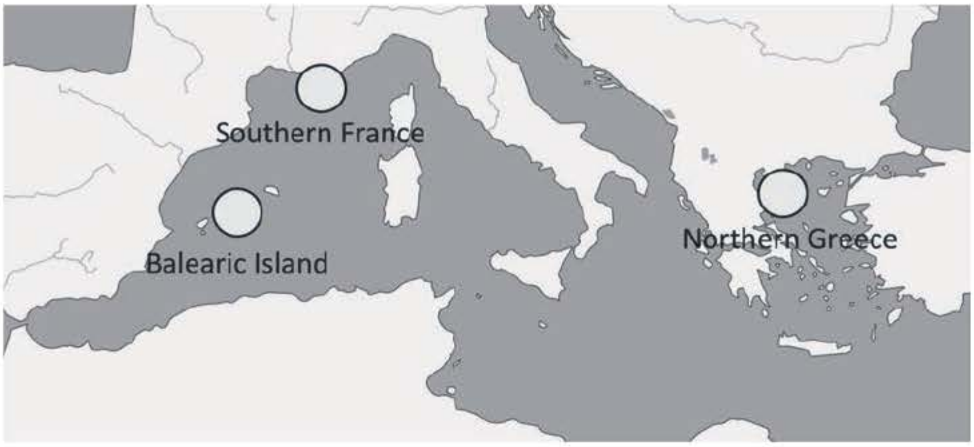
Research projects that measured discard rates in the Western Mediterranean found that the bulk of discards were composed of non-commercial species. Discards of species with a high commercial value (e.g. octopus, shrimp, Norway lobster) were very low or nil. Discards appear to be highest on the shelf and lowest on the middle slope; and significantly higher in summer, in line with the recruitment of most commercial species (Mallol, 2005). Minimum and maximum discard rates for species subject to the LO are given in Table 2 below. It can be noticed that discard rates are lower than many species subject to the LO in other EU regional seas.

Table 2. Minimum and maximum discard rates of MED species subject to the Landing Obligation (Evaluation of the landing obligation joint recommendations, STECF-16-10).

	Western Med		**Central-Eastern Med**		**Adriatic Sea**	
	Trawl	Set gears	Trawl	Set gears	Trawl	Set gears
Hake *Merluccius merluccius*	3.6 – 20.8	0 – 4.9	3.0 – 5.7	5.5	3.8 – 15.7	0
Red Mullet *Mullus barbatus*	2.2 – 14.7	1.4 – 1.8	0.1 – 2.2	3.1	1.6 – 13.1	3
Striped Red Mullet *Mullus surmuletus*	1.0 – 10.3	1.0 – 3.0	0	0	0	4.5
Rose Shrimp *Parapenaeus longirostris*			6.1	0		
Common Sole *Solea solea*					1.3	0.5 – 2.4

Reasons for discarding are highly variable; they can be driven by regulatory, economic, sociological, environmental or biological factors which often act together. It is therefore quite difficult to separate them, especially in multispecies fisheries. Interviews with MED fishers and other stakeholders were realized in three areas with the objective to identify their reasons to discards, the impact of LO implementation to their activity and fisheries enterprises and also their ideas on strategies of adaptation. The main results of these interviews are presented in the following section.

Discards: three case studies



Stakeholders' vision

This section gives the main results of the analysis of qualitative data gathered during semi-structured interviews and among focus groups in the West and East Mediterranean and at EU level regarding Environmental Non-Governmental Organisations (ENV NGOs). The questions used for the interviews and focus groups were the same, and also for the different groups of actors. They cover the following main topics: opinions towards Article 15, opinions about the implementation process, causes of discards, impact on fishing enterprises and the ecosystem, use of discards, adaptive strategies. Here follows a short synthesis:

Fisheries sector vision

Individual fishers knowledge of the LO or its implementation was very limited; and the majority of them, when provided with an explanation, expressed a very negative opinion towards this measure. Mediterranean fishers feel that the LO is tailored for the quota system in Atlantic fisheries, and that it does not account for fishery management issues in the Mediterranean. Having participated in numerous national or MEDAC meetings, fishers representatives have better knowledge about the LO and its implementation process. The overall attitude of industry representatives towards the LO, as expressed in the MEDAC proposal for a Joint Recommendation, is one of concern about economic costs, short implementation timescale and difficulties in improving selectivity.

NGOs' vision

The Landing obligation is perceived by ENV-NGO representatives as a first step for more sustainable fisheries. But they consider that the industry, with the support of national administrations, prioritised exemptions over avoidance of unwanted catches through more selective gears. During the discussion and vote on demersal discard plans within MEDAC, two ENV-NGOs voted against the MEDAC proposal.

Administration's vision

National administrations support the LO as a tool to reduce discards and resource waste. However, LO implementation is time-consuming and demands flexibility, which possibly explains the high number of exemptions. National administrations consider exemptions as a way of adapting to the LO. Exemptions are a possibility provided for in Article 15; from a legal perspective, approval of exemptions means that the LO is applied. According to some local authorities, it seems that the EU has realized that the LO creates implementation difficulties in the Mediterranean. At meetings between the EU and regional fisheries directors, the emphasis has been on reductions in the fishing effort as a more effective measure in improving management than the LO.

For administrators and some fishers, the LO creates a risk of developing a market for undersized fish. This reversal of previous policies counters efforts made over the last few decades to reduce the commercialization of small-sized fish. In some areas, local administrations have expressed their concern: “Landings of below minimum size fish have been confiscated up to now, and we now have to let them go”. Administration, fishermen and NGOs have also commented that the LO should be used as an opportunity for a decrease in all discards and not only for species with minimum landing sizes.

Experience on pelagic species

The pelagic discard plan in the Mediterranean came into force on 1st January 2015, running until 31st Dec 2017. In order to avoid discards under certain conditions, Mediterranean pelagic fishers occasionally practice “slipping” (referring to fish caught in a net and subsequently released into the sea without being brought on board). This, in combination with the *de minimis* exemptions, means an absence of major consequences for most pelagic fishers. There are administrative uncertainties about how discard percentages will be recorded and controlled.

There is derogation for bluefin tuna (BFT) and swordfish, as the management of these species is regulated by ICCAT. Licensed vessels targeting tuna can land and use BFT for human consumption up to 5% of undersized individuals. Also, 5% incidental catch by vessels not licensed to target BFT is allowed.

Handling unwanted catches

Unlike Greek bottom trawl fishers, French, Catalan and Balearic fishers said that the storage room on board is insufficient for retaining unwanted catch, especially on vessels targeting small pelagic. The extra cost (ice, boxes, additional crew and crew effort) entailed by LO implementation is a concern identified by all fishers. Further, transport of unwanted catch will make the boat heavier, thus reducing safety. Some fishers are against the use of unwanted catch for aquaculture, which is perceived as a competing sector.

There is a general lack of infrastructure to handle discards in mainland and island ports. There is no fish processing industry for discards in the Mediterranean, and in many areas even cold storage facilities are lacking. MEDAC have raised the issue of disproportionate cost of transport of small quantities of discards between widely separated small ports. Investment in infrastructure would be needed and may be difficult to justify as the objective of the LO is to reduce quantities of discards over time.

For ENV-NGOs, this desired reduction in quantity of unwanted catch implies that there is no sense in developing new industrial sectors based on discards. They also stress that incomes which potentially could be obtained from the sale of discards should benefit community purposes (e.g. research, social funds) rather than individual fishers.

Technical Measures

In all cases, the mitigation strategy most frequently mentioned is to reduce discards by improving selectivity. Western Mediterranean (Spanish, French) and Eastern Mediterranean (Greek) fishers said that gear selectivity can be improved greatly with the introduction of the 40 mm square-mesh cod-end on trawlers. However, this measure has not been well implemented in all areas, as noted in an EU report which found that most Mediterranean vessels still use 50 mm diamond-mesh cod-end. Reports from Greek industry sources and a collaborative research project indicate that trawlers use the 40 mm square-mesh cod-end. The use of 50 mm diamond-mesh cod-end is authorized only after proving that its *size selectivity is equivalent to or higher than that of 40 mm square-mesh cod-end*; but there is no scientific information to justify it.

Fishers felt that the 40 mm square-mesh cod-end should be used in all Mediterranean trawler fleets, not just EU-MS ones. The MEDAC Joint Recommendation proposal outlines how further improvements to gear selectivity may be explored with European Maritime and Fisheries Fund financial support. In some cases, small-scale gill and trammel net fishers have been using mesh larger than the legal size in the red mullet and cuttlefish fisheries to avoid discards. In the Balearic picarel fishery, fishers agreed to implement daily quotas per vessel (200 kg) to avoid low prices owing to market saturation, which also helps to reduce discards. This scheme may be expanded to cover horse mackerel, given that this species also has high discard rates in the Balearic Islands.

Spatial management is widely used and supported in the Mediterranean as another strategy to reduce unwanted catches. French and Spanish fishers highly support the mapping of juvenile hotspots, which should be based on scientific knowledge. Better identification of discards by area, by gear and by species would significantly contribute to LO implementation; and some projects are already addressing this issue. Fishers mentioned the use of enforceable real-time closures to avoid undersized hake in the trawl and purse seine fisheries. Spatial closures are widely used in Greece, where trawlers and purse seiners face year-long closures in inshore areas and additional seasonal (2 to 4 months) closures. Greek trawl fishers also suggested the enforcement of real-time spatial closures. New permanent closures are not supported by fishers as the presence of undersized fish is seasonal, and since a network of MPAs already exists.

Control Issues

Some fishers said that logbooks did not have any specific cell to record discards. In practice, even where logbooks have been updated, unwanted catch, discards or the number of slipping operations are not registered. This attitude may be due to the fact that fishers have only a poor knowledge of the LO, and that all stakeholders are still learning about its implementation.

Conclusion

After one year, it can be said that LO is not really implemented, except in terms of exemptions. Recording of discards is still not done, and fishers continue business as usual. This is due to the fact that National fisheries administrations have not really enforced this rule, and continue to operate as in the past. But in some countries, fisheries organizations are looking for new solutions to avoid discards as much as they can, and trials of more selective gears are being conducted, for example in France. Real-time closure, due to the presence of undersized fish, is mentioned by fishers as another solution; but they avoid requesting such a measure because they are concerned that the national administration will end up implementing it on a permanent basis. In some countries, such measures cannot be taken rapidly as this requires a national decision which may take time to achieve. Fishers therefore favour more informal decision-making rather than national decisions. In all cases, they should change fishing practices to adapt to the new rule, and such changes require some time. Time is also needed to change their ideas concerning the negative impact of LO on the ecosystem. For them, releasing fish in the water would benefit birds and other fishers; and bringing fish on land can act as an incentive for some fishers, especially when there is compensation. So, they are against any compensation and any use of discards.

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The role of marine stakeholders in the co-production of scientific knowledge: lessons from Galicia (NW Spain)

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Abstract
Small scale fisheries (SSF) are managed worldwide under data-poor situations. In this scenario, the use of fishers' ecological knowledge (FEK) about the local marine environment has been found useful to provide data to management, but also to foster the involvement of the fishers in the management of common pool resources. We show here that the engagement of fishers in co-management processes and the development of initiatives to collect and use the FEK in fisheries management are mutually reinforced processes. We found that the production of scientific knowledge based in the use of FEK can be very reliable. For example, in Galicia (NW Spain) the use of the FEK helped to design new marine protected areas (MPAs), manage relevant commercial and recreational fisheries, and also identify adaptive strategies for fishing fleets. FEK can help managers and policy-makers ensure more coherent and realistic management of complex marine socio-ecological systems and promote the self-regulation of the fisheries sector. The development of general frameworks to systematize the integration of FEK in the management of the fisheries is recommended.

Key Words: co-production of knowledge, traditional ecological knowledge, co-management, fisheries, Galicia (NW Spain).

Introduction

The management of small-scale fisheries (SSF), traditionally poor in scientific data, has been extensively based on the use of fishery-dependent information to perform fisheries assessments (Weeratunge *et al*., 2014). Moreover, the involvement of scientists, managers and fishers in the collection of fishery-dependent information fosters the development of co-management models, which in turn increase the empowerment of SSF fishers and their sense of responsibility (Jacobsen *et al*., 2012; Mora *et al*., 2009). Local ecological knowledge (LEK) is conceived as a knowledge system derived from the continued use of an ecosystem that integrates practices and beliefs related to a sociocultural framework different from normal science. LEK differs from normal science, not so much by the type of observations that are collected, as by the way in which they are interpreted and organized. LEK complements and enriches scientific knowledge, since it increases the spatial and temporal resolution of observation, while increasing the level of detail and other novel information. Thus, fishers' ecological knowledge (FEK) about local marine environments is, in addition to a knowledge contrasted by the accumulation of information over generations, a continuously updated source of knowledge collecting the latest changes and dynamism occurred in the local marine environment. FEK should be considered not only as a history of practices, where fishers learn and transmit working techniques, but also as a history of the representation and understanding of the local environment in which they operate. In this way, FEK, in addition to being linked to practice as know-how, is also related to a conceptual network of spatial and environmental knowledge as essential or more than manual and technical culture. FEK arises from a process that presupposes an active cognitive subject in constant interaction between mental and manual work, and with its environment (field of reference and action). It is the constrictions imposed by the marine environment that trigger the fishers' need for knowledge to solve them. Consequently, FEK can be considered as a source of alternative information, complementary to traditional scientific knowledge (Agrawal, 1995; Davis and Wagner, 2003; Goldman and Schurman, 2000). Thus, FEK has huge applications and can be integrated into fisheries sciences at different levels (e.g., for marine spatial planning, fisheries management, etc.) although its true potential remains unexplored (Huntington, 2000). We hypothesize here that the involvement of fishers in co-management processes and the development of initiatives to collect and use the FEK in fisheries management are mutually reinforced processes. Therefore, we have analyzed the connections between relevant co-management procedures in Galicia (NW Spain) and initiatives that used the FEK in the production of scientific knowledge. In the end, we provide general conclusions about how to improve the use of FEK to take advantage of opportunities and cope with future challenges in fisheries management.

The fisheries management framework in Galicia
Galicia is the main fishing region of Spain, accounting for over 40% of the country's fleet, 50% of catches reported by Spanish vessels fishing in EU waters and more than 60% of total employment in fisheries-related sectors (Scientific Technical and Economic Committee for Fisheries, STECF, 2017). Therefore, many coastal populations are highly dependent on fishing activities (Freire and García-Allut, 2000; Villasante, 2012).

The Autonomous Government of Galicia (Xunta de Galicia) has been managing commercial and recreational coastal fisheries for nearly 40 years, while fisheries in external waters are managed by the Spanish Government (Jefatura del Estado de España, 1981). Management of some benthic, sedentary marine organisms is based on territorial user rights to fisheries (TURFs) (Xunta de Galicia, 2009a), but despite recent demands for more co-management by fishers' associations for some fisheries, e.g., the case of the common octopus (Pita *et al*., 2016), most coastal fisheries are still managed by a conventional top-down approach (Macho *et al*., 2013). Moreover, the implementation of new management measures has been limited by the lack of scientific information and statistical databases (Arnáiz, 2001; Molares and Freire, 2003; Pita *et al*., 2017).

1. The case of marine protected areas of fishing interest of Galicia

1.1 The relevance of collective construction processes in the management of fisheries resources as common goods: the case of the marine reserve of "Os Miñarzos"

In 2002, artisanal fishers from Lira (North-central coast of Galicia) began a process to create a marine protected area (MPA) of fishing interest that conclude its formalization in April 2007, under the name of Marine Reserve of Fishing Interest "Os Miñarzos" (Xunta de Galicia, 2007) (Fig. 1).

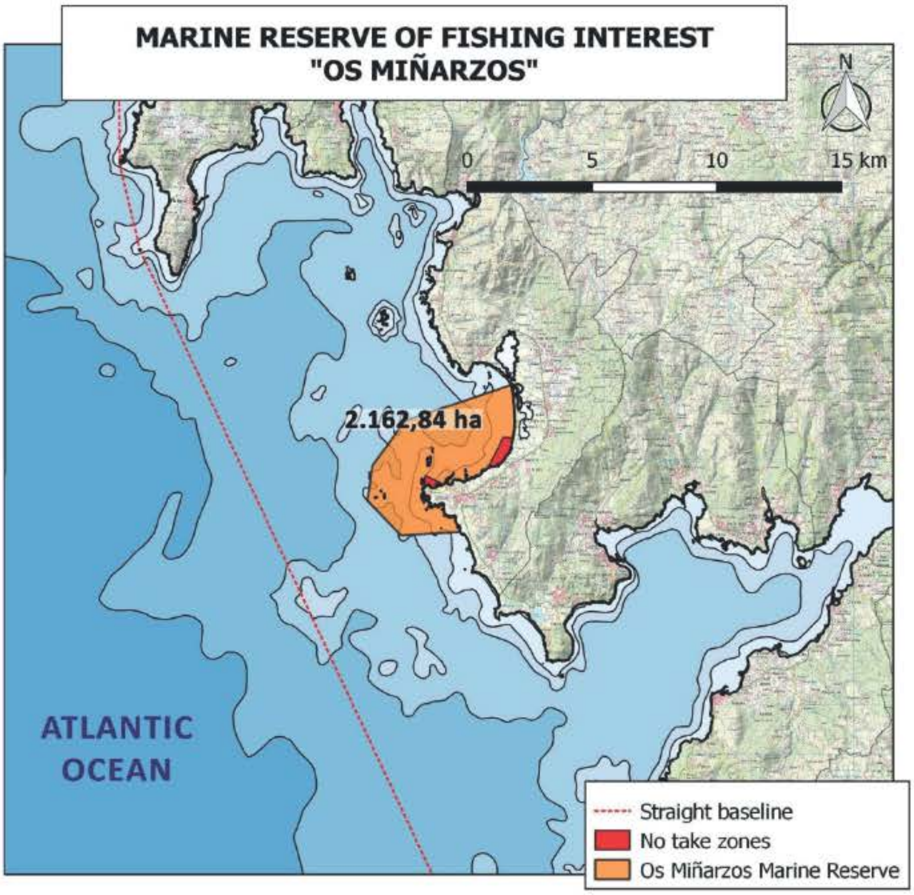

Figure 1. Location of the MPA of fishing interest "Os Miñarzos", on the North-central coast of Galicia.

Under the Fisheries Law of the Xunta de Galicia (Xunta de Galicia, 2009a), the MPAs of fishing interest are tools for the management and conservation of the marine ecosystem. The creation process of this MPA, different from other MPAs, is of interest to the scientific community and managers of the marine environment because: (1) the initiative was developed by the local fishers' community.[In the field of fishing, it is not usual for fishers to propose the creation of a MPA because they usually perceive them as a constraint to develop their fishing activities. The reason for this proposal lies in a previous process of diagnosis about the future of SSF that has led to the belief that the MPA is a solution of continuity for the local fishery sector]; (2) the fishers of this community have maintained an active participation for the five years that the process lasted until its formalization (2002-2007). The best explanation to understand this perseverance, unusual in the fishing sector, is the incentive generated by the MPA in terms of the best expectations for the future; (3) the process of design and creation of the MPA had a high participation of the local fishing sector. This orderly and inclusive participation of the local fishing sector has been facilitated by the earlier building of a strong personal and institutional trust with an external organization through previous collaboration in other projects with this community; (4) the local FEK was integrated with the scientific knowledge for the MPA design, including zoning and spatial management proposals. The local FEK proved highly relevant in this case to define the size, shape, location and management of the no-take zones; and (5) perhaps the most relevant factor in this case was a management proposal that included a governing body made up of fishers, public administration, scientists and NGOs with interests in marine space conservation. The peculiarity of this management model is that the representation of the fishing sector and of the administration was equal, although consensus constitutes the deliberation criterion of the Management Body. Thus, peer co-management is the tool that the artisanal fishing sector of this community has proposed as a formula of co-responsibility in the management of fishery resources.

Ten years after the creation of the marine reserve of "Os Miñarzos", this MPA has shown its effectiveness in several aspects. Thus, trust and collaboration between fishers and scientists has been improved, because the fishers have been providing data and participating in different monitoring programs. Furthermore, there has been a notable reduction in mistrust between the fishing sector and administration, favoring that most decisions of the Management Body have been made by consensus. Moreover, regarding the biological results, although the biological monitoring of fisheries was interrupted in 2011 due to lack of funding, it has been shown that the abundances of sessile and territorial species have been boosted (Fernández-Márquez, 2015).

In any case, this MPA has inspired other neighboring communities to propose another MPA of fishing interest on the Northern coast of Galicia (Xunta de Galicia, 2009b). Furthermore, a procedure for the extension of this MPA has been initiated in 2009 and it is currently in the final stage. The purpose is to move from the current 2 162 ha to 50 000 ha (in coastal waters), where eight fishing communities and 750 boats will be potentially benefiting (Fig. 2).

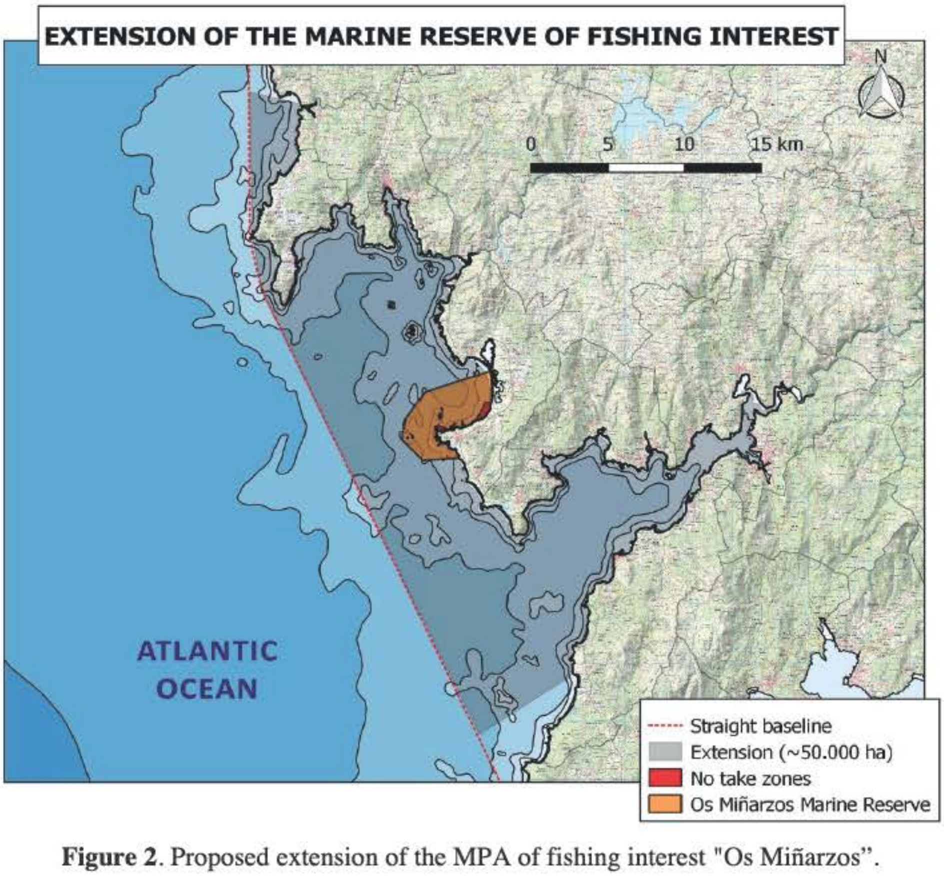

Figure 2. Proposed extension of the MPA of fishing interest "Os Miñarzos".

1.2 The role of local ecological knowledge of fishers in the design and zoning of the extension of the marine reserve of "Os Miñarzos"

In this process, a similar methodology to the original case of "Os Miñarzos" has been followed, where the use and application of FEK for the development of a habitat cartography has been a central point.

From the methodological point of view of the design for this new MPA, the changes made in comparison to other MPAs include a modified attitude of the facilitating entity towards fishers and the methodological focal points adopted. Throughout the process the entity has had a low and neutral profile. A bottom-up approach was adopted, and participative methodologies and community mediation, in an inclusive, open and flexible way were applied, checking the legitimacy of each step. A systemic and holistic approach to the social situation enabled the integration of complexity throughout the process; starting with a fragmented and divided fishing sector, the main challenges were to construct a common expectation for the future, encourage communication, for fishers to build up trust in themselves (awaken collective awareness) and with scientific and management institutions, and generate a spirit of necessary social entrepreneurship and autonomy.

In the process of creating the MPAs of "Os Miñarzos", fishers have taken part in the design and collectively defined the most suitable management plans for the sustainable fishing of common fishing resources. Proposals for regulation were more restrictive than those proposed by general laws. Furthermore, they incorporated criteria of spatial management which includes no-take zones. The process of collective construction and transformation of new management frameworks is slow and complicated, but it is necessary, not just to achieve consensus in the proposal but also to increase the fishing sectors' commitment to sustainability targets. In order to involve it in this process it was necessary to point out the advantages of constructing a model based on the general rather than individual interest. All this is boosting change, from a more competitive mentality to a more cooperative one, to the point that it is almost impossible for the fishing sector to consider going back to the previous scenario. In this specific case, local FEK have been used to identify species' essential habitats, perceptions of scarcity and abundance in the annual cycle of some species, identification of spawning and recruitment of target species, etc. (Fig. 3). Such information and data were essential to identify essential habitats to support the proposal of the extension of the MPA and the proposed zoning.

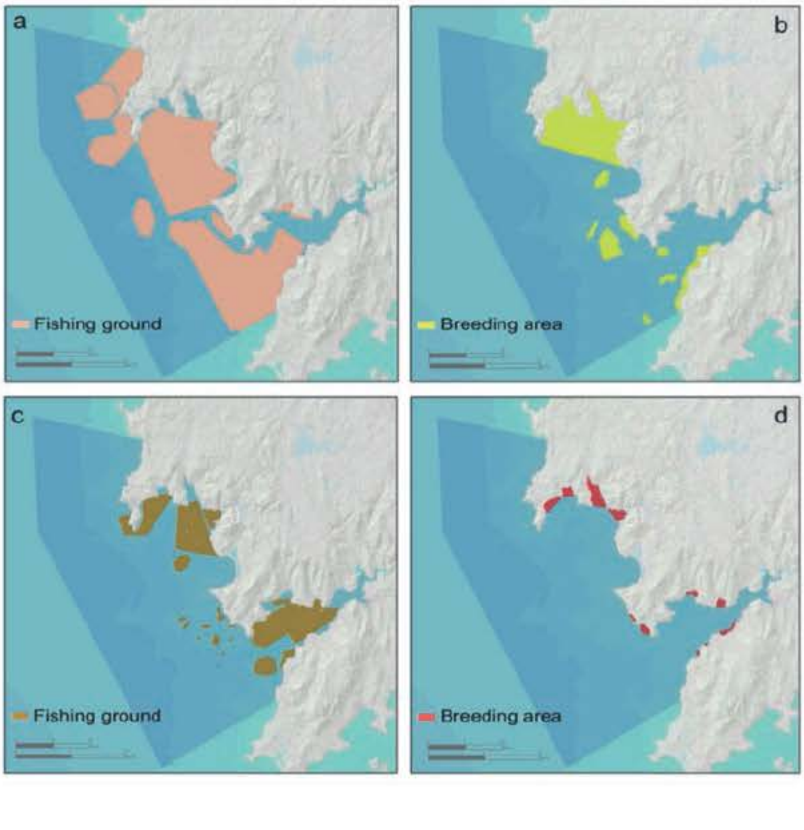

Figure 3. Map of the proposed extension of the MPA of fishing interest "Os Miñarzos" (shaded area) showing: (a) distribution of the fishing grounds of common octopus, based on local FEK; (b) distribution of the breeding areas of common octopus, based on local FEK; (c) distribution of the fishing grounds of European spider crab, based on local FEK; and (d) distribution of the breeding areas of European spider crab, based on the local FEK.

2. The case of the industrial purse seine fleet of Galicia

2.1 The role of social transformations in global fisheries

Research on marine social-ecological systems (SES) and sustainability goes with calls for deep social change (Steffen *et al*., 2015). Most of the research done on marine SES was focused on the transformations of the marine ecosystems and their ecological functions (Folke *et al*., 2011). However, it is highly difficult to address today's great challenges in global marine change and sustainability without a better understanding of how real and enduring social transformation comes about and how it can be initiated, promoted or (re)directed (Villasante *et al*., 2017).

To date there has been no systematic review of the social transformation of marine SES globally. Under the financial support of the ICES Science Fund Project "*Social transformations of marine social-ecological systems*", scientists, NGOs and the fisheries sector co-developed a new theoretical and a global database (Social Transformations Database, STD) with detailed information about the different human dimensions of the oceans and their drivers that have been documented.

Villasante *et al*. (2017) defined a social transformation in marine SES as a fundamental and critical change of values, institutions and practices of a social structure at the same time. To analyze the phenomena of social transformations in the marine arena, they examined the following core elements: (1) *values*, which refers to shared ways of living and thinking that include symbols and language (verbal and non-verbal); knowledge and beliefs (what is "good" and "bad"); (2) *institutions*, which contains the diversity of laws, regulations and costumes with competence to adopt decision on marine activities; and (3) *practices*, which includes the changes experienced by different marine activities (e.g., industrial and small-scale fisheries).

The STD provides a high-quality, descriptive, open-source information resource for students, lecturers, policy makers and researchers. The database was created based on a systematic literature review (Villasante *et al*., 2017). The authors searched for scientific papers published between 1950-2015 period in the Web of Scopus, by using the following criteria: "resilience", OR "shift", OR "change", OR "transform", OR "adapt", OR "transition", AND "marine", OR fisheries", AND "social". No geographical boundaries were stated in the selection criteria as preliminary test. Searches included all articles published until our cut-off date of 31 December 2015. These articles were then filtered at three different stages of detail, each filter excluding studies which are not related to the key words used in the search. A total of 456 articles were sourced from peer-reviewed literature and because of the filters and selection criteria employed and described above, 122 articles were reviewed fully in detail (Villasante *et al*., 2017).

Villasante *et al*. (2017) extracted from the literature review key information on twenty very common variables that helped evaluate whether social transformations could be applied to marine SES. The results of the literature review showed that the topic of social adaptation, change and transformation in marine SES attracted little attention for the scientific community in the 1950-2014 period (Villasante *et al*., 2017).

Further these topics started to receive important attention only since 2010, when a total of 10 papers were published, while the highest number of papers (15) was published in 2015.

2.2 Navigating transformations of the Spanish purse seine fishery

Based on the variables extracted from the literature review, Villasante *et al*. (2017) co-constructed with the FEK of key actors of the main industrial fisheries sector association of Galicia (ARVI) the social transformations of the Spanish purse seine fishery under the European Union (UE) Common Fisheries Policy (CFP). The fishing fleet is composed by vessels <25 m longitude and most vessels are based in Galicia. The fishing fleet mainly harvests key commercial pelagic species such as sardines, anchovies, mackerel and horse mackerel.

The social transformations of the Spanish purse seine fishery consisted in restructuring the fisheries sector, changing in the harvested species and diversifying the seafood markets over the last 25 years (Table 1). These changes are considered "*undesirable*" due to the lack of quotas and the application of the CFP, which at the national level is adopted by the Spanish Government. The implementation of the CFP to the fleet generated losses of fishing vessels, catches and employment in Galician coastal communities, but also lack to achieve key United Nations Sustainable Development Goals (SDG). This represents a valuable contribution to achieving key sustainable development goals, specifically by contributing to economic growth (SDG 2.3), employment growth (SDG 8.1), primary producer productivity (SDG 8.5), and gender equality (SDG 5.1).

Table 1. Source: Social Transformations Database of the ICES Science Fund Project. Main characteristics of the social transformations of the Spanish purse seine fishery.

Drivers	Impacts on fisheries sector	Impacts on human well-being	Adaptive strategies
-Change in the fisheries management system (from national quota to the TAC system)	-Reduction of fishing vessels	-Loss of seafood products for human consumption	-New species to compensate (mackerel)
-Lack of TAC/quota	-Reduction of catches -Loss of employments in coastal zones -Knock-on effects on the rest of the economy	-Loss of cultural ecosystem services	-Development of annual production and commercialization plans

Due to the lack of opportunities to modify the CFP, the adaptive strategies developed by the Galician fisheries sector have been focused on harvesting other commercial species and the development of annual production and commercialization plans to promote the self-regulation of the fisheries sector. The revitalization of the purse seine fleet would help avoid the socio-economic consequences of past mismanagement and generate new growth opportunities not only for the fisheries sector but also for the canned industry in key Galician coastal communities.

3. The use of the fishers' ecological knowledge, cost-effective tools and participatory models in fisheries management

3.1 The case of the common octopus trap fishery in the Ría of Arousa

Spain is among the largest consumers and importers of octopus (FAO, 2014), and Galicia is the Spanish region in which this species has greater economic and social relevance (Cornide, 1788; Cunqueiro, 1973). However, the management of coastal common octopus in Galicia generates many disagreements between fishers and policy makers (Pita *et al*., 2016). To improve this management we successfully used the FEK and cost-effective monitoring techniques based on participatory models developed with the participation of the main association of small-scale fishers of Galicia (*Federación Galega de Confrarías de Pescadores*, FGCP). In our study, we used FEK to obtain maps with the distribution of the fishing grounds of common octopus in the Ría of Arousa (central coast of Galicia), while GPS data-loggers and log-books were used to monitor the activity of vessels fishing octopus with traps to estimate the distribution of the intensity of the fishing effort and of catches per unit of effort (CPUE). Following Pita and Muiño (2014), key octopus fishers sketched the location of the octopus fishing areas on maps; this information was included into independent layers in a GIS, and finally added to achieve a single layer in which the zones where two or more fishers agreed on the distribution of octopus fishing grounds were added. In our study, 174 km^2 of octopus fishing grounds, mainly distributed in the mid and outer parts of the Ría of Arousa (Fig. 4a), were identified.

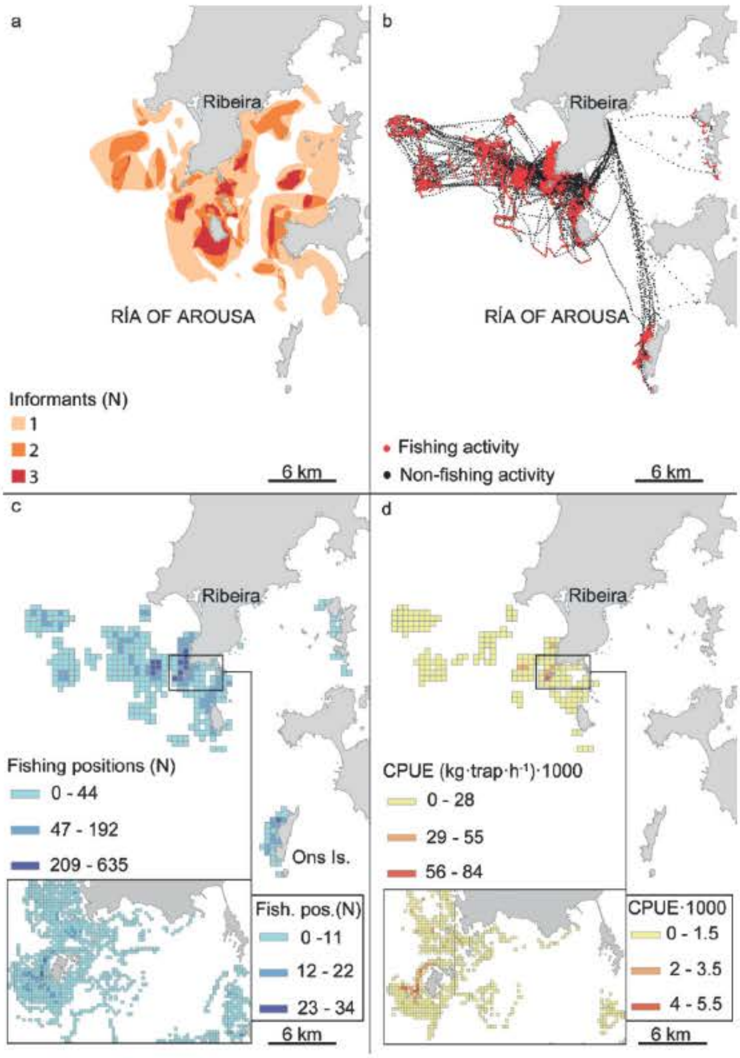

Figure 4. Source: Pita *et al*. (2016). Map of the study area in the Ría de Arousa showing: (a) distribution of the fishing grounds of common octopus, based on the FEK. The number of informants for each of the identified areas is indicated; (b) distribution of the records stored in GPS data-loggers carried on the vessels. Based on analyses of vessels' speed, the fishing activities and non-fishing activities have been distinguished; (c) estimated number of fishing positions for common octopus obtained in on-board GPS data-loggers by 500×500 m cells. In detail, fishing positions by 50×50 m cells; and (d) estimated CPUE (kg·trap^{-1}·h^{-1}·1000) of common octopus obtained in on-board GPS data-loggers by 500×500 m cells. In detail, CPUE by 50×50 m cells.

On the other hand, fishing vessels participated in a monitoring program, carrying low-cost GPS data-loggers that recorded the position of the vessels and provided information about catches in fishing log-books (Pita *et al*., 2016). Fishing and non-fishing activities were differentiated by Pita *et al*. (2016) through the analysis of the speed of the vessels, and the CPUE of each of the fishing hauls was distributed equally among their GPS positions (Fig. 4b). Most of the fishing effort was exerted in the outer part of the Ría of Arousa (Fig. 4c), also the most valuable fishing grounds in terms of CPUE (Fig. 5d) (Pita *et al*., 2016).

Pita *et al*. (2016) showed that the results of the fisheries monitoring were coincident with the FEK-based cartography because most of the fishing positions (70%) were located within the fishing grounds indicated by the fishers (Fig. 4a-c).

3.2 The case of the squid and cuttlefish fishery of the Ría of Vigo

Despite their ecological, social and economic relevance (Hyder *et al*., 2018), marine recreational fisheries (MRF) have been little studied in Southern Europe (Pita *et al*., 2017). Thus, MRF share with artisanal fisheries a strong lack of valid data for fisheries management Europe (Lloret *et al*., 2016; Pita *et al*., 2017).

To test new methods and tools to provide information about MRF, Palas *et al*. (2017) demonstrated that a combination of the use of FEK and low-cost GPS data-loggers provide data that can be also successfully used in the management of coastal ecosystems. In their study, Palas *et al*. (2017) performed interviews with key local informants selected among recreational fishers operating in the Ría of Vigo (South of Galicia), targeting squid and cuttlefish. In the interviews, ecological, social and economic information was collected, and following Pita and Muiño (2014) fishers sketched their fishing grounds for each species (Palas *et al*., 2017). Moreover, following Pita *et al*. (2016) fishing logbooks and GPS data-loggers were used to monitor this recreational fleet (Palas *et al*., 2017).

Palas *et al*. (2017) showed that the access points for shore anglers are in the port facilities, and that boat anglers target squid and cuttlefish over a fishing area of 30 km^2.

Moreover, the results of the fisheries monitoring (Fig. 5) were coincident with the cartography of the fishing grounds (Palas *et al*., 2017) who showed that the intensity of the fishing effort was greater around the mussel farms in the North of the study area. Also, the authors showed that the productivity of the fishing grounds of squid and cuttlefish varied with their location in the study area: catches of squid were higher in the outer part of the Ría, while catches of cuttlefish were higher in the innermost fishing grounds (Fig. 5).

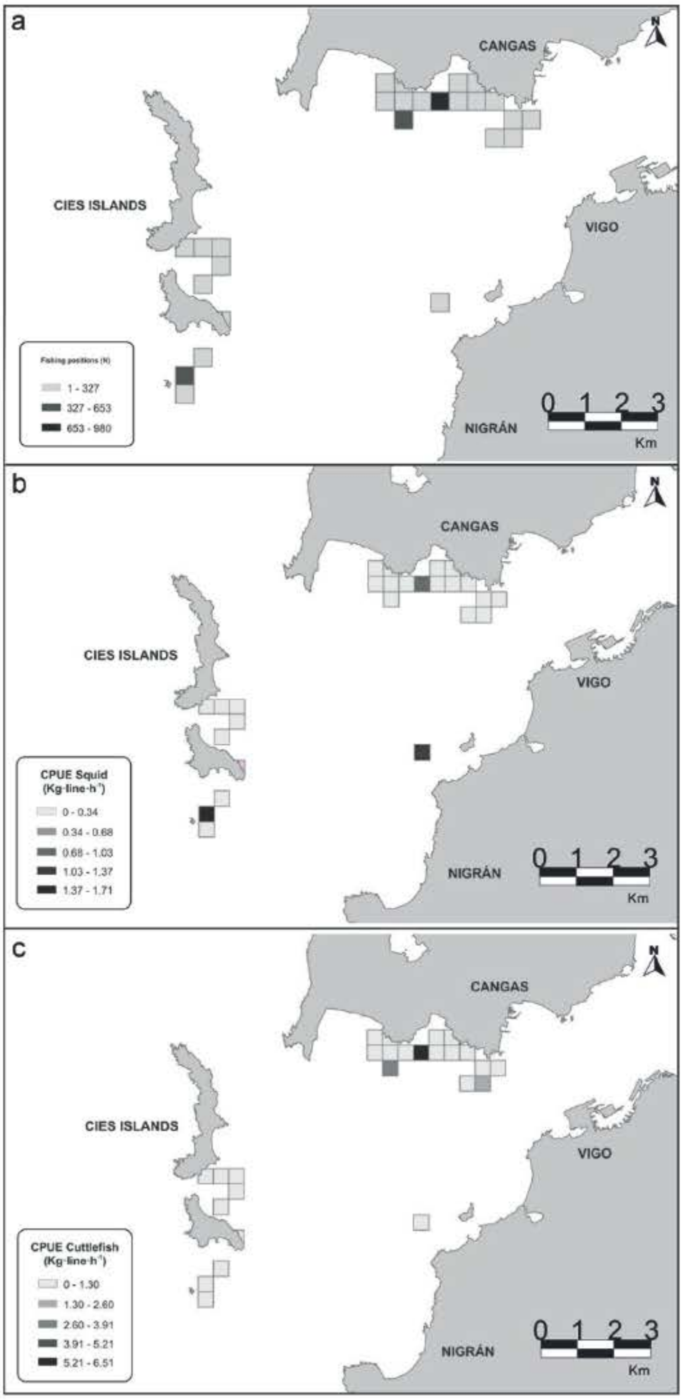

Figure 5. Source: Palas *et al*. (2017). (a) Distribution of fishing effort as the number of fishing positions for squid and cuttlefish obtained in on-board GPS data-loggers by 500×500 m cells , and estimated CPUE (kg·line^{-1}·h^{-1}) of squid (b) and cuttlefish (c) obtained in on- board GPS data-loggers by 500×500 m cells.

3.3 Evaluating the use of the Fishers Ecological Knowledge: the case of the Galician purse seine fleet in the Ría of Arousa

There are few studies that analyze the reliability of information based in the use of FEK. However, the results of FEK-based cartographies of fishing grounds have been found highly coincident with fisheries monitoring in the same areas (Palas *et al*., 2017; Pita *et al*., 2016). In this sense, Pita *et al*. (2014) compared the results of a FEK-based fishing ground cartography and the results of a fishery monitoring performed by the same vessels in the Ría of Arousa, showing that fishers tended to fish in the same areas of the FEK cartography, especially when GPS positions were associated with catches (Table 2).

Table 2. Source: Pita *et al*. (2014). Coincidences of the GPS positions with the FEK-based cartography (for the nine-coincident species; 0 = out of the cartography, 5 = 5 fishers coincided).

Species	Coincidences within layers of a FEK-based cartography											
	Total						Reported catches					
	0	1	2	3	4	5	0	1	2	3	4	5
Ammodytidae	2063	41	6	0	0	0	39	0	0	0	0	0
Diplodus sargus	1149	292	261	337	69	2	24	0	2	24	9	0
Engraulis encrasicolus	0	0	0	0	0	0	0	0	0	0	0	0
Pagellus bogaraveo	2035	75	0	0	0	0	15	0	0	0	0	0
Sardina pilchardus	671	1439	0	0	0	0	20	46	0	0	0	0
Scomber scombrus	364	1303	443	0	0	0	124	200	49	0	0	0
Spondyliosoma cantharus	1956	154	0	0	0	0	214	10	0	0	0	0
Trachurus trachurus	398	164	833	182	533	0	251	125	685	168	373	0

In their study Pita *et al*. (2014) used logistic additive multiple regression models (GAM) (Hastie and Tibshirani, 1990) to analyze the relationships between the different layers of a FEK-based fishing ground cartography and the positions of the fishing hauls obtained in a fishery monitoring program on a purse seine multispecies fishery. Pita *et al*. (2014) found a clear relationship ($P<2e^{-16}$) in the case of Atlantic horse mackerel *Trachurus trachurus*, the most captured species, with a very detailed FEK-based cartography with many overlaps between informants (Fig. 6).

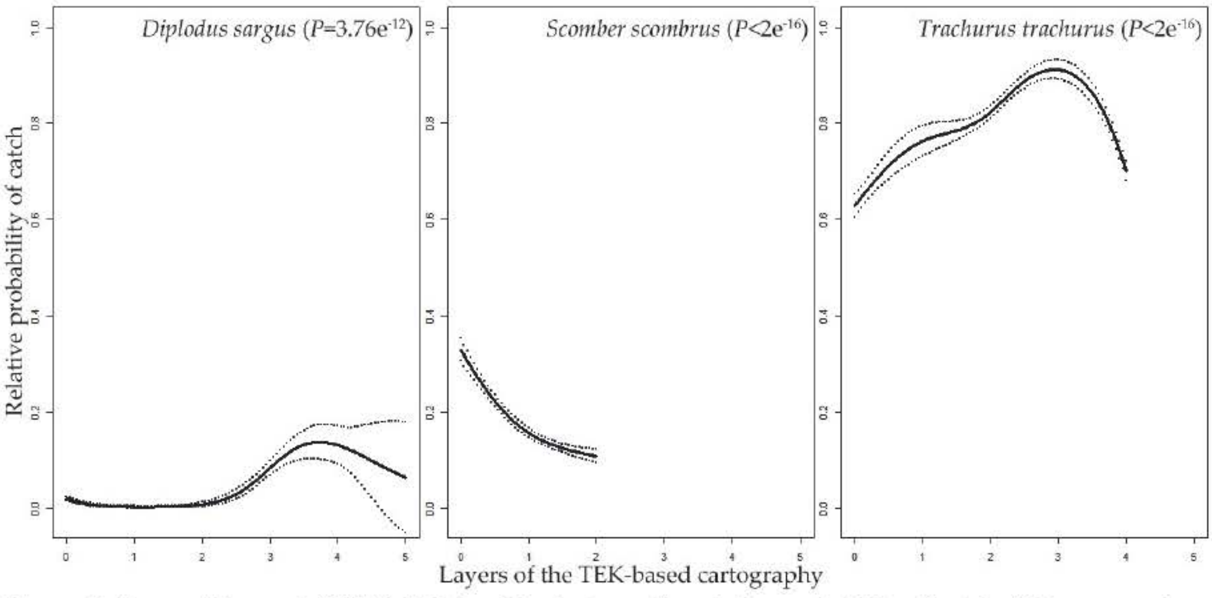

Figure 6. Source: Pita *et al*. (2014). Relationships between the relative probability of catch of the purse seiners and the layers of the FEK cartography by species (0=out of the cartography, 5=5 fishers coincided), obtained by GAM. Models with non-significant effects were not represented.

4. Conclusions

4.1 Lessons learned about the involvement of marine stakeholders in the co-production of scientific knowledge and in the fisheries management

The process of collective construction and transformation of pre-existing management schemes is slow, complex and complicated. Moving from traditional top-down management to frameworks that includes fishers in the management of common resources must overcome powerful inertias. However, the integration of local FEK with the existing scientific knowledge has fostered relevant bottom-up management proposals in Galicia. These initiatives included the use of FEK to define the size, shape, location and management of new MPAs, the use of FEK in combination with cost-effective monitoring techniques based on participatory models developed with the fishers to provide relevant information for the management of commercial and recreational fisheries, and the use of FEK to identify social adaptive strategies developed by the fishers to cope with emergent threats to their activity. The processes of coproduction of scientific knowledge and co-management are facilitated by the progressive strengthening of pre-existing relations of trust based on mutual knowledge among fishers, scientists, managers and policy-makers, and generated through previous experiences.

4.2 Opportunities and future challenges

The information based in the use of FEK was found highly reliable. Thus, by integrating local FEK into scientific knowledge in the management proposals, the fishers' vision of sustainability is also incorporated and more coherent and realistic management measures are legitimated and guaranteed. FEK provides not only information about the local marine environment, but also about the activity of the fishers, which can be used to manage complex SES. Therefore, the use of FEK to identify adaptive strategies developed by the fishers to cope with emergent threats to their activity can be used to evaluate different future alternative scenarios and to promote the self-regulation of the fisheries sector. The development of general schemes that help systematize the orderly integration of this knowledge should be developed in the future.

Acknowledgements
PP is grateful to the Xunta de Galicia for financial aid through RECREGES project under Grant ED481B2014/034-0, GAP2 project, FP7-SiS-2010-1-266544, and GEPETO project, INTERREG 2011-1/159. PP also thanks the Galician Federation of Fishermen's Associations (FGCP), the Provincial Federations of Fishermen's Associations of A Coruña, Lugo and Pontevedra, of the Fishers' Associations of Aguiño, Cambados and Ribeira, and of the fishers of the Ría of Arousa. PP finally thanks the recreational fishers from the Ría of Vigo and the Autonomous Fisheries Government of Galicia for their valuable support. SV is grateful to the Xunta de Galicia for financial aid through project GPC 2013-045, the ICES Science Fund to the project "Social transformations of marine social-ecological systems" and the European Commission "Ocean Governance for Sustainability - challenges, options and the role of science" (COST Action CA15217).

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Building trust between fishermen and scientists in Morocco: a role for women?

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1. Personal experience - first encounters with Moroccan fishermen.

My story with the fishing world began in Larache (Fig. 1) in the first fishing harbor I visited as a fishery student. In fact, the academic purpose of that visit was simply to discover the different harbor activities linked to fisheries as well as understanding the mission of each harbor institution. However, being passionate about marine science, the question was bigger than that...it concerned learning about and from fishermen as well.

Figure 1. Geographical localization of the Moroccan fishing harbors studied.

In general, fishermen do not have a good reputation in Morocco: they are commonly viewed as alcoholics, stubborn, solitary and irascible men. While the population often expresses great consideration toward the fisher's audacity and bravery for choosing this hard and high-risk job, it is frequent to hear among Moroccan citizen, "*The fishermen are rude, they use an abusive language and one should be careful near them.*"

What's more, when accessing a fishing harbor, the first thing you can easily observe is a purely male-environment where women are usually rarely seen. From fishing to selling the product, even in town, women are quasi-absent (Fig. 2). Further in the vein of the fishermen reputation, women are discouraged from accessing landing ports alone because they risk being catcalled and disrespected; the moment a woman steps into a crowd of fishermen unaccompanied, all eyes will undoubtedly be on her, and her safety is not guaranteed: "*Never go alone to a fishing port, otherwise you risk being raped*". Nevertheless, convinced that living experiences and learning from people that spend a thousand days and nights on the sea interacting with its resources can teach us more than we can ever learn from books, I did not let these prejudices prevent me from approaching fishermen and accessing their world… I accepted to take the risk.

Figure 2. Fish market. Tangier, Morocco

My first contact with them was not rewarding, same for the second. Gradually, I realized that something was going wrong and that I must deal with this challenge. Careful observation and many tries allowed me to find appropriate times to approach the fishermen. As one fishing skipper said: *"when I'm so tired after a fishing trip or when I'm preparing the ship to leaving the fishing port, I have neither the time nor the patience for anything else ", " the fishes do not wait, we have to sell them as soon as possible. "* (Fig.3).

A second, quite simple, element proved to be important: reserving enough time to introduce myself and explain the purpose of my visit. In that moment, I realized to what extent a small introduction removed misunderstanding and confusion. Most fishermen interviewed first thought that I came from the fisheries authority. As a secretary of Tangier's Fishermen Association stressed and as I noted myself later when I worked with fishermen from Tangier, Ksar-segher, M'diq, Al-Hoceima and Nador ports (Fig.1): "*any well-dressed person coming to the port with printed documents in hand is automatically considered to be from Fisheries Authority*".

Usually, Moroccan fishermen do not make a distinction between fisheries scientists and Fisheries Authority. They just believe that scientists work for the authorities. They even link them to management and regulations as they are always present in the negotiation meetings for implementing management measures. Due to scientific institutions' dependence on the Fisheries Administration, many Moroccan fishermen mistrust scientific results. Generally, this lack of credibility is considered as a significant hindrance toward trusting scientific results and toward establishing the credibility of science in general (see Hudson, 2014). In addition, fishermen express frustration at their inability to clearly understand the scientific language and at the inability of Moroccan fisheries scientists to adapt and simplify their speech. This fact clearly affects mutual understanding and hinders effective communication between fisheries scientists and fishermen (Hartly and Robertson, 2006).

Figure 3. The post-fishing work - Larache fishing port

Furthermore, many Moroccan fishermen expressed their skepticism toward the competence of Moroccan scientific institutions plus a misunderstanding of fisheries scientific work: "*How could they understand the state of marine resources from their office, behind their computers*", '*they are university graduates who have no field experience nor equipment appropriate for scientific research as do the European fisheries scientists*". Contrary to what the vast majority of Moroccan fishers believe, the Moroccan National Institute of Fisheries Research (INRH) is an organization established to develop and maintain the sustainability of Moroccan fisheries through performing up-to-date scientific research. In other words, it is created for the fishery sector. To fulfil its mandate, the INRH has its own budget, the scientific equipment, and the human competence needed. In addition to the central laboratories of Casablanca, the INRH has five regional laboratories each equipped with all material required to perform and accomplish the scientific studies and programs as well as respond to the region specific issues. Moreover, the national institute possesses two scientific vessels that conduct annual surveys. During their fieldwork, Moroccan national scientists spend up to a month at sea assessing the state of small pelagic and demersal resources[8]. This reveals a disconnection between the scientists and the fishers and a poor level of communication. These factors added to the non-inclusion of fishers in the scientific work could explain these misunderstandings.

Confronted with such confusion and misunderstanding, I understood then that I must pay particular attention not only to what I say but also to my behavior and, specifically, be careful not to patronize the fishermen. It is interesting to note that fishermen will respond in accordance with the way they feel they are treated, if they are valorized or, on the contrary, belittled. In fact, some people who worked closely with fishermen in their professional organizations confirmed that fishers felt valorized when they were invited to sit down, including when they had just returned from the sea with their clothes still wet and smelling of the sea, something rarely done in fisheries administration offices when interviewing fishers. Ms Hasna, from Tangier Fishermen Association raises this point:

[8] http://www.inrh.ma/fr/departement-ressources-halieutiques/laboratoire-de-prospection-des-ressources-demersales

"*The fisherman spends all night at sea, fishing. Once he returns in the morning exhausted to his home port he still is under the obligation to undergo administrative procedures and, due the scarcity of his free time, in those moments he might wish to seek some official documents from the fisheries authorities, yet he is usually met with contempt and feels visually despised because of his working clothes*". She adds: "*Cleaning chairs is not an arduous task to do, on the contrary I feel happy to do that especially when I see fishermen's satisfaction each time they access the association office*". Our communication with fishermen must improve. Basically, we must relearn how to unite the humanistic side of things with the technical side; to be professionals without losing our humanity identity is crucial.

After a few days, I realized that I was no longer perceived as an extraterrestrial who landed at the fishing port. On the contrary, marks of respect came to be manifested by most of the fishermen operating in the landing port I visited during our long conversations. Giving this evident stakeholders' poor relationship that well marked by mistrust, for a professional activity dominated by males for centuries and in an environment where women are rarely seen or expected to be mistreated, their first reaction was completely normal. In fact, this perception was also expressed by the two women working now with fishermen in Tangier fishing port: *"I'm really satisfied to be working with fishermen; contrary to what is commonly believed, they respect the women, they are even proud to have women working with them"*.

2. Onboard Moroccan fishing vessels

Clearly, visiting harbors and questioning fishermen is useful, but this approach is far from enough to understand and gain the fishermen community's trust. Therefore, the next steps had to be more profound…establishing a common ground and sharing fishermen's experience. To reach this ambitious goal, living in the same conditions as their own, at least for a couple of days, is crucial. This is necessary not only to closely see Moroccan fishermen working environment on board fishing vessels, but also to demonstrate concretely the interest in learning from and working for fishers. Therefore, I have spent about one month attending fishing trips aboard coastal purse seiners and trawlers operating in Agadir (Fig.1) marine waters.

In this context a Moroccan fisherman operating onboard Mediterranean coastal longliners said: **"***we, as fishermen need scientists having a significant field experience, who are apt to go at sea with us***"**. Another one operating on purse seiners added, **"***We have never closed our doors to someone asking to be taken on board for sharing our fishing experience, simply no one ever asked before*.**"**

My first fishing day was on board a purse seiner. Suspicions and worries were evident on the crew faces when I met them in Agadir's fishing harbor, just a few minutes before leaving the port. I realized that receiving people from fisheries administration on board fishing vessels is far from a reassuring event for the crew. As some fishermen reported at the end of this experience: **"**we *thought that the vessel was going to be under fisheries inspectors control or that new management measures would soon be implemented, namely banning fishing in some areas or during certain seasons or prohibiting targeting certain species, etc. We feared that something like that would mean a steep decrease in our incomes, or worse, losing our only source of income entirely if the activity should no longer be economically profitable for the owner*". In order to resolve this misunderstanding, I reassured them by introducing myself as someone passionate about learning from their experience. And I demonstrated it by showing a high curiosity to learn and to understand each fishing step, sharing the fishermen's living conditions as well as participating as much as possible in work aboard the vessels. In return, the skipper and their crew became collaborative and interactive; they helped me understand the vessels' technical operation, the fishing activity, the crew's payment system, the fishing costs and benefits as well as the landing commercialization. In fact, just taking the risk to be onboard a coastal vessel offshore, dealing with seasickness and learning the work onboard were in some way, weaving the first links of trust between us.

Crew's worries are actually well justified in a country where finding a job is becoming more and more difficult (unemployment rate did rise from 9.9% to 10.2% from 2016 to 2017)[9], where in many cases only one person works to feed a large family, where fishermen's fishing income is well below national average (World Bank, 2013) and where all seasons closed for biological reasons are not always subsidized. Going on a fishing trip on a coastal fishing vessel will help you understand the arduousness of working on board costal vessels. This fishing segment composed in 2016 by about 1 779 active fishing units, according to the Moroccan Ministry of Agriculture, Fisheries, Forest and Water. Each unit of the purse seiners provides up to 40 direct jobs[10], indicating the high socio-economic importance of this activity.


Figure 4. Fishing operation onboard a purse seiner (Agadir, morocco).

Disconnected from land and from internet, I struggled to maintain a precarious balance on the slippery floor and in a very cold and high risk working surface - in narrow shared space where even the oxygen seemed a little short, with the relentless noise of the vessel's engines (Fig. 4). I reflected on these conditions, on these fishermen who have to spend more time at sea than in their house with their families. I wondered how they could do that, considering that they must commercialize the catch and perform administrative procedures in the morning to finally go home, utterly exhausted, to sleep a few hours before re-leaving the fishing harbor in the evening. This situation encourages the fisher's estrangement from the non-fishing population and create an instability and stress within their own families[11]. This fact explains, in some way, the fisher's bad reputation among Moroccan citizen who do not try to understand the why of things.

Fifteen days on board three different vessels provided the opportunity not only to observe closely their work onboard but also to discuss a lot different subjects and issues. These discussions revealed considerable knowledge and skills of Moroccan fishers not only on fish harvesting but also on the bio-ecology of marine resources and their status. In addition to some perceptions on the state of the ocean (Fig. 5).

[9] https://www.hcp.ma
[10] http://www.reapcmaroc.com/pages/pub/doc/portrait_peche.pdf
[11] http://www.fao.org/docrep/004/Y1290E/y1290e04.htm

Figure 5. Moroccan fishermen knowledge.

Fishers, notably the skippers know exactly where to find and how to catch fish. The observation and the experimentation are key elements they rely on to improve at daily basis their understanding of the marine ecosystem and the resources. Precisely, they know a lot about how the abundance and the distribution of marine animals change with the type of habitat, water depth, seasons, time of day, even with lunar phases. In fact, Moroccan purse seiners' skippers are convinced that the vertical migration of pelagic fish change with lunar phases. *"During the full moon, small pelagic go down in the water, so we don't catch them."*- report purse seiners' fishers. Moreover, some fishers report that during the first and the third quarter of the moon the small pelagic fish are very abundant close to the water surface due to the concentration of their prey (zooplankton). In line with that, Poisson et al. (2010) emphasize the fact that large pelagic species behaviors and longliners catch composition are directly and indirectly affected by the lunar cycle. What's more, the fishers are very familiar with the winds and water currents. Their direction and strangeness allow them to identify the area of fish abundance and anticipate the fishing conditions. "*The strong current drift away fish, while they stay in the area and feed in slow current*". "*We avoid fishing when both water current and wind are in the same direction given that this prevents the opening of the net*." The fishers also use the seawater color and the marine birds as important clues of the fish shoal presence/absence and abundance. "A *large flock of birds flying close to water surface indicates the presence of important fish shoal*" (Fig. 6), "no *bird in the area means no fish is close to water surface*"- express Moroccan fishers.

Figure 6. Marine birds in the fishing ground.

A combination of numerous factors derived from a long-term empirical observation directly guides their behavior and fishing strategies to predict where fishing can be successful. The accumulation of such information allows them to develop their own mental map of the ocean. Furthermore, the older Moroccan fishers observe the marine resource declining trend in both abundance and size. In this sense, they report that: "*From 1990, the fish in our fishing grounds decreased continuously.*", "*the fish are shrinking in size*", "*the big fish are so scarce.*" Likewise, many fishermen are aware that the pollution and the habitat' alteration are threatening heavily the ocean health. "*Everywhere we fish we catch garbage as well*". "*Of course, this pollution harms the ocean and, therefore, affects its resource.*" - add the fishers interviewed.

However, all these valuable knowledge, expertise and perceptions are considered by the fishers as unrecognized, even ignored by the scientists, making them frustrated against science in general.

3. A sharp division of roles and space among men and women in Moroccan fishing communities

To better understand and integrate the fishermen population's daily life as a future fisheries scientist, I considered essential to spend a few weeks in a fishing village. The area I chose is called "Moulay Bousselham" (Fig. 1), a fishing village situated 70 km north of Kenitra and 35 km south of Larache. In addition to tourism and agriculture, small-scale fishing is one of the main socio-economic activities exercised there, thanks to the lagoon "*Marja zarga*". This lagoon plays a double function as (i) a spawning area yielding a considerable offshore fishing activity; and (ii) a significant natural clam deposit supporting an important in-shore activity.

I first went to the local office of the fisheries ministry, notably to the sub-delegation of maritime fisheries, to get fishing authority authorization to go at sea and to conduct my interviews with stakeholders. I met there some small-scale boat owners and fishermen, who expressed satisfaction toward this initiative and suggested to rent me a studio apartment at a meager price. Being in a house located in an area inhabited only by fishers was a gold opportunity to integrate quickly the fisher's society. Trust is not something we buy or can demand from others; it is something that we earn. To this end, considerable efforts and time were invested to be able to integrate this community. I especially invested time to listen carefully and actively to their problems, difficulties, social stories as well as attending their social events and accepting all the invitations (Fig.7). In addition, a socio-economic study was conducted to understand well the small-scale fishing activity in this area.

Figure 7. With the fishers and their family.

The first observation I made was that contrary to other fishing ports visited, Larache and Agadir, the fishermen of Moulay Bousselham were more trustful towards fisheries authority and scientists. They even talked positively about them. Indeed, to improve the socio-economic conditions of Moroccan artisanal fishers, this fishing village was recently equipped with modern artisanal boats (in polyester) and with the necessary infrastructures for catch landing and commercialization. Moreover, in order to organize the local fishers and involve them in managing the new implemented structures, a fishers' cooperative was created by fisheries authority. This cooperative not only involved and empowered the local fishers but also allowed improving the communication between the stakeholders, which explains the positive perception of fishers from Moulay Bouselham toward the authority.

Men operating in small-scale fishery (offshore) Women gleaning for clams inshore.

Figure 8. Fishing activities practiced in moulay Bousslham fishing village.

My second observation concerns an evident gender division of labors in this fishing village. Men work on artisanal fishing boats offshore and women on collecting invertebrates in-shore (Fig. 8). In Morocco, for centuries, fishing offshore, including gear repair, has been reserved for men. While, the women dominate fishing inshore and the post-harvest processing of fish (Fig. 9) (Naqrachi, 2007). Gradually, many Moroccan Degree-holders women from maritime training institutes and fish processing institutions are involved in the fishing research and management establishments, some of them even managed to hold successfully responsibility positions.

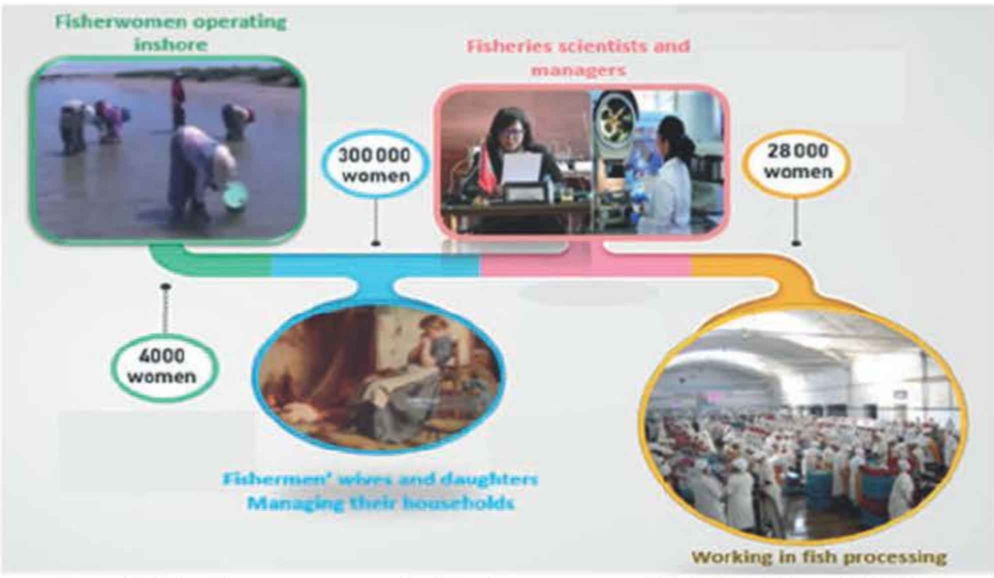

Figure 9. The Moroccan women in fisheries sector, modified from Naqrachi (2007).

Many reasons can explain Moroccan women's absence in fishing offshore, with traditions and socio-cultural reasons as a main driver. In Moroccan communities, the idea of fisherwomen working onboard fishing vessels was neither accepted nor encouraged. First, it is anchored in Moroccan traditions that fishing is a masculine activity only devoted to men. A clear majority thinks that the female body cannot endure the difficulty of working aboard fishing vessels. Even many women are sure of that. Some fishermen express that clearly: "*even men find working onboard hard, some couldn't endure sea sickness*", "*This kind of work isn't for women; their place is at home or in other kinds of jobs*". A fisheries scientist who worked in "Imsouan" fishing village stressed that: "*Given the required physical effort and the conservative lifestyle of families in the region, the woman is very present in many activities other than fishing onboard vessels such as agriculture, crafts or Argan production, all in addition to her role as housewife*.". Even some fishermen's wives expressed that: "*For me as a woman, I don't want to risk my life in this kind of work, nor working in a male environment*", "*I can't work in an isolated environment at night with fishermen*".

What's more, in some Moroccan regions, some fishermen consider women as bad luck once they are onboard vessels. "*After several fishing trips, some girl students in the fishing industry field managed to be boarded by a coastal trawler operating at the port of Larache. Three days later, the ship sank. Automatically, many fishermen linked the accident to the woman's presence onboard this vessel. Others blamed the vessel owner for accepting to take them onboard"*, as it is reported by these women themselves.

As mentioned previously, some women are convinced, as well, that their place is not in fishing vessels; not only due to the arduous work onboard, but specifically fearing society's rejection. Another reason is their family obligations. Taking care of house and kids are a fishermen wives' sacred functions to which men rarely contribute, in accordance with customs and traditions. Consequently, scarce are the women who have the audacity to try accessing fishing offshore. In fact, the women operating in shellfish collection do not consider themselves as fishers, a thing also pointed out by Calhoun *et al*. (2016). In addition, the women from Moulay Bousslham stressed that collecting clams allowed them to have their own income, thus improving their household's livelihood. Moreover, it is a part-time activity, close to home and could be performed in the company of their children.

These perceptions are not an absolute evidence, nor are they true for all women and forever. As mentioned in Keleiber *et al*. (2014), the idea of women's inability to work offshore is far from universal and to think that ideas are unchangeable is not realistic. Now, there are many women who have shown their ability to assume this kind of work at the same level if not better than men.

"*I worked at sea almost one year as a skipper assistant onboard five different coastal purse seiners operation in two different fishing ports. From my first day onboard, the skipper was so surprised with the fact that I never had sea sickness, I even felt comfortable despite the vessel's instability…. all the crew were shocked, they reported this around the whole port. Some days later, I was able to pilot the vessel; both the skipper and the crew were so proud of me that they named me the brave fisherwoman*"- expresses a skipper graduated from the Marine Fisheries Technology Institute- (ITPM) Al-Hoceima.

Another Moroccan woman operates onboard a large-scale industrial trawler as a skipper assistant, a vessel that keeps fishing four months long at sea. "*She worked with me first onboard my coastal longliner as a trainee, she was a special girl with high capacities and enthusiasm for learning. Now she works in Dakhla, onboard a large-scale trawler. For me as a man I cannot work 4 month long at sea: I* *feel as I am in prison. She demonstrated very well that she can do it... so just bravo!*"- reported a Tangier longliner skipper.

Many other engineering students attend fishing trips for training purposes. They report that their ideas and perceptions about fishermen and about working onboard were changed by the experience. In contrast to their a priori, they were well accepted by the fishermen community, who they say were so helpful, satisfied and cooperative with them on board. In the end, it seems that fishermen enjoyed having women onboard (Fig. 10).

Skipper women studding fishing activities in a official institution

Skipper and fisherwomen trainees on fishing vessels

A fishery scientist' students on board Moroccan coastal trawler, storing fish with fishermen

Figure 10. Moroccan women involved in fishing activities onboard fishing vessels.

However, the scarcity of available information about Moroccan women successful experiences onboard and on their existing roles in the fisheries sector is something that cannot be denied. This fact raises the need to make their presence and their contribution acknowledged. In this respect, some international initiatives to make the role of women visible and increase attention on their contribution in fisheries sector in general are worth mentioning: the Global Symposium on Women in Fisheries (Harper *et al.*, 2013; Tindall & Holvoet, 2008), the European network of fisherwomen's organizations in Europe (AKTEA)[12], Too Big to Ignore (TBTI) Research cluster on women and gender, and the FAO Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (SSF Guidelines). However, the role of women from the south shore of the Mediterranean Sea, mainly those operating offshore vessels, is still ignored. An additional effort is required to make tangible actions to redress gender inequities in this region, increase awareness of gender issues and, especially, to dispel perceptions that women are weak and helpless. Not to forget the importance of creating an appropriate working environment for women that is free from discrimination and harassment and, why not, encouraging them to access this sector by offering fishing vessels to the 'role model' women as was done by the Algerian fisheries ministry (Fig. 11).

[12] http://akteaplatform.eu/

Figure 11. The Algerian skipper women winning the coastal fishing vessel.[13]

4. Conducting a collaborative research with fishers – putting the pieces together.

In the frame of end of study' project, a scientific research on "the exploitation of Bluefin tuna and swordfish in the Moroccan Mediterranean" was carried out in 2014. The Moroccan fisheries authority was collaborative and helpful, which allowed accessing all statistical data needed to perform the study. Convinced that the local fishers have a valuable and accurate knowledge that could complement this work and make it more reliable and profitable for these fisheries, I decided to include fishers' information as well. Conscious that meeting this goal requires, first, establishing a solid basis with local fishers, all the lessons learned from my previous experiences with stakeholders were joined together to found a working strategy (Fig. 12).

Figure 12. The strategy pillars used.

First, a 'bottom-up' approach was adopted. In other words, a democratic approach which involves the principal stakeholders, the local fishers and vessels' owners, in a collaborative context is used. In this context, the resource users were the starting point and they were contacted directly without an official

[13] https://www.youtube.com/watch?v=MqLBxMYKgyM

or apparent intervention of fisheries authority. In fact, to include a significant number of fishers in the most easily and organized way, meeting the fishers' associations and cooperatives was given particular attention. During the first encounter, explaining clearly how I'm and why I'm here as well as stimulating fishermen to participate in this research were the main objectives. The study subject was in itself a considerable incentive to involve them. In fact, recently (in 2012) the Moroccan government adopted the ICCAT recommendation on banning fishing with gill net, the main fishing gear used to catch swordfish in the Moroccan Mediterranean water. Therefore, the analysis of the evolution of swordfish exploitation and the identification of the immerged problems recommending the appropriate solutions were so needed, specifically, for the fishers' community. In the end, fishermen themselves are the beneficiaries. Moreover, expressing the interest in learning from their valuable knowledge and underlining their potential role in making the present study results robust and reliable motivated the local fishers and their associations to collaborate.

Throughout the study, a particular focus on effective communication was made to build trust and respect, and improve teamwork. In fact, having some field experience (in fishing ports and onboard fishing vessels) played a crucial role. Specifically, it helped to simplify the scientific language and speak the same technical dialect 'jargon' as fishers. Without forgetting that, in general, fishers consider scientists with experiences on the water and with fishers as competent, one of the most significant determinants of trust on scientific community. Another major element that significantly contributed was to invest the time to listen actively to fishers' detailed explanation, often mixed with their own professional problems and issues. That not only contributed to a better understanding but also made the speaker feel heard and understood, which allowed a stronger and deeper connection between us. When necessary, the humor was also used to manage some imbalances and confusions. Moreover, opportunities (coffee and lunch breaks) were created to promote some informal talks and trust building, a property of lasting relationship.

Moroccan fishers got involved and motivated. They not only shared their knowledge but also incited the fishers from neighboring fishing villages to participate. As a result, the number of interviewed fishers raised significantly. In addition to the four pre-selected studied areas, two other mean Bluefin tuna landing zones were acknowledged and included in the study, making both the data and results more reliable. Moreover, the most sensitive fisher's working secrets were also shared, such as the fishing grounds, the incomes and the illegal practices. It is here that the accuracy and breadth of knowledge shared by fishermen is crucial. Furthermore, thanks to this positive experience, the fishermen's associations recruited two women and the relationship with local fishers has been maintained until now.

5. How Moroccan fishermen perceive the competition with dolphins and with jellyfish.

5.1. Dolphin depredation

As in many other coastal countries, Moroccan fishermen suffer from marine mammals' depredation on their catches. However, the issue's perception and socio-economic impact seriousness level differs from one Moroccan region to another, and even from one period to another. It seems that Atlantic Moroccan fisheries are more sheltered from this problem. During my trips on board coastal fishing vessels, dolphins swam around the seine net, but no damages were caused. Fishers from Agadir reported that they were not impacted by dolphins nor disturbed during fishing operations as dolphins only fed on fish escaping from seine nets.

On the other hand, fishermen operating onboard purse seiners offshore Kenitra (Fig.1) declared that dolphins have become more present in their fishing grounds and attack their seine nets from time to time. The fishermen have adopted a strategy to overcome this problem: once their seine net is closed, some fishermen swim in the net to frighten the dolphins away. However, their method only works if the dolphins are swimming away from the group and if the fishers act before the attack, which is not always the case.

In Mediterranean waters, notably in Al-Hociema and M'diq (Fig. 13) harbors, fishers seriously suffer from the attacks of Bottlenose dolphins, *Tursiops truncatus*. This species is locally called "El *Negro*" (black one in Spanish). This mammal is considered as their "*biggest enemy*". Others consider it as "*a real nightmare*".

Figure 13. Moroccan fishing vessels owners operating in mediterranean harbors reporting their high economical loss caused by dolphins (Moroccan local official news channel, "2M").

Almost all seiners are under dolphin attack in this region, causing considerable economic losses, like nets repairs, catch losses, fuel and time wastes. "*This strong mammal waits calmly until we retain the shoals fish and then goes through the seine net damaging it and drawing out quasi all the catch*"-report fishermen. In addition, as the fishermen pointed out, when the net is damaged and then repaired many times, it loses its effectiveness to retain shoals fish. Therefore, they are obliged to replace it by a new one. As this crisis makes a stable income unlikely, many fishermen now flee Al-Hoceima harbor, leaving their family there, to the nearest Atlantic ports such as Tangier and Larache. Many others sell their boats and nets to convert to longline fishing, as dolphins tend not to attack fishing lines. However, this perception is not true everywhere and forever. In fact, in other sectors of the Mediterranean Sea, notably in the Balearic Islands, Bottlenose dolphins mainly attack the bottom fishery (see Brotons, this volume). Moreover, this species has a highly varied diet coupled with high level of flexibility and adaptation (Giménez *et al.,* 2017) and is able to learn quickly new behaviors and skills from foreign individual dolphins, once they join the group. A finding expressed by Brotons as "Tursiops' invasive culture". This seriously puts the question of the long-term effectiveness of the purse seiners' conversion into a new fishing method to resolve the issue.

Furthermore, some Tangier fishermen stressed the emergence of a new conflict between Mediterranean and Atlantic fishers. In fact, the former use light to attract small pelagic fish during fishing operations, a method considered unsustainable and forbidden in the Atlantic fisheries. "*They collapsed their small pelagic resources in Al-Hoceima with this technique and now they want to do the same in our fisheries*"-reports a Tangier fisherman. As their neighboring counterparts underlined, the local fishers are not completely the dolphins' innocent victims. They simply pay the result of their practices and we must stop blaming dolphins. In fact, irresponsible fishing practices are behind the significant decrease in marine resource in this area. In Al-hoceima, small pelagic is targeted in its spawning area using a fishing net with a small mish size. In this context, an older fishermen said :" *in the Al-Hoceima bay, fishers catch the very small sardine include its eyed stage " larvae" using a fish net in which even the water is hardly filtered*.". Moreover, in this region fishers use light to attract large fish shoals, making a high pressure on this stock. The resource scarcity coupled with the increase in abundance of these marine animals, caused a high competition on fish. Fishermen said that "*this species is protected by a regional conservation agreement, and so multiplied progressively. To get food, they become violent.*" "*This species is very intelligent, strong and lazy, it uses its intelligence to feed itself without any effort*". Other fishermen think that Bottlenose dolphins try to save fish from seine nets or they do that for revenge.

Trying to deal with this issue, ultra-sound emitting devices on fishing boats were introduced by authorities. However, this method was not successful in scaring away the dolphins for long; soon they re-attacked nets, in greater numbers this time (Zahri *et al*., 2004). Confronted with vessel owners' pressure, the State was forced to compensate them for loosing nets. Certainly, this ephemeral solution allowed calming the tensions, but it is far from enough in solving this complex situation. The presence of dolphins in our marine water could make the area more attractive for tourism, which may considerably raise the economic profitability to the local fishers and the coastal population (e.g. increased demand on hotels, restaurants and seafood).

5.2 Jellyfish proliferation

Nowadays, jellyfish outbreaks have become a worldwide phenomenon and Morocco is no exception. In fact, since 2011, several Moroccan beaches live, gradually, to the rhythm of jellyfish invasions. Precisely, between Larache and Agadir. These stinging gelatinous planktons not only spoil the swimmers' vacations but their presence also starts to be a nuisance for Atlantic fishers. Several fishermen from this region have seen their work disrupted by large quantities of *Physalis* caught in their nets. Recently, the Mediterranean beaches, between Tetouan and Tangier, are facing the invasion of large colonies of jellyfish (*Pelagia noctiluca)* as well, perturbing the most frequented Moroccan seaside resorts. Nonetheless, some fishers from Tangier declare that their catches and more generally their incomes are not negatively impacted by jellyfish blooms presumably thanks to the presence of the Sunfish *Mola mola* (Fig. 14), which preys on jellies, in their fishing ground. Sometimes jellyfish are retained in their fishing nets but only in very low numbers. Fishermen consider this event as normal. "*This kind of species appears from time to time and then disappear*"-express fishers. However, some of them stressed that they suffer a burning sensation when getting jellyfish out of fishing nets.

Figure 14. Ocean sunfish, *Mola mola*; illustration by Michael Viney.

The problem of jellyfish blooms is bigger than Moroccan fishers think. This very small and beautiful animal could, indirectly, affect more heavily their incomes than Bottlenose dolphin' visible attacks. Most fishermen ignore that this species prey on fish eggs. Further, it competes with fish larvae and juveniles on the available food. Beside global warming and overfishing, the jelly's invasion could become an additional stressor to Moroccan fish stocks, making the recruitment success unlikely. The presence of sunfish in some Moroccan Mediterranean fishing grounds may help mitigate, locally, this problem.

6. Concluding remarks - some reasons for hope.

The stakeholders' perceptions emerging in this chapter reveal the poor quality of Moroccan fishermen-scientists relationship, suggesting a need for change. Giving that trust is the cornerstone of lasting relationships, it is urgent to invest substantial efforts in this direction. Especially within the growing challenges facing the fishing activities' sustainability, such as jellyfish blooms and Bottlenose dolphin' depredation on the catch. This imposes a growing need for (i) high quality science based on a reliable and an accurate data, (ii) continuous spatio-temporal sea monitoring, (iii) tangible and effective results and (iv) all that with low costs. This requires involving stakeholders, specifically the fishermen. As seen previously, creating opportunities for scientists to closely work with fishers and share their life conditions, valorizing fishermen knowledge and listening carefully to their problems and ideas would offer tremendous potential to build a mutual understanding and bridge gaps between fisheries scientists and fishermen. So they can face the fisheries key issues. Promising trails to break down misperceptions, develop a common language and enhance mutual learning between scientists and fishermen could start with collaborative research. In passing, this would demonstrate the importance of fishermen' expertise and role and increase the credibility of scientific results, which also could contribute in enhancing the management measures compliance.

This male-dominated fisheries world, so closed for centuries, now appears to open at last, even if slightly, to Moroccan women. Despite the socio-cultural beliefs of Moroccan society, many women now accept the challenge to enter the fishing sector, not only as fishery scientists but also as skippers and fisherwomen. Certainly, these "role model" women are paving the way for others, demonstrating that both men and women could exercise such jobs successfully as long as one gives them the opportunity to try. At present, women are increasingly interested to learn fishing activities in high schools. , It becomes more and more possible therefore to envisage women onboard fishing vessels together with fishermen offshore. This has long been a taboo and beyond imagination in Moroccan society.

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Stakeholder perceptions of disruptive biological factors affecting coastal activities

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Abstract
Coastal areas support many human activities, which are backed up by stakeholders. These activities may suffer from biological disruptions that consequently affect the outcomes in an undesirable manner. There is a number of recent surveys on stakeholder perceptions considering particularly coastal and marine issues but few of them have focussed solely on disruptive issues. Stakeholder perceptions can be obtained by applying stakeholder analysis approaches, namely by finding a goal or purpose for a given change (or another), identifying stakeholders, classify them by type, determining their power, finding out their interest, and get their engagement. Some published cases dealing with stakeholder perceptions have shown that few disruptive factors were identified and prioritized. Usually stakeholders are able to provide their empirical experience, whether they are well aware of the object of study or not. Stakeholder representatives much appreciate to be included in the process of research analysis.
Keywords: Stakeholder perceptions, coastal activities, disruptive factors, aquaculture, fisheries

1. Introduction

Coastal zones support many human activities. Those activities have been in constant evolution through times. Technology is important to turn such activities more and more efficient and bring welfare to people. Thus, as more activities develop, more competition for scarce resources will exist, making coexistence compulsory (Hennessey and Sutinen, 2005). Economic and leisure activities are supported by stakeholders, which represent groups of people or individuals (Stocker and Kennedy, 2009). Stakeholders have different interests and power in order to assist or refrain activities (Ernoul and Wardell–Johnson, 2015). In each activity, stakeholders could be allocated either into the supply or demand side of a given stake (Béné, 2005).

Humans have developed coastal activities such as fisheries and trade shipping through times. By an anthropocentric view, technology improvement has been useful for more economic efficiency of activities (Billé, 2008). Nevertheless, at the cost of some negative impact due to pressure on living organisms, as is the case of overfishing particularly since the 1960s (Hiscock, 2014). By the other way around the disruptive impact, some living organisms inflict on human activities (Sharma, 2009) can be observed. The term disruptive can be defined as "disturbance or problems which interrupt an event, activity, or process" (Anonymous, 2014).

The objective of this paper is: first, to review the scientific literature dealing to stakeholders' perception thematic in general terms, but more focused on coastal activities; second, to describe in brief within the methodology by one hand which instruments are more useful in social sciences in order to collect data from stakeholders and on the other hand to carry out a stakeholder analysis focusing on stakeholder perceptions; third, to describe in short, three cases published where stakeholders' perceptions were studied.

2. Literature review on stakeholder perceptions

The term "stakeholder" appeared in 1963, but was only widespread in the 1980s, after a theoretical background developed by Edward Freeman (Miles, 2012). The theory addresses the "principle of who and what really counts" (Mitchell *et al.*, 1997). The term stakeholder has several definitions and is not very consensual. It has been used interchangeably as "social actor" and "interested party" (Newton and Elliott, 2016). It can, thus, be defined as any individual or group of people who have or claim ownership, rights, or interests in a corporation and their activities, whether at present time or in the future (Clarkson, 1995). A stakeholder can be positively or negatively impacted by something. There are applied methods of stakeholder mapping, often in addition to power/interest matrices. These approaches are usually used to not only identify stakeholders, but also to pinpoint their influence on the study objects (either impacts, projects or any other) (Olander and Landin, 2005). A stake involves a certain degree of risk, including loss (Donaldson and Preston, 1995). The term "stakeholder" was usually applied to the firm, but it was widespread to other areas of research (Polonsky, 1995).

Concerning "stakeholder perception studies", until 1995 there were only 26 works found in the academic literature. But in the five-year period thereafter, that figure more than doubled based on a Google Scholar search on the literature (Fig. 1).

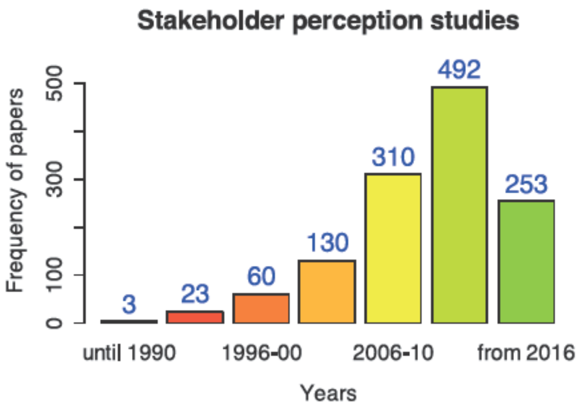


Figure 1. Frequency of stakeholder perception papers worldwide (source: Google Scholar, February 2018).

Most of these early studies were related to education (Lawrence, 1989) or health care issues (Wheeler and Zuckerman, 1984). Until recently, education dominated the number of studies, but there was a wide diversification of issues. As far as disruptive factors are concerned, one can find a few "stakeholder perception studies" since the late 1980s (Pate and Nielsen, 1987). Studies on "stakeholder perception" treating marine issues only appear in late 1990s (Martin and Nielsen, 1997). In the more specific literature on aquaculture and fisheries, one finds that most of the studies were carried out just quite recently, basically since the last 15 years or so (Table 1). Studies focused on disruptive factors are not common and when they exist, their central point is on diseases (in the aquaculture case), or management issues (in the fisheries case).

Table 1. Some examples of stakeholder perception studies carried out on the aquaculture and fisheries scope.

Study area	Activity	Main issue / theme	Year	Reference	Stakeholders
US & Norway	Aquaculture	Expansion or not	2010	Chu *et al.*	Key aquaculture stakeholders (online survey)
Chile (Patagonia)	Aquaculture	Salmon socio-economic impacts (ISA virus)	2015	Salgado *et al.*	Government, NGOs, local communities, fishermen, aquaculture firms
Chile	Aquaculture	Mussel	2017	Rivera *et al.*	Seed collectors, growing centres, processing plants, service providers
Canada (NS)	Aquaculture	Eco-labelling	2018	Weitzman & Bailey	Fish farming, food industry, scientists, managers, wild capture fishing industry, environmental groups
Portugal	Fisheries	Artificial reef impacts	2007	Ramos *et al.*	Fishermen (7), anglers (7), divers (6), administrators (8), scientists (8), other stakeholders (8)
EU (Scotland)	Fisheries	Decision making process	2010	Pita *et al.*	Fishermen
England	Fisheries	Inshore co-management	2011	Rodwell *et al.*	Inshore fisheries & conservation authorities (IFCAS) (40 in an online Q – 4 IFCA chief officers)
Czech Republic	Fisheries	Otter vs inland fishermen	2011	Václavíková *et al.*	Fishermen (125), conservationists (36)
Cape Verde	Fisheries	Decision-making process	2011	Ramos *et al.*	Biologists (6), diving operators (3), NGOs (3), managers (4), recreational divers (26)
India (Kerala)	Fisheries	Lack of technological transfer	2015	Jayapradeep & Nair	Primary stakeholders
Southern North Sea	Fisheries	Pulse fishing	2015	Kraan *et al.*	Representatives of governments, NGOs, fishing industry, scientists – (7 meetings)
European countries	Fisheries and others	Coexistence of coastal activities	2015	Ramos *et al.*	Fishing industry (17), aquaculture producers (16), tourism operators (13), energy and scientists (21), authorities (22), NGOs (18)
Solomon islands	Fisheries	Small-scale fisheries co-management	2015	Brewer & Moon	Fishery stakeholders (133) 10 dominant roles on 7 stakeholder types
Brazil	Fisheries	Closed season and integrated management	2017	Musiello-Fernandes *et al.*	Artisanal fishermen (80)

3. Methodology

In order to get useful information from people in studies of stakeholder perceptions, there are different instruments that can be used. Some of them may arguably be more adequate than others. Surveys, focus groups and unobtrusive methods are usually adequate instruments to collect data (Robson and McCartan, 2016).

3.1. Instruments to collect data

A survey is a method intending to gather information from a sample of individuals (Fig. 2A). It is common that the group from which the information is collected shares some common characteristics (Fink, 2003). The sample is just a certain portion of the whole population where there is an interest to be studied. From the perspective of the researcher this is important in order to gather factual information needed to evaluate perceptions on the object of analysis. In a survey, detailed proof of what is being examined is less important than the understanding of the activity that has been reviewed (Frankfort-Nachmias and Nachmias, 2007).

A focus group is a particular type of group interview with a given focus (Fig. 2B). It is based on an open-ended group discussion on a topic, moderated by typically one researcher and a support person. It can take at least one hour and be extended to two or more hours. It consists of at least four people, but groups of eight to twelve people are more common (Kamberelis and Dimitriadis, 2013). The propensity for homogeneity or heterogeneity of the groups depends on the research topic. Homogeneity groups allow a common background, position or experience, easing the debate of ideas; whether heterogeneity of groups can enrich the discussion because other perspectives are brought about, but can lead to a dominant participation or lack of respect from others (Stewart and Shamdasani, 2014).

In addition to the above technique, it is also important to develop unobtrusive methods where stakeholders are studied, but where there is no direct contact with them (Fig. 2C). An unobtrusive method is non-reactive, as is the case of a document that is not affected by the reason of the researcher in using it (Robson and McCartan, 2016). The rationale for using such method is based on the importance of investigating in an unbiased manner stakeholders' expressed values, beliefs and attitudes either by the supply and demand sides of the subject in analysis. Methods focusing on media such as newspapers and internet sources are commonly believed to be very useful to reach the intended results (Hansen, 1998).

A B C

Figure 2. A) Carrying out a survey in a dockyard. B) A group interview involving fishers and researchers in a local village association. C) Online news used as research document (unobtrusive).

3.2. Conceptual model for a stakeholder analysis

A stakeholder analysis consists in several steps that should be followed in order to obtain the best results. For instance, MacArthur (1997) carried out a stakeholder analysis by applying a conceptual model consisting in six steps (see below). Here we followed this approach, with certain adaptations.

3.2.1. Goal purpose

In a stakeholder analysis, it is common to use policy objectives as the goals to attain. These usually imply an anthropocentric view as appropriate. Accordingly, goals that are perceived to have direct utility to people are identified and prioritized. These goals are related to the delivery of the benefits derived from a given change, project, issue to certain stakeholder groups.

3.2.2. Stakeholder identification

Social approaches may include the possibility of diversifying the range of stakeholders' inquiry by using a methodology where they are distributed into different groups, contacting directly the key ones and not focusing only on the ones being affected by the object of study, but also in other stakes (Vos and Achterkamp, 2006).

It is fundamental to know who are the stakeholders. Pre-defined key-stakeholders should be invited to evaluate perceived impacts provoked by the given change by means of a questionnaire survey using attitude scales. In the research design of such analysis it is necessary to address most important issues related both with the pre- and post- occurrence of a given change. The ranking of items can be used as indicators of social perception of impacts. The strength of this methodological approach is to gather people from different groups and backgrounds in order to evaluate the impact inflicted according to their own perceptions in an objective manner. The corresponding drawback is that it oversimplifies the results, because all items are analysed in the same manner and gathered altogether whatever the dimension they come from.

3.2.3. Stakeholder classification

Different authors present different ways to list and categorise stakeholders. One way is to allocate stakeholders into three categories, as follows: primary, secondary, and external (Table 2). Primary stakeholders are all those people and groups that are affected by a given change or project. They are usually operational and facing directly a given change or project. This includes both intended beneficiaries or those negatively affected. Secondary stakeholders are the intermediaries in the process of delivering a given project or being aware of a change faced by primary stakeholders. Local or regional authorities, local public administrators (including funding, implementing, monitoring organisations, or governmental). External stakeholders are other individuals or institutions which have personal interests at stake, as well as formal institutional objectives. Here can be identified and listed all those stakeholders who are perceived as participating in the response of a given change or project.

Table 2. One approach to stakeholder classification in maritime or coastal studies.

Category	Group examples
Primary	Fishermen, aquaculture operators, tourist operators, sand mining, ferry firms, container shipping companies
Secondary	Managers, administrators, local councils
External	Scientists, environmentalists

3.2.4. Stakeholder power

In the coastal areas the main activities and groups of stakeholders usually include fishermen, aquaculture firms, tourism operators, local or higher level authorities, energy producers and suppliers, science people from universities or other institutions, NGOs, and other (e.g. ports, shipping, sand mining, military, etc.). Stakeholders have different lobby power and influence (their weight). In the decision processes, the different stakeholders exert differentiated levels of pressure. Thus, in a stakeholder analysis it makes good sense to use the same weight for the different stakeholders whatever their intervention.

3.2.5. Stakeholder interest

The different stakeholders can interact with a given issue, change or project through demonstrating to have private, public or cooperative interest. Stakeholders can show interest in making money (e.g. operational stakeholders such as fishers, aquaculture owners) (Fig. 3A), or delivering a project (e.g. local administration bodies) (Fig. 3B).

A

B

Figure 3. Aquaculture production pilot area of Armona (South-east Portugal): A) Offshore aquaculture and fishermen (operational stakeholders). B) Research vessel with researchers, skipper and technicians carrying out experimental fisheries.

As a given change or project occurs, operational stakeholders (users) accumulate empirical knowledge of their effects. This may influence both their attitudes and behaviour (e.g. fishing patterns). Attitudes may, of course, be negative as well as positive. Experience and theory suggest that there is a range of impacts which may be perceived as in different ways according to the different stakeholders. To deal with the perceptions that stakeholders have about a given change or project may not be an easy task. Thus, those stakeholders that can 'touch' and 'see' more often a given change or project are potentially the ones who can have the clearest picture as a whole. All these insights are important to take into account when asking stakeholder group representatives about their perception of impacts.

It is important to investigate local community's perceptions of a given change or project, and to see to what extent people regard it. We would contend that the opinions of stakeholders are crucial in this context. When there is a consensus amongst key individuals and groups over the issue, it becomes easier to establish whether this issue has been adequately addressed and how close it is to being reached. By contrast, lack of consensus makes it more difficult to derive a clear and unambiguous indicator for the evaluation. Stakeholder opinions about socio-economic as well as environmental impacts need to be considered, and this sort of data typically has to be collected via surveys (Milon *et al*. 2000).

3.2.6. Stakeholder engagement

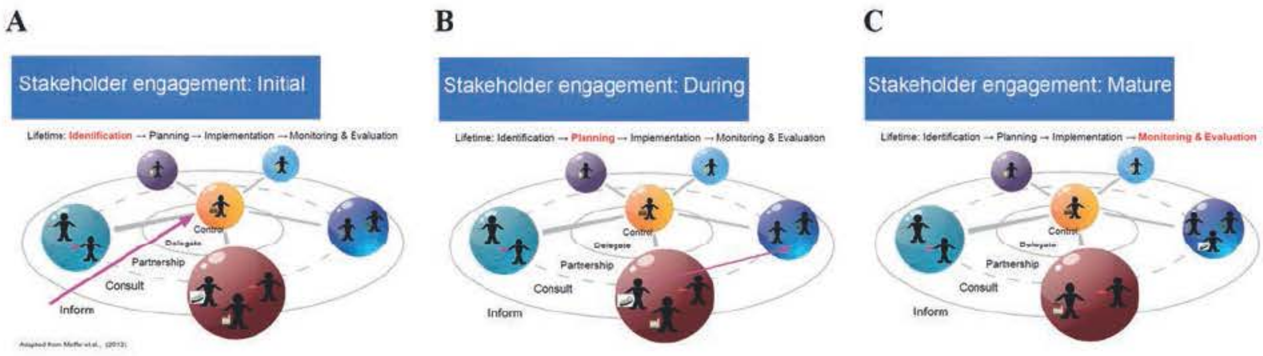


Figure 4. Stakeholder engagement throughout the lifetime of a project (a change, or other). Different stakeholder types will have different levels of involvement, depending on the phase, power and interest: A) Initial phase. B) Middle phase C) Mature phase.

The involvement of stakeholders is dependent on the degree of ownership felt and attributed to the goal (either a change, a project, or any other) (Brugha and Varvasovszky, 2000; Lim *et al.*, 2005). All the interested stakeholders should be invited to participate in the process in analysis (Fig. 4). This action is called the "principle of inclusivity" (Meffe *et al.*, 2002). Despite the need to include as many stakeholders as possible, the inclusion of the entire set of stakeholders in all decisions and actions is probably not a right choice. This can raise problems because those stakeholders defending opposite or conflicting ideas can be invited to participate on common ground. Notwithstanding, it is possible to achieve valuable involvement from the different stakeholders and get different viewpoint supporters to work together and reach the goals intended. Some mediation may be necessary in order to achieve these trade-offs.

4. Some stakeholder perceptions

Now follows a selection of three case studies related to stakeholder perceptions, concerning changes in the coastal areas (first and second examples) and prioritization of coastal issues aiming coexistence between activities (third example).

4.1. Artificial reefs modules off the coast of Algarve (southern Portugal)

The main goal was to identify from a previously provided list of items impacts potentially provoked by artificial reefs (ARs) (Table 3). Items were allocated into three dimensions: environmental, social and economic. Stakeholders were consulted from a panel composed by six different groups (Fig. 6B–E). Results showed that stakeholders' perception was more favourable and sensitive towards environmental impacts. Thus, stakeholders have chosen some items that could eventually provoke some disruptions.

Table 3. Brief description of the 12 factor-sets and the number of impacts addressed to the key-stakeholders.

Dimension	Factor-set	Brief description	No. items
Environmental	A. Deployment area use	To assess stakeholders' perception on the use that can be found in the area.	4
	B. Ecological impact and bio-diversity	Effects caused on the species, namely their aggregation and protection after reef deployment.	5
	C. Pollution	The contribution of the structures as a factor of pollution to the environment (water or sediment).	3
	D. Fishery and management	ARs as a management tool for fisheries (traditional fishing, off-shore aquaculture, etc).	6
Social	E. Demography and employment	Signs of changes in social aspects (people migration, employment, and social benefits).	3
	F. Enforcement and communication	The need to establish sea use rules and communication between the different players.	4
	G. Opinion	How is the AR' deployment perceived by stakeholders and the public in general.	5
	H. Conflicts	Possibilities of conflicts occurrence between the different stakeholders involved.	6
Economic	I. Production and benefits	To evaluate the chances of extra catches and returns after reef deployment.	4
	J. Costs to society	Awareness of the costs involved in the reef deployment process.	5
	K. Changes in local economy	Signs of changes in the local economy in all the sectors of activity after reef deployment.	5
	L. Safety at sea	Reefs contribution to promote safer fishing activities in their deployment area.	4

4.2. Sunken vessels off the coast of Sal island (Cape Verde)

The main goal was to establish the best practice for marine biodiversity conservation off Sal island (Fig. 5A). In order to help achieve this objective, obsolete vessels were sunken. Four management strategies and four diving spot types were defined for biodiversity conservation and stakeholders had to decide from their perception which strategy was the most adequate. To decide that, a survey was carried out using a questionnaire with the analytic hierarchy process (AHP) measuring technique (scale: -9 to 9). Stakeholders were allocated into five different groups (Fig. 5B). Results showed stakeholders' perception was not consensual about sinking an obsolete structure (Fig. 5C–E) as a management alternative, i.e., the choice was somehow dependent on the stakeholder group.

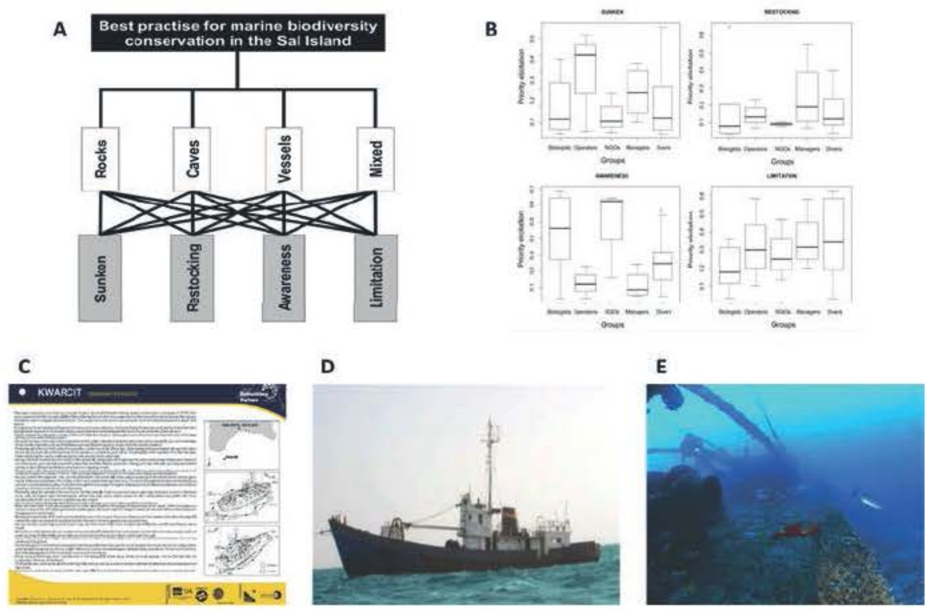
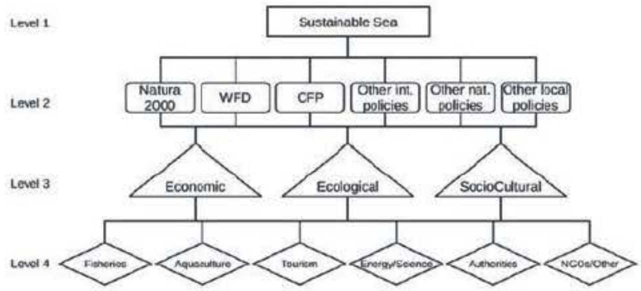


Figure 5. A) The analytic hierarchy process (AHP) tree model used to facilitate decision making for biodiversity conservation off Sal Island (Cape Verde). B) Sensitivity analysis for the best management decision according to stakeholder group. (Source A and B: Ramos *et al*., 2011). C) An obsolete vessel (Kwarcit) in the deployment day – January 6, 2006 (photo: © Manta Diving Center). D) Kwarcit, underwater route. Santa Maria, Sal. E) Kwarcit, a fishing trawler wreck full of sea-life approximately two years after deployment (photo: © Vasco Pinhol). (Source C – E: Oliveira 2016).

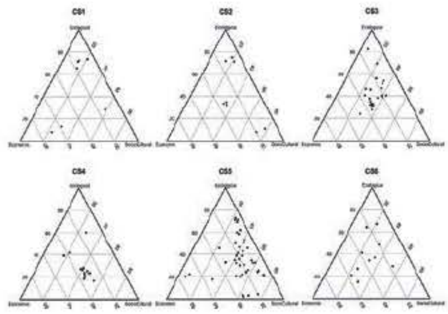
4.3. The coexistence of coastal activities across Europe

Within the COEXIST project it was agreed for all case studies across Europe that the main goal was to "sustain a viable coastal/marine ecosystem" in each area aiming for long-term coexistence of stakeholders considering their differing local agendas (whether economic, social, or environmental). The idea of "sustainable use of the resource" was taken in a broader sense to consider not only activities, but also to preserve important values, such as competitive economic activities, good environmental status, and get high living standards (Fig. 6A). The selected stakeholders in each case study were surveyed using a questionnaire with AHP measuring technique (-9 to 9). Stakeholders were allocated into six different groups. The research was carried out in six different European case studies (Fig. 6B). Data were collected from the whole set of European stakeholders and the results of the project were delivered to each of the local case study stakeholders (Fig. 6C–E).

A



B



C

D

E

Figure 6. A) Conceptual framework of the COEXIST project. B) Ternary plots showing stakeholders' preferences across six European coastal case studies. C) Project delivering: Stakeholder meeting flyer. D) Stakeholder meeting oral presentations to the audience. E) Coexistence and interaction between different stakeholders in a navigational route inside the Ria Formosa lagoon (stakeholders: ferry companies, bivalve plot owners, small-scale fishermen, anglers, lighthouse technicians, navy and coastguard) (Source: Ramos *et al.*, 2015).

5. Conclusions

Concerning marine and coastal themes, there is a growing number of stakeholder perception studies on aquaculture and fisheries. Few of them present a focus on disruptive factors such as invasive species, jellyfish blooms or marine mammals competing with fisheries. From an anthropocentric view, operational stakeholders tend to give more importance to non-disruptive phenomena. Any disruptive biological factor is interpreted as a problem and consequently stakeholders may ask for solutions.

It is very important to consult properly all the local stakeholders and interest groups and get their feedback on a given changing factor or project. Usually stakeholders provide their empirical experience whether they are well aware of the object of study or not. Here the knowledge derived from experience matters.

Fisheries and aquaculture operational stakeholders and the way they share their empirical knowledge on costs and benefits concerning their activity, are very important. So, when dealing with changing factor(s) such as invasive species, jellyfish blooms on fisheries and aquaculture, and the impacts of marine mammals' depredation on fisheries, it is imperative to obtain information from human activities effectiveness facing such novelty, which implies a given perceived change. Concomitantly it is fundamental to document operational stakeholders' costs and benefits on both the demand and supply sides.

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Interactions of cetaceans and the Sardine Portuguese Purse Seine fishery: integrating knowledge among fishermen and scientists, bycatch levels and mitigation approaches

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Abstract
Along the Portuguese continental coast, the Sardine Portuguese Purse Seine Fishery (SPPSF) interacts with dolphins, particularly with the common dolphin, *Delphinus delphis*. The level of this interaction is directly correlated with fishing effort and is mainly attributed to the fact that the sardine *Sardina pilchardus*, the target of the fishery, is also the favored prey of this cetacean species. To address this problem, a strong partnership between scientists and fishermen is fundamental, not only to acquire good quality data, but also to enhance fisheries' management. Data collection and monitoring in Portuguese fisheries is made under the scope of the combined effort of the Portuguese monitoring programme PNAB (EU-DCF) and dedicated projects. This work presents a summary of the most recent findings during monitoring of the level of interactions and resource overlap of cetaceans with the fishery. Mitigation approaches have demonstrated that changes in fisher behavior such as increased onboard surveillance and communication, and improved release techniques, if adopted could be effective. Ongoing work to promote other mitigation techniques will be discussed as they will be carried within a new project (iNOVPESCA) as a combined effort between scientists and fishermen.

Context of legislation for cetacean protection in EU waters
In Europe, recent legal frameworks (e.g. Marine Strategy Framework Directive, 2008/56/EC) aim at "achieving Good Environmental Status (GES) of the EU marine waters by 2020". This urgency is obvious as human population keeps rising and fishing fleets get modernized, leading to a continuous unstoppable pressure in marine ecosystems and to the scarcity of many marine resources. Moreover, human knowledge on marine ecological processes such as fish maturity or spawning is still scarce or absent for many fish species and this puts pressure on the fishing industry to practice illegal actions to accommodate human consumption preferences (e.g. consumption of immature/juvenile fish). This fact has led for example to the increase of competition between fishermen and marine top predators (e.g. cetaceans) that are attracted to the same fishing or feeding grounds (Gilland 2002: Northridge *et al*., 1999: Hall *et al*., 2000: Read 2008). With less food to share, the possibility of interactions to occur between the two groups has been increasing, leading to negative aspects for both the fishermen (e.g. loss

of catch through depredation or gear damage) and for the animals (e.g. incidental capture leading in most cases to death) (Figure 1).

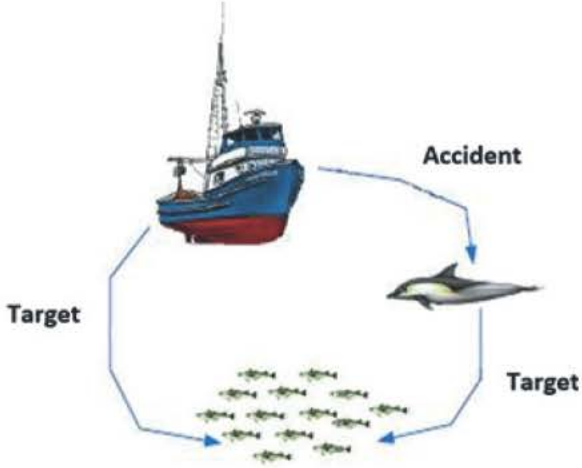

Figure 1. Diagram representing the competition between fisheries and top marine predators (e.g. cetaceans) for the same resources and generalized capture intentions.

Cetaceans in European waters are protected through the Habitats Directive (92/43/EEC, 21 May 1992), with some species of priority protection (Annex II and IV) such the harbor porpoise, *Phocoena phocoena*, or the bottlenose dolphin, *Tursiops truncatus*. As such, EC member states have been promoting studies to gather information about the ecology and anthropogenic impacts that could lead to more efficient management plans and promote mitigation measures. Moreover, finding mechanisms and tools to reduce negative interactions and mortality of these protected species are very site/area and species specific (Cox *et al*., 2007, Hamer *et al*., 2008; 2012). For such reasons, continuous research in this field is crucial to find measures which could be suitable for the Portuguese fisheries scenario.

Cetacean interactions with Portuguese fisheries

About 28 species of cetaceans inhabit the continental Portuguese waters (Pereira, 2016). Studies about interaction of cetaceans and Portuguese fisheries were scarce up to the beginning of the 20th century. Until then, works based on strandings and diet analysis indicated that the common dolphin, *Delphinus delphis*, the most abundant cetacean species along the coast, was frequently captured by coastal fisheries, namely in gill and trammel nets, or interacted occasionally with presence only events (no captures observed) with purse seiners (Sequeira & Ferreira, 1994; Silva 1999; Silva & Sequeira, 2003, Wise *et al*., 2007). Most recently, projects dedicated to this issue in Portugal have emerged (e.g. SafeSea-EEAGrants; Life^{+}MarPro), identifying "hotspots" for interactions between cetaceans and fisheries along the coast suggesting a considerable habitat and resource overlap; as well as identifying the level of interaction and bycatch levels of some cetacean species (Marçalo *et al*., 2015; 2018; Goetz *et al*., 2015; ICES, 2016; Wise *et al*., in press). In particular, from an intensive two year observation study on board, in 96 % of the trips (163 trips/302 hauls) observed, the common dolphin was the species found to interact the most with the purse seine fishery, although the animals were observed in only 15 % of the events as presence only outside the net, with 2% of the events with incidental capture and 1% with mortality of the animals (Figure 2).

Figure 2. Interactions of cetaceans with the purse seine fishery presence only events with common dolphins swimming outside the net during hauling of the net (left), a live common dolphin retrieved out of the net and tentatively released alive by fishermen (right).

Extrapolations to the fleet with encirclement and mortality rates were of 264 (95 % CI 75–490) and 113 (95 % CI 0-264) (Table 1, Marçalo *et al*., 2015) common dolphins, respectively. Also, observations of gear or fish damage by the dolphins were not observed in this fishery.

Table 1 Summary information of the encirclements and mortalities derived from observer records, presented as the total number of individuals, the number of events, in which they occurred, plus the corresponding rate (animals per set) and number of animals raised to fleet level, with bootstrap estimates of 95% confidence limits.

		Encirclements					Mortalities				
Year	Area	N animals	N events	Rate (Animals per-net-set)	Fleet wide estimate	Species	N animals	N events	Rate (animals per-net set)	Fleet wide estimate	Species
2010	North	2	2	0.015	138 (73-183)	DD	1	1	0.007	69 (37-110)	DD
	Centre	0	0				0	0			
	South	1	1	0.026	91 (55-165)	DD	1	1	0.026	91 (55-165)	DD
2011	North	3	3	0.017	477 (246-575)	1DD, 1TT,1PP	0	0			
	Centre	0	0				0	0			
	South	1	1	0.025	78 (47-140)	DD	1	1	0.025	78 (47-140)	DD
Fleet wide estimate/yr	Country			0.015	264 (75 - 490)	DD,TT,PP			0.010	113 (0 - 264)	DD

The Sardine Portuguese purse seine fishery (SPPSF) and why the interaction occurs

The Sardine Portuguese purse seine fishery (SPPSF) is a relevant case study, as this fishery is considered the most important in the country, responsible to capture about half of the landings and representing >90 % of sardine catch in weight (Silva *et al*., 2015) and was MsC certified during the Marçalo *et al*., 2015 study. Note that during the certification, one of the criteria is the impact of the fishery on protected species, thus the necessity to eliminate or reduce cetacean mortality during the fishing practice. The southern stock of sardine, also known as the Iberian sardine stock, is managed by Portugal and Spain. For both countries, the bulk of sardine landings (97% in weight and 98% in value) is made by purse seine boats (Silva *et al*., 2015). Sardine abundance is dependent on the magnitude of recruitment, which has been poor in the southern-Iberian stock since 2004, leading to a recent historical low level of biomass (Silva *et al*., 2015). To protect the stock, a new management plan for the southern Iberian sardine stock was implemented from 2011 onwards by Portuguese and Spanish administrations, with severe restrictions on catches. This led to sharp annual decline in landings of 70% and above from 2011 to 2014. A study on the diet of the common dolphins along the Portuguese continental coast used stomach contents from 1989 to 1997 (Silva 99) indicating that sardine was the favorite prey. With the recent decline on sardine abundance, a new and more recent quantitative description of the diet of common dolphins along the Portuguese mainland coast was performed, using stomachs from 2010 to 2013, showing that sardine continues to be the favored prey (Table 2, Marçalo *et al.*, 2018). Therefore, the drive for both the fishery and dolphins continues to be the same: sardine.

Table 2. Diet composition of common dolphins along the Portuguese mainland coast based on the analysis of stomach contents (N= 150) from dead stranded animals. N=Number of prey. % N=Numerical percentage. W=prey weight. % W=Percentage of reconstructed weight. In parentheses are 95% confidence limits.

Family	Species	N	%N	W	%W
Clupeidae	*Sardina pilchardus*	1749	16.22	100276.1	36.36
			(11.75-21.31)		(29.90-42.64)
Carangidae	*Trachurus* sp.	1589	14.73	43315.73	15.71
			(9.64-21.15)		(11.26-20.26)
Scombridae	*Scomber colias*	774	7.18	64909	23.54
			(4.90-10.22)		(18.31-29.38)
	Scomber scombrus	107	1	13220.98	4.79
			(0.25-2.03)		(1.69-8.90)
Other species		6567	13.11	61409, 95	21.69
			(7.69-18.55)		(16.33-27.12)

Further, average small pelagic biomass removed by fisheries from 2010 to 2013 exceeded that removed by common dolphins by a factor of 5.5 (Figure 3). This would suggest that the damage caused by common dolphins to fishery yields is fairly modest.

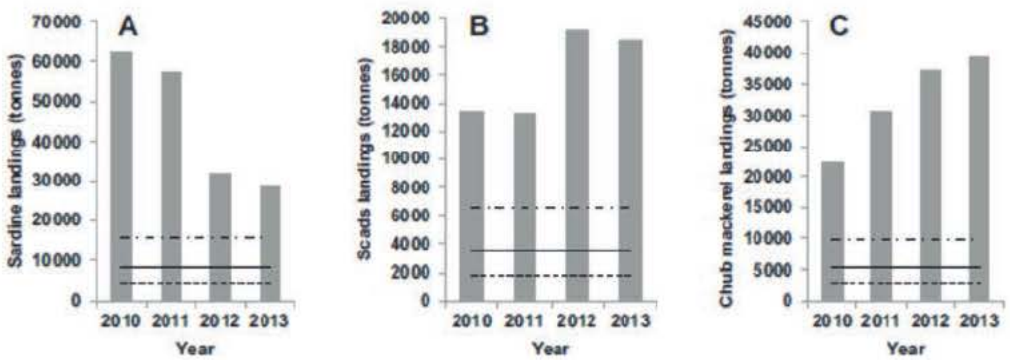

Figure 3. Comparison of biomass removal by dolphin predation and by fisheries for three small pelagic species: **A** sardine, **B** scads and **C** chub mackerel landed annually in Portugal for 2010–2013 in ICES areas subdivision 9a (official fishery statistics). The solid horizontal lines represent the (static) estimates of annual mean common dolphin consumption; the dashed lines represent the upper and lower 95% confidence limits.

Mitigation approaches for the SPPSF: Past and future

Mitigation approaches to reduce interactions and bycatch of cetaceans in the SPPSF from past projects tested the use of acoustic alarms (FUMUNDA pingers) or the development of manuals of best practices delivered to the fishing sector specifying fisher behavior changes (Figure 4).

Figure 4. a) Delivery of best practice workshops to fishermen in participatory meeting; b) example of best practice manual to avoid bycatch in the Portuguese Purse seine fishery; c) Technique to avoid while attempting to release dolphins alive out of the net and shown in the manual.

A mix of results led to consider that the pingers used may have not been adequate, as can be attested by the fact that encirclement and mortality rates did not decrease (Ana Marçalo pers. comm.). At the time, other mitigation tools to improve techniques to release the animals from the net were recommended but never thoroughly implemented, nor the fisher behavior changes effectiveness re-evaluated. Onboard observations led to consider that avoiding setting the net in the vicinity of cetaceans and improving release techniques already tested in other purse seine fisheries for small pelagics in other parts of the world can be easily adapted to the SPPSF scenario (Ward *et al*.,. 2018). Such techniques include for example avoiding the common practice of lifting the animal alive by putting a rope around the peduncle (Figure 2b and Figure 4c) and use other less physical abrasive tools.

New work under the scope of a new project (Mar2020-iNOVPESCA) is more localized and concentrated in the Portuguese Southern coast-Algarve, so interactions are better evaluated and other mitigation approaches and tools tested. Most recently, a method suggested to accomplish this objective is to do it in a direct cooperative way with the fishing sector and including several stakeholders such as the fishermen, fishing associations, scientists and governmental institutions responsible for the management of the marine environment, protected species and fisheries. This approach, known as 'cooperative research', is thought to strengthen relationships and trust among resource users, scientists and managers through participation, and consequently improve the scientific data that are required for management and governance.

Conclusions

Modifications to commercial fishing practices should be adopted and implemented in purse seiners operating off mainland Portugal and in other European purse seine fisheries with similar cetacean bycatch issues (same operations and cetacean species interacting). Fortunately, in Portugal, this industry is known to be proactive in collaborating with the scientific community and in providing suggestions for strategies to reduce discarding and bycatch of protected species. Proper uptake of the proposed mitigation techniques depends on having a clear code of good practice (CoP) that should be properly disseminated, adopted and implemented. Bycatch of cetaceans in Portuguese waters is not an intentional practice, and many fishermen are voluntarily involved in strategies to reduce the accidental capture of whales, dolphins and porpoises, and to promote more sustainable fisheries which would be more profitable to them. The approaches required will often be fishery specific, and the solutions will depend on positive relationships and involvement with fishermen. Participation of fishermen in the management process must be seen as necessary, so that cetacean bycatch reduction approaches can be implemented successfully, and individual level incentive-based management measures will likely be more effective.

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Dolphin depredation: stakeholder perceptions

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Abstract
The interactions between humans and dolphins have been known for a long time. Since the last century, the anthropic pressures have been increasing, changing natural habitat and in some cases also the animal behaviour. The Mediterranean bottlenose dolphins are not outdone, and their foray on fishing gear it is known to fishermen communities. One of the reasons could be referred to the state of fisheries resources overexploitation where the catches are poor both for dolphins and for fishermen, inducing the dolphins to approach more frequently the fishing gear. The consequences of such animal behaviour produced damages on fishing gears, fishing loss, and dolphins bycatch. The involvement of relevant stakeholders in the dolphins depredation mitigation plans is important to ensure the economic and ecological sustainability of the management initiatives.

This study, adopted the SWOT (Strengths, Weaknesses, Opportunities, and Threat) method to assess the perceptions of six stakeholder groups (professional fishing, recreational fishing, tourists, marine protected areas managers, researchers, fisheries local group actions) regarding dolphin depredations. Here some initiatives to mitigate the economic losses occurred are suggested.

Keywords: Dolphin depredation; stakeholder perception; ICZM; coastal communities

Introduction
Dolphin depredation probably exists since the fisheries exist. It is clearly evident from the observation of archaeological remains that dolphins stimulated the curiosity of the ancient Mediterranean coastal population. Mosaics, crockeries, coins, and many artistic works of the ancient Rome and Greek show dolphins and fishermen together without interferences between them.

Nowadays it is possible to observe analogous cooperative behaviour in other areas of the world. In this regard, Irrawaddy River of Mandalay, Myanmar second-largest city and Laguna, southern Brazil are the best known sites. But today, these cooperation examples are at risk: in the Irrawaddy River economic growth has brought increased pollution from heavy metals, fertilizer and industrial wastes. Further, shipping traffic, overfishing and accidental trapping of dolphins did not exactly improve the conservation of these human-dolphins cooperative interactions. Preservation of dolphins from anthropic pressures should be part of a wider strategy of coastal habitat protection, and should involve the most relevant stakeholders in the environmental governance system.

Fishing-cetacean interactions

Fishing-cetacean interactions are a matter of growing interest both for the scientific and trading world. Depredation generates conflicts in a context of limited resources with negative repercussions on economic sustainability for fisheries. An aspect of this problem concerns the impact of dolphins on different typologies of fishing equipment. The implications are numerous and include not only the scientific community and the fishing operators, but all other "sea resource" users. Behavioural dynamics that induce marine mammals to adopt this feeding strategy has been studied for a long time (Orams, 1997).

In general, this phenomenon is linked to fish stocks overexploitation and increasing anthropic pressures on marine ecosystems but studies on the economic damages suffered by the fishing operators are lacking.

Dolphins depredation is widespread in the world, including the Mediterranean Sea where the maximum sustainable yield (MSY) has been reached for many fish stocks. In Italy the Sicilian Channel is one of the most exploited fishing areas in Mediterranean Sea, where many fishing trawlers are used. In the last thirty years, a general decrease in pelagic and demersal stocks due to the combination of anthropogenic, climatic and ecological factors has been observed in this zone together with an increase of the interaction between fishing activities and cetaceans.

Other kinds of interactions

Dolphins-humans interactions are not limited to fishing activities. In many cases, to encourage interaction with tourists, fish hand-outs are offered to animals, although laws and local regulations for the protection of wildlife would not allow it. Tourist cruises for cetacean observations are increasing in many parts of the world. Dolphins watching on smaller boats for excursions of a few hours is carried out in many touristic areas. Several touristic resorts offer the opportunity to swim with wild dolphins, making this a most popular service. Since dolphins are seen by people as species to be protected, it seems paradoxical that the same people show little consideration for their welfare (use of harmful or stressful behaviours for animals). The bottlenose dolphin has been declared a "vulnerable" species, exposed, as other species, to the effects of pollution and loss of habitat. In this regard, over the past 50 years anthropogenic activities (pile driving, seismic prospecting, marine traffic, etc.) in the seas have drastically increased the underwater noise including also the sea background noise (Hildebrand, 2009; Ross, 2005), driving a change of the acoustic characteristics of marine ecosystems (coastal, pelagic, and deep water) globally.

Stakeholders' perceptions

Although dolphins' depredation appears as a problem limited to fishermen and authorities, the actors who can take part in the management of the phenomenon are several. Recently, the process for implementation of environmental policies has recognized the role of stakeholders as significant part in participatory processes for the protection of endangered species or habitats.

Evaluation of the results of natural resources management policies is often hard to obtain. In absence of empirical data, the assessment of the success can be based on the perception of experts or stakeholders. Clarkson (1995) defined stakeholders as individuals or groups who have property rights or interests in relation to a company and its present and future activities. One can distinguish between primary, without which the company could not carry out its activity, and secondary stakeholders with the role to influence or to be influenced by the companies. Secondary stakeholders have the ability to mobilize public opinion for or against the performance of a company (Fig. 1).

	Social	Non-Social
Primary	• Shareholders & Investors • Employees and managers • Customers • Local communities • Suppliers	• Natural resources • Future generations • Nonhuman species
Secondary	• Government • Institutions • Media and Trade bodies • Competitors	• Environmental interest grups • Animal welfare organizations

Figure 1. Categorization of stakeholders by Primary social and non-social and Secondary social and non-social. Adapted from Carroll and Bucholtz's (2014).

In the specific case of fishing-dolphins interactions, the involvement of stakeholders in the conservation and sustainable management of coastal areas is important. In particular, in the Strait of Sicily, the relevant stakeholders involved in the management processes are: professional fishermen, sport fishermen, tourists, Marine Protected Areas and Fisheries Local Action Groups (FLAGs). The perception of the dolphin depredation by these stakeholders changes significantly depending on the different interests of the groups.

Assessment of stakeholder perception

The perception of stakeholder groups is important for developing and implementing policy in support of dolphin protections and local fisheries, including the sustainable policy on stocks assessment. Understanding stakeholder perceptions will allow to identify the issues to address in coastal zone management policy (Simmons and Lovegrove, 2005).

To assess the different perceptions of six different stakeholder groups (professional fishermen, recreational fishermen, tourists, MPA managers, researchers and fisheries local group actions managers), the SWOT (Strenght, Weaknesses, Opportunities, Threats) analysis associated to an evaluation table has been adopted. The stakeholder perceptions, presented here, are referred to a local condition, but the approach could be applicable in analogue situations.

Scientific literature is rich in applicative examples (Pickton and Wright, 1998), and the SWOT approach used as strategic management tool to analyze strength, weaknesses, opportunities and threats in companies, project or management objectives has been used for long time (Helms and Nixon, 2010). In order to assess the stakeholder perceptions, one of the most useful strategy used to rank the SWOT factor and identify the main issues is the combination of brainstorming and SWOT session.

The assessment of six stakeholder perception groups of the dolphin-fisheries interactions was made by using a contact list based on personal contacts, publications, projects awarded by different government and private companies. The SWOT factor interview and brainstorming method was used and enabled to define seventeen different SWOT factors (Fig. 2).

	HELPFUL To achieving the objectives	**HARMFUL** To achieving the objective
Internal origin (attributes of the Organization)	S • Promote deterrent instrument • Reduce bycatch • Less or no competitions with other activities • Quality of fisheries	W • Inaccurate use of the technologies to reduce bycatch • Lack information on biomass consumed by dolphins • Poor knowledges of the distributions and the numbers of population specimen
External origin (attributes of the environment)	O • Enter in the seafood quality market • Support /commitment of Public administrations • Favourable public opinion • Improve the safety of endanger species • Support the fisheries communities	T • Interference whit others user • Reductions of fisheries resources • Possible damage of natural behaviour • Increase coast of fishing gear damages

Figure 2. Relevant factors identified in each SWOT category.

A brief description of the different perceptions of the six stakeholder groups analyzed is presented below.

Professional Fishing

In South-Western Sicily, the dolphins-fishing interactions mainly involve the bottlenose dolphin *Tursiops truncates*. Ship-owners that use trammel nets, purse seine and trawl, refer an increasing of damage caused by dolphins in their fishing equipment, causing catch loss. The damages on purse seine equipment are not only referred to repairs on the net but also to the time required to restorations or find new equipment. In general, purse seine fishermen do not see the presence of dolphins in their fishing areas positively, nor do they believe that additional services (such as fishing-tourism) are able to compensate the economic losses. Particularly interesting is the interaction of bottlenose dolphins with equipment of artisanal fishing. In this case the fishermen report a constant presence of the animals in their fishing areas that decreases during the summer season. Fishermen think that this decreasing rate could be attributed to several concomitant factors such as the presence of other types of fishing in the same area (purse seine and trawl), and increase in traffic and tourist transport. For the gill nets, the replacement of the damaged parts or entire net is cheap in the off season.

In the Sicilian channel, the interaction between trawl fisheries and bottlenose dolphins concerns the feeding of fish discarded by boats or directly torn from the mesh (Bearzi, 2002). The fishermen refer that sometimes those specimens remain trapped inside the bag, leading to suspect that the activity can also concern the capture of specimens both in front of net and coming out of the mesh.

Figure 3. Bycatch of bottlenose dolphin by mid-water trawling.

However, both bycatch and damage caused to equipment represent a problem that could be limited by adopting avoidance technologies to prevent dolphins from approaching the nets. For this reason, some fishermen who practice trawl and purse seine have tried acoustic dissuasion tools. In the case of small-scale fishing however, the propensity to reinvest part of the gains in technological instruments to improve the efficiency is scanty due to both economic and social factors. Compared to other fishing typologies, artisanal fishing can count on lower profit margins despite the higher average value of the product, and it needs to considerer also the high average age of the vessels and crews that makes it difficult to adopt technological innovations (Maccarrone *et al.*, 2014).

All the fishing activities practiced in the Sicilian Channel are concerned by the interference with cetaceans. It is necessary therefore that the local authorities start specific monitoring plans to quantify the loss of catches and the damages to the equipment. These studies should be aimed at encouraging the adoption of tools and technologies to minimize the economic losses.

Recreational fishing

Compared to professional fishing, the stakeholders of sport fishing perceive the phenomenon of dolphin depredation differently. For many sport fishermen, the presence of dolphins in fishing areas is a clear sign of good ecological status of the sea associated to a high level of biodiversity. There are no cases of direct depredation both for the lines and trolling fishing, during which the dolphins snatch their prey from the lines. However for recreational fishermen, dolphins' presence is often related to poor catches, so that the boats change fishing areas frequently. The interaction of large cephalopods (such as squid) with sport fishing occurs often in areas with higher depths. In this particular case, the depredation is mainly due to the Risso's dolphin *Grampus griseus* that tears the captured preys from the equipment (Cruz *et al.*, 2014).

Sport fishermen perceive interaction activities as an integral part of fishing activities, although they realize how much this phenomenon can limit their professional activity. Often specific tourist packages are organized, and in these cases the inability to fish due to the presence of dolphins is perceived negatively because the capture of fish becomes an essential part of the "offered product".

Tourists

Tourist demand is increasing worldwide. The challenge for European coastal and maritime locations is to exploit this aspect in a sustainable way in order to provide attractive jobs to local residents. The perception of the dolphin depredation by coastal citizens and tourists can become a critical success factor for the promotion of maritime tourism (Catlin *et al*., 2013).

Although tourists are not directly involved in fishing activities, they perceive positively the presence of dolphins in coastal areas as indicator of sea quality. In many cases the presence of dolphins near coastal waters has allowed the creation of specific tourist packages with the main objective of sighting dolphins.

A strategy of local tourism development would encourage visitors to spend more time in those areas, with attention to local attractions (natural and cultural resources, historical monuments, local gastronomy and drinks, etc.).

Figure 4. Tourists engaged in a dolphin watching tour.

MPAs' and fishing/cetacean interactions

Currently, the most promising tools for Integrated Coastal Zone Management are Marine Protected Areas (MPAs) and Biological Protection Areas (ZTB). They are seen as necessary measures in the management of marine ecosystems heavily exploited by fishing, in consideration of their proven effectiveness in terms of habitat conservation and biodiversity, two elements reflecting on the recruitment of fish species and, therefore, on catches in adjacent areas. MPAs, in particular, are the most effective agents when interacting with the fishing operators that suffer increased gear damages, and ask with increasing insistence for an intervention by the competent authority.

Research

Cetaceans depredation is known from different areas of the globe, and has been investigated for long (Dawson *et al*., 2013), while the related fish losses are still highly unknown. Very often, the fishermen declare that in the presence of dolphins their gears have a poor ability to catch, although this statement is rarely corroborated by sighting data or damage on the equipment attributable exclusively to the depredation. In many cases low catch rates are related to other factors such as a general reduction in stocks and/or in the quality of the marine environment (Dawson *et al.*, 2013).

In some fishing areas such as archipelagos or bays, where depredation can reach unsustainable levels, experimental activities were carried out to test the effectiveness of acoustic deterrents such as the pinger net.

Further investigation is required, in particular a correct assessment of the mitigation and management tools able to compensate the economic damages. The use of technologies to mitigate the depredation should be supported by socio-economic studies to contextualize the phenomenon as an integral part of the risks and of the economic and environmental opportunities that characterize the coastal areas.

Fisheries local action groups (FLAGs)

To achieve sustainability of the fisheries and aquaculture sectors, local participatory development should be implemented through a 'bottom-up' approach with local partnerships consisting of representatives of public, private and civil society sectors (Sawchuk *et al.*, 2015). The local operators are likely in the best position to define and implement multi-sectorial strategies of local fishing areas development. In the development strategy of FLAGs, dolphin depredation plays a bivalent role. On the one hand, the economic losses and damage to equipment are a risk factor for the activity that FLAGs have to support.

Figure 5. Example of product/process fish promotion: a show cooking organized at Eataly in Milan to promote the anchovies fished in Sicilian channel using traditional fishing methods.

On the other hand, the presence of dolphins in the areas managed by the FLAGs could represent a driving force for the promotion of maritime cultural heritage in the fishing areas. In some specific coastal areas, the activity of territorial animation could enhance the cultural and natural heritage through the promotion of museums or exhibitions (Fig. 5).

Perception: measuring and comparing

The perceptions of SWOT analysis factors were weighed using a five scale level in the six stakeholder groups. The low values were assigned to activities perceived as not important for managing dolphin-fisherman interactions, while the high values were evaluated as priority actions to do. A summary of the priority scores is presented below in Table 1.

Table 1. Summary of the priority scores of all SWOT factors for each stakeholders group.

	Professional fishing	Recreational fishing	Tourist/Citizen	MPA	Researchers	Fisheries local group actions	Relevant factors
S	*****	**	*	**	**	****	Promote deterrent instrument
	*****	*****	*****	*****	*****	*****	Reduce bycatch
	*	***	*****	*****	**	***	Dolphins watching trips
	**	**	*	*	**	***	Quality of fisheries seafood
W	*****	***	*	***	****	***	Use improperly the technologies to bycatch reductions
	*	***	*	*****	*****	**	Lack information on biomass consumed by dolphins
	*	***	**	*****	*****	***	Poor knowledges of distributions and numbers of specimen population
O	*	*	*	**	***	*	Enter in the seafood quality market
	****	**	***	****	***	*****	Support /commitment of Public administrations
	*	**	*****	****	*****	*****	inform the public opinion
	**	****	*****	*****	*****	***	Improve the safety of endanger species
	*****	***	**	***	***	***	Support the fisheries communities
T	**	***	**	**	***	*	Interference whit others user
	*****	***	*	**	*****	****	Reductions of fisheries resources
	**	****	**	*****	*****	***	Possible damage of natural behaviour
	*****	****	*	****	****	***	Increase cost of fishing gear damages

As showed in SWOT analysis, for all stakeholder groups except the tourists, the interaction/predation activities were perceived as set of negative factors. In fact, they are not balanced by strength and opportunities factors .

Regarding the strength factors identified, there was a substantial evaluation convergence from all stakeholder groups. In particular, bycatch reductions, dolphin watching and promoting the quality of artisanal seafood were identified as key factors to mitigate depredation.

The responses on weakness factors were heterogeneous. This suggests a lack of information and a poor knowledge of the cause-effect chain, that could induce some stakeholder categories to underestimate the analyzed factors. Researches and MPA managers seem to show more sensitivity to the risks arising from a bad use of dissuasion methods.

According to the SWOT analysis, the Risk was perceived differently by the different stakeholders. The absence of management initiatives to support good practices was more relevant for the groups that are closer to marine issues. Tourists would seem almost unaware about the risks presented by the four relevant factors.

Perspectives and opportunity

Many studies show that dolphin depredations represent a cost for fishing activities. The monitoring of the fishing gear associated to a controlled pingers use could be considered as a part of a wider integrated strategy aimed to sustain cetaceans and fishermen protection in areas massively involved in the interaction process. Furthermore, European Directives as MSFD and MSP, if efficiently applied at local scale, could allow the characterizations of the qualitative and quantitative uses of maritime activities and of potential conflicts.

The fisherman behaviour is influenced by the environmental status. Fishermen obtain a part of their production in the form of natural removable resources. Qualitative or quantitative modification of productive factors can be converted in a decrease of the production levels and/or in an increase of the production cost (see Fig. 6).

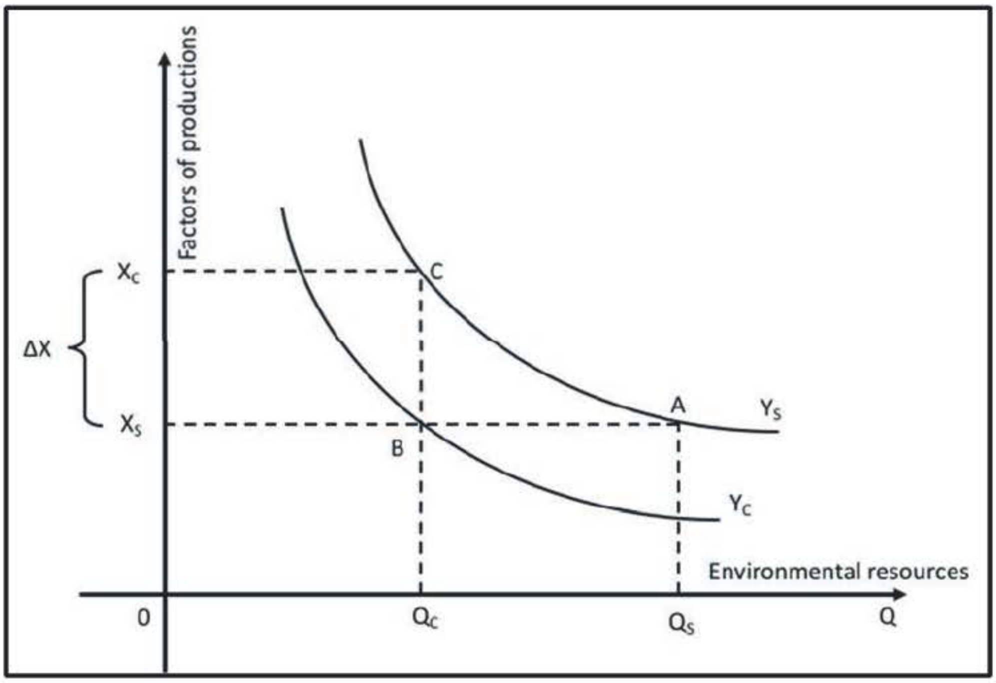

Figure 6. Restoring the productions levels by recovering the environmental quality (qc-qs) or with surrogate (xc-xs).

When dolphin depredation occurs on the fishing nets, the fisherman choices are tied to achieve a given production level Y, using factors of production X available on the markets and a qualitative environmental factor Q. Fishing loss and nets damages are factors that influence the production factor. The possibility to substitute environmental resources with factors of production reflects a direct measure of the damage suffered and opportunities for compensation.

In case of dolphin depredation, overfishing decreases the stock status quality and the environmental quality from Qs to Qc. In this case, if fishermen reduce their production levels, there are two choices: maintain the starting level Ys by increasing the cost of the production factor as subrogation or sustain environmental restoring cost to initial status.

The examples given above are referred to not catastrophic cases, where the damage is not sufficient to modify the market price or the production factors. If dolphin depredation becomes much more widespread, this could generate a reduction of supply. In this case, the final effects could be assessed in their whole complexity and unforeseen, in particular when the damages are protracted in time.

The permanent settlement of many dolphins could be seen as a purpose to share their fishing area with fishermen. From another point of view, the characteristic of permanent settlement could be used by the local coastal communities as added value for promoting the local fisheries. In fact, sustainability catches and cetacean depredations monitoring help the adoption of quality of fishing labelling. In this regard, the ecolabelling would extend not only to the fishing products, but to a wide aspect of tangibles and intangibles values that the coastal communities like to spread (Pauly, 2018).

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Interactions pêcheurs-cétacés: un problème culturel ? L'exemple du grand dauphin aux Îles Baléares.

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Introduction

Le grand dauphin, *Tursiops truncatus*, est l'une des espèces de cétacés les mieux connues grâce aux nombreuses études faites au niveau mondial (Leatherwood & Reeves, 1990, Reynolds *et al.,* 2000, Wells & Scott, 1999). En Méditerranée il s'agit de l'une des espèces les plus fréquemment observées (Reeves & Notarbartolo di Sciara, 2006). Si sa présence dans les eaux côtières est bien répertoriée, les connaissances quant au statut des populations, leur dynamique, leur degré d'isolement, etc., sont limitées (Bearzi & Fortuna, 2006).

De très nombreuses zones habitées par le grand dauphin, comme les détroits de Gibraltar, de Bonifacio ou de Messine, ou encore les Golfes du Lion, de Gênes ou de Trieste sont exposées à une intense activité humaine. La distribution de cette espèce n'est pas homogène et sa densité est très faible dans certaines régions. Ceci est dû à différents facteurs parmi lesquels l'habitat, la disponibilité des proies potentielles et la nature grégaire de l'espèce. Les campagnes de chasse passées et les divers facteurs actuels ont également contribué à une distribution discontinue de l'espèce en Méditerranée (Bearzi *et al.,* 2004).

Le grand dauphin de Méditerranée se différencie génétiquement des populations contiguës de l'Atlantique Nord-Est et des eaux écossaises. De même, on a pu distinguer différentes populations entre la Mer Noire et le Méditerranée à partir de l'analyse de l'ADN nucléaire et mitochondrial (Natoli *et al.,* 2005). À partir d'échantillonnages effectués en continu de la Mer Noire jusqu'au nord de l'Est Atlantique, on a pu observer que les différentes populations sont distribuées selon leur habitat. En effet, les cinq zones (Mer Noire, Méditerranée Est, Méditerranée Ouest, Atlantique Nord-Est et Écosse) sont caractérisées par des différences de topographie sous-marine et différentes valeurs de salinité superficielle, productivité et température (Natoli *et al.,* 2005).

Dans la péninsule ibérique, la population du grand dauphin a été étudiée par l'analyse d'isotopes stables et de contaminants organochlorés prélevés à partir de tissus d'animaux échoués en Catalogne, à Valence, aux Îles Baléares et dans les eaux atlantiques adjacentes, à Huelva et au Portugal (Borrell *et al.,* 2006). Des différences significatives dans les pourcentages d'isotopes de carbone ($^{13}C/^{12}C$) et les profils PCB ont indiqué un faible mélange des populations entre les dauphins atlantiques et méditerranéens. En revanche, on ne peut pas différencier les populations de Catalogne et de Valence, du fait de la proximité de ces deux zones. Cependant, les différences de ratio DDT/PCB et des autres profils PCB entre les animaux des Îles Baléares et ceux de la Méditerranée sur le littoral ibérique indiquent que les eaux profondes entre les Îles et la péninsule représentent une barrière effective pour les déplacements de l'espèce (Borrell *et al.,* 2006).

Ces résultats, similaires aux résultats observés pour d'autres espèces (Fossi *et al.,* 2004, Gaspari *et al.,* 2007a, Gaspari *et al.,* 2007b, Natoli *et al.,* 2008), suggèrent que des limites physiques autres que le détroit de Gibraltar ou celui des Dardanelles sont une barrière pour le mouvement des animaux.

En Méditerranée, le grand dauphin est principalement côtier, mais on peut le trouver sur le plateau continental ou au début du talus continental, à n'importe à quelle distance de la côte (Azzellino *et al.,* 2008, Bearzi *et al.,* 2004, Ben Naceur *et al.,* 2004, Gannier, 2005, Gnone *et al.,* 2006, Gómez de Segura *et al.,* 2006, Gómez de Segura *et al.,* 2004, Notarbartolo Di Sciara *et al.,* 1993). On peut le trouver dans une grande variété d'habitats dans les eaux continentales (Azzellino *et al.,* 2008, Gómez de Segura *et al.,* 2004), dans les mers fermées (Bearzi *et al.,* 2008) et dans les eaux circonscrites aux îles et archipels (Bearzi *et al.,* 1997, Forcada *et al.,* 2004, Mussi & Miragliuolo, 2003).

Le comportement du grand dauphin change considérablement entre groupes selon son habitat. Son comportement est flexible et son régime alimentaire est très varié (Barros & Odell, 1990, Cockcroft & Ross, 1990, Connor *et al.,* 2000, Shane *et al.,* 1986).

Près des côtes méditerranéennes, le grand dauphin capture principalement des proies des fonds marins (Blanco *et al.,* 2001, Mioković *et al.,* 1999) lors d'apnées qui durent entre 3 et 5 minutes, au maximum 8 minutes, selon la profondeur (Bearzi *et al.,* 2005, Bearzi *et al.,* 1999). Parmi les espèces capturées, le pourcentage d'espèces dites commerciales est élevé (Blanco *et al.,* 2001), dont plusieurs espèces en déclin (FAO, 2005). Le grand dauphin entre ainsi en conflit avec l'activité de pêche dans de nombreuses zones (Reeves *et al.,* 2001).

Les interactions entre cétacés et pêcheries sont spécialement importantes en Méditerranée (UNEP, 1998) et ont été étudiées dans différents régions (Consiglio *et al.,* 1992, Díaz López, 2006, Lauriano *et al.,* 2004). Aux Îles Baléares, jusqu'à 30 animaux morts par interactions avec la pêche ont été comptabilisés au début des années 90, sans en connaître le bilan total (Silvani *et al.,* 1992).

La capture accidentelle, conjointement avec les contaminants, la surpêche et le trafic maritime ont mené à une diminution drastique des populations de grand dauphin et à une fragmentation démographique intense de l'espèce. On peut considérer le grand dauphin comme l'espèce la plus exposée de Méditerranée (Di Natale, 1992, Natale, 1990).

Ainsi nous avons une espèce qui montre un comportement flexible, avec des différences éthologiques entre groupes, et qui est très liée à la côte où les activités humaines sont plus fréquentes, plus diverses et plus changeantes, associées aux traits culturels des sociétés riveraines qui l'habitent. Ces différences de comportement du grand dauphin sont-elles aussi culturelles? La capacité élevée d'apprentissage de ces animaux les rend extraordinairement rapides à la découverte de nouvelles opportunités pour l'obtention de nourriture et la diffusion de cette information peut désagréger temporairement les groupes (Whitehead *et al.,* 2004). Ces processus font qu'une partie de la population en arrive à être dépendante des déprédations exercées sur l'activité des pêcheurs (Chilvers & Corkeron, 2001).

Matériel et méthodes
Les interactions entre le grand dauphin et l'activité des pêcheurs autour des Îles Baléares ont exigé le développement de plusieurs études afin de minimiser leur impact (Brotons *et al.*, 2008a, Brotons *et al.*, 2008b, Brotons *et al.*, 2009, Brotons & Grau, 2005, Brotons *et al.*, 2008c, Brotons *et al.*, 2008d, Brotons *et al.*, 2011, Fernández-Contreras *et al.*, 2002, Gazo *et al.*, 2002, Gazo *et al.*, 2001, Gonzalvo *et al.*, 2014, Gonzalvo *et al.*, 2008). Ces études ont fourni un grand nombre d'informations sur la présence, la distribution et le comportement de l'espèce. Les données incluses dans ce document proviennent, principalement, de: (1) l'étude de l'estimation de l'impact économique des interactions entre le grand dauphin et les pêches artisanales aux Îles Baléares (Brotons *et al.*, 2008c), (2) l'évaluation de l'efficacité des « pingers » pour la réduction des interactions entre le grand dauphin et les filets de pêche aux Baléares (Brotons *et al.*, 2008d), (3) le suivi par photoidentification de la dynamique du grand dauphin autour des Baléares (Brotons *et al.*, 2008a, Brotons *et al.*, 2008b, Brotons *et al.*, 2009, Brotons & Grau, 2005, Brotons *et al.*, 2011), (4) l'analyse isotopique et génétique pour l'étude du degré d'isolation de la population des Baléares (Alomar *et al.*, 2013, Brotons & Islas-Villanueva, 2013) et (5) la surveillance acoustique pour l'estimation de la relation entre les Aires Marines Protégés (AMP) et le grand dauphin (Brotons *et al.*, 2010, Castellote *et al.*, 2015).

1. Les interactions entre la population de Grand dauphin et la pêche artisanale aux Îles Baléares ont été mises en évidence entre 2001 et 2003 avec le suivi de 1040 opérations de pêche et la présence d'observateurs à bord pendant 389 jours de mer. Cette présence était indispensable pour l'objectivité des prises de données, sans sous-estimer l'aide des pêcheurs à la connaissance du problème, aide bien documentée à plusieurs travaux (voir Pita; Maccarrone ; Miliou dans ce volume). La prise de données et la présence ou absence de déprédation pour chaque activité de pêche ont été standardisées. L'évidence de déprédation consistait en l'observation directe ou la présence de capture abîmée (Lauriano *et al.*, 2004). Les observations de dauphins autour des filets ont également été enregistrées. La présence ou l'absence d'évidence de déprédation a été modélisée en employant un Modèle Linéaire Généralisé (GLM) binomial avec l'aire géographique (Fig. 1), heure, mois, année, état de la mer, temps de permanence du filet en mer, typologie du filet et durée de la manœuvre comme indicateurs. Pour les détails méthodologiques, voir Brotons *et al.*, 2008c.

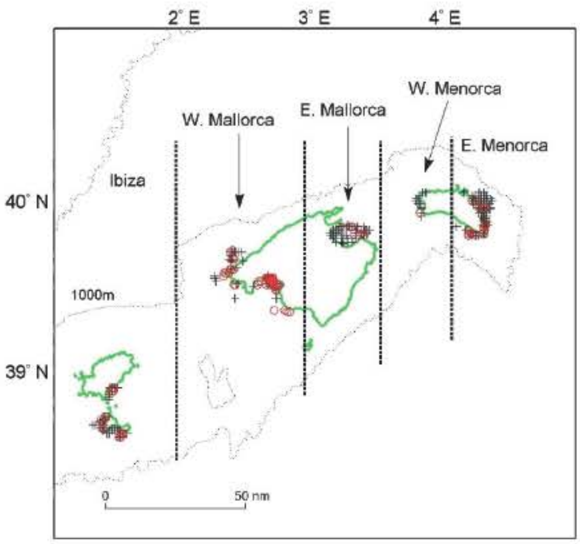

Figure 1. Localisation d'activités de pêche avec (◦) et sans (+) déprédation et différentiation des zones, Brotons *et al.*, 2008c.

2. L'étude pour l'évaluation de l'efficacité des « pingers » pour la réduction des interactions entre le grand dauphin et les filets de pêche aux Baléares a été réalisée dans les eaux côtières qui bordent les Îles Baléares à des profondeurs allant jusqu'à 60 mètres. Dans cette étude, jusqu'à 59 bateaux ont collaboré en utilisant des filets expérimentaux identiques. Les données ont été prises par des observateurs indépendants présents sur les diverses embarcations. Des formulaires standardisés pour le registre des données relatives à l'activité de pêche ont été utilisés. Pour calculer le rendement économique, on a combiné l'information sur la capture avec le prix moyen de vente au marché aux poissons. Les observateurs ont noté aussi la présence ou l'absence d'évidences de déprédation par les dauphins. Les bateaux ont été assignés aléatoirement à l'une des trois conditions expérimentales suivantes : contrôle (sans pingers), pingers inactifs (placebo) et pingers actifs. Les observateurs et les pêcheurs ne savaient pas à quelle condition expérimentale les bateaux étaient assignés. Pour plus d'informations, voir Brotons *et al.,* 2008d.

3. Entre 2003 et 2013, différents projets d'étude de la population du grand dauphin par photoidentification ont été effectués, les plus importants entre 2004 et 2010 dans la zone de Port d'Andratx (Sud-Ouest de Majorque) et en 2007/2008 à Cala Rajada (Nord-Est de Majorque) (Fig. 2). Pour la photoidentification du grand dauphin, les marques et cicatrices de la nageoire dorsale, sa forme et les différences de pigmentation du dos sont utilisées (Irvine *et al.,* 1981, Wells *et al.,* 1980, Wells *et al.,* 1987, Würsig & Jefferson, 1990, Würsig & Würsig, 1977). Les techniques photographiques et les systèmes d'approche sont largement documentés (Gunnlaugsson & Sigurjonsson, 1990, Markowitz *et al.,* 2003, Mazzoil *et al.,* 2004, Stevick *et al.,* 2001, Würsig & Jefferson, 1990, Würsig & Würsig, 1977). Les données géographiques ont été analysées avec les systèmes suivants : Systèmes d'Information Géographique (SIG), Arcview et les extensions Animal Movement, Home-Range et X-tools.

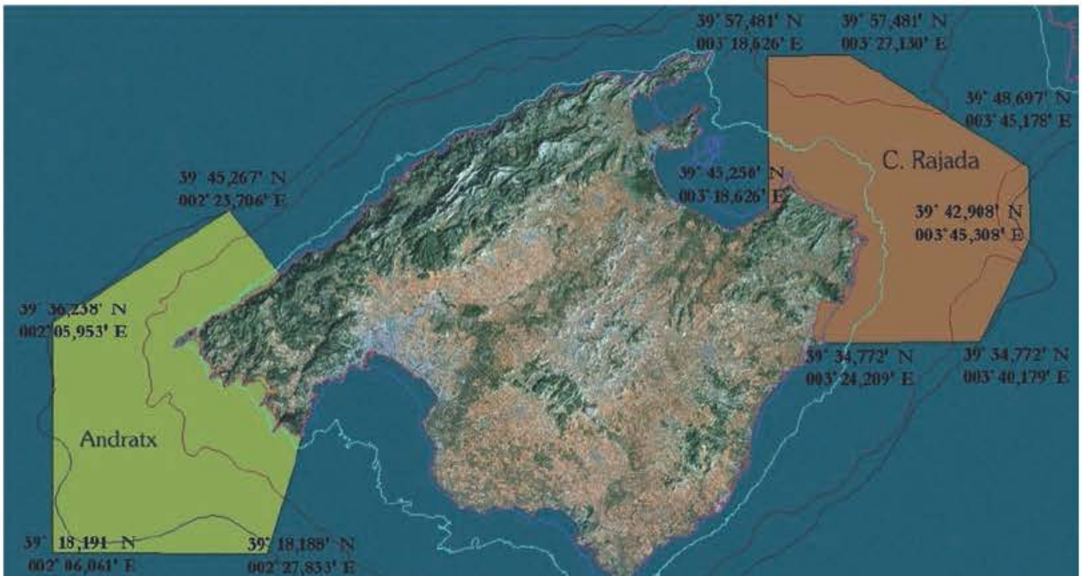

Figure 2. Aires d'étude par photoidentification à Majorque, Brotons (2016).

4. Entre mars 2009 et mai 2011, des biopsies ont été faites aux Îles Baléares et sur la côte de Valence sur 50 grands dauphins, au niveau de la zone postérieure de la nageoire dorsale (Fig.3). Pour son obtention, on a employé une arbalète de 150 lb de puissance, armée de flèches de fibres de carbone et d'une partie flottante pour la récupération de l'échantillon, avec tête tranchante

de 25 mm, mise au point par Ceta-Dart, F. Larsen, Copenhague, employée et testée dans d'autres études (Nicolas *et al.,* 2001, Quérouil *et al.,* 2007). Chaque échantillon a été séparé pour l'analyse indépendante isotopique et génétique. Pour la méthodologie plus précise, voir Alomar *et al.,* 2013, Brotons & Islas-Villanueva, 2013, Brotons, 2016).

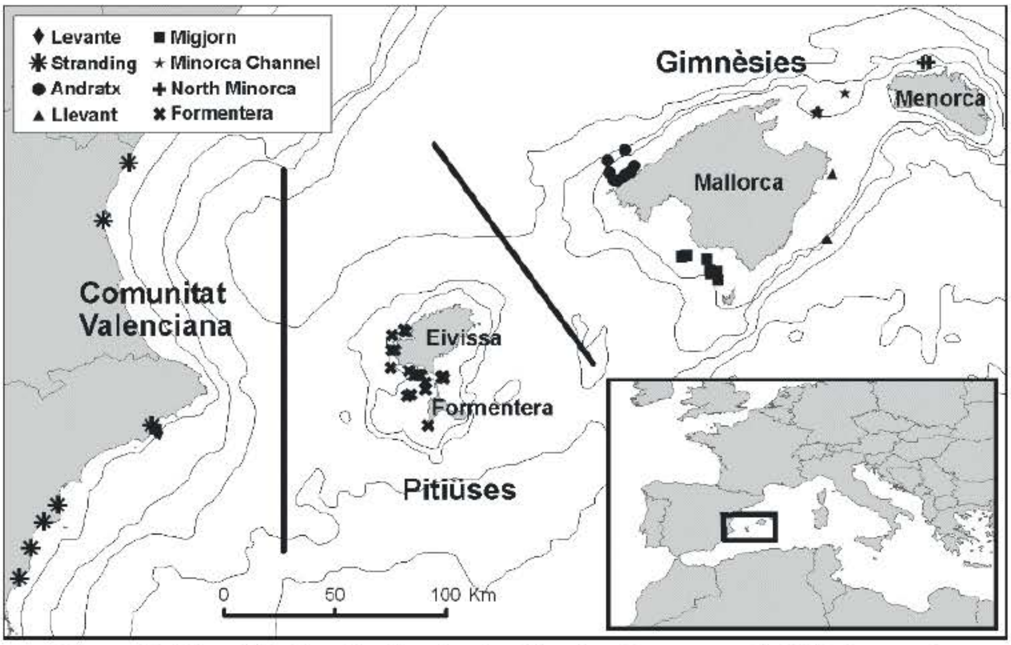

Figure 3. Aires d'étude et localisation des biopsies (Brotons *et al.,* 2018, in press).

5. Les PODs (littéralement "POrpoise Detectors") sont des ordinateurs submersibles connectés à des hydrophones de haute qualité qui identifient et enregistrent les « clics » d'écholocalisation des cétacés. Grâce à un transducteur en céramique incluant des filtres pour sélectionner les débits de fréquence du son, les PODs peuvent être programmés selon différents protocoles pour optimiser la détection de « clics » selon l'espèce. Toute cette information s'enregistre en fonction du temps. Les filtres et les protocoles d'échantillonnage permettent d'écarter le bruit ambiant. On a commencé à employer ces appareils à la fin des années 90. Au début des années 2000 on les a employés pour évaluer l'efficacité des « pingers » (Culik *et al.,* 2001) et pour des projets de conservation du Marsouin commun (*Phocoena phocoena*) (Tregenza *et al.,* 2001) et du grand dauphin (Gazo *et al.,* 2002). Aujourd'hui, son usage s'est étendu à toute l'Europe et à différentes espèces. Le POD employé dans cette étude est le T-POD de *Chelonia-Marine Conservations Research*. Il a une autonomie variable dépendante de l'information reçue jusqu'à 60 jours et une profondeur maximale de travail de 150 mètres. Les T-PODs ont été programmés spécialement pour la détection du grand dauphin dans des zones où la présence de décapodes est élevée. Dans le cadre d'un grand projet sur l'influence possible des AMP (Aires Marines Protégées) sur les dauphins (Castellote *et al.,* 2015), des PODs avaient été placés dans différentes AMP près des côtes catalanes, de Valence et des Baléares.

Résultats et discussion

Différentes étapes sont nécessaires pour résoudre les conflits entre pêcheries et cétacés, dont la première est de déterminer la nature, l'étendue et le coût du conflit (Perrin *et al.,* 1994).

Entre janvier 2001 et avril 2003, pour 1040 activités de pêche artisanale surveillées aux Îles Baléares, 138 (13%) cas de déprédation par des dauphins ont été rapportés. Le coût total pour l'industrie était de

6,5% de la valeur de capture (I.C.95% - 12.3/-1.6), avec un total de 219'115 € pour 2005 (I.C. 95% 53,936/414,633). Pour plus d'informations, voir Brotons et al, 2008c.

Il y a une série d'observations intéressantes à faire. D'une façon générale, on remarque que les interactions entre le grand dauphin et la pêche artisanale sont un problème commun, généralisé et important. Cependant, la fréquence de déprédation est très irrégulière : la dernière année d'étude, des conflits ont été rapportés dans 75% des activités à l'ouest de Majorque (Fig. 4). Pourquoi ? On peut penser à deux hypothèses: une diminution locale des ressources ou l'augmentation d'animaux spécialisés dans la déprédation. Cette dernière hypothèse a de très importantes répercussions pour la gestion du problème. Les données obtenues sur l'interaction grand dauphin/pêche artisanale indiquent une relation complexe, car la déprédation sur les filets est sélective, d'autant plus que le cétacé montre une préférence pour certaines espèces capturées (Fig. 4).

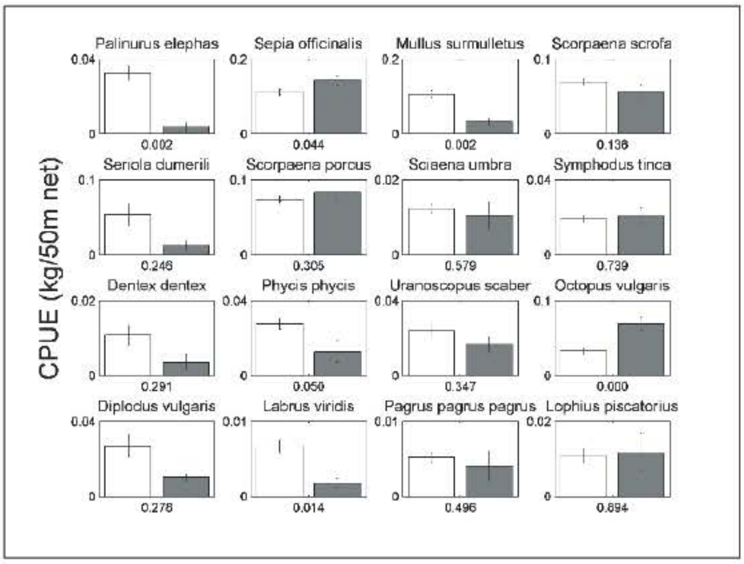

Figure 4. Captures moyennes par espèces sans (blanc) et avec (gris) déprédation (Brotons *et al.*, 2008c).

De plus, il existe une variabilité saisonnière (Fig. 5) qui peut être associée à la disponibilité des proies ou aux déplacements des animaux ou encore aux différentes activités de pêche qui ont elles aussi une variabilité saisonnière. Ce dernier aspect introduit une variable culturelle à tout le problème.

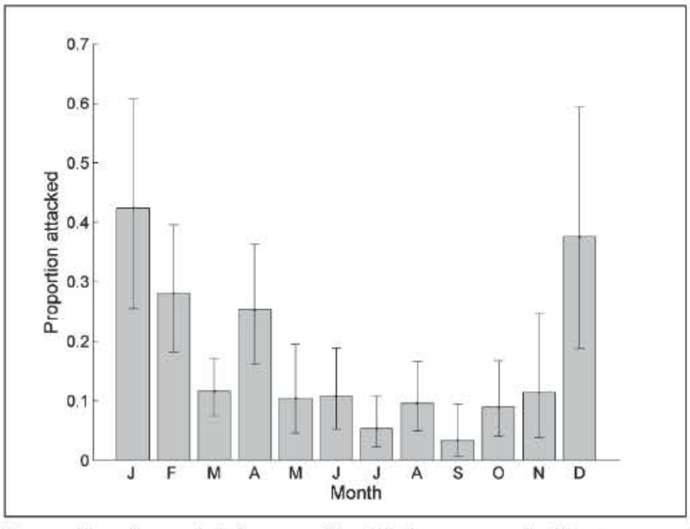

Figure 5. Proportion des activités avec déprédation par mois (Brotons *et al.*, 2008c).

Une autre donnée à relever est la mortalité des dauphins pendant l'étude. Deux individus ont été capturés parmi les 1040 activités de pêche. Si l'on extrapole au total de l'activité de pêche, il en résulte une perte totale d'effectifs de 60 animaux par an. Cependant cette donnée a un haut degré d'incertitude au vu du nombre d'animaux capturés. Les différences d'interaction par année et par saison ont été observées aussi dans des études antérieures et lors des tests de validation de « pingers » entre juillet et décembre 2015. Dans cette étude, le taux moyen est notablement plus bas, 0.08 (I.C. 95% 0.04-0.13) pour les filets contrôle (sans pingers) (Brotons *et al.,* 2008d) en comparaison à 0.13 en 2001-2003. S'il existe une différence significative pour le taux d'interaction avec les pingers, celle-ci n'est pas homogène selon le modèle testé, et on peut trouver des indices d'accoutumance (Brotons, 2016). Cette accoutumance peut être considérée comme un apprentissage qui peut être transmis, et pourtant, on parle de nouveau d'une situation affectée par la culture.

Entre mars 2004 et décembre 2010, 5381 milles nautiques ont été parcourus pour la photoidentification du grand dauphin à Majorque. Parmi les 121 observations, 183 individus ont été photoidentifiés à partir de 7200 photos. Parmi les 183 individus, seuls deux individus ont été observés dans deux zones d'étude, indiquant une très haute-fidélité géographique.

La présence du grand dauphin est constante tout l'année, car on ne trouve pas de différences significatives par mois (Anova, F (11.38) = 0.94494 ; p = 0.51012).

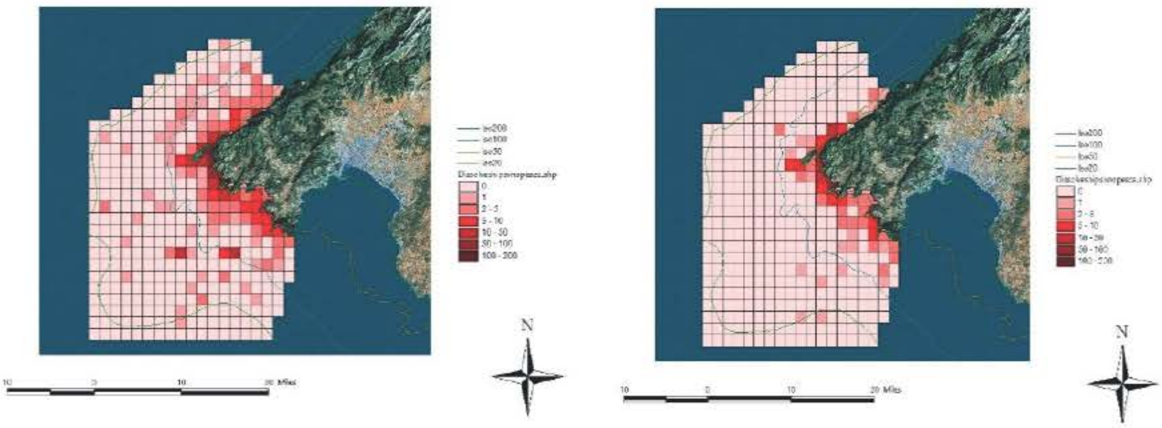

Figure 6. Densité de bateaux, à gauche en été, à droite en hiver, (Brotons, 2016).

La zone d'étude, comme toute l'île de Majorque, subit un haut impact humain saisonnier, car les embarcations se multiplient en été. Si l'on analyse le nombre de bateaux observés pendant les sorties de recherche par mois, il y a une différence significative (Kruskal-Wallis test H (11, N=97), p=0.0008), d'autant plus évidente si l'on groupe les données par saison, été (avril à septembre) et hiver (octobre à mars) (Mann-Whitney U-test z=-4.39547, p=0.000014). Le grand dauphin a une présence constante, toutefois la localisation des cétacés n'est pas égale en hiver et en été. Les distributions temporelles de la population de dauphins selon les distances à la côte moyennes par observation et par saison ont des différences significatives (Mann-Whitney U-test Z=2.842861, p=0.004474), plus côtiers en hiver, plus au large en été. Ces différences, bien que significatives, ne sont pas élevées globalement, 7244.822 m (I.C. 95% 5,921.040-8,568.603) en été et de 5183.356 m (I.C. 95% 2,920.596-7,446.116) en hiver. Si on fait le même calcul pour les bateaux rencontrés, il y a des différences significatives été-hiver (Mann-Whitney U-test Z=-4.49614, p=0.01256). Cette différence est mise en évidence (Fig.6) par la densité d'observations de bateaux par quadrillage.

Les dauphins font des changements saisonniers de distribution préférentielle en relation avec l'activité anthropique, changements décrits dans d'autres études (Gonzalvo *et al.*, 2014). Les relations entre le comportement des dauphins et les activités humaines ont été aussi corrélées à des AMP des Îles Baléares pendant le suivi acoustique de sept AMP différentes en Espagne. Ainsi, le Grand dauphin montre une plus grande fréquence de détection en hiver, juste quand l'activité humaine est plus basse. La même étude montre une différence de présence par mois liée aux activités anthropogéniques et une utilisation différentielle des zones par le Grand dauphin (Castellote *et al.*, 2015).

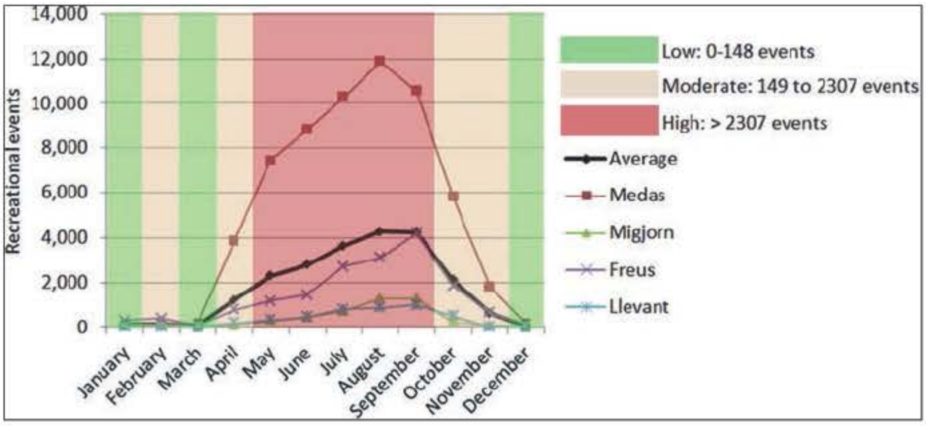

Figure 7. Evènements cumulés par mois pour 4 AMP sur 7 incluses dans cette étude (Medas, Freus, Migjorn et Levante) divisés en 3 niveaux d'intensité, bas (vert), modéré (rose) et haut (rouge) selon le percentile 33 et 66.

Si on trouve un lien entre l'activité des dauphins et celle des humains, mais uniquement dans certaines zones, et qu'on observe aussi un comportement différent dans des zones proches et petites, le lien résultant est extraordinairement complexe et il est très difficile de le concevoir sans la possibilité d'une transmission culturelle, où les groupes locaux, avec une haute-fidélité géographique, apprennent et appliquent de nouvelles stratégies qui peuvent ou non être exportées. Cette situation, si elle existe, doit être mise en rapport avec la dynamique des groupes autour des Baléares.

Les valeurs isotopiques de $\delta^{13}C$ et $\delta^{15}N$ d'animaux échantillonnés autour des Îles Baléares ont montré des différences entre les zones, parfois éloignées, comme Pitiüses et Gimnèsies, mais pas de manière statistiquement significative. Lors de l'analyse des sites à l'intérieur de Gimnèsies, les valeurs de δ15N étaient les plus élevées dans le Canal de Minorque (Nord de Majorque), et les plus faibles à Andratx (Sud-Ouest de Majorque). Les valeurs de δ13C étaient les plus élevées à Migjorn (Sud de Majorque) et les plus faibles à Andratx. Cependant, des différences significatives ont été trouvées seulement entre les valeurs de δ13C de Migjorn à celles de Andratx et les valeurs de δ15N du Canal de Minorque étaient significativement différentes des autres sites d'échantillonnage. Les valeurs de δ13C ont montré une plus grande variabilité entre les sites d'échantillonnage que les valeurs de δ15N. Pour les valeurs de δ15N, les échantillons du canal de Minorque ont montré la variabilité la plus élevée et ceux d'Andratx la plus basse (Alomar *et al.*, 2013).

Les traits isotopiques révèlent des informations sur le régime alimentaire des animaux lors des 90 derniers jours (García Tíscar, 2010), alors, si l'on trouve des différences isotopiques entre groupes dans des zones très proches (par exemple, Sud-Ouest et Sud de Majorque), cela signifie qu'il y a une exploitation des ressources différentes. Le grand dauphin a des capacités élevées d'apprentissage, ce qui lui permet de découvrir rapidement de nouvelles opportunités de recherche de nourriture et la diffusion de ces informations peut désagréger les populations en relativement peu de temps (Whitehead *et al.*, 2004).

Mais comment ce scénario culturel se reflète-il dans les interactions avec la pêche ?

En 2002, les pêcheurs artisanaux utilisant des palangres de fond à Ciutadella, à l'Ouest de Minorque (Fig. 8) ont constaté la déprédation des captures par le grand dauphin sur leurs lignes. Cette déprédation est très technique car le dauphin, pour enlever le poisson de l'hameçon, doit attendre que le pêcheur tire la ligne pour qu'elle soit tendue et en tension pour prendre à la bouche la proie et la libérer de l'hameçon. À ce moment-là, l'unique endroit des Îles Baléares où cette interaction avait été constatée était Ciutadella. Cinq ans plus tard, le problème s'est propagé aux zones voisines, Cala Rajada, au Nord-Est de Majorque et Fornells, au Nord de Minorque. Même si la fidélité géographique est très importante, les petits mouvements des individus permettent la diffusion de stratégies, et leur application et modification aux nouveaux environnements.

Figure 8. Situation et années d'apparition des interactions grand dauphin/palangre de fond.

Aujourd'hui, la baie de Palma de Majorque a de graves problèmes avec la déprédation par les dauphins, sur la pêche à la Seine ce qui provoque des grandes pertes quand ils cassent les filets. Quand les mêmes bateaux se déplacent dans les baies du nord (Alcudia et Pollença), les problèmes disparaissent malgré la présence du grand dauphin. Ce problème existe aussi sur la côte du Portugal, (Marçalo, dans ce volume), mais il affecte une autre espèce (*Delphinus delphis*) et ses problèmes n'impliquent pas la cassure du filet. En résumé, le facteur culturel des populations locales de *T. truncatus* fait que les problèmes d'interactions ainsi que leurs solutions, ne peuvent pas être exportés sans examen et adaptation aux conditions locales.

Remerciements
À tous les pêcheurs pour eur aide et leurs données. Sans eux, ce travail n'aurait pas été possible. Nos remerciements à la *Swiss Cetacean Society*-SCS pour l'aide à la rédaction en français (www.swisscetaceansociety.org).

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Interactions between marine mammals and fisheries: case studies from the Eastern Aegean and the Levantine Sea

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Abstract
Anthropic presence is growing in the oceans worldwide, causing an alarming rise in dolphin-human interactions. The current report summarizes the results of fishery interactions with small marine mammal species, including the endangered Mediterranean monk seal (*Monachus monachus*), the Bottlenose dolphin (*Tursiops truncatus*) and the Common dolphin (*Delphinus delphis*). These species have been regularly sighted in the close vicinity of fishing vessels, while entanglement and depredation events in the artisanal fishing gear, purse seiners and trawlers have been recorded. Additionally, deliberate killing of striped dolphins (*Stenella coeruleoalba*) have been documented. Due to the increasing interaction rates within the last decades, direct consequences such as behavioral modifications, injuries and death are unavoidable. Similarly inevitable are the indirect effects like the growing hostility of fishermen to certain species due to the depredation of their nets but also due to the overall decrease of common prey stocks. Therefore, focused and joint studies on the short and long-term interactions between marine mammals and fishery activities in line with awareness campaigns are crucial to improve the understanding of the direct and indirect impacts resulting from fishery practices. This is an important prerequisite to develop effective conservation measures before this pressure causes significant effects on the entire Mediterranean populations of these data-deficient species at risk.

Introduction

Anthropogenic pressure on marine mammal populations has substantially grown worldwide as a result of the intense and increasing demand for seafood in recent decades and certainly the Mediterranean Sea is no exception (Lotze *et al.,* 2006; Parsons *et al.,* 2015). Apart from fisheries, pressures from multiple other economic activities such as tourism, maritime transport, aquaculture and agriculture also cause a lasting footprint in all aspects of the fragile Mediterranean environment and biodiversity (UNEP/MAP-Plan Bleu, 2009). It is however the poorly regulated and uncontrolled fishery practices that are considered as the main cause of the alarming decline in fish stocks worldwide: around 90% of the world stocks are either fully or partially overfished (FAO, 2016), while the Mediterranean fish stocks are showing a severe decline since 1982 (Pauly & Zeller, 2016). According to a recent analysis, 93% of the assessed Mediterranean fish stocks are overexploited, while a number of them are on the verge of depletion in particular the Mediterranean Sea is estimated to have lost 41% of its marine mammals and 34% of the total fish population over the past 50 years (STECF 2017).

The dramatic overexploitation of fishery resources has resulted in numerous ecosystem impacts, but also in changes over time in the types and frequency of interactions between marine mammals and the various fisheries practices. As the fish stocks decline, it is becoming increasingly difficult for both fishermen and marine mammals to locate and capture adequate amounts of fish, which in return adds more pressure on the marine ecosystem, as the effort to catch fish increases both in artisanal and industrial fishing practices. The potential impacts of marine mammal predators on other species in the trophic chain include: reduced recovery of forage fish (Surma and Pitcher, 2015), increased competition between marine mammal species that share the same prey (Marshall *et al.,* 2015) and increased direct competition between marine mammal populations and fisheries (Gerber *et al.,* 2009). Increased fishing effort and therefore increased presence of fishing vessels results in entanglement and by-catch, but also provides a foraging opportunity for dolphins and seals that seek easy preys in fishing gear (Chilvers and Corkeron, 2001;Chilvers *et al.,* 2003), not without associated risks leading to injury or death (Christiansen *et al.,* 2015; 2016). There are several reports of foraging activities of marine mammals in the close vicinity of fishing vessels in the last decades (Mattson and Thomas, 2005; Siegel *et al.,* 2015; Pennino *et al.,* 2016; Bas *et al.,* 2016, Rios *et al.,* 2017, Maccarrone *et al.,* in this volume; Marcalo *et al.,* in this volume; Brotons *et al.,* in this volume and Kafaf, in this volume). This habituated behavior towards fishing vessels has been classified as new foraging strategies under begging, depredation and scavenging behaviours (Powel and Wells, 2010; Kovacs and Cox, 2013). These highly risky behavioral adaptations towards fishing vessels stand apart from the behavioural reactions towards the other vessel types, such as speedboats or ferries (Lusseau, 2003; Bas *et al.,* 2017; Oakley *et al.,* 2017). The interaction between the fishery practices and marine mammals brings about both short and long-term negative effects. Short-term effects include behavioral changes while long-term effects include physical stress, injury and even death (Genov *et al.,* 2008; Christiansen *et al.,* 2016).

The constant increase of interactions between human activities and marine mammals has resulted in the deterioration of the conservation status of the Mediterranean marine mammal subpopulations. Since 2001 more species have been listed as “vulnerable” and even “endangered” in the IUCN Red List (IUCN, 2017). The major threats include by-catch, fish depletion, habitat destruction, chemical and noise pollution, ship strikes and marine traffic (Bearzi 2003; Wright *et al.,* 2007; Birkun and Frantzis, 2008; Bailey *et al.,* 2010; Thompson *et al.,* 2010; Bearzi *et al.,* 2012; Birkun, 2012; Dunlop *et al.,*2017; Bas *et al.,* 2017; Oakley *et al.,* 2017). Their impacts on the marine mammal populations are estimated to increase in the future, if effective conservation measures are not taken (Coll *et al.,* 2010).

Due to the lack of targeted monitoring programmes, there exists a large knowledge gap on the levels and types of interactions between marine mammals and the various fisheries practices in many parts of the Mediterranean, while the existing information is frequently scattered and unpublished. As a result it is difficult for management measures to be developed and implemented, in order for these interactions to be mitigated.

This paper provides a preliminary assessment of the marine mammal-fishery interactions in the regions of the Eastern Aegean Sea and Antalya Bay in the Levantine Sea, through the compilation of unpublished data and information gathered through different survey approaches (dedicated boat and land surveys, opportunistic surveys from research and fishing vessels, questionnaire-based surveys, and reports from marine mammal stranding network). In combination with the information provided in this Monograph on the interactions off Sicily (Maccarrone *et al.,* this volume), in Portuguese continental coast (Marçalo *et al.,* this volume), the Balearic sea (Brotons *et al.,* this volume) and the waters of Morocco (Kafaf, this volume), an understanding of the characteristics and frequency of marine mammal-fishery interactions in selected Mediterranean regions can be generated.

Case Study 1. Marine mammals-fisheries interactions in the Eastern Aegean Sea, Greece

Between 2000 – 2018, the interactions between marine mammals and fisheries practices in the region of the eastern Aegean Sea, were assessed opportunistically, using direct observations during dedicated boat surveys monitoring marine mammal populations, a qualitative questionnaire based surveys addressed to artisanal fishermen, as well as reports from a marine mammal stranding network.

Cetacean – Fisheries Interactions

Between 2000 and 2010, the Bottlenose dolphin *Tursiops truncatus* was the only cetacean species that was recorded to depredate both artisanal fishing gear and trawlers. Depredation behavior on artisanal fishing gear was mainly recorded by solitary dolphins or small pods, rather than larger pods that rarely showed such a behavior. Since 2010, the Common dolphin *Delphinus delphis* was also observed to start demonstrating gradually a depredation behavior, initially interacting with benthic trawlers and since 2013 with artisanal nets.

Figure 1. Interaction of *T. truncatus* (left) and *D. delphis* (right) with trawlers

Since 2010, throughout the trawling season for Greek waters (October-May), there are regular sightings of *T. truncatus* and *D. delphis* interacting with trawlers, demonstrating scavenging or depradation behaviours (Fig. 1). No interaction has ever been observed nor reported between Striped dolphins *Stenella coeruleoalba* and any type of fisheries, although six of the *S. coeruleoalba* that were found stranded in the region had marks of deliberate killings inferred to be caused by interactions with fisheries activities (Fig. 2).

Risso's dolphins *Grampus griseus* have been reported to be entangled on surface long lines and this is the only form of depredation recorded for this species (Fig. 3). No evidence or information was reported in relation to interactions between the purse-seine and boat-seine fisheries with cetaceans. No interactions with fisheries activities has been reported or recorded between larger cetacean species found in the region (*Ziphius cavirostris*, *Physeter macrocephalus* and *Baleanoptera physalus*).

Figure 2. Stranded *S. coeruleoalba* with marks of deliberate killings.

Figure 3. Stranded *G. griseus* withmarks of deliberate killing.

Monk Seal– Fisheries Interactions

The incidents of depredation of Mediterranean monk seals *Monachus monachus*, with artisanal fishing gear, and both nets and long-lines have been increasing since 2000, with more incidents being recorded and reported in the south-eastern Aegean Sea, than in the north-eastern Aegean Sea, likely reflecting the larger monk seal population in the SE Aegean. In a study carried out in 2014 assessing the interactions between monk seals and the artisanal fishery of the small island of Lipsi in the SE Aegean, (Rios *et al*., 2017), evidence of depredation by monk seals was recorded in 19.1% of fishing journeys comapred to 5% by cetaceans. Analysis of landings data showed that gear and depth were the variables most likely to influence the occurrence of depredation, whereas the total cost of monk seal depredation was estimated to be 21.33% of the mean annual income of the artisanal fishermen.

Figure 4. A juvenile *M. monachus* entangled in an artisanal fishing net

There has only been one incident where a young *M. monachus* was found entangled on a fishing net (Fig. 4) and such bycatch was not been reported in any other occasion. The incidents of *M. monachus* that were found stranded with evident marks of deliberate killings are considered to be caused by certain fishermen as a manner of reducing depredation on their fishing gear and the large loss of their income, but is certainly not a common practice among the local fishing communities.

Case Study 2. Marine mammals-fisheries interactions in Antalya Bay

Through a combination of opportunistic surveys from artisanal fishing vessels and dedicated land surveys that took place in the coastal zone of Antalya Bay between 2015 and 2017, Bottlenose dolphins (*T. truncatus*) were recorded regularly in the close vicinity of fishing practices. Dolphin-fishery interactions were recorded in 106 of 119 sampling occasions (5 minutes) in close vicinity (less than 400m) of artisanal fishery and trawlers. In only three of these incidents interaction with trawlers was recorded, but it should be noted that the coastal zones of Antalya Bay are mainly free from the trawler pressure.

Additionally, an adult Mediterranean Monk Seal (*Monachus monachus*) was documented scavenging from an artisanal fishery boat on 28 August 2015 in Antalya Bay (Bas *et al.,* 2016). The event took place near a fishing net, and the seal spent over 30 min between diving and resurfacing around the net, often coming up with fish in its mouth, while in close proximity (less than 50 m) to a group of ten swimmers. No apparent reaction of the local seal to the swimmers was recorded (Bas *et al.,* 2016).
Pre-determined qualitative questionnaires were disseminated to 30 artisanal fishermen registered in the Antalya Fishery Cooperative. All fishermen interviewed reported depredation on their nets, assumingly from bottlenose dolphins.

Conclusion

The current paper summarises the interactions between marine mammals and fisheries from two different locations in the Mediterranean, the Eastern Aegean and Northwestern Levantine Sea. In these areas, the scarce knowledge available on the marine mammal populations and the factors of threat poses an important barrier to effective conservation actions. In both regions, *T. truncatus* regularly demonstrated depredation behaviors from trawlers and artisanal vessels. The same scenario is also present off the Balearic Islands in Spain (Brotons *et al.,* this volume), off the Mediterranean coasts of Morocco (Kafaf, this volume), as well as in the Sicilian Channel in Italy, one of the most exploited fishing areas in the Mediterranean Sea, where the competition between fishermen and Bottlenose dolphins is estimated to have intensified due to the general decrease in pelagic and demersal fish stocks (Maccarrone *et al.,* this volume). In the eastern Aegean Sea, the interactions between *D. delphis* and fisheries activities were not recorded or reported until 2010. Since then small pods of the species were observed to start demonstrating gradually a depredation behavior. This initially involved interaction with trawlers and since 2013 also with artisanal nets. Fishery interactions of *D. delphis* are also recorded and studied since the beginning of the 20th century along the Portuguese continental coast, where this species is the most abundant and is often victim of bycatch in gill and trammel nets or of interaction with purse seiners (Sequeira and Ferreira, 1994; Silva, 1999; Silva and Siqueira, 2003; Wise at al., 2007; Marçalo *et al.,* this volume).

In the Eastern Aegean Sea the six individuals of *S. coeruleoalba* that were found stranded with marks of deliberate killing, as well as the rare bycatch of *G. griseus* in longlines draws the attention to the wide range of unintentional catches during fishing practices. The endangered *M. monachus* was also recorded to have frequent interactions with artisanal fisheries in both regions. Such seal-fishery interactions are frequently reported in many parts of the Greek and Turkish seas, but are not common in other sectors of the Mediterranean, due to the limited distribution of the species.
Therefore, the negative impacts of fisheries, ranging from bycatch to behavioural modifications and direct hostility to the animals, were documented in the two study areas. While the results of entanglement and bycatch can be immediate, the consequences of behavioural modifications (such as area avoidance, development of risky foraging strategies), need to be addressed with caution. Their

effects include habituation, hostility of fishermen, intentional and unintentional injuries and death, as a result of following, approaching and staying with the vessels.

With the lack of efficient fisheries management measures, these interactions are only expected to exacerbate in coming years due to overfishing and related impacts.

It is important to highlight that the species exposed to these threats are currently classified at risk in part due to the high incidence of entanglement events (Bearzi, 2003; Birkun, 2008; Bearzi *et al.*, 2012). The human-dolphin interactions are not limited to fishing activities but also to tourist interactions such as dolphin watching activities and fish hand-outs offered to dolphins, even though laws and local regulations for the protection of wildlife do not allow such practices (Maccarrone *et al.*, this volume). Therefore, a focused investigation on the short and long-term interactions between marine mammals and fisheries, in line with awareness campaigns, is crucial to understand the extent of the threat posed by fisheries. Filling this knowledge gap is an important prerequisite for the development of effective conservation measures.

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Impacts of marine invasive alien species on European fisheries and aquaculture - plague or boon?

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Abstract

Many invasive alien species highly impact fisheries and aquaculture in European Seas. Despite the fact that mostly negative impacts are reported in the literature, many alien species can have important positive impacts and can restore or secure ecosystem processes and functions, especially in degraded ecosystems. These negative or positive impacts occur through a variety of mechanisms such as blooms of toxic algae, the degradation of important habitats, predation, competition, fouling shellfish, gear or equipment, damage of catch or fishing gear, entanglement in nets, disease transmission, new commodities, new food source for commercial species, biological control of other invasives, and creation of novel habitats. The balance between positive and negative impacts is difficult to assess, and in many regions alien species are considered as a boon to fisheries and aquaculture. In some regions, climate change has caused the loss of temperature-sensitive species. In such cases, alien species can be beneficial overall by fulfilling the lost ecological roles. Further research is needed to conduct proper impact and risk assessments and address the inherent uncertainty.

1. Introduction

Alien species are taxa that have managed, by human agency, to overcome bio-geographical barriers and get established in new regions beyond their natural distribution (Falk-Peteren *et al*., 2006). In the last decades, introductions of alien species have been accelerated due to the rapid globalization and unprecedented rates of trade, travel, and transport (Essl *et al*., 2015; Seebens *et al*., 2017). This increasing trend of new introductions has been documented in the European Seas (Katsanevakis *et al*., 2013), and in the Mediterranean Sea in particular, the latter mainly due to introductions of Indo-Pacific species arriving through the Suez Canal (Zenetos *et al*., 2012; Tsiamis *et al*., 2018).

Some of the established alien species may have important impacts on biodiversity, human health, infrastructure, and ecosystem services by modifying habitats and community composition, causing local extinctions, and affecting food-web properties, ecosystem processes and functioning (Mazza *et al*., 2014; Katsanevakis *et al*., 2014; Bellard *et al*., 2016). On the other hand, alien species can also have positive impacts, the latter through provision of food and shelter, creation of novel habitats or by securing ecosystem processes and functions (Hobbs *et al*., 2009; Schlaepfer *et al*., 2011; Katsanevakis *et al*., 2014).

The reported socio-economic impacts of alien species often exceed their ecological impacts, perhaps because the former are more readily perceived by humans (Vilà *et al*., 2010). There have been many attempts to assess the socio-economic impacts of alien species based on utilitarian approaches of monetizing their costs (e.g. Zavaleta, 2000) or, recently, by proposing a standardized system for classifying the magnitude of impacts on human well-being (Bacher *et al*., 2018). Nevertheless, most efforts have so far focused on negative impacts - and mostly on the terrestrial environment - ignoring any positive contribution of alien species to ecosystem services. Katsanevakis *et al*. (2014) critically reviewed >2000 articles on impacts of invasive alien species on ecosystem services and biodiversity in the European seas. As seen in the Table 1, both negative and positive impacts must be accounted for.

Table 1. Negative (red) and positive (green) impacts of alien marine species on fisheries and aquaculture in European waters, as reported in the literature. The table includes only species that have been considered as high-impact species. (Cr): cryptogenic species. Modified and updated from Katsanevakis *et al*. (2014).

Impacts of alien species in Europe on fisheries and aquaculture

Dinophyta (Myzozoa)	**Cnidaria**	**Mollusca**
Alexandrium minutum (Cr)	*Cordylophora caspia*	*Anadara kagoshimensis*
Alexandrium monilatum	*Oculina patagonica*	*Anadara transversa*
Karenia mikimotoi (Cr)	*Rhopilema nomadica*	*Arcuatula senhousia*
Gymnodinium catenatum (Cr)	**Ctenophora**	*Crassostrea gigas*
Haptophyta	*Beroe ovata*	*Crepidula fornicata*
Phaeocystis pouchetii (Cr)	*Mnemiopsis leidyi*	*Ensis directus*
Ochrophyta	**Polychaeta**	*Mercenaria mercenaria*
Coscinodiscus wailesii (Cr)	*Ficopomatus enigmaticus*	*Mya arenaria*
Fibrocapsa japonica (Cr)	*Hydroides dianthus*	*Pinctada imbricata radiata*
Pseudochattonella verruculosa (Cr)	*Hydroides elegans*	*Rapana venosa*
Macroalgae	*Marenzelleria spp. (neglecta & viridis)*	*Spondylus spinosus*
Acrothamnion preissii	**Crustacea**	*Urosalpinx cinerea*
Asparagopsis armata	*Acartia (Acanthacartia) tonsa* (Cr)	*Venerupis philippinarum*
Caulerpa cylindracea	*Amphibalanus improvisus* (Cr)	**Fish**
Caulerpa taxifolia	*Austrominius (Elminius) modestus*	*Liza haematocheila*
Codium fragile subsp. *fragile*	*Callinectes sapidus*	*Fistularia commersonii*
Gracilaria vermiculophylla	*Cercopagis pengoi*	*Lagocephalus sceleratus*
Grateloupia turuturu	*Chionoecetes opilio*	*Neogobius melanostomus*
Lophocladia lallemandii	*Eriocheir sinensis*	*Nemipterus randalli*
Polysiphonia morrowii	*Gammarus tigrinus*	*Plotosus lineatus*
Sargassum muticum	*Homarus americanus*	*Saurida undosquamis*
Undaria pinnatifida	*Marsupenaeus japonicus*	*Scomberomorus commerson*
Womersleyella setacea	*Palaemon macrodactylus*	*Siganus luridus*
Tracheophyta	*Paralithodes camtschaticus*	*Siganus rivulatus*
Halophila stipulacea	*Portunus segnis*	*Upeneus moluccensis*
Spartina alterniflora	*Rhithropanopeus harrisii*	**Ascidiacea**
Spartina anglica		*Microcosmus squamiger*
		Styela clava

2. Review of impacts on fisheries and aquaculture

Food provision is the ecosystem service impacted by the greatest number of alien species both positively and negatively. The indicators most commonly used to assess the impacts of alien species on fisheries and aquaculture included abundance or biomass of commercial marine living resources, sea food quality, catches, landings, number of viable fisheries, and income and jobs from fisheries and aquaculture (Liquete *et al*., 2013).

Alien species can impact fisheries and aquaculture through a variety of mechanisms which are developed below:

- **Algal Blooms**: Many invasive phytoplanktonic species have been reported to cause severe damage to both aquaculture and fisheries because of persistent toxic blooms (Gourguet *et al*., in this volume). Severe economic losses to aquaculture have been caused by the alien dinophyte *Alexandrium minutum* in northern Europe since 1985 (Nehring, 1998). Massive mortalities of fish have been caused by *Karenia mikimotoi* in north-western Europe from 1968 onwards, including farmed finfish and shellfish (Raine *et al*., 2001). The alien dinophyte *Gymnodinium catenatum* is well-established in the Alborán Sea and is associated with frequent toxic events, causing paralytic shellfish poisoning episodes along the west coast of the Iberian Peninsula, leading to the interruption of harvesting of shellfish, with severe economic losses to the sector (Ribeiro *et al*., 2012). The ichthyotoxic flagellate *Pseudochattonella verruculosa* caused the death of hundreds of tonnes of farmed Norwegian salmon in 1998 and 2001 (Edvardsen *et al*., 2007) and massive mortality of wild fish (garfish, herring, sandeel and mackerel) along the west coast of Denmark. During *Coscinodiscus wailesii* blooms, high amounts of mucilage can be produced, often causing extensive clogging of fishing nets, aquaculture cages and other equipment (Boalch and Harbour, 1977; Boalch, 1984). *Phaeocystis pouchetii* has been reported to reduce growth in farmed salmon (Aanesen *et al*., 1998).

- **Degradation of important habitats:** Alien species may have an indirect negative impact on fisheries by impacting essential habitats for fish stocks, which provide food, refuge and nursery grounds. The alien herbivore fishes *Siganus luridus* and *Siganus rivulatus* have caused, through overgrazing, the gradual transformation of the eastern Mediterranean sublittoral ecosystem from one dominated by lush and diverse brown algal forests – essential habitat for many commercial species – to one dominated by bare rock or algal turf (Sala *et al*., 2011, Verges *et al*, 2014). Alien macroalgae such as *Acrothamnion preissii*, *Caulerpa cylindracea, C. taxifolia, Codium fragile subsp. fragile, Gracilaria vermiculophylla, Lophocladia lallemandii, Sargassum muticum, and Womersleyella setacea*, and also encrusting alien animals such as the coral *Oculina patagonica* may cause the degradation of essential habitats for fish.

- **Direct predation or competition**: One of the most marked examples of how biological invasions can impact fisheries due to predation is the invasion of the carnivorous ctenophore *Mnemiopsis leidyi* in the Black and Caspian Seas, which caused dramatic reductions in zooplankton, ichthyoplankton, and zooplanktivorous fish populations in the 1980s and early 1990s (Shiganova, 1998; Shiganova *et al*., 2001b; Leppäkoski *et al*., 2009). This species, probably in combination with other stress factors (Niermann, 2004), affected stocks of many small pelagic fish, causing an estimated annual financial loss in the fisheries sector of approximately 200 million USD in the Black Sea and 30-40 million USD in the Sea of Azov (GESAMP, 1997). Another predatory alien species in the Black Sea, the gastropod *Rapana venosa*, is responsible for the depletion of large stocks of commercial bivalves (esp. *Mytilus galloprovincialis* and *Ostrea edulis*) and the associated communities in the Black Sea since the 1950s

(Zolotarev, 1996; Salomidi *et al*., 2012). Decline of commercial stocks due to direct predation or competition for resources (food or space) is the presumed mechanism of negative impact in the cases of many other alien species, such as the decapods *Homarus americanus* and *Paralithodes camtschaticus*, the fishes *Fistularia commersonii*, *Neogobius melastomus, Saurida lessepsianus, Liza haematocheila, Siganus luridus* and *S. rivulatus*, the bivalves *Crassostrea gigas* and *Pictada imbricata radiata*, and the gastropod *Urosalpinx cinerea*. However, these associations and impacts are difficult to prove empirically and will require more research to assess measurable effects.

- Fouling shellfish, gear and equipment: Some alien macroalgae (e.g. *Codium fragile subsp. fragile, Gracilaria vermiculophylla, Grateloupia turuturu, Sargassum muticum, Undaria pinnatifida*) can have a negative economic impact on aquaculture and fisheries by fouling fishing gear, shellfish facilities and shellfish beds, smothering mussels and scallops, clogging scallop dredges, and interfering with harvesting. The cladoceran *Cercopagis pengoi* attaches to fishing gear and clogs nets and trawls, potentially causing problems and substantial economic losses for fishermen and fish farms. Many fouling species such as the polychaetes *Ficopomatus enigmaticus*, *Hydroides dianthus* and *Hydroides elegans*, the barnacles *Amphibalanus improvisus* and *Austrominius modestus*, the gastropod *Crepidula fornicata*, the ascidians *Microcosmus squamiger*, and *Styela clava*, and the hydrozoan *Cordylophora caspia* may compete for space with cultured bivalves causing a reduction of production, bring additional costs for sorting and cleaning fouled shells before marketing, and lead to extra costs for maintenance of fishing gear or aquaculture equipment.

- Damage of catch and fishing gear, entanglement in nets: The invasive silver-cheeked toadfish *Lagocephalus sceleratus* has been reported to attack the catch of nets or longlines and cause extensive damage to the fishing gear, causing substantial economic losses to coastal small-scale fisheries (Ünal and Göncüoğlu - Bodur, in this volume). Fishers often have to change their fishing practices (gear, depth, time, etc) to avoid encounters with the species (Katsanevakis *et al*., 2009). The entanglement of some species (e.g. *Eriocheir sinensis, Gammarus tigrinus, Plotosus lineatus*) in fish and shrimp nets may increase handling times, injure fishers and damage the nets or the target species. Coastal trawling and purse-seine fishing are often disrupted in Israel due to massive swarms of the jellyfish *Rhopilema nomadica*, which damage the catch, clog and tear nets, impair hauling equipment, sting fishers and make it difficult to sort the catch (Rilov and Galil, 2009; Angel *et al*., 2016).

- Disease transmission: Alien species can transmit diseases, causing increased mortality in native populations of commercially important species or in holding facilities. For example, the alien crab *Rhithropanopeus harrisii* was identified as a carrier of the white spot syndrome, a viral infection causing a highly lethal and contagious disease in commercially harvested and aquacultured penaeid shrimp (Payen and Bonami, 1979), and the alien American lobster *Homarus americanus* transmitted *gaffkaemia* to native European lobsters, a bacterial disease caused by *Aerococcus viridans var. homari* (Stebbing *et al*., 2012).

- New commodities: Many of the species that have caused the decline of native commercial species are fished or farmed and can have at the same time substantial a positive impact on food provision. For example, *Rapana venosa* (which has caused the decline of bivalve fisheries in the Black Sea) is edible and has supported very profitable fisheries (Sahin *et al*., 2009). The following alien species are edible and are important, some on a large-scale and others locally, for fisheries or aquaculture in their introduced range (see Kaiser and Kourantidou, in this volume): the fishes *Liza haematocheila*, *Saurida lessepsianus*, *Scomberomorus commerson, Upeneus moluccensis, Nemipterus randalli, Siganus luridus, S. rivulatus,* the mollusks *Ensis directus, Mercenaria mercenaria, Mya arenaria, Venerupis* *philippinarum, Sepia pharaonis* and *Crepidula fornicata*, the decapods *Chionoecetes opilio, Marsupenaeus japonicus, Palaemon macrodactylus, Paralithodes camtschaticus*, and *Portunus segnis*, and the brown alga *Undaria pinnatifida*. For example, *V. philippinarum* is one of the most important species in shellfish farming with a production accounting for >20% of the global shellfish market; Italy is the largest European producer with a production worth over 100 million euros (Otero *et al*., 2013).

- New food source for fish: Many alien species provide important food sources for commercial fish populations or contribute indirectly to such populations through more complicated trophic web interactions. For example the polychaetes *Marenzelleria neglecta* and *Marenzelleria viridis* are a significant food source for demersal fish such as plaice (*Pleuronectes platessa*) and flounder (*Platichthys flesus*) in the Baltic Sea (Winkler and Debus, 1997). The copepod *Acartia tonsa* constitutes significant prey for pelagic fish, and has been used to produce live feed for aquacultured species (Sørensen *et al*., 2007), such as turbot reared in the Black Sea. The invasive cladoceran *Cercopagis pengoi* is a very important food source for many fishes in the Baltic Sea, such as small herring, stickleback, smelt, and bleak (Ojaveer *et al*., 2004; Kotta *et al*., 2006).

- Biological control: Species that control species having a negative impact on fisheries or aquaculture are actually having a positive impact on food provision. A marked example is the establishment of the ctenophore *Beroe ovata* in the Black Sea. *B. ovata* is a predator of *M. leidyi* and has been reported to cause its decline in the Black Sea, and consequently a partial recovery of the planktonic food web structure and pelagic fish populations that had collapsed (Shiganova *et al*., 2001a; Finenko *et al*., 2003).

- Novel habitats: Katsanevakis *et al*. (2014) reported 49 invasive species in Europe to be ecosystem engineers that fundamentally modify, create or define habitats by altering their physical or chemical properties (Wallentinus and Nyberg, 2007; Berke, 2010). The novel habitats created by some of these ecosystem engineers differ in composition and structure from past and present native habitats, and result in different species interactions and functions. Some of these novel habitats created by reef-builders, tube-builders, macroalgae, and seagrasses can increase the spatial complexity of benthic habitats, offer novel microhabitats, and provide nursery grounds, shelter for macro- and microfauna, and strongholds for a diverse community of algae and invertebrates, potentially supporting stocks of commercial species.

3. The balance between negative and positive impacts

In general, invasive alien species do not have only positive or only negative impacts on biodiversity or ecosystem services but they have a mixture of both, with differing impacts on different services or ecological features (Katsanevakis *et al*., 2014). With the exception of some invasive species that have clearly only negative effects, such as microalgae causing toxic blooms (see Table 1), in many cases it is quite difficult to assess the overall balance of the effect on food provision, which may vary depending on several factors. Many alien species (especially fish, crustaceans and mollusks) are edible and are of high value for fisheries or aquaculture but they may cause the decline of native commercial species through a variety of mechanisms. For example, in the Levantine Sea, the world's most invaded marine region because of the opening of the Suez Canal, the catch of commercial fisheries is now dominated by alien species (Edelist *et al*., 2013) (Fig. 1), many of which are considered by local fishermen as an important gain for Levantine fisheries (Galil, 2007).

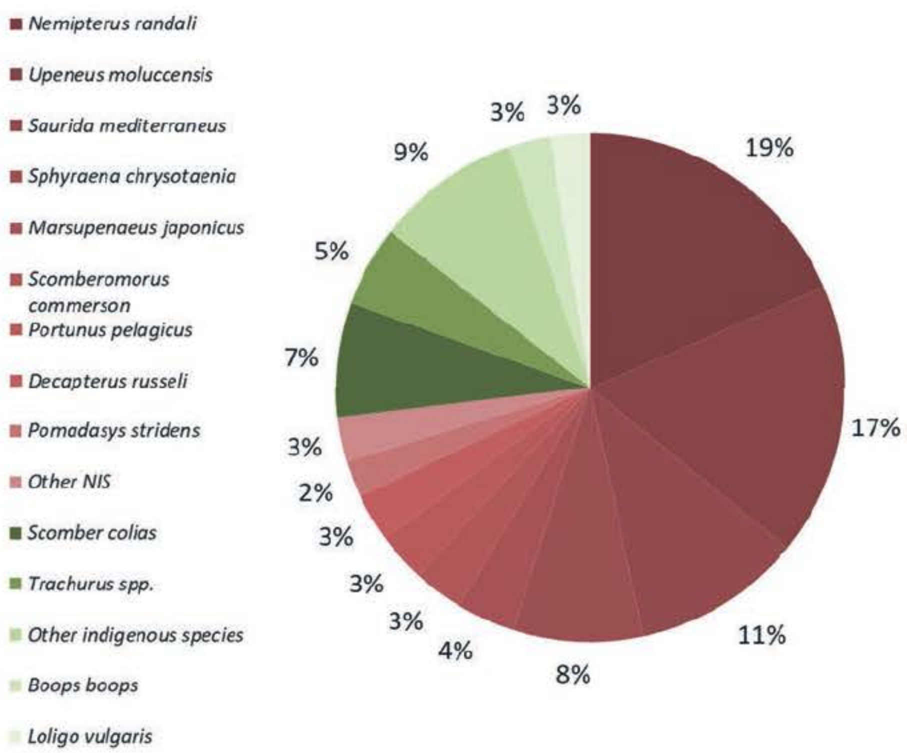

Figure 1. Catch composition in 78 commercial trawl hauls conducted between May and December of 2017 along the Israeli coast between Ashdod and Hadera in depths of 30-60m. Red shades refer to non-indigenous species, while green shades refer to indigenous species. Source: Edelist (2018).

A good example reported by Galil (2007) is the case of the alien penaeid prawns in the Mediterranean. Eight species, in particular the highly prized *Marsupenaeus japonicus*, compose most of the prawn catches off the Mediterranean coast of Egypt and Israel. They are considered by fishermen as a boon as they bring in a substantial part of trawl catches and income. Nevertheless, this comes along with the decline of the native species *Melicertus kerathurus*, which, probably due to competition with the new invaders, has nearly disappeared from its previous fishing grounds.

The complexity of species interactions and the variety of impacts make risk assessments and management decisions challenging, especially in view of often-conflicting stakeholders' perceptions (e.g. Kaiser and Kourantidou, in this volume). Although the positive impacts of alien species are under-reported due to a common perception bias against alien species, i.e. a 'native good – alien bad' perception (Goodenough, 2010), they are now receiving increasing consideration as providers of ecosystem services or even as having conservation benefits (Schlaepfer *et al*., 2011, 2012; Thomsen *et al*., 2014; Giakoumi *et al*., 2016).

4. Invasive species and climate change

Climate change is estimated to substantially affect fisheries and aquaculture production in various ways, with important variation of yield impacts among countries, and not all impacts necessarily being adverse (Barange *et al*., 2014). What is supported by new evidence and models is that climate change will cause a redistribution of benefits and losses at multiple scales and across marine and coastal socio-ecological systems, because of species shifts and ecosystem modifications and changes in primary productivity (Weatherdon *et al*., 2016).

Climate change directly influences the likelihood of alien species managing to get established in a new territory and is thus assisting or driving the expansion of species towards previously uninhabitable regions (Walther *et al*., 2009). In many regions, the loss of temperature-sensitive species might compromise food provision, especially in land-locked seas such as the Mediterranean or the Black Sea, in which species shifting their range from southern latitudes cannot fill the gap. In such cases, alien species are more likely than native species to persist, and could be beneficial overall by fulfilling the lost ecological roles and providing a novel exploitable source for fisheries. Some alien species that are currently considered as pests with mainly negative impacts might in the climate-modified future become acceptable or even desired species as they will assure ecological functions and the provision of ecosystem services (Walther *et al*., 2009). In the Levantine Sea, multi-species collapses of native shallow reef species have been, at least partially, attributed to climate change (see Box 1 adapted from Rilov, 2016). In one case, that of the sea urchin *Paracentrotus lividus*, it was experimentally demonstrated that its decline was related to the fast ocean warming (Yeruham *et al*., 2015). In that region, where alien fish dominate today in the shallow shelf communities and in the commercial catches (Edelist *et al*., 2013; Rilov *et al*., 2017), it is quite probable that food provision and the income of the fishers would have seriously declined if there were no alien species.

Box1

In the past three decades, temperatures on the Israeli coast have increased by 2-3°C. In the 1960-70s, peak summer temperatures were around 29°C and today they are 31-32 °C (Fig.2). Comparing historical taxonomic descriptions and anecdotal data of shallow reef species in the region with data from extensive ecological surveys between 2009-2016, showed that dozens of species (mostly molluscs but also sea urchins; Fig 2) that were described as abundant or very abundant in the past are now absent or very rare (Rilov, 2016). It was speculated that the warming might have reduced the fitness of temperature sensitive species and, at least partially, caused this decline. This was experimentally proven for sea urchins, that die when temperatures cross 30.5 °C (Yeruham *et al*, 2015), which occurred on the Israeli coast every summer for the past two decades (Fig 2). But, the reefs are not empty. Instead of the absent native molluscs, the reefs are totally dominated by alien molluscs (Fig. 2). It is quite reasonable to believe that many of them serve ecological functions that are similar to that of the missing natives. If so, and if indeed the natives' decline was driven by warming, then these aliens are critical for compensating for the loss of functions due to climate change. The collapse of the grazing urchins was "overcompensated" by the invasive rabbitfish that totally decimate native macrophytes (e.g., *Cystoseira* species) which are important habitat for many benthic species. *Cystoseira*, also show sensitivity to warm temperatures (Guy Haim, Rilov *et al*., unpublished data) which means that its populations are affected by both intensive overgrazing and warming.

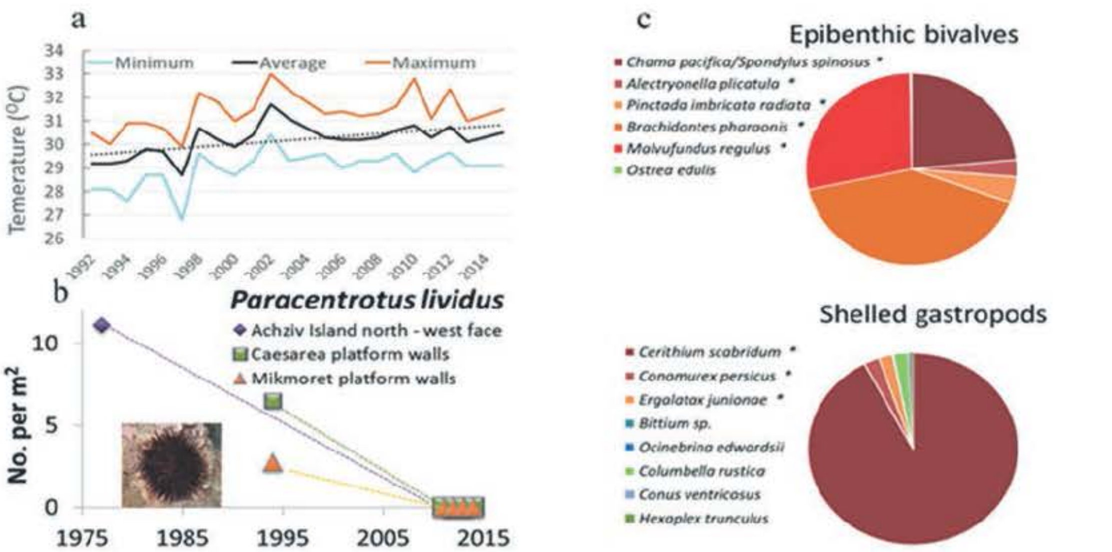

Figure. 2. a. Sea surface temperatures measured from a buoy 2 km offshore in south Israel. b. anecdotal (early years) and survey data (later years) showing the decline of the sea urchin *Paracentrotus lividus* in a site in north Israel that has been a marine reserve for two decades. c. the relative abundance of epi-benthic molluscs species on shallow reefs on the Israeli coast.
* denotes alien species. Figure modified from Rilov, 2016.

5. Needs for further research

Although many impact and risk assessments of biological invasions have been conducted with various protocols (Essl *et al*., 2011; Gallardo *et al*., 2016), our knowledge base is still far from being sufficient for proper and efficient management decisions. In particular, the assessments of impacts on ecosystem services and socio-economic activities, and the effect of climate change on such impacts constitute major gaps in the knowledge required for conducting risk assessments (Roy *et al*., 2018). Some negative or positive impacts on fisheries and aquaculture are directly observable (e.g. algal toxic blooms, fouling of equipment and gear, damage of catch and gear, entanglement in nets, new commodities) but others, in particular those that are related to changes in trophic webs, habitat modification or effects on wider ecological processes and functions need deeper investigation and targeted research. At present, they are mostly based on assumptions and expert judgment but not on targeted research testing the impact. The complexity of species interactions and the variety of both negative and positive impacts linked to alien species often make such research extremely difficult.

Climate change effects as well as cumulative effects of human pressures that act jointly with the effects of biological invasions further complicate impact and risk assessments as it is difficult to separate the different drivers and identify the real causes of observed impacts. For example, simple correlations between the decline of a native population and the increase of an alien population have often been used as evidence of alien species negative impacts (Katsanevakis *et al*., 2014). However, such non-experimental-based correlations do not offer strong evidence for causality, as there are many other alternative hypotheses. Other biotic or abiotic factors (e.g. temperature rise) or cumulative impacts of human pressures (e.g. pollution, overfishing, habitat destruction) could also correlate with the declining native population and thus provide other possible causal explanations. Disentangling cause-effect pathways is inherently difficult and would probably necessitate a combination of experimental and modelling approaches. The development of a variety of ecosystem modelling techniques, such as dynamic ecological models, may offer extremely useful tools for our understanding of interactions among native and alien species to better understand processes and predict the future dynamics of marine systems (Wonham and Lewis, 2009). This would greatly advance impact and risk assessments of biological invasions on food provision services of marine ecosystems. Such modeling attempts have been recently conducted for the Israeli trawl catch data with interesting insights, for example on the possible competition between invasives and natives based on biological trait analysis and on the effect of warming on natives and alien fish (Belmaker *et al*., 2013; Givan *et al*., 2017; Rijn *et al*., 2017; Arndt *et al*., 2018).

The quality of impact assessments can be jeopardized by uncertainty and its insufficient treatment (Stelzemüller *et al*., 2018). Assessments of the impacts of alien species on marine ecosystems and ecosystem services suffer from uncertainties related to insufficient data, type of responses of ecosystems to invasive species, type of multiple species effects (additive or with synergistic or antagonistic interactions), and resolution of spatial data (Katsanevakis *et al*., 2016). Additional research effort is needed to develop proper tools that will allow addressing uncertainty in impact and risk assessments in an adequate and transparent way (Katsanevakis and Moustakas, 2018).

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Invasive crab species in the Barents Sea: stakeholder perceptions, incentives, and path dependencies

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1. Introduction

New ecological and economic opportunities and challenges that arise as climate and human behavior shift socio-ecological systems will create new stakeholders in marine species. The perceptions of scientific stakeholders and economically impacted groups are likely to differ depending on many interwoven factors. These include missing or uncertain information on the impacts of change, and opportunity costs of human decision-making at the individual and group levels. This chapter focuses on the ongoing invasions of two different crab species in the Barents Sea: the red king crab (*Paralithodes camtschaticus*) and the snow crab (*Chionoecetes opilio*) in this context. Both species are benthic predatory feeders that are creating new ecosystem dynamics, but in different parts of the Barents. Though the two crabs are highly valued market commodities with internally competing complementary and substitutable demand characteristics, as well as some joint production possibilities in their native Pacific range fisheries, their invasion stories in the Barents are evolving quite differently.

The differences are important not only economically and ecologically, but also in terms of international agreements and other legal and institutional concerns. By addressing the two species together, we are better able to disentangle the causes and effects of various perceptions and path dependencies, as well as examine the incentives of Norwegian and Russian, and third-party international, primary and secondary stakeholders for valuable commercial species whose ecological and economic contexts are shifting with globalization and climate change.

2. Overview of the invasions as fisheries

Both crab species are high value export commodities with little domestic market in the Barents Sea area, but high market value elsewhere. This renders them a rather different problem than the jellyfish and pufferfish invasions considered by Luisetti, Liu and Unal in this volume. The potential for long run profits is significant, but limited by substitutes and high transport costs, with particular challenges regarding quality concerns related to transport distances, particularly for live export. Global conditions for the species are in flux, and in several native habitat areas, population problems including poor recruitment and long term fishing pressures are resulting in management decisions to lower quotas and increase monitoring and enforcement of Illegal Unreported and Unregulated (IUU) fishing.

2.1. The Barents red king crab fisheries in brief

Soviet scientists successfully introduced the red king crab to the Barents in the 1960s. The scientists brought larvae, juveniles, and adults from Russian waters in the Far East to waters close to the Murmansk fjord with the hopes of creating new productive fishing grounds (Orlov and Ivanov, 1978). Russia neither consulted nor informed Norway about the introduction. Over the next decades, the crab spread west into Norwegian coastal waters; whereas in Russia it has mainly expanded in the southern offshore Barents (see Fig. 1). The crab became a nuisance species in Norway, where it interfered with coastal fishing (Sundet, 2014).

Meanwhile, Russian interests continued to want to develop the valuable stock. Norway and Russia have managed transboundary stock fisheries jointly since the 1970s under the joint Russian-Norwegian Fishing Commission, and the reasonable assumption was that the crab would also become jointly managed; this did not evolve as one might have expected. Attempts at cooperation were not able to resolve Norwegian stakeholder conflicts with other coastal fisheries and Russian crab interests simultaneously, particularly in light of the growing awareness of the potential losses from the invasion (WWF Norge, 2002).

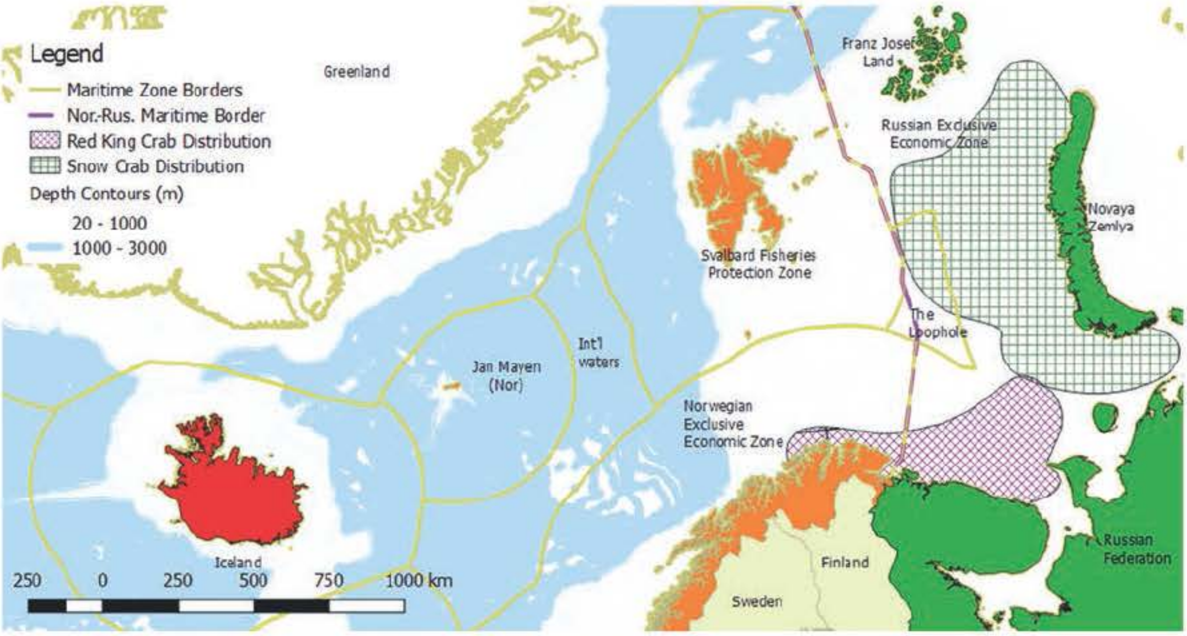

Figure 1. Map of the Barents Sea with Maritime zones and documented extent of invasions by red king and snow crabs. Projection: WGS 84/ EPSG Norway Polar Stereographic. Sources: Institute for Marine Research (Norway), European Environment Agency. Produced using QGIS.

Current management in the Barents is divided into four parts: a closed Russian coastal area, a large vessel Russian quota zone with a dominant vessel and quota owner accruing the rents, a small vessel coastal quota zone in Eastern Norway (East of 26°E and South of 71.30°N), and a small vessel open access zone in Western Norway. The Russian zones are purposed for long run stock conservation and profit; these benefits accrue mainly to the very few participants involved in the fishery. The eastern Norwegian quota zone encompasses both demand for profitable local enterprise and accommodation of the Russian fishery's longevity; the western Norwegian open access zone aims to prevent the further spread of the species to the west and south.

The fishing in Norway started with coastal fishers, primary stakeholders in the marine habitat, noticing the crabs as bycatch in their gear. This early warning from the Fisher's Ecological Knowledge (FEK) (Azzurro and Pita, in this volume) alerted the secondary management stakeholders to the ecosystem changes in the 1970s, but it took until the 1990s to persuade the Fisheries Directorate to start an experimental fishery. Part of the delay was due to Russia's persistent calls for allowing the crab stock to continue to grow.

In the first years of the fishery, crab-fishing rents accrued to those who were experiencing losses from the invasion. The crabs became sufficiently numerous, and cod fishing technology adapted sufficiently to reduce bycatch damages to gear so that ongoing bycatch costs no longer justified exclusive compensation measures, and that a second group of stakeholders was granted quota access. Any Norwegian with an eastern Finnmark address and a vessel less than 15 m in length could become part of the crab fishing fleet. This new set of stakeholders has evolved to include over 500 vessels. This policy has now turned contentious and efforts to reduce the ease of entry into the quota fishery are underway. This can be seen as a negotiation amongst Finnmarkians over who should count as a primary stakeholder in the crab. While open discussions are occurring, with official hearings to include stakeholders in quota decisions (Fiskeridirektoratet, 2017a), the fisheries managers have the ultimate responsibility to determine the balance amongst stakeholders. To date, they have chosen a middle path where barriers to entry in the form of other fish landings are required to obtain crab quota shares, but these barriers are not as high as quota holders who make their primary living from fishing might prefer.

Figure 2. A happy tourist with Red King Crab, Finnmark, Norway.

Currently, there is a third group of primary stakeholders evolving in red king crab tourism. Tourists in the north can now choose from a variety of interactions with the crab and industry, which generally include a photo opportunity with a king crab (Fig. 2) and a crab dinner.

These stakeholders also obtain quota for operations in the quota zone under a different set of regulations. Finally, a variety of mobile and fixed infrastructure investments for the export of live red king crab continue to develop.

In the western open access zone, fishers are also calling for expansion of the quota area further to the west to create increased and more long-lived rents from fishing; infrastructure decisions that affect community dynamics will follow any changes in the quota area. Implications are discussed in Section 4. This drive to expand the red king crab habitat is borne of the tremendous profitability of the crab and is progressing faster than the scientific knowledge that can identify whether the monetization of this particular invasive element of the ecosystem is a net gain or loss when ecosystem damages are measured and included. This is perhaps an extreme example of the discussion found in Katsanevakis (this volume).

While formal projections of the potential spread of the red king crab are not readily available, some scientific research suggests the species may tolerate quite cold and warm waters, perhaps in the range of -2 to 18° C, at least for some life stages. This can be interpreted as allowing, for example, a small probability of potential for spread as far south as the Mediterranean, where there has been at least one documented observation of a live crab (Faccia *et al*., 2009). Though this documentation is published in a reputable journal and is expected to be a true case, there is growing concern that the speed with which information now travels from seaside to the unfiltered internet, as well as to scientists and professional journalists, may result in misrepresentation of threats, poor science, and subsequently damaging policy implementation. This is discussed at greater length in the overview of this volume as well as in the respective chapters of Unal, Azzurro and Hemida in this volume.

Other oceanographic considerations of currents and depths, as well as human movements of vessels and ballast water, will affect exactly where and when the species might arrive in new locations. The species was identified as spreading down the coast of Norway before the open access fishery and before stringent regulations on movement of the crab were put in place (Windsland, 2014; Windsland *et al*., 2014).

Red king crab from Norway are increasingly being transported and sold live to high-end markets around the world. Russian red king crab are mainly processed and frozen on board the vessels for a broader world market. Actual and potential infrastructure impacts in Norway are considerably more significant than in Russia, and stakeholder entrenchment in the crab's continued fishability in the Barents is stronger. Russia can sell live crabs to Asian markets in better physical condition at lower cost by delivering directly from vessels in the Far East, so a similar set of investments for live crab in the Barents is unlikely.

2.2 The Barents snow crab fisheries in brief

The snow crab was first found in Russian Barents waters to the west of Novaya Zemlya in the mid-1990s and it arrived through unconfirmed means. Ballast water is the primary suspected pathway (Kuzmin *et al*., 1998) though some scientists suggest that the invasion may be a range expansion from the Pacific Arctic (Konstantin Sokolov, 2015). The annual trawl survey conducted jointly by the Institute for Marine Research (IMR) and the N. M. Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO) has tracked the growth and spread of the incipient snow crab population. The agencies have recognized the potential for a profitable new enterprise (Hvingel and Sundet, 2014).

Norway and Russia did not open fisheries until after vessels began to use the International Loophole to fish crab in 2012. Norwegian and EU vessels quickly increased catch from a few tons to over 9 million rounds in the first four years of fishing in the Loophole (see Fig. 3). The bulk of this activity was carried out by fewer than a dozen vessels, and the crab has mainly been processed and frozen on board for export. The snow crab are less hardy, the fishery is further out to sea, and the snow crab have historically commanded lower market prices, than red king crab; to date there has been less investment in live export of crabs, though there is some interest and experimentation (Lorentzen *et al.*, 2018; Nofima, 2015, unk.)

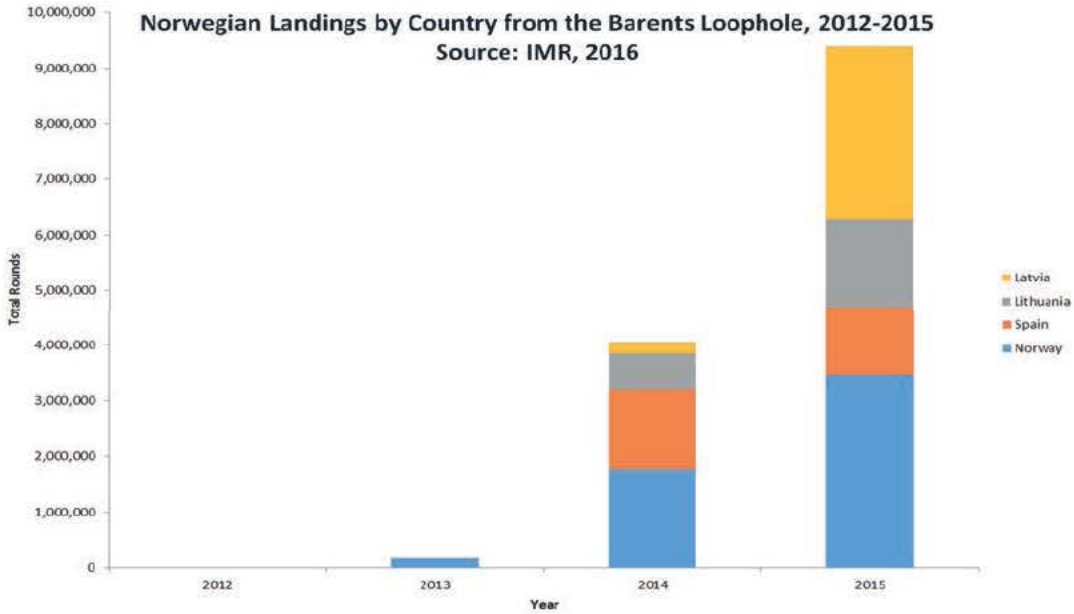

Figure 3. Snow Crab Landings in Norway showing rapid growth in the fishery, 2012-2015.

As with the case of the red king crab, Russians and Norwegians have failed to agree on joint management of the snow crab. They have cooperated, however, where their interests are directly aligned. In 2015, they agreed to a designation of the crab as a sedentary species, effectively transforming the snow crab from a fisheries resource whose international boundaries are determined by 200 nm Exclusive Economic Zone (EEZ) borders to a continental shelf resource (sedentary species) whose international boundaries are determined by the extent of the country's continental shelf. In the Barents, the shelf extends considerably beyond the EEZ boundaries, and the re-definition of the snow crab effectively closed the international waters of the Loophole to foreign vessels. Russia and Norway have subsequently excluded EU vessels from the Loophole (Kaiser *et al.,* 2018).

Adjacent and to the west of the Loophole is the Svalbard Fisheries Protection Zone; the crabs, and the fishers, have spread to this internationally managed commons. The designation of the snow crab as a sedentary species, however, has set up a conflict between Norway, upon whose continental shelf the Zone rests, and the rest of the world. Norway disagrees with the rest of the world (primarily EU vessels), who argue that the 1920s Svalbard treaty, which grants equal rights to commercial opportunities in the archipelago, applies to this part of the Continental Shelf. After the Norwegian arrest of an EU-licensed snow crab-fishing vessel, the conflict is proceeding through the Norwegian and European court systems. Resolution of the conflict has greater stakes than snow crab fishing as valuable rights to hydrocarbon and mineral exploration on the seabed floor surrounding Svalbard will be affected by the ultimate court decisions (Kaiser *et al.*, 2018).

3. Ecosystem Change and Incentives for Conservation

Both crab species are predatory benthic feeders. The baseline scientific understanding of the benthos in the Barents is historically limited; untangling the baseline from the impacts of the crab simultaneously adds extra uncertainty to the already highly uncertain ecosystem processes underway. While change is certainly occurring, there remain questions over a number of basic impacts of the invasion, including the range potential for expansion and the direction of impact on available benthic biomass for consumption by other trophic levels (Hansen, 2015; ICES, 2017; Jørgensen *et al*., 2017; Jørgensen and Spiridonov, 2013). Magnitudes of impact on e.g. biodiversity loss are decidedly unknown. This renders it impossible to meaningfully apply such valuation methods as described in Luisetti and Katsanevakis, this volume. Ignoring these values because they do not create monetary or monetarizable value for primary stakeholders sets society up to overvalue the fishery compared to other ecosystem changes.

As marine invasions, a precautionary approach that limits the spread of the species would be sensible. Since the species are now established, the earliest opportunities to prevent change by preventing or eradicating the initial introductions have been foregone. Thus implementing the precautionary approach going forward requires active management and expenditures to maintain the status quo in areas that are not yet invaded, while the 'wait and see' approach accommodates irreversible change, at low current financial cost but unknown current and future ecological and ecosystem productivity costs. The current profitability of the crabs lends local stakeholder support to the latter policy, under which fisheries have been established.

According to Principle 15 of the Rio Declaration on Environment and Development:

"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".

The 1960s red king crab introduction to the Barents pre-dates the UN Convention on Biological Diversity (1760 UNTS 79; 31 ILM 818 (1992)), to which both Norway and Russia are signatory parties; the unintentional nature of the later snow crab introduction also reduces liability to the countries. The preamble of the CBD reads, "*Where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat*."

While the entire treaty's purpose is to foster national and international actions that increase biological conservation, specific portions address invasive species more directly. Article 8(h) of the treaty requires contracting parties to "Prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" – at least, "as far as possible and as appropriate." Article 14(2) gives the Conference of the Parties (COP) power and responsibility to examine "liability and redress, including restoration and compensation" for damages to biological diversity imposed by one country on another. COP 6 Decision VI/23 (2002) provides non-binding guiding principles for the implementation of Article 8(h).

The compromises needed to secure agreements for multilateral treaties often reduce their scope for implementing forceful compliance mechanisms in return for higher acceptance and compliance, and the non-binding nature and comprehensive scale of the Convention is no exception. The individual nation states maintain most responsibility for decision-making over invasive species management, and incentives to incur costs when most or all of the benefits will occur outside one's own borders are weak. Invasive species management is a classic weaker-link public good problem (Burnett, 2006), and the additional profit incentives of maintaining these species' populations make it even more unlikely that individual nations will take costly actions to stem the spread beyond their borders. This may also influence scientific inquiry. By maintaining ignorance about the origins of the snow crab invasion, liability cannot be assigned. The influence of direct and indirect regulation on both primary stakeholders, with the secondary stakeholders providing scientific understanding, needs integrated consideration to assess how marine species may affect human activities.

4. Management under uncertainty

There are a multitude of interacting economic, ecological, institutional, and climate uncertainties affecting the evolving crab invasions in the Barents Sea. Management choices, including delayed or no action, will define not only the outcomes for today's stakeholders but also the parameters under which future outcomes can and will come to fruition. Social scientific questions over what Barents Sea ecosystem productivity should consist of, who should gain from that productivity, and what human actions can do, and are doing to affect it explicitly underlie decisions about invasive species management in the region.

4.1 Stakeholder perceptions

Stakeholders involved in Barents Sea ecosystem productivity are many and diverse. Here we separate them into local, regional and global primary and secondary, social and non-social stakeholders, following the discussion in Maccarrone (this volume).

<u>4.1.1 Local primary and secondary social stakeholders: Russia, Norway, and Svalbard</u>

Norway and Russia have long considered the Barents Sea, and its resources, their joint domain. The maritime border between the two countries was only resolved in 2010; the delineation treaty addresses just two issues –how to split the fish and how to split the hydrocarbon resources ("Maritime Delimitation Treaty," 2010). Cooperation has been strong and resilient. The Norwegian and Russian peoples have not waged war against one another for centuries, choosing instead to settle peaceably, from earliest days of Norwegian inhabitation in the north through the treaty of Novgorod in 1326, the question of how they should each tax the Indigenous Sami residents, and how natural resources should be shared between the three groups (Pape, 2004).

In Norway relations between primary fisher stakeholders and secondary stakeholders, including scientists and regulators, exhibit high trust and open communication. The communities are small and heavily fishing-oriented; there is little need to 'get to know' the fishers and their perspectives as there is regular interaction between the stakeholder groups. In Russia, the primary fisher stakeholders are highly concentrated and are well integrated into the decision-making regime of the secondary stakeholders.

Fishery resources have been jointly managed under the Joint Russian-Norwegian Fisheries Commission since the mid-1970s, with less formal cooperation extending further back (Stokke and Hoel, 1991); the Commission has worked together to e.g. set quotas and gear regulations and to conduct stock assessments and research for all transboundary stocks, but now the red king crab is an exception. The appearance of the new species has created tensions that the Commission could not resolve; since

2007, the countries have agreed to manage the red king crabs separately, and the snow crab has similarly failed to come under joint management, in spite of initial expectations in 2012-2013 that it would become so.

The rest of the world has direct footholds through Svalbard's 1920 open access treaty and through the international waters of the Loophole, though the Svalbard archipelago is under Norwegian sovereignty. The treaty may be considered a puzzle piece in the many centuries of nominal peace between the two countries and a unique solution to a complicated case in the long historical progression towards seemingly more permanent borders, rights, and the closing of global commons.

The North-east Atlantic Fisheries Commission, the Regional Fisheries Management Organization (RFMO), works in concert with the countries to prevent overfishing in the Loophole. The snow crab invasion is causing conflict within and beyond the RFMO because mutually beneficial trades such as those that have been negotiated in the past cannot work when the institutional framework of future rights, and the returns to non-social, future generation primary stakeholders, is up for grabs. Trades in fishing quota have traditionally been possible in a static institutional analysis of the returns to fishing the international waters of the RFMO, such as those that resolved the Barents Sea 'cod wars' of the 1990s (Churchill, 1999). These trades are less attractive when historical behavior in the fishery or related fisheries may determine legal outcomes for future rights now contested in court.

As the resources of interest – and the ecosystem services they depend upon - change over time, we are reminded now that institutions too will continue to change as well, and that the forces at work on these incentives may be strongly driven by economic influences that may be multidimensional, crossing species, ecosystems, industrial, sectoral, geographical, and political lines.

4.1.2 Local primary stakeholders: ecosystem consumers

Both ancient peoples and more recent Norwegian immigrants have relied on the productive coastal waters to feed themselves; marketization for Barents Sea fish as early as the 12th Century created fishing wealth for the North (Sjögren, 2009). The Sami, local Indigenous peoples traditionally more focused on reindeer hunting, became more integrated with coastal and fjord fishing over the 19th Century (Søreng, 2013). These rich and complex fishing communities and ways of life have been threatened in recent decades by shifts in global markets and in technologies for harvest that have moved activities from coastal fleets to offshore activities.

This threat to all coastal communities has raised pressures from individual concerns where the choice is to continue as a fisher or shift to other occupations, to community concerns about continued existence. The red king crab is a new resource, with no historical claims or use in the Barents, presenting a new opportunity for the development of perceptions and claims. Individual residents have the right to harvest small numbers for personal use, and slightly more for is being used under tourism licensing; this is generating some small scale local consumption but still the crab is considered mainly an export commodity.

The red king crab fishery's high profitability and low costs (Kourantidou, 2018) have rejuvenated fishing in Finnmark, with increasing numbers of vessels involved in the fishery over time particularly since 2008.

Meanwhile, the population growth of the crab in the quota area is stabilizing after the expansionary phase of the invasion and the introduction of fishing mortality (Fig. 4). The profits to individual fishers are thus becoming more dependent on the overall number of quota holders amongst whom the total allowable catch is shared, which is in turn increasing calls from within the quota-holding group to restrict entry, and actions by the Fisheries Directorate do so. Starting in 2016, the share of red king crab quota available to a vessel is now tied to the value of other fish harvested (Fiskeridirektoratet, 2017b).

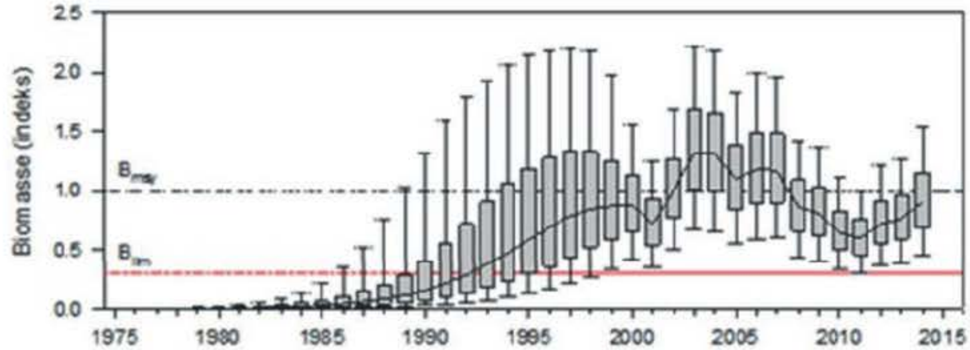

Figure 4. Development of the relative population size of male red king crab (Carapace length>130 mm) in the Norwegian Zone (Biomass Index), 1975-2016. (Sundet, Hvingel, and Hjelset, 2016).

Fishers' calls for stability and long-run production of red king crab are amplified by onshore investments in infrastructure and technology for landing, processing and exporting live crab long distances to market. Live processing requires rapid access to air networks and a different set of infrastructure criteria from that of former fish processing plants now idle throughout Finnmark. The red king crab is spawning new investment in infrastructure in the region, as shown in Figure 5.

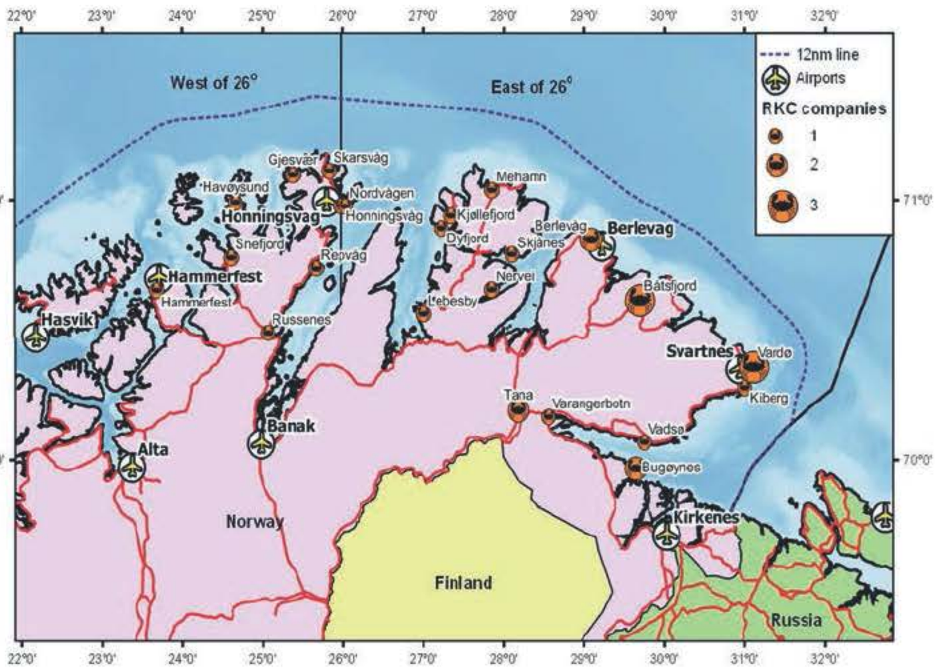

Figure 5. Red king crab company facilities and transportation infrastructure in Finnmark, 2016 (Kourantidou, 2018).

The demands of the onshore processing industry have already been instrumental in changing regulations so that red king crab fishing is now year-round, rather than seasonally limited to the fall and winter as it was initially and still is in Alaskan and Russian waters. These limitations, however, are partly ecologically based; the crabs molt in the spring and summer, producing lower quality and volume of meat. Norway's decision to attempt to capture the off-season market speaks to the economic marginality of their enterprises. Costs of air delivery in season are too high to compete with low cost Far Eastern Russian live crab shipboard deliveries. On the other hand, volumes have been too low to compete with frozen production from Pacific sources. See Fig. 5 for representation of this global production, and the closer proximity of the Pacific crabs to their main Asian markets.

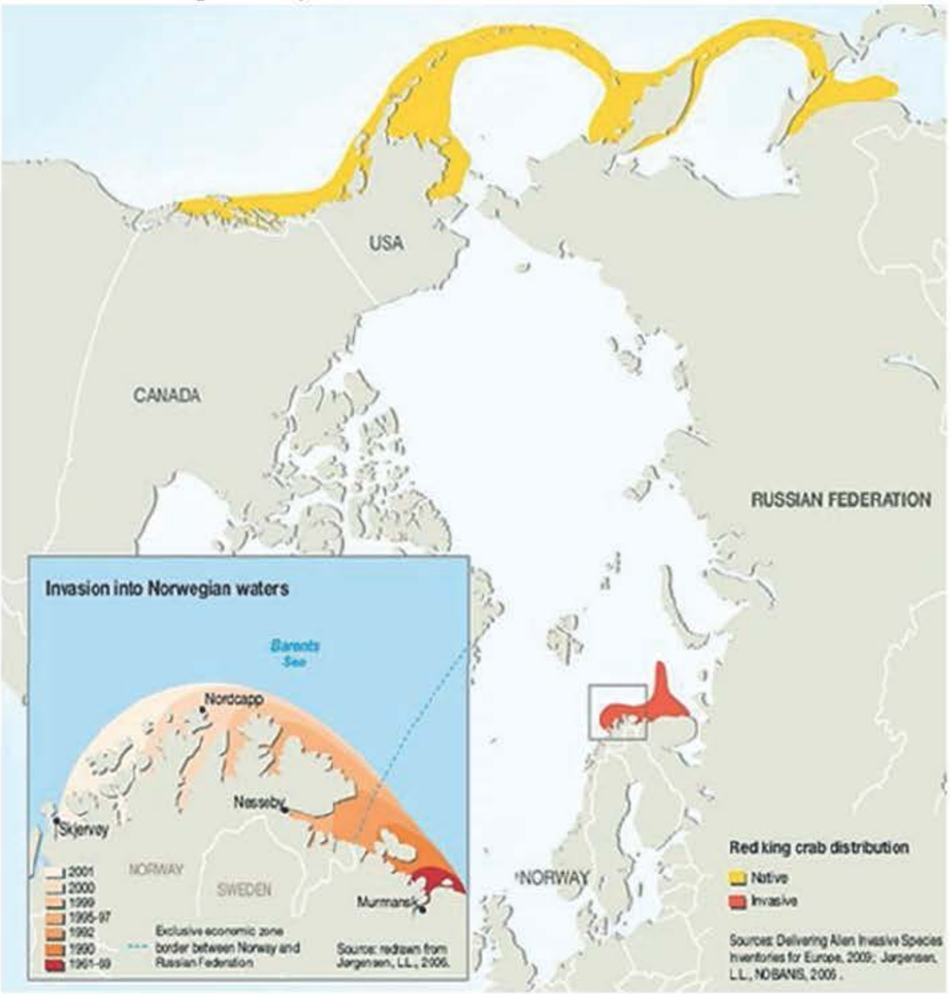

Figure 6. Global distribution of Red King Crab, with inset detail of Barents Sea Invasion. (Jørgensen, 2006).

Live snow crab processing has to date been less successful, but many of the same firms and enterprises that have invested in red king crab processing and supply are turning their efforts to snow crab in an attempt to benefit from economies of scope. If more snow crab comes to land live in Norway, the distribution of returns will improve for local Finnmark interests and further entrench stakeholder interest in maintaining and/or expanding both crab species' commercial viability in the region.

In addition to wishing to restrict access to quota, fishers both within and outside the quota group are asking to expand the quota area to the west in order to better regulate and conserve the crab stock for long run fishing profit (Berg, 2018). Perceptions of the crab as a dangerous biological invasion (Falk-Petersen, 2014) appear to be fading as crab profits expand (Kourantidou and Kaiser, 2017). The election of a conservative government in 2017 is increasing pressure for consolidation of social resources, a merger of Finnmark and Troms counties, and a focus on profits from natural resources. While it has been agreed that this will not directly affect Finnmark's control of its natural resources, it may challenge how the species is managed as an invader in the western portion. The open access fishery in the west has kept populations low for almost a decade, at low economic cost political and economic pressures are increasing the likelihood of a shift of the quota area further west. A choice to accommodate ecosystem changes in favor of crab habitat over other ecosystem functions is unfolding, and it is being made without full scientific information regarding the consequences.

Once further west, the decision becomes irreversible, and the pressure to expand even further west begins anew. Stakeholders may in fact transform from those who value the current ecosystem productivity to ones who value the transformed ecosystem productivity. The role of scientific research in this transformation is discussed in Section 4.1.3 below.

The effect of the closing of the commons for snow crab fishing in the Loophole and the Svalbard Fishery Protection Zone will be similar. The de-facto open access fishing that worked as a low-cost implementation of precautionary measures to retard the spread of the species has ended and the potential profitability to Russia and Norway is resulting in conservation efforts for the snow crab stock in exchange for unknown ecological costs.

There are fewer local primary stakeholders involved in the snow crab industry, both at sea and onshore. In principle, this could make it easier to regulate with a precautionary approach. This also distances the local stakeholders from witnessing the ecosystem changes, however. With this reduction in transparency and the high stakes both for the profitability levels and the rights to even more potentially valuable assets, there is even less discussion of the snow crab as an invading species than there is of the red king crab; profits are the focus.

The crabs are transforming benthic habitat. While the overall ecosystem impacts are uncertain, there is some evidence of reduced biodiversity, while at the same time available biomass may be increasing or decreasing. There are spatial distinctions in what benthic habitat is currently used for either in ecosystem or human production.

4.1.3 Regional primary and secondary stakeholders: neighbors to invasion

Neighboring jurisdictions to the current invasion areas stand to become recipients of externalities from the further spread of the invasions. Unlike future generations who cannot be present at the bargaining table, these future potential recipients of the current direct stakeholders' decision-making have the potential opportunity to engage socially in the decision-making over the management of the marine environment through negotiations. Their voice, however, may be limited by conflicting interests of the already directly impacted locales, and they may choose to take unilaterally defensive actions rather than work to achieve more generally beneficial cooperative approaches to preventing the spread of the species to their waters. The problem is analogous to that of the internal Norwegian debate over the balance between ecosystem preservation for current ecosystem values or ecosystem transformation for crab production, but at the international scale. The mechanisms for negotiating outcomes that originate in the Convention for Biological Diversity, and their potential weaknesses, have already been described.

While the cases of the crabs are made more complicated by their profitability, other invasive species may bring only external costs to existing fisheries or other ecosystem services. The unknowns are significant and the global track record for predicting, intercepting, and managing marine invasions is historically poor, with costly consequences (Ruiz *et al.,* 1997). Warming conditions in Arctic waters under climate change are expected to increase vectors and pathways for introductions through increased vessel traffic and greater marine economic activity (Miller and Ruiz, 2014). Snow crab vessels that move among several fishing locations may contribute to this problem by carrying other invaders in their ballast water or on their hulls, increasing the odds of introducing new species in new locations.

4.1.4 Global stakeholders

4.1.4.1 Active ecosystem consumers: crab consumers as primary stakeholders

Both red king and snow crabs have differentiated food product markets that range from high-end live crab to processed and frozen products. A summary of recent data provided in Lorentzen *et al.* (2018) is reproduced here as Table 1. One can see that there are significant differences in willingness to pay for live and frozen crab, and willingness to consume frozen crab by destination; South Korea for example imports live red king crab almost exclusively, while Japan is the opposite.

Table 1. Export markets for Norwegian red king and snow crab, 2016. Reproduced from Lorentzen *et al.* (2018).

	Japan		South-Korea		U.S.	
	Volume, tonnes	Value, 1000 NOK	Volume, tonnes	Value, 1000 NOK	Volume, tonnes	Value, 1000 NOK
Red King Crab (RKC)						
Frozen	463	107,835	22	5880	68	11,621
Live	–	–	776	161,370	161	36,672
Snow Crab (SC)						
Frozen	1005	92,272	108	10,552	1587	118,288
Live	1	106	30	3695	27	2763

Japan, South Korea and the US all also harvest snow crab, while Japan and the US also harvest red king crab. Additionally, Japan and South Korea have a relative of the snow crab, *S. Japonicus*, that they consume as a substitute for imported snow crab. Other shellfish, fish, and proteins serve as potential substitutes for these products, so that in spite of high and increasing prices, demand elasticities are high, with the exception of short seasonal celebrations that place traditional emphasis on consumption of live crabs.

To our knowledge, the awareness of consumers regarding the ecosystem impacts of their imported crabs has not been directly measured, but informal discussions in live markets and with restaurant patrons and operators in Japan and South Korea suggest at least anecdotally that considerations of whether the crabs are an invasive species or not are inconsequential. Price appears to be the main driver of consumption behavior, and the more crab available, the lower the price can be.

Without information over the sourcing of crabs and their ecosystem impacts, price is not likely to capture the full ecosystem costs of production, even if consumers do hold active and/or passive use values for these ecosystem inputs.

4.1.4.2 Competitive producers

One concern for Barents Sea producers is that their costs are higher than other locales. The distributions of both crabs are illustrated in Figure 6 and 7. As with the red king crab, the snow crab's native habitats are much closer to its principal markets. If other source locations' ecosystem conditions improve, e.g. in the Alaskan or Canadian fisheries, through either natural restorative processes or human-assisted recruitment or other stock enhancement, Barents Sea production will become unprofitable and fishing pressure on the crabs will be reduced, increasing the intensity and breadth of spread.

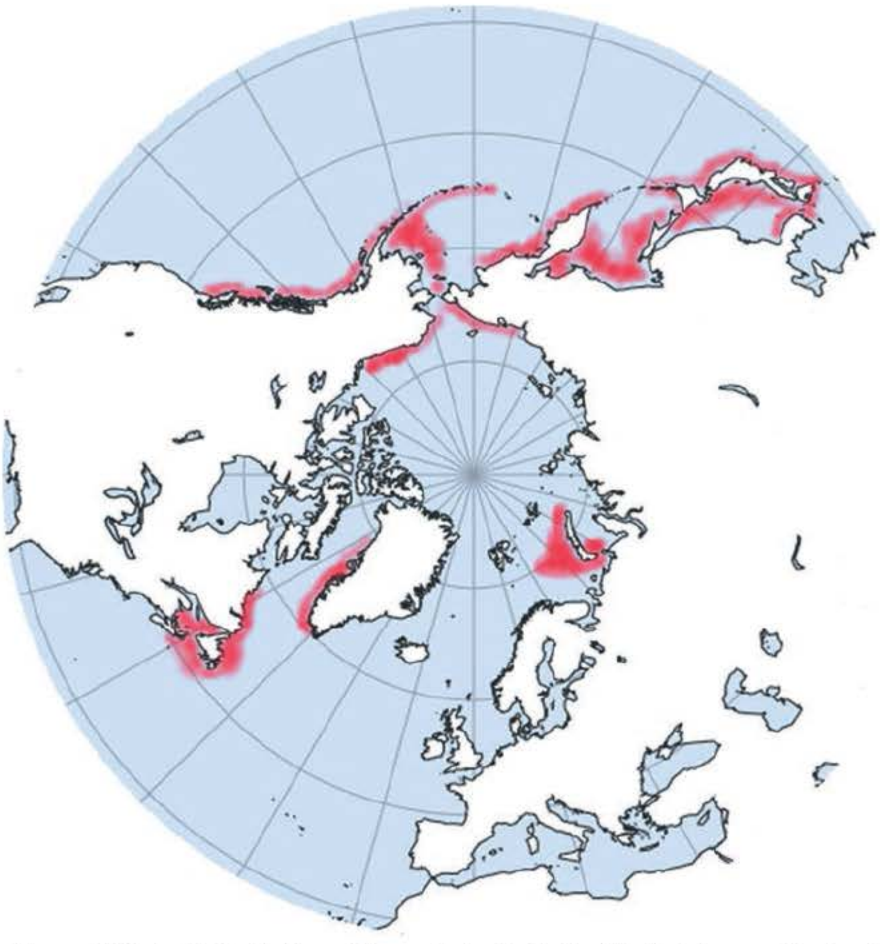

Figure 7. Global Distribution of Snow Crab, C. Opilio. (K. Sokolov and Pavlov, 2016)

This potential vulnerability of managing species via market mechanisms also highlights risks that could be associated with any policy proposals to pay fishers directly for harvesting nuisance species, in that incentives to spread the species for gain may ensue.

4.2 Scientific and managerial incentives and biases

The two species are spreading in different directions. The red king crab's tolerance for warmer waters and expansion path to date is likely to promote spread to the west and south, whereas the snow crab's preferred habitats would predict an expansion to the north and north-west. With different stakes, optimal management of limited Barents conservation resources would equate marginal net benefits of activities at the frontiers of each of the invasions; the scale and scope of marine resource management matter in determining whether better use can be made of limited resources. Simultaneously, research resources would be spatially allocated within species' invading positions, so that the marginal dollar of research is allocated optimally between answering questions about uncertainties in the baseline ecosystem productivity and uncertainties in managing areas that are already invaded (Kourantidou, 2018).

These decisions are, however, subject to incentives held by the research agencies that may affect the agendas in ways that favor one set of findings over another. We find, for example, that in the case of the red king crab, Norwegian and Russian research agendas in the Barents may systematically favor research and results that buffet the continued use of the resource for fishery profit (Kourantidou and Kaiser, 2017). Furthermore, this is likely to be the case whenever profitable fishing opportunities are put up against highly uncertain ecosystem changes, and particularly when there exists vertical integration of research and management in the production of resource commodities. It is essential that valuation efforts such as those described in the chapters by Luisetti, Katsanevakis and Gourguet in this volume directly incorporate these unknowns and uncertainties to provide clear and accurate voice to non-social stakeholders (Maccarone, in this volume).

To the extent that stakes are similar (benthic habitat at risk) and can be transferred from one part of the Barents to another, joint production of e.g. new research knowledge broadly analyzing e.g. baseline conditions of the benthic habitat may have greater benefits than more narrow research into one species or the other. This in turn requires some knowledge or additional research into the question of how similar the habitats at risk actually might be. The research decisions and research needs can benefit from increasing cooperation between agencies and stakeholder interests.

5. The development of path dependencies: lessons in contrast

As profitable invaders, incentives for management of the crab species are mixed. Questions of whether and how to treat the newcomers abound, and answers will put ecosystems and the humans who depend upon them on vastly different economic and ecological paths. Should they be treated as species in need of eradication to prevent ecosystem changes and protect other commercial and non-commercial ecosystem assets that may be affected by their entry into new ecosystems? Or should they be treated as species to protect and conserve - desirable food commodities whose home range habitats in other parts of the Arctic are experiencing climate variabilities and/or other human pressures that make their continued production in those locations uncertain? What are the benefits and costs of these potential paths? How do the answers vary spatially and temporally? Upon what current uncertainties do decisions rest, and what incentives, ranging from funding to stakeholder interests in the questions asked, affect when and how these uncertainties can be resolved?

Perhaps the most valuable lesson from addressing these questions for two species, whose commodity outputs are highly related market goods, invading what might seem at a casual glance to be almost the same place at almost the same time, is that despite many similarities, the details matter extensively. These details need to be evaluated temporally and spatially; the scale and scope matter as well. These findings are not necessarily novel in environmental and resource economics, whether they pertain to the difficulties of using benefits transfer in meaningful ways (Lewis and Landry, 2017); to the spatial scale at which bio-economic parameters are applied in models of spread and damages (Burnett *et al.*, 2007; Kaiser and Burnett, 2007); or to the scope of institutions and commodities impacted (Kaiser *et al.*, 2018). They do remain underutilized in ecological-economic assessments and policy determinations, in part due to their high information costs.

Second, commodification of natural resources such as the crabs fits with a broader global shift, over the past two centuries, to markets and property rights systems that support smooth functioning of these markets. When the commodification captures only part of the ecosystem inputs into production, due to uncertainties or biases in the process, or when rights are spatially or temporally incomplete, then markets cannot function efficiently to allocate resources. Choosing to favor current commodity outputs from ecosystems over broader diversity interests puts those ecosystems on paths that potentially change their overall production capabilities irreversibly. Dependence on market systems to resolve invasive species challenges through such commodification, even in cases where invasive species pressures and/or management expenditures can be significantly reduced under existing framework conditions, may be a costly mismatch between sustainable ecosystem productivity on the one hand and full long run management costs on the other. A more fundamental alignment of valuation and decision-making is required to improve management of marine invasive species.

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Impacts of pufferfish on human activities in Turkey, Eastern Mediterranean: special emphasis on *Lagocephalus sceleratus*

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Abstract

The present study focuses on the socio-economic and cultural impacts of pufferfish, particularly the common *Lagocephalus sceleratus*, on people and their activities (e.g. fishers/fisheries). Pufferfish, especially *L. sceleratus,* directly affects some human activities in many Mediterranean countries including Turkey, creating pressure for some and opportunities for others. In Turkey, the estimated damages reported in 2011 by small-scale fishers was 2 million euros, and it escalated to 5 million in 2013 and 4.5 million in 2016. Unless immediate measures are taken and potential benefits assessed (or put to practical use), adverse effects will continue increasingly.

1. Introduction

There are 190 pufferfish species within the Tetraodontidae family in world waters (Hastings *et al*., 2014); 11 of them have already been localized in the Mediterranean (Uygur and Turan, 2017). It is widely accepted that the invasive pufferfish *Lagocephalus sceleratus* (Gmelin, 1789), also known as silverside pufferfish, silver-cheeked toadfish or silverstripe blaasop, is the best known species in terms of its direct impacts (mostly negative) on people. This aggressive predatory pufferfish is the most devastating and dangerous species to fishers, fishes, mollusks, crustaceans and many others like fish consumers, divers, even people swimming in shallow waters. For example, according to Ulman *et al*. (2015) since the 2000s, the most urgent issue affecting the fisheries of Cyprus is the population explosion of invasive silver-cheeked toadfish.

For such reason, *L. sceleratus* has been included in the IUCN black list as one of the worst 18 invader fish species (Otero *et al*., 2013) and considered as one of the worst invasive species in the Mediterranean Sea due to its significant impact on the ecosystem and on the fisheries sector (Zenetos *et al*., 2005; Peristeraki *et al*., 2006; Streftaris and Zenetos 2006; Öztürk 2010; Nader *et al*., 2012).

Since the opening of the Suez Canal in 1869, the eastern Mediterranean Sea has been subject to the establishment of nonindigenous species (NIS), predominantly of Indo-Pacific origin (CIESM Atlas, 2001). *L. sceleratus* is widely distributed in the tropical Indo-West Pacific Ocean as well as the Red Sea and was recorded for the first time in the Mediterranean in 2003, in Gokova Bay, Turkey (Akyol *et al*., 2005). Since then, it invaded whole Levantine basin and then after few years, it was recorded in various southern Mediterranean and Adriatic countries. Lately, *L. sceleratus* reached the Marmara Sea (Irmak and Altınagac, 2015), Algeria (Kara *et al*., 2015) and Spain (Izguerdo-Munoz and Izguerdo-Gomez, 2014) in 2014 (Akyol and Ünal, 2017). The present study will focus on the socio-economic and cultural impacts of pufferfish, particularly *L. sceleratus* on human activities.

Today *L. sceleratus* is part of the Mediterranean marine ecosystem. It has been spreading across the Mediterranean, posing severe health hazards as it contains a strong neurotoxin and causing socio-economic impacts by damaging fishing nets, eating fish caught in fishing gears, requiring extra labour and gear modification costs. However, only few studies (Ünal *et al*., 2015; Ünal and Göncüoğlu Bodur, 2017; Öndes *et al*., 2018) provide some numerical results on economic loss of small-scale fishers caused by this species. Similarly, we do not know much about how it affects the ecosystem in the Mediterranean. The Fig.1 reflects the expansion of the Pufferfish species in the Mediterranean and mostly along the coasts of Greece and Turkey.

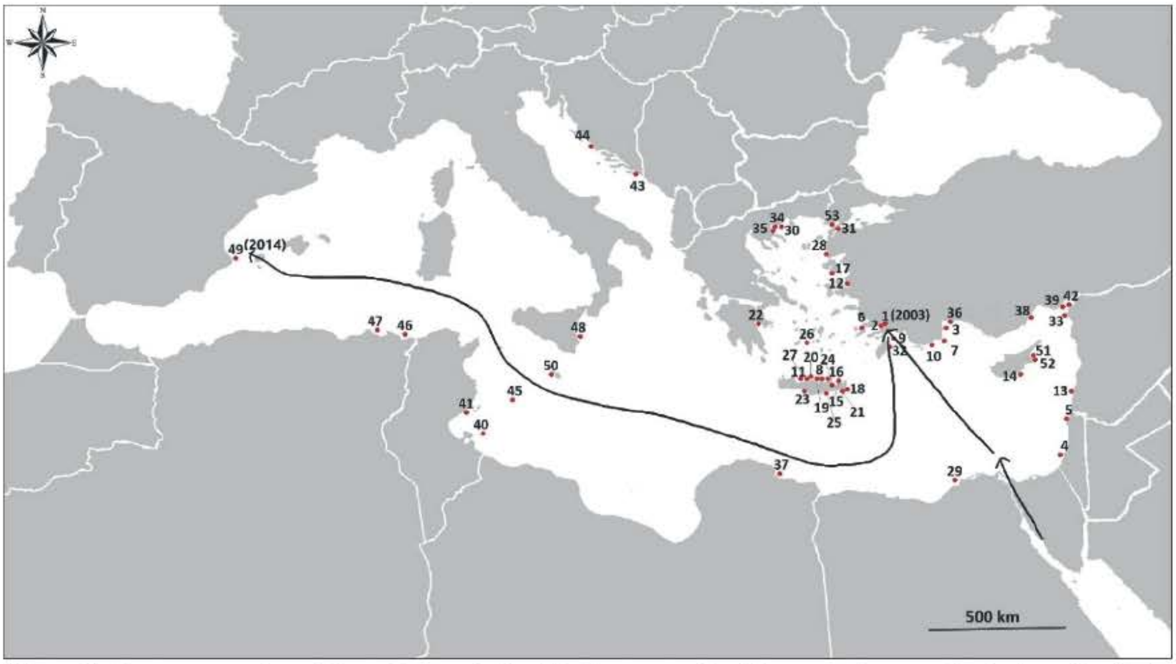

Figure 1. Range expansion of *L. sceleratus* in the Mediterranean Sea (the years in parenthesis show the first and last records of the species; updated from Kalogirou, 2013 and Akyol and Ünal, 2017).

1.1 The expansion of pufferfish species in turkish waters

Pufferfish species are represented in Turkish waters, including Aegean, Levant and Marmara Sea, by four genera and eight species. These are *Lagocephalus gunteri, L. lagocephalus, L. sceleratus, L. spadiceus, L. suezensis, Sphoeroides pachygaster, Torquigener flavimaculosus, Tylerius spinosissimus* (Uygur and Turan, 2017). Table 1 shows the recorded time, area, and reference of these species (Öndes *et al*., 2018).

Table 1. Pufferfish species first recorded and reported in Turkish waters

Species name	Initial Record Observation Year	Location	References
✓ *Lagocephalus spadiceus* (Richardson, 1845)	1949	İskenderun	Kosswig, 1950
✓ **Lagocephalus lagocephalus* (Linnaeus, 1758)	2016	İskenderun	Erguden *et al*., 2017
✓ *Lagocephalus suezensis* (Clark and Gohar, 1953)	1998	Mersin	Avşar and Çiçek, 1999
✓ *Sphoeroides pachygaster* (Müller and Troschel, 1848)	1999	Saros	Eryılmaz *et al*., 2003
✓ *Torquigener flavimaculosus* (Hardy and Randall, 1983)	2002	Fethiye	Bilecenoğlu, 2005
✓ *Lagocephalus sceleratus* (Gmelin, 1789)	2003	Gökova	Akyol *et al*., 2005
✓ *Tylerius spinosissimus* (Regan, 1908)	2010	İskenderun	Turan ve Yağlıoğlu, 2011
✓ *Lagocephalus gunteri* (Miranda Ribeiro, 1915)	2015	Çandarlı	Akyol and Aydın, 2016

* Although the first record of *L. lagocephalus* in Turkish waters was reported by Aksiray (1987), author did not write the sampling area and sampling year.

1.2 The expansion of L. sceleratus in Turkish and Mediterranean waters

First recordings of pufferfish go back as early as 1930 (Sanzo, 1930) in the Mediterranean, and 1950 in Turkish waters (Kosswig, 1950). One of these species has a particular importance: no other pufferfish species has advertised itself in Turkey (or even Mediterranean) like *L. sceleratus*. The effects of this species on Turkish and Mediterranean (specifically Eastern Mediterranean) people have been surprisingly high and diverse although its introduction is quite recent (2003). Curiously, *L. sceleratus* causes different levels of impact ranging from hate to sympathy among various sectors from fishers to fisheries managers, from children to entrepreneurs. Due to its high level of toxic TTX, consumption-related deaths made it instantly known. Significant damages on fishers constantly force managers to create solutions. All of these reasons earned pufferfish, especially *L. sceleratus*, more visibility that other fish species ever received. Similarly, Kalogirou (2013) reported that *L. sceleratus* received considerable public attention shortly after its first reports in 2003 from Gökova Bay along the southeastern coastline of the Aegean Sea. Nevertheless, this species keeps spreading rapidly in both Turkish and Mediterranean waters. Akyol and Ünal (2017) reported the long journey of *L. sceleratus* in the Mediterranean between 2003 and 2017. In fact, since the first record of *L. sceleratus* in 2003, this fish rapidly invaded the whole Levantine basin, especially western and southern Anatolian coasts, Israel and Lebanon, Greek Islands in the Aegean Sea, especially Crete and Rhodes, Egypt and Libya. The northernmost records of *L. sceleratus* were given from the Adriatic Sea in both 2012 and 2013. Recently, the fish reached Algeria and Spain in 2014. In Turkey, the last record of the *L. sceleratus* was given from the Marmara Sea. It has not been seen in the Black Sea yet. Table 2 and Figure 1 show the distribution of *L. sceleratus* throughout the Mediterranean Sea (Akyol and Ünal, 2017).

Table 2. Chronology of documented records of *Lagocephalus sceleratus* in the Mediterranean

Map Ref.	Location	Coordinates Lat. N - Lon. E	Depth (m)	Record Date	Size TL, mm	References
1	Gökova Bay, Turkey	37°09'-28°16'	15	17.2.2003	459	Akyol *et al*. (2005)
2	Gökova Bay, Turkey	37°02'-28°19'	-	?.8.2003	-	Filiz & Er (2004)
3	Kemer, Antalya, Turkey	36°82'-30°64'	30	18.9.2004	389	Bilecenoğlu *et al*. (2006)
4	Jaffa, Israel	-	-	9.11.2004	101	Golani & Levy (2005)
5	Haifa Bay, Israel	32°84'-35°00'	30	24.2.2005	618	Golani & Levy (2005)
6	Bodrum, Turkey	-	-	10.3.2005	-	Bilecenoğlu *et al*. (2006)
7	Adrasan, Antalya, Turkey	-	3	14.5.2005	200	Bilecenoğlu *et al*. (2006)
8	Heraklion Bay, Crete, Greece	35°20'-25°15'	-	?.7.2005	348	Kasapidis *et al*. (2007)
9	Rhodes, Greece	36°31'-28°27'	15-20	21.9.2005	376	Corsini *et al*. (2006)
10	Kaş, Antalya, Turkey	-	-	3.10.2005	-	Bilecenoğlu *et al*. (2006)
11	Georgioupoli Bay, Greece	35°21'-24°21'	30	20.12.2005	>300	Kasapidis *et al*. (2007)
12	Hekim Island,Izmir, Turkey	38°26'-26°45'	10-12	21.4.2006	498	Bilecenoğlu *et al*. (2006)
13	S Beirut, Lebanon	33°81'-35°42'	-	2005-2006	-	Carpentieri *et al*. (2009)
14	Cyprus	35°49'-33°74'	-	2006	-	Katsanevakis *et al*. (2009)
15	Elounda Bay, Greece	35°20'-25°72'	8	7.12.2006	-	Peristeraki *et al*. (2006)
16	Hersonissos Bay, Greece	35°31'-25°45'	9	11.2.2007	-	Peristeraki *et al*. (2006)
17	Lesvos, Greece	38°99'-26°15'	-	28.2.2007	-	Peristeraki *et al*. (2006)
18	Atherinolakos, Greece	35°00'-26°21'	20	1.3.2007	-	Peristeraki *et al*. (2006)
19	Hersonissos Bay, Greece	35°30'-25°44'	10	2.3.2007	-	Peristeraki *et al*. (2006)
20	Chania, Greece	35°38'-24°52'	10	5.3.2007	-	Peristeraki *et al*. (2006)
21	Makry Gialos, Greece	35°00'-25°87'	-	13.3.2007	-	Peristeraki *et al*. (2006)
22	Tolo Argolidas, Greece	37°53'-22°77'	28	13.3.2007	-	Peristeraki *et al*. (2006)
23	Kokkinos Pyrgos, Greece	35°07'-24°64'	15	16.3.2007	-	Peristeraki *et al*. (2006)
24	Vathy-Lithino, Greece	34°89'-24°77'	33	17.3.2007	-	Peristeraki *et al*. (2006)
25	Keratokampos, Greece	34°92'-25°24'	20-25	27.3.2007		Peristeraki *et al*. (2006)
26	Folegandros, Greece	36°57'-24°94'	-	22.4.2007	-	Peristeraki *et al*. (2006)
27	Palaikastro, Chania, Greece	35°24'-26°29'	-	23.4.2007	-	Peristeraki *et al*. (2006)
28	Asos, Çanakkale, Turkey	-	60	?.7.2008	-	Türker Çakır *et al*. (2009)
29	Alexandria, Egypt	-	80	2008	-	Halim & Rizkalla (2011)
30	N Aegean Sea, Greece	40°49'-22°79'	-	?.10.2008	-	Minos *et al*. (2010)
31	Sea of Marmara, Turkey	40°24'-26°40'	6	?.10.2008	95	Irmak & Altınağaç (2015)
32	Rhodes, Greece	-	5-35	2008-2009	53-631	Kalogirou (2013)
33	Iskenderun Bay, Turkey	36°19'-36°56'	40	?.2.2009	388-611	Torcu-Koç *et al*. (2011)

34	N Aegean Sea, Greece	40°23'-23°81'	-	?.3.2009	-	Minos *et al*. (2010)
35	N Aegean Sea, Greece	40°12'-23°20'	-	?.12.2009	-	Minos *et al*. (2010)
36	Antalya Bay, Turkey	-	-	2008-2010	125-650	Aydın (2011)
37	Ain Al Ghazala, Libya	32°09'-23°15'	15-25	?.9.2010	279	Milazzo *et al*. (2012)
38	Mersin Bay, Turkey	-	72	10.11.2010	75-84	Yağlıoğlu *et al*. (2011)
39	Iskenderun Bay, Turkey	-	53	29.11.2010	65-75	Yağlıoğlu *et al*. (2011)
40	Gulf of Gabes, Tunisia	33°50'-11°52'	-	8.12.2010	600	Jribi & Bradai (2012)
41	Tunisian coasts	-	-	2010-2013	520-640	Ben Souissi *et al*. (2014)
42	Iskenderun Bay, Turkey	-	8-50	2011-2012	89-784	Başusta *et al*. (2013)
43	Jakljan Island, Croatia	-	-	17.10.2012	663	Sulic-Sprem *et al*. (2014)
44	Tribunj, Croatia	42°38'-17°50'	-	17.3.2013	492	Dulcic *et al*. (2014)
45	Lempedusa Island, Italy	-	20	7.10.2013	410	Azzurro *et al*. (2014)
46	El Kala, Algeria	-	-	14.12.2013	-	Kara *et al*. (2015)
47	Annaba, Algeria	-	50-60	11.1.2014	320-480	Kara *et al*. (2015)
48	Syracuse, Italy	36°55'-15°10'	15-20	16.1.2014	650	Tiralongo & Tibullo (2014)
49	Alicante, Spain	39.067°-03.166°	350	31.7.2014	580	Izguerdo-Munoz & Izguerdo-Gomez (2014)
50	Gnejna, Malta	35°55'-14°20'	15	?.8.2014	568	Deidun *et al*. (2015)
51	Off Pernera, Cyprus	35.039°-34.037°	70	12.9.2014	259	Iglesias & Frotté (2015)
52	Off Pernera, Cyprus	35.039°-34.037°	70	16.9.2014	575	Iglesias & Frotté (2015)
53	Saros Bay, Turkey	40.368°-26.321°	-	2014	556	Tunçer & Önal (2014)

2. Versatile ımpacts of pufferfish species

The impacts of pufferfish are ranked from 0-not exist yet, 1-minimal concern, 2- minor, 3- moderate, 4-major, to 5-massive. The groups affected by pufferfish are as follows:

- **fishers** (damaged fishing gears and unwanted fishes, decreasing fisher income, fish composition and quality)
- **public** (great risk for human health if consumed, symbolic and aesthetic values, pharmaceutical-medical use, recreation and tourism, newsworthy)
- **entrepreneurs** (potential usage of TTX as an analgesic, usage as a therapeutic drug treatment, potential aquarium use)
- **fisheries managers** (pressure to formulate and implement management tools to overcome the pufferfish problem) (see Table 3).

Table 3. List, type, existence, level of the impact of pufferfish in Turkey

Impact level	Type of impacts*	Existence of impacts	Level of impacts
Fishers	Damaging fishing gears	+	5
	Damaging fishes caught by the gear	+	5
	Decreasing fisher income	+	5
	Fish composition and quality	+	4
	Reinforcement using steel lines	+	3
	Creating additional work (discarding unwanted fish)	+	4
	Reducing local stocks of commercial species (e.g. squid, octopus, shrimps) through predation	+	5
Public	A great risk for human health if consumed	+	2
	Symbolic and aesthetic values	+	1
	Deterring customers from buying fish	-	0
	Pharmaceutical-medical use	-	0
	Recreation and tourism	+	1
	Newsworthy	+	5
Entrepreneurs	Potential usage of TTX as an analgesic	-	0
	Usage as a therapeutic drug treatment	-	0
	Potential aquarium use	+	1
	Aquaculture	-	0
	Processing	-	0
Fisheries managers	Pressure on formulating, implementing management tools to overcome the pufferfish problem	+	4
	Reducing local stocks of commercial species (e.g. squid, octopus, shrimps) through predation	+	4

*Types of impacts are compiled from following studies: Katikou *et al.*, 2009; EASTMED., 2010; Bilecenoğlu, 2010; Çınar *et al.*, 2011; Nader *et al.* 2012; Kalogirou, 2013; Corsini-Foka, 2014; Ünal *et al.*, 2015; Ulman *et al.*, 2015; Ünal and Göncüoğlu, 2017; Shotton *et al.*, 2017).

We now explore the aforementioned impacts in Table 3 through the following issues and stakeholders:

2.1 Fishers

Fishers affected by pufferfish are (in order of importance) small-scale, large-scale and recreational fishers. However, we focus its impact on the commercial fisheries on this section. Its effects on recreational fishers will be covered under recreation and tourism. The economic losses related to *L. sceleratus* reported by the limited number of studies consist of three elements: fishing gear losses, labour losses, and catch losses: - the impacts of pufferfish on the fish composition and quality, - labour losses

(extra work to repair and replacement of fishing gears), - catch losses (predation on already captured fish in the fishing gears).

A recent study reported that around the south coasts of Turkey, 75 % of commercial fishers declared that pufferfish had negatively or very negatively affected their activity, versus 97 % of small-scale fishers, and in particular, longliners and set netters (Öndes *et al.*, 2018). These rates are much lower at the west coast where pufferfish are less present most probably due to lower water temperatures.

2.1.1 Damaging fishing gears

L. sceleratus damages passive fishing gears used in small-scale fishing (e.g., Katsanevakis *et al*., 2009; Turan, 2010; Kalogirou, 2013; Ünal *et al*., 2015; Tuney, 2016). Fishing gear losses due to the damage occur mainly in two ways: (a) requirements for changing damaged parts of the gears, and (b) requirements for modification in fishing gears. Katsanevakis *et al*. (2014) report that fishers even alter their fishing practices (gear, depths, time of the day, etc.).

2.1.2. Changing fish composition and quality of fishes caught to the gear

Pufferfish does not only damage fishing gears, it also attacks the fish entangled there with its powerful jaws. Pufferfish reduce the quality of catches and the catch amounts of other species, thereby considerably reducing fishers' income. Its attacks to catch of fishers and eating some parts of fishes already caught are reported in many studies (Katsanevakis, 2009; Michailidis, 2010; Kalogirou, 2013; Ünal *et al*. 2015; Ünal and Göncüoğlu, 2017). It was confirmed that existence of the *L. sceleratus* has negatively affected fish composition, quality of fishes caught to the gear, fishing operations and incomes of small-scale fishers in Turkey (Ünal *et al*. 2015; Ünal and Göncüoğlu, 2017; Öndes *et al*., 2018). In Turkey, in 2011-2012, 78% of fishers claimed that fish caught by their fishing gears were attacked and eaten by *L. sceleratus* (Ünal *et al*, 2015); however, the recent study indicates that this rate increased to 93% in 2016-2017 along the southern coast of Turkey (Öndes *et al*., 2018). The change on the rates reflects the clear increasing on the affected fishers by the pufferfishes, especially *L. sceleratus*. In fact, there are many indications to show us that pufferfish eats the catch of fishers in their lines and nets (Figure 3). The fishers stated that they observed a decrease in their products fished by them in fishing areas since the time *L. sceleratus* started to create problems. The fishers defined the damage on the fish in fishing gears caused by *L. sceleratus* such as (Ünal and Göncüoğlu Bodur, 2017):

a. "Due to the structure of its mouth and teeth, it cuts the place it has bitten at one time and takes it"
b. "I recognize pufferfish from its way of eating fish in the fishing gear; when pufferfish comes, only the fish's head remains in the longline I use"
c. "I recognize pufferfish from the form of biting-cutting (in the form of crescent)"
d. "It comes to the surface when we pull the net up or pull the longline, and we see it"
e. "It breaks off the hook"
f. "It gets in the net and tears the net into pieces; every day, around 3 kg of fish become torn to pieces and unsaleable"
g. "Fish comes eaten in our fishing gear. We see that tail and internal organs, soft parts of the fish are eaten"
h. "It bites off the part of the fish in the net and goes away"
i. "It cuts the net or fishing line like a knife"

L. sceleratus was estimated to account for 5% of total commercial catches in 2003, which was increased to 50% of commercial catches by 2008, held constant to 2010 for both the north and the south of Cyprus (B.A. Cicek, 2013 artisanal fisher survey results, A. Petrou, pers. obs. in Ulman *et al*. 2015). As of 2012, this species contributed to approx. 50% of total catches by weight in Cyprus (B.A. Cicek, 2013 artisanal fisher survey results, A. Petrou, pers. obs. in Ulman *et al*. 2015).

Figure 2. Pufferfish and partly eaten bonito in the same line (Photo: M. Yahşia)

Figure 3. Poster illustrating the adverse impacts and associated economic losses linked to the arrival of *Lag*

2.1.3. Increasing loss and decreasing fishing income

Many commercial species, particularly the small-scale fishers are affected by presence of *L. sceleratus*, due to its direct effects on the quality of catches, requirement of additional labour, and damages on the fishing gears (table 5).

According to Kalagirou (2013), *L. sceleratus* eats many species of molluscs, crustaceans, and fish and total prey identified to species is 92. Considering the statement of Kalogirou (2010) and along with the aforementioned damages caused by the species to small-scale fishers along the Turkish coasts, negative impacts of this species may reach totally different points. Ünal *et al*., 2015 confirms that incomes of small-scale fishers has negatively affected by *L. sceleratus* in Turkey. The fishing gear loss per vessel in 2013-2014 is 2,554 TL/year (approx. 945 euro). It creates also additional labour costs. However, the damage caused by pufferfish to the fish entangled in the fishing gear could not be digitized in any study published so far.

Figure 3 illustrates the overall problems and economic losses associated with *L. sceleratus* throughout the Mediterranean Sea, which remain difficult to assess precisely (Michailidis, 2010).

2.2 Public

2.2.1. A great risk for human health if consumed

L. sceleratus is considered to be a serious hazard for consumer since it contains a strong marine toxin called Tetrodotoxin (TTX), a heat-stable and water-soluble neurotoxin which can be lethal to humans (Nader *et al*., 2012; Ünal *et al*., 2015; Tuney, 2016). The toxin TTX is not produced by the fish itself, but by the *Vibrio alginolyticus* bacteria that enters its body through nutrition. Indeed, in recent studies some crustaceans have been observed to contain TTX as well, albeit in harmless levels. Arakawa (2010) reported that consumption of *L. sceleratus* is banned in Japan. Fishing, landing, and selling of pufferfish species are also banned in Turkey, Egypt, Cyprus, Greece, and many other countries. In the Mediterranean, several cases of poisoning have been recorded as *L. sceleratus* is marketed regardless of the risk it poses to public health. Its large size might be one of the reasons behind this species being sold. There have already been 13 recorded cases of death in the Eastern Mediterranean as well as other cases of intoxication (Chamandi *et al*. 2009, Kalogirou *et al*. 2010). Two recent studies (Giusti *et al*, 2018; Lisa *et al*., 2018) focus on emerging public health risk in Italy and the E.U. However, according to the studies based on face-to-face interviews with fishers in Turkey (Ünal *et al*., 2015; Ünal and Göncüoğlu Bodur, 2017; Öndes *et al*. 2018), unconscious consumption of *L. sceleratus* by fishers is quite common. The rate of the fishers consuming pufferfish was determined to be 29% in 2011-2012 (19% of them got poisoned), 38% in 2013-2014 (11% of them experienced the symptoms of intoxication). There are no relevant records for 2016 or 2017. An increase in the consumption of pufferfish shows that efforts at raising awareness about its toxicity have not been effective enough.

2.2.2. Recreation and tourism

Divers, swimmers and anglers who benefit from the recreational uses of the sea are negatively affected by the presence of pufferfish. The fatal toxicity of species like *L. sceleratus* makes divers and swimmers anxious. Recreational fishers also say that the pleasure of fishing has vanished as pufferfish harms their fishing gears and targets their catch (Fig. 4). On the other hand, it is alarming that some recreational fishers in Antalya (Turkey) have admitted that they both catch and consume pufferfish (Çınar, *et al*., 2011) and further offer it to others for consumption.

Figure 4. Recreational fisher, predator pufferfish, and the prey (Antalya-Turkey) (Photo: M. Yahşi)

According to Arslantaş *et al*. (2017), increased pufferfish population has affected anglers and recreational fishing activity in Iskenderun Bay and pufferfish is one of the species most frequently caught in angling in this region.

This species has powerful jaws that can easily cut bottom longlines (Bilecenoğlu, 2010); complaints of local fishermen on this matter have been published several times in newspapers. A hobby fishing attempt in Fethiye Bay (Antalya-Turkey) resulted with three broken fishing lines, ten missing hooks and one *L.sceleratus* caught (slightly over 1 kg), just within five minutes!

2.2.3. Symbolic and aesthetic values

Pufferfish surprisingly gained symbolic and aesthetic value soon after it entered the Mediterranean. It was soon represented in various domains such as tattoo art (Fig. 5), textile industry, souvenirs (Fig. 6), and animated cartoons (Fig. 7), manifesting its presence either positively or negatively.

Tattoo art

Despite being a carnivorous, toxic, aggressive creature, the feature of inflating when threatened generates a nice picture in people's minds.

a b c

Figure 5. (a) Pufferfish tattoos, (b) Pop singer Miley Cyrus, (c) A chewing gum rub-on transfer tattoo.

Souvenir Use

Balloons are dried and used as decorative accessories and rear-view mirror accessories. Dried balloon fishes are sold between 10 TL and 250 TL; (1 TL= 0.2 Euro).

Figure 6. Puffer fish clothing (Turkey)

Animated Cartoons

The pufferfish is among the sea creatures used in the social, emotional and intellectual development of children especially, between ages 3-6 (Fig.7).

Figure 7. Storybook featuring pufferfish (Turkey)

Newsworthy

News such as pufferfish entrance to the Mediterranean through the Suez Canal, its being an invasive species causing death and injuries, awareness-raising campaigns are all over, in print, visual media, social platforms. A search on pufferfish on Google Turkey in March 2018 yielded 300,000 news, 206,000 videos, 31,100 newspaper articles and 23,100 videos on YouTube Turkey. The most interesting topics were the following:

1. Pufferfish nightmare in Mediterranean Sea;
2. Pufferfish eating soda can;
3. Panic over toxic pufferfish;
4. Authorities warn against Pufferfish;
5. Pufferfish attack.

2.2.3. Pharmaceutical-medical use

TTX is a sodium channel blocker. It is important in neurophysiological studies. Many researchers are evaluating TTX's analgesic activities in cancer research. The results show that TTX can be used as an effective pain reliever. It relieves severe, treatment resistant cancer pain in the majority of the patients studied. TTX is also useful in the treatment of pain caused by various problems such as migraine, neuralgia, rheumatism and heroin withdrawal. Given the proven benefits of TTX in the pharmaceutical industry, the establishment of laboratories in East Mediterranean countries by companies interested in the purification and subsequent use of the toxin can be considered. Eastern Mediterranean countries could then establish a fishery for *L. sceleratus* specifically oriented towards the pharmaceutical sector. Such an option would create many employment opportunities in the region, but more importantly, it would create a fishery that will yield economic benefits to the fishers and control wild *L. sceleratus* populations. Countries clearly would have to introduce very strict legislation to ensure that the fish caught is not landed on the market nor consumed in any way (Nader *et al*., 2012).

2.2.4. Entrepreneurs

Puffer fishes are commonly used in aquariums all around the world, regardless of their toxicity (Corsini-Foka *et al*., 2014). Since they are increasing in number in the Eastern Mediterranean region and are spreading rapidly, it would be relatively easy for fishers to catch them in large enough quantities for the aquarium trade. The fish could be caught at any size according to market demand and would become available for household tanks. This is not considered to have a significant impact on the wild populations of *L. sceleratus*. As in the pharmaceutical industry trade, strict regulations and monitoring are necessary to ensure that the public health is not endangered (Nader *et al*, 2012)(Fig. 8).

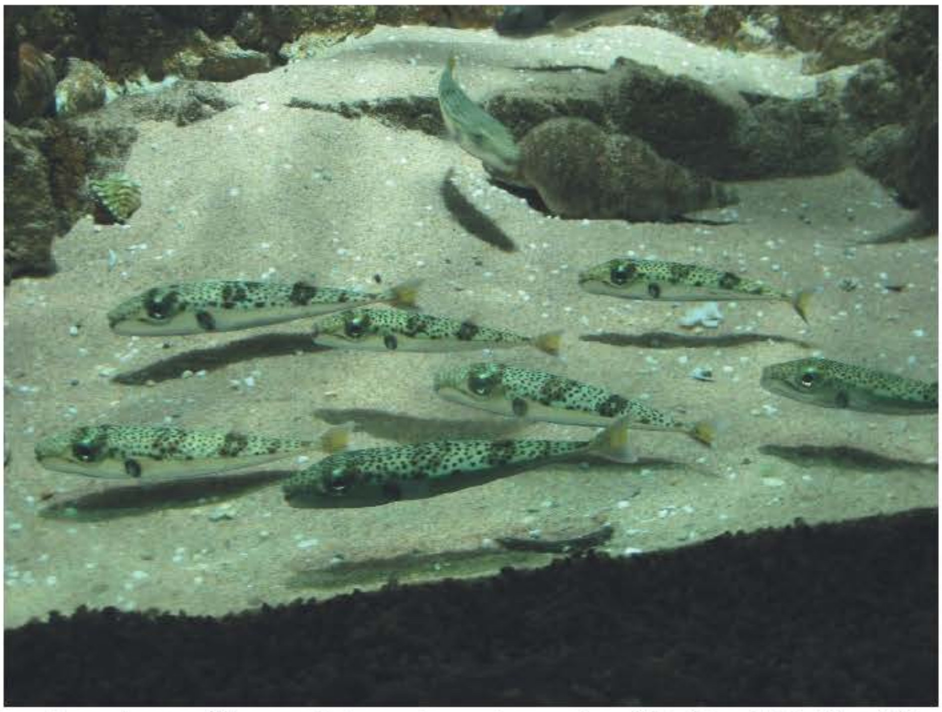

Figure 8. Juvenile specimens of *Lagocephalus sceleratus* in aquarium (Total length 15-18 cm) (Aquarium of the Hydrobiological Station of Rhodes/HCMR. Photo: Maria Corsini-Foka, Source: Corsini-Foka *et al*., 2014.)

2.2.5. Fisheries managers

Problems accrued to pufferfish force responsible managers to develop solutions, in particular remedy programs, in order to compensate the losses of groups mostly affected such as fishers; to raise awareness about the fatal effects of TTX and to take measures against the effects of the species on the ecosystem.- Pressure to put effective instruments into practice for combatting pufferfish (e.g. bounty system, fishing permission in a certain time of the year) does exist.

3. Next steps and alternative solutions

Currently we do not exactly know how *L. sceleratus* affects the Mediterranean ecosystem, as it is difficult to assess its role and impacts. Michailidis (2010) reported that the social and economic effects of the presence of the *L. sceleratus* to the fisheries as well as its impact on the ecosystem are very difficult to assess. For instance, based on reports from the artisanal fishermen, there seems to be an effect of the increasing *L. sceleratus* population, at least since 2006, on the cephalopod populations in Cyprus (Ulman *et al*., 2015, Michailidis, 2010). If this is the case, then many commercial species that feed on these cephalopods are indirectly affected by presence *L. sceleratus*, and this in its turn affects the catches and income of artisanal fishermen (Michailidis, 2010). According to Kalagirou (2013), *L. sceleratus* eat many species of molluscs, crustaceans, and fish with a number of prey species reaching 92. This indicates that *L. sceleratus* has various impacts within the marine ecosystem that are difficult to predict and mitigate.

Suggestions to mitigate negative impacts of pufferfish

- establish marine protected areas (MPAs) with no take zones (NTZs); indeed, an effective way to engage the pufferfish problem is through increase in the number and area of NTZs with MPAs where tuna, shark, grouper, seabream species are also present. Declaring well-protected zones strictly closed to any fishing activity where habitats can be preserved, where all elements of the food chain are present, where key species can survive would reduce the effects of *L. sceleratus* on the ecosystem. Pufferfish, which consumes almost everything including its own species (and also nets and needles of fishing gears, even garbage in the sea) is eaten by some predator's fish species. This was shown by observing pufferfish remains in the digestive systems of fish such as tuna and bluefish.

- develop new gears or modify current ones that can hunt these species (Nader *et al*. 2012; Kaykaç *et al*., 2017) and allowing controlled commercial fishing at specific periods (Ünal and Göncüoğlu Bodur, 2017); One of the methods to increase a fishing pressure on pufferfish and lighten its impact on the ecosystem could be allowing controlled commercial fishing action in specific periods using gears capable of fishing large quantities.

- catch pufferfish by specific recreational fishing methods (Çelik *et al*., 2017).

- increase fishing pressure on big individuals before they reproduce (Michailidis, 2010); fishing pressure on individuals with large eggs may help reduce the presence of the species on the ecosystem.

- implement a bounty system to provide a satisfactory payment per pufferfish (Ünal *et al*. 2015; Ünal and Göncüoğlu Bodur, 2017); this may help create fishing pressure by encouraging the targeting of the species while also compensating the economic losses of fishers. A premium system has already been implemented in some countries. Ünal *et al*. (2015) recommended that the bounty system could be established to pay for every individual pufferfish caught. Such aid is given to farmers exposed to natural disaster or plagues of insects, and should be considered for the fishers too.

Suggestions for future research, studies, actions

- conduct a multidimensional monitoring studies (association and interaction with other species and ecosystem, impact on food web, biodiversity, socio-economic impact); we need to understand how *L. sceleratus* will affect the food web structure and function of its new ecosystem, but most importantly we should also focus and create solutions on the social and economic benefits for humans (Kalogirou, 2013; Ünal and Göncüoğlu Bodur, 2017).

- initiate investigations on the biology and population dynamics of *L. sceleratus* (Nader *et al*., 2012)

- evaluate the impacts of *L. sceleratus* on ecosystem health and equilibrium (Nader *et al*., 2012)

- investigate the mechanisms regulating the bio-concentration of TTX in the organs and tissues of *L. sceleratus* as a function of the size (Nader *et al*., 2012)

- assess the economic value and potential of TTX as a pharmaceutical agent on the world market (Nader *et al*. 2012)

4. Conclusion

In recent years, there have been many news articles, projects, activities, on pufferfish in Turkey. This situation is similar also in other countries of the Mediterranean since the recent appearance of this fish. A single *L. sceleratus* brought by a Turkish fisher to the author of this article in 2003, saying "first time in my life I've caught such a fish", has become a problem of not only for Turkey, but for the entire Mediterranean after 15 years. The impacts of the species have caused emergence of innumerable problems, affecting mostly the fishers. While it was only the problem of Turkish and Greek fishers at first, it is now the nightmare of Maltese, Egyptian, Croatian and Italian fishers as well; so much so that scientists felt the need to discuss the extents of problem at the International Symposium on Pufferfish, held on October 13-14 2017 in Bodrum, Turkey. The symposium was attended by scientists from Mediterranean countries and others such as Japan and New Zealand. The symposium addressed the issues arising from the invasion and proliferation of pufferfish, especially *L. sceleratus* in the Eastern Mediterranean including consequences of its extreme toxicity; its destructive effects on the fishing industry and the consequences of this species on the wider marine ecosystem. It was agreed that the situation with *L. sceleratus* can be described as an unfolding ecological catastrophe that may spread beyond the Mediterranean Sea. It was also agreed and concluded that it will not be possible to eliminate *L. sceleratus* from the Mediterranean, rather only its effects can be mitigated (Shotton *et al*., 2017).

Fishers are faced with enormous monetary losses and death due to unconscious consumption. Measures are insufficient and all attempts to revert threat to opportunity have been fruitless. Meanwhile the life cycle, ecology, population dynamics and potential of pufferfish remain largely unknown. Actually, *L. sceleratus* poses more complex impacts than seen. The gravity of the situation is more clear when we consider that this species eats many fish species, including target species with economic value to fishers (e.g. shrimp, octopus, squid, crab and almost any other fish species), and fishers have to increase their days at sea in order to increase catch capacity so as to cover their losses. For instance, 5 years after the emergence of *L. sceleratus* in Gökova Bay in Turkey, shrimp fishing in the area ended since there was no more shrimp to catch any more. 5-6 years after the declaration of No Fishing Zones (NFZs) in the bay in 2010, top predators in the food chain started to return, helping the slow emergence of shrimp. All these relations need to be explored through comprehensive scientific studies and the results should be implemented in managerial decisions. Adverse effects of pufferfish are escalating, particularly for the fishers. Apart from this, there are episodes of fishers intoxicated from consumption or having lost a finger to a pufferfish, of divers and tourists bitten by pufferfish. With warming waters in the summer season, such instances may be more frequent as the pufferfish population increases in coastal waters. This species shows a highly invasive character (Çınar *et al*., 2011): in terms of biomass, *L. sceleratus* is already the most common pufferfish on Turkish coasts (Bilecenoğlu, 2010). In conclusion, neither *L. sceleratus* nor its impacts will stop in the long term. It has already reached as far as Spain in the Mediterranean and the Marmara Sea in Turkey. However, there are alternative solutions to mitigate its many impacts. It is time to act.

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Impact de l'ichthyofaune non indigène de la côte algérienne: réalités et artefacts

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Résumé
Quatre-vingt-dix espèces nouvelles s'installent ou se sont installées en Méditerranée. Ce nombre représente environ 13 % environ de la faune ichtyologique de cette région. L'examen des apports récents permet de recenser un certain nombre d'espèces nouvelles de poissons dans le bassin algérien. Les origines géographiques de ces espèces sont variées et révèlent une influence atlantique et indo pacifique. Parmi ces nouveaux immigrants, on peut citer le poisson chirurgien, le poisson trompette, le poisson globe. Aucun impact majeur du aux espèces exotiques n'est signalé dans le bassin algérien.

Mots-clés : poissons marins; espèces exotiques; côte algérienne

Introduction

Le réchauffement climatique qui depuis plusieurs décennies affecte la planète de manière significative, concerne également le monde marin, et notamment la Méditerranée CIESM, 2008). Le résultat le plus évident d'un tel phénomène est l'invasion de cette mer par des espèces en provenance de régions adjacentes plus chaudes, l'Indo-Pacifique à l'Est, via le canal de Suez, migrations lessepsiennes, et l'Atlantique oriental tropical à l'Ouest, via le détroit de Gibraltar, migrations herculéennes. La côte algérienne sur toute son étendue (Fig. 1) n'est pas à l'abri d'une telle invasion. Les migrations d'espèces de poissons semblent les plus notoires d'après les captures de la pêche et les investigations sous-marines (Ben Raïs-Lasram et Mouillot, 2009).

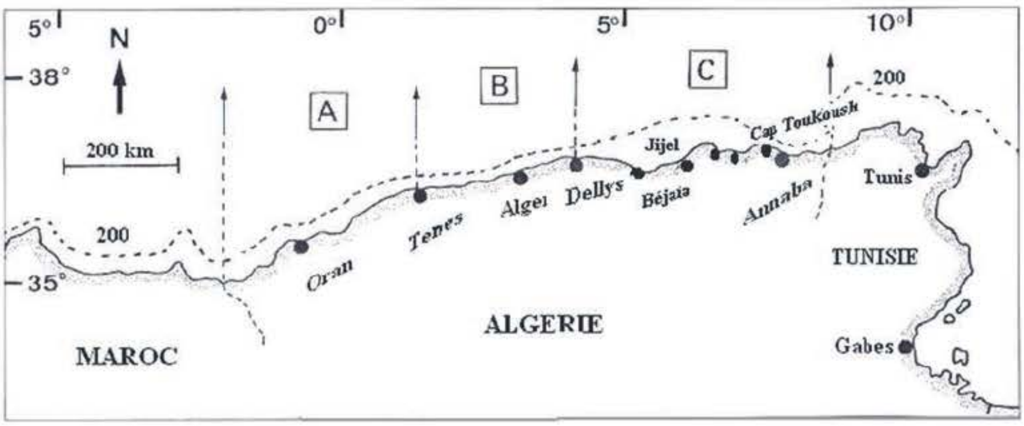

Figure 1. Carte du bassin algérien (A : région Ouest ; B : région Centre ; C : région Est).

L'action conjuguée de nos propres observations et la consultation de documents nous a permis d'établir une liste préliminaire de ces espèces nouvelles pour la région : certaines sont signalées mais non observées ; beaucoup sont exploitées mais non identifiées. Les espèces exotiques recensées ne se sont pas installées ; les réseaux sociaux qui s'y intéressent focalisent sur celles dont la réputation est surfaite et provoquent des réactions négatives au sein de la population en propageant des informations souvent sans fondements.

CHONDRICHTHYENS

Famille des Mobulidae

L'exploitation de *Mobula japanica* (Müller et Henle, 1841), cité par Hemida et al (2016) est actuellement intensive : ses apparitions impressionnantes entrainent des captures régulières abondantes toute l'année (contrairement à *M. mobular,* qui est observée en hiver seulement).

OSTEICHTHYENS

Famille des Acanthuridae

Acanthurus monroviae Steindachner, 1876, migrant herculéen signalé pour la première fois en Algérie par Hemida et al (2004), a disparu de la côte du Maghreb.

Famille des Kyphosidae

Kyphosus sectator (Linnaeus, 1758), migrant herculéen a été observé pour la première fois en Algérie par Hemida et al (2003). Cette espèce semble s'établir avec succès en Méditerranée ; elle apparait sporadiquement dans certaines régions comme la Tunisie (Lelong, 2012). En revanche sa présence n'est plus établie dans le bassin algérien.

Famille des Dussumieriidae

Etrumeus golanii DiBattista, Randall & Bowen, 2012. L'espèce a été constatée localement pour la première fois par Kassar et Hemida (2017).

Très peu abondante, confondue avec la sardine, elle passe toujours inaperçue même si certains pêcheurs arrivent à faire la différence, pour des raisons commerciales évidentes. L'espèce a été citée dans le sud de la Tunisie, puis a migré vers les régions septentrionales de ce pays, où elle a été capturée en très grande abondance ; ce phénomène n'a été observé qu'une fois et depuis aucun spécimen n'a été signalé (Rafrafi *et al*., 2017)

Figure 2. *Seriola carpenteri* capturé en mars 2018 dans la région d'Oran (ouest du bassin algérien)

Famille des Carangidae
Alectis alexandrinus (Geoffroy Saint-Hilaire, 1817), migrant herculéen, a été signalé pour la première fois en Algérie par Hemida et al (2005) ; l'espèce n'apparait plus localement.
Une nouvelle espèce de cette famille semble capturée par les pêcheurs plaisanciers à Oran, dans la région Ouest de l'Algérie; il pourrait s'agir du limon guinéen (Fig. 2) *Seriola carpenteri* Mather, 1971.

Famille des Centrolophidae
Deux ordres regroupent deux espèces rarement présentes sur le marché (Fig. 3) : *Centrolophus niger* et *Schedophilus ovalis*. Quoique recensés par la littérature, aucun professionnel de la pêche n'est capable de les catégoriser, ni même les identifier.

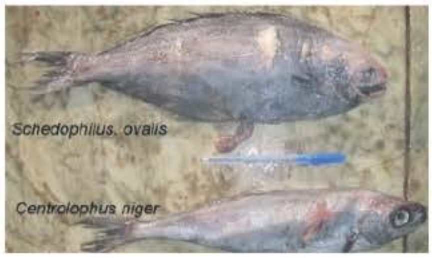

Figure 3. Représentants de la famille des Centrolophidae observés à la pêcherie d'Alger (mai 2016)

Elles restent inconnues à un point tel que souvent les profanes les considèrent comme de nouvelles espèces et saisissent les scientifiques ou les pouvoirs publics. L'identification des représentants des Centrolophidae n'est pas aisée même pour les ichthyolgistes. La problématique de cette famille résulte des confusions qui apparaissent entre certaines espèces. La littérature la concernant est ambigüe et même contradictoire. *Schedophilus medusophagus* n'a été rencontré qu'une seule fois, en 2016 dans la région de Dellys (Fig. 1). Capturé par un senneur, l'animal se trouvait dans un banc de sardines encombré de méduses.

Famille des Fistularidae
Fistularia commesonii Rüppell, 1838, migrant lessepsien qui fait l'objet d'un premier signalement en mars 2009 Hemida et al (2009), puis en mai 2009 (Kara et Oudjane, 2009). La cornette bleue apparue localement en 2008, atteignant la frontière marocaine en 2009, avait proliféré et était pêchée en grandes quantités dans certaines régions ; elle a même été commercialisée. Pourtant, on ne la capture plus, depuis les années 2010. *Fistularia* n'a pas réussi à s'adapter.

Famille des Lobotidae
Lobotes surinamensis (Bloch, 1790), migrant herculéen signalé pour la première fois en Algérie par Hemida et al (2002), il est considéré rare en Méditerranée. Le cordonnier bossu n'apparait plus dans les débarquements des différents ports de l'Algérie.

Famille des Scombridae

Deux espèces de thon fréquentent les eaux algériennes: *Thunnus thynnus thynnus* (Linnaeus, 1758) *et Thunnus alalunga* (Bonnaterre, 1788). Une nouvelle espèce *Thunnus obesus* (Lowe, 1839) non signalée en Méditerranée, apparait sporadiquement dans les apports du bassin algérien (Fig. 4).

Figure 4. *Thunnus obesus* observé à la pêcherie d'Alger (avril 2008).

Famille des Tetraodontidae

Sphoeroides pachygaster (Müller & Troschel, 1848), migrant herculéen signalé pour la première fois en Algérie par Hemida et al (2005), est une espèce rare localement, mais qui semble se répandre de plus en plus en Méditerranée. L'examen de la carte de répartition de *Sphoeroides pachygaster* montre qu'elle serait fréquente sur tout le pourtour de la Méditerranée occidentale. *Lagocephalus sceleratus* (Gmelin, 1789) provenant de la mer Rouge, a été observé en Méditerranée orientale et signalé au sud de la Tunisie (Jbiri et Bradai, 2011) ; des auteurs ont mentionné sa présence du côté septentrional tunisien (Ben Souissi *et al.*, 2014). Avant cela aucune note scientifique n'en a fait mention en Algérie ; seules des photos avec commentaires ont été présentées dans les réseaux sociaux et ont servi de base aux décisions prises par le ministère de la pêche. Suite à la note de Ben Souissi et al (2014), on évoquera l'inquiétude occasionnée au sein de la population (consommateurs et pêcheurs) par les mesures prises par le ministère de la pêche, qui à force de posters affichés dans les marchés, les différents services vétérinaires et autres antennes de pêche, interdisent la commercialisation de cette espèce supposée présente (ou à l'affut) et même de se débarrasser de tout produit marin qui aurait été en contact avec, allant même jusqu'à menacer les pêcheurs de sanctions pénales. Il y a eu une nette confusion de la part des services concernés, entre le poisson lapin (appartenant au genre *Siganus*) et le poisson coffre (ou globe) appartenant au genre *Lagocephalus*. L'étymologie des noms scientifiques *Lagocephalus* et *Siganus* leur donnant la même signification est à l'origine de la confusion : le poisson coffre est incorrectement nommé poisson lapin. La détermination erronée des spécimens de *Lagocephalus* rencontrés ou pris en photo a ajouté à la confusion: Dieuzeide *et al* (1953), chercheurs au centre de Castiglione (actuel CNRDPA), signalaient des individus de l'espèce *L. lagocephalus* (Linnaeus, 1758), appelé « arnab » en Algérie, échoués sur les plages après un gros temps. Des spécimens isolés apparaissent toujours régulièrement dans les apports et sont indûment considérés comme représentants de *L. sceleratus*. Kara et al (2015) signalent sa capture dans la région d'Annaba (Est Algérie) sur la base de photographies ; la dispersion de cette espèce vers l'ouest de la côte algérienne n'est toujours pas vérifiée.

Conclusion

Zone de passage obligée entre les secteurs de l'Atlantique septentrional et méridional et le reste de la Méditerranée, la côte algérienne est amenée à s'enrichir de nouvelles espèces qui pourraient avoir un rôle négatif ou régulateur au sein des écosystèmes marins. À cela s'ajoutent des modifications importantes de la répartition géographique d'espèces locales due aux variations du milieu générant une compétition entre elles et un cycle d'apparition/disparition.

Certaines populations dites exotiques considérées comme rares dans le secteur ont pu être observées. On ne statuera pas de manière ferme et définitive sur la présence et l'accoutumance des espèces non-indigènes dans la région considérée. Ce sont pour la plupart des espèces peu connues des profanes et des professionnels de la pêche d'autant plus qu'elles n'ont pas de valeur commerciale. A priori, les poissons osseux exotiques recensés ne réussissent pas à s'implanter dans le secteur méditerranéen ouest, notamment dans bassin algérien. Les informations fournies par la littérature ichthyologique sont relativement infimes; un effort sera spécialement consenti pour faire connaître les espèces locales rares ou occasionnelles (appartenant entre autres, aux Centrolophidae, aux Alepocephalidae…) afin de ne pas les confondre avec les espèces introduites.

Seriola carpenteri et *Thunnus obsesus* feront l'objet de publications prochaines qui mettront en évidence leur existence dans les eaux marines algériennes. Ces espèces nouvelles ainsi que les poissons-coffre, la chadine et autres, n'ont jamais eu de biomasses importantes et n'ont présenté jusqu'ici aucun intérêt, exceptée la cornette bleue qui a été commercialisée et appréciée pendant un court moment.
Les spécimens identifiés sont conservés avec un numéro d'inventaire dans une collection disponible pour permettre la confirmation de leur identification. Cette démarche, pas toujours respectée, valide les informations. Cela évite de propager des informations non vérifiées et de répéter l'inquiétude vécue en 2014 dans le cas de *Lagocephalus*, provoquée par une médiatisation basée sur des informations inexactes. On ne peut pas encore confirmer dans le bassin algérien la présence *Lagocephalus sceleratus* : signalée pour la première fois en Algérie en 2015, aucun autre signalement fiable n'a été relevé depuis ; les signalements d'individus isolés dans différentes régions de l'Est algérien ne prouvent en aucun cas sa présence ni surtout son installation.

Les deux espèces de *Siganus* potentiellement invasives se concentrent dans le bassin siculo-tunisien mais n'ont toujours pas atteint le bassin algérien, pas plus qu'elles n'ont envahi la rive nord de la Méditerranée occidentale. L'arrivée de *Lagocephalus sceleratu*s, *Siganus rivulatus* et *Siganus luridus* ainsi que d'autres envahisseurs est inéluctable. L'expérience internationale partagée permettra d'atténuer l'impact socio-économique que cette arrivée ne manquera pas d'apporter.

La capture de toute espèce inconnue, pouvant entrainer une sanction ancrée à une mauvaise appréciation des risques, sera occultée par certains professionnels de la pêche. La source d'information tarie, cela créera l'illusion d'une invasion qui se stabilise, voire qui cesse. Seuls des travaux scientifiques soutenus et réguliers peuvent apporter des solutions à d'éventuelles colonisations qui se traduiraient par des remplacements d'espèces à haut intérêt commercial par d'autres de moindre intérêt et risqueraient alors de bouleverser l'économie de la pêche en Algérie. À ces données, pourraient s'ajouter d'autres espèces dangereuses pour la santé publique comme le poisson lion *Pterois miles* qui soulève une certaine inquiétude en Méditerranée orientale et dont la dispersion rapide pourrait lui permettre d'atteindre nos côtes, puisqu'il est déjà signalé en Tunisie du nord-est par Ounifi-Ben Amor et Ghanem (2016).

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Emerging jellyfish and its significance in local fisheries - a *Periphylla periphylla* story in the Trondheimsfjord

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Abstract
The helmet jellyfish (*Periphylla periphylla*) has become an increasing biological and economic problem for the fishers in many Norwegian fjords over the past few decades. It is known to prey on a variety of planktonic species including small crustaceans such as krill and calanus as well as on fish larvae. Thus, this jellyfish is both a predator and a food competitor of crustaceans and fish species. Recent studies suggest that an increasing abundance of jellyfish may have contributed to a decline in the cod population and productivity in some Norwegian fjords. Abundant local jellyfish populations may cause substantial economic losses for fishers, particularly in small-scale fisheries, due to the reduction in annual fish catches and extra effort required for cleaning and fixing fishing nets.This, in turn, has led to changes in the fishing behavior and well-being of the local fishers. This paper explores the potential ecological and economic consequences of an ongoing *Periphylla periphylla* bloom on the small-scale cod fisheries in the Trondheimsfjord, Norway. Participatory methods of combining interactive workshops and structured questionnaires were used to elicit stakeholders' perceptions and reactions to the emerging jellyfish blooming and their potential adaptation strategies. The study provides valuable insights into the impact of a newly established but permanent jellyfish population on the ecologically and commercially important species in the cod family, and how fishers might adapt to such a continued high local jellyfish presence in their prospects for a future as fishers, and also help policy makers on how to incorporate the experience from this emerging issue into future management and policy process.

Key words: *Periphylla*, cod, Tondheimsfjord, artisanal fishers, stakeholder workshops, questionnaires, perceptions.

Introduction

Over the last few decades, mass occurrences of the helmet (or crown) jellyfish *Periphylla periphylla,* hereafter called *Periphylla*, have been reported in several fjords along the Norwegian coast from Lurefjorden on the south-west coast to Saltenfjorden in Bodø in the north (Fosså, 1992; Youngbluth & Båmstedt, 2001; Sneli, 1984; Hetland, 2008; Bozman, 2010, Tiller *et al*., 2016). *Periphylla* is a long-lived deep-sea predatory scyphozoan jellyfish belonging to the order Coronatae of the phylum Cnidaria

(Jarms, 1997). It is found in all world oceans including the Arctic and Antarctic. Occasionally it has been caught at depths of 7 000 meters, and is perfectly adapted to a dark environment (Kramp, 1959). It is holopelagic and has a direct development from eggs to adults. The fertilized eggs are dispersed into the open water where they develop into medusa through 14 stages (Jarms *et al.,* 1999). *Periphylla* appears to breed throughout the year, with a possible peak in autumn and early winter in the northernmost infested fjords, including the Trondheimsfjord (Bozman, 2010; Borgersen, 2013). *Periphylla* prey on a variety of planktonic organisms including larvae and juveniles of its foodweb rival species like codfishes, and on small crustaceans like krill and calanus spp (Kaartvedt *et al.,* 2007 & 2011; Tiller *et al*., 2015). Because other scyphozoan jellyfish are known to prey on fish eggs (Purcell *et al.,* 1994; Barz & Hirche, 2007), it has been suggested that *Periphylla* may become a potential predator on these as well.

Equipped with some of the largest stinging cells amongst jellyfish species (Jarms *et al.,* 2002), this predatory jellyfish appears as a serious threat to the juvenile stages of important local fish stocks in Norwegian fjords, like those of the various codfishes, herring and sprat. The threat is not only as a competitor for the same food sources (Hansson *et al*., 2005), but also as a predator of their competitor's fragile larvae and juveniles (Zeman *et al.,* 2016; Eriksen *et al*., 2012). When reaching a certain level of population biomass in a local ecosystem, the jellyfish may outcompete its rival species and potentially become the top predator in the ecosystem, a process named the "*jellyfish spiral*" (Uye, 2008), from which its rival species find it difficult to recover, and might even disappear.

The causes of jellyfish blooms have been suggested to be a combination of anthropogenic stressors and natural changes in ecological processes, including eutrophication, overfishing, introduction of non-indigenous, species and climate change (e.g., Lynam *et al.,* 2005; Hay, 2006; Purcell *et al.,* 2007; Richardson *et al.,* 2009; Purcell, 2012; Roux *et al.,* 2013). In some cases, overfishing may remove predators of jellyfish (Condon *et al.,* 2012; Milisenda *et al.,* 2014), further complicating the ability to survive and maintain healthy populations for rival fish species already threatened by their gelatinous competitors (Robinson *et al.,* 2014). Global climate change has caused the ocean to warm up rather unpredictably over the years (IPCC 2014). Jellyfish, in contrast to boreal fish species that are negatively affected, have enjoyed the warm climate (Chiaverano *et al.,* 2013; Robinson *et al.,* 2014), and thrived in environments which they previously did not inhabit, exemplified by the *Periphylla* infestations along the Norwegian coastline and fjords (Tiller *et al*., 2016). Increased water temperatures and pollution have resulted in richer nutrient levels that may enhance plankton growth and change the ocean productivity. When the waters of the Norwegian fjords are darkened owing to climate change and eutrophication and thus light attenuation is increased, jellyfish have a unique advantage over fish by being non-visual hunters. Fish species rely on eyesight for hunting and thus struggle to find prey in dark environment, while the jellyfish find prey by physical contact with their tentacles (Youngbluth & Båmstedt, 2001; Sørnes *et al.,* 2007; Aksnes *et al.,* 2009). It is evident that jellyfish and forage fish display replacement cycles on intradecadal time scales (Robinson *et al*., 2014).

The rapid increase in the abundance of *Periphylla* has become an increasing ecological and economical problem for the traditional fisheries in many Norwegian fjords (Tiller *et al*., 2016). With dense populations consistently throughout the year on traditional fishing grounds, *Periphylla* clearly poses negative effects on fishing activities, especially on the traditional and small-scale fisheries. This is certainly the case for the Trondheimsfjord, the focus of this study. Small-scale fishers use traditional net gear in the coastal areas and fjords on a daily basis. It is mainly for subsistence and is the common source of livelihood (Jentoft and Johnsen, 2015). Recently, fishers have reported that *Periphylla* have replaced the commercial fishing stocks in some fishing areas, which leads them to relocate fishing grounds, resulting in longer working hours, increased fishing costs and decreased income due to loss of traditional fishing grounds. Jellyfish venom is highly toxic to fish species (Helmholz *et al.,* 2010). Dependent upon the degree of physical contact with the tentacles, it can cause severe stress, blindness and even death to the fish (Båmstedt *et al.,* 1998). Whenever trapped together with *Periphylla* in the fishing nets or trawls, the fish is severely stung by the toxic tentacles of the jellies and the commercial value of the fish is decreased. Furthermore, when *Periphylla* die and sink to the bottom, the decaying corpses sap oxygen from the local environment and change nutrient compositions leading to reduced amounts of available oxygen and irregularities in nutrient cycles for the bottom species inhabiting the area (Titelman *et al*., 2006; West *et al.,* 2009). These effects on the ecosystem and environment are observed, but difficult to quantify (Nakar, 2011). The economic pressures might, in a worst case scenario, force fishers to change profession or even end up to be unemployed depending on sources, e.g., social support, and thus imposing potential costs on the society.

***Periphylla* and fishing in the Trondheimsfjord**

The Trondheimsfjord is the third longest and the seventh deepest fjord in Norway. The fjord is 126 km long, 630 m deep, and the total volume is about 235 km^3. The fjord is located in the west-central part of Norway in Trøndelag County, stretching from Ørland municipality in the west to the Steinkjer municipality in the north. The fjord is naturally divided in three basins (largest and mean depths in parentheses); Outerfjorden (600m/212m), Midtfjorden (400m/130m) and Innerfjorden (240m/86m), separated by shallower sills at Agdenes, Tautra and Skarnsundet. Innerfjorden includes Beitstadfjorden and a narrow side-arm called Verran and including two shallower basins called Verrasundet (100m) around station 2 and Verrabotn (65m) around station 1 (Fig.1). Six large rivers discharge fresh water into the fjord from land areas on the east and south sides of the fjord. These discharges set up a strong estuarine circulation transporting the water masses from these rivers to the inner part of the fjord and then as a main outgoing water transport along the northwestern side of the fjord. The tides are semi-diurnal with an average amplitude of 1.8 m.

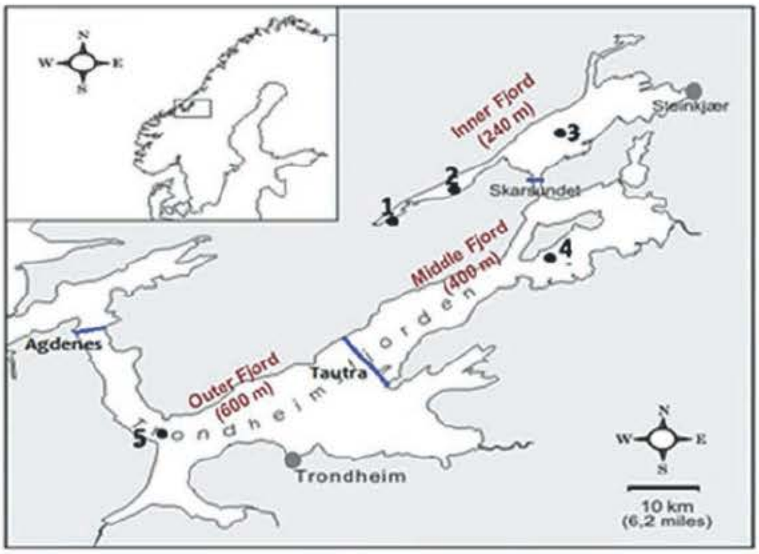

Figure 1. The Trondheimsfjord with the three basins marked together with five hydrographic stations. The three basins are outer fjord, middle fjord ans inner fjord, divides by three sills at Agdenes, Tautra and Skarnsundet as indicated by solid blue bars.

The hydrographical conditions (estuarine circulation) of the fjord are heavily influenced by the sills, basins depths and the presence of several large rivers which empty in the inner parts of the fjord, *e.g.* by causing large spring floods and substantial vertical density stratification-differences between basins. Annual inflows of heavier Norwegian Coastal-current water and Atlantic water replace the bottom water at least once a year. The depths and distances to the river estuaries along the fjord influence a variety of ecosystems. The fjord lies in a boreal-arctic transition zone and is a relatively self-sustained and fully functional ecosystem. Over 100 species of fish use this fjord as their vital habitat, including a number of important marine species and resources such as cod and herring. The local cod stock has traditionally been the keystone species in the ecosystem and has supported local fishers for their livelihood for centuries (Mork *et al*. 1982, Mork *et al*., 1985).

Periphylla has established a self-recruiting stock in the Middle and Inner Trondheimsfjord since 1999, especially in the Beitstadfjord basin where the *Periphylla* bloom has been more extensive than in other parts of the fjord. It first became a notable nuisance for local fishers in the Trondheimsfjord in the early 2000s. The infestation of the fjord and the establishment of a large jelly biomass took about 10 - 12 years (Borgersen, 2013). The current jelly population is estimated at > 60 000 metric tons in the Beitstadfjord alone, where also the assumed *mother population* is located (Hetland, 2008; Jøssang, 2015). The jelly population is effectively recruiting itself and now thriving. For example, the biomass estimates in 2015 were more than five times higher than those in 2007 (63 998 tons *vs*. 11 291 tons respectively, Jøssang, 2015). Unlike most fish species, *Periphylla* have high tolerance to environmental changes such as increased temperatures, salinity variations, reduced oxygen saturation and increased light attenuation. These are environments to which most fish species struggle to adapt, and may lead them to being gradually outcompeted in the Trondheimsfjord by the jelly over the last decade or so (Hetland, 2008; Solheim, 2012; Borgersen, 2013; Jøssang, 2015). Fig.2 shows the different sizes of *Periphylla* caught in one bottom trawl hawl by R/V "Gunnerus" of NTNU in the inner Trondheimsfjord in 2014. Such size series and an overall large over-representation of small individuals in the trawl catches indicate a continuous successful recruitment to the standing *Periphylla* population in the inner Trondheimsfjord during the last decades.

Figure 2. Common *Periphylla* size distribution in routine bottom trawl catches from the inner Trondheimsfjord (Photo by Jarle Mork).

The jellyfish has caused a series of problems to the local ecosystems and marine resources that coastal fishers in the areas depend on for their livelihood. These artisanal fishers are very vulnerable to *Periphylla* infestations. Those fishers who use Beitstadfjord as their major fishing grounds are affected considerably by *Periphylla*. However, the level of impacts depends on the fishing gears being used, the fishing grounds and seasons fished, and the abundance of jellyfish in the ecosystem. The jellyfish can clog the nets and engines of fishing vessels. Fishers are stung while removing the jellyfish from the nets as well as bearing the subsequent cost of cleaning the nets. Harvested fish are likely damaged, resulting in reduced value of the catch. However, the economic losses and social impact are difficult to be quantified due to lack of data and level of impacts. Currently, the most important fish species for the coastal fishers in the Trondheimsfjord are codfish species including cod, pollock and saithe. Emerging species like pollock and crab have also gradually become important to local fishers as an income supplement in light of declining cod stocks possibly due to the jellyfish infestation combined with other factors such as climate change and dynamics of fish market. The artisanal fishers have witnessed the changes in the fisheries resources and fishing conditions over time. The main fishing season takes place in spring from March to May when the fish are residing in the coastal areas for spawning. Local artisanal fishers use 30 - 35 feet coastal fishing vessels with conventional and low-tech gears such as gillnets to harvest these fish species. They fish in the areas close to their homes due to strict regulations on landing sites and their daily possibility to travel. They depend on these fisheries as their livelihood and a way of lifestyle.

Materials and data

Data and information were collected through the combination of field surveys, interactive stakeholder workshops and structured questionnaires with fishers. The stakeholders who participated in the workshops and questionnaires are full-time/part-time artisanal or small-scale commercial fishers who have been fishing in the Trondheimsfjord, especially in the inner fjord for over a decade. Fishing has been the source of their income to support their livelihood, also been the way of their lifestyle for generations, and they are not willing to change. These fishers have extensive knowledge about the sea and marine resources, and have encountered *Periphylla* in their catches, and observed *Periphylla* starting to bloom over the years.

Field surveys

During decade-long scientific surveys and data collections in the Trondheimsfjord, data have been collected by Trondhjem Biological Station (TBS) for *Periphylla* and cod in spring and autumn samples. Five sampling stations covering the relevant fjord basins (Fig. 1) were selected for field surveys which covered both spring and fall hydrographical and planktonic conditions. A specially designed Light Weight Video Trawl (LWVPP) performing U-dives enabled size measurements and counting of individual *Periphylla* (see details in Jøssang, 2015). On each survey, at least two repeated hauls were made at each location. Trawling speeds and times were recorded, thus enabling calculations of filtered water volume and catch per unit effort (CPUE) of *Periphylla* and cod. Parallel bottom shrimp-trawl catches on the same locations were manually counted for *Periphylla* and fish species and their numbers. Based on information from these sources, the respective biomasses of *Periphylla* and the various fish species were calculated.

Participatory workshops.

Two interactive and participatory workshops were organized with local fishers in both Sør- and Nord-Trøndelag to collect qualitative information on the fishers' perceptions about *Periphylla*, including their opinion on *Periphylla* occurrence in the fjord and their adaptive capacity to *Periphylla* infestations. The first workshop was held in Trondheim located in Sør-Trøndelag with four independent fishers who live in the city of Trondheim. They were commercial fishers and not affected by *Periphylla* themselves, but they were aware the presence of *Periphylla* and heard that other fishers in the fjord were affected by *Periphylla*. The second workshop was held in Steinkjer, a city in Nord- Trøndelag. Seven local fishers were invited and attended the workshop. They were active fishers in the fjord either full-time or part-time and they had encountered *Periphylla* on several occasions and therefore had personal experiences and views on the matter. The detailed approaches from these workshops can be found in Tiller *et al.* (2014 & 2015).

Structured questionnaire survey.

Following the workshops, a structured questionnaire survey was designed and conducted among the small-scale artisanal fishers in the inner Trondheimsfjord for cod fishing. This survey was to explicitly examine the potential impacts of jellyfish on their fishing activities and possible adaptation strategies. The fishers surveyed are those who have encountered *Periphylla* and were affected to some extent occasionally. The questionnaire was divided into a few sections, including basic fishing information like fishing area, gear and season, economic components like catch and catch composition, price and cost, their views on *Periphylla* effects and social-demographic characteristics of fishers. The questionnaire was administrated by mail to all the fishers, and phone calls were followed up after a couple of weeks later. Half of which replied with relatively complete answers resulting in a response rate of 50%. Both qualitative and quantitative data were collected.

Results

The results from the field surveys clearly indicated that there is a negative relationship between the abundance of *Periphylla* and cod stock size (Fig. 3). The catch per unit effort (CPUE) of *Periphylla* has sharply increased (dotted red line) while the CPUE of cod has drastically fallen down (solid dark blue line) for the same period. This divergent development suggests that *Periphylla* may have had negative impacts on cod, and certainly on the fishing patterns of the local fishers. It should be noted that the decreases in the catch of cod is due to sample size, location and time of fishing, thus, it didn't imply that cod stock is on the brink of extinction. However, the sharp drop in the spring sample of 2013 was contributed by a documented mass death of *Periphylla*.

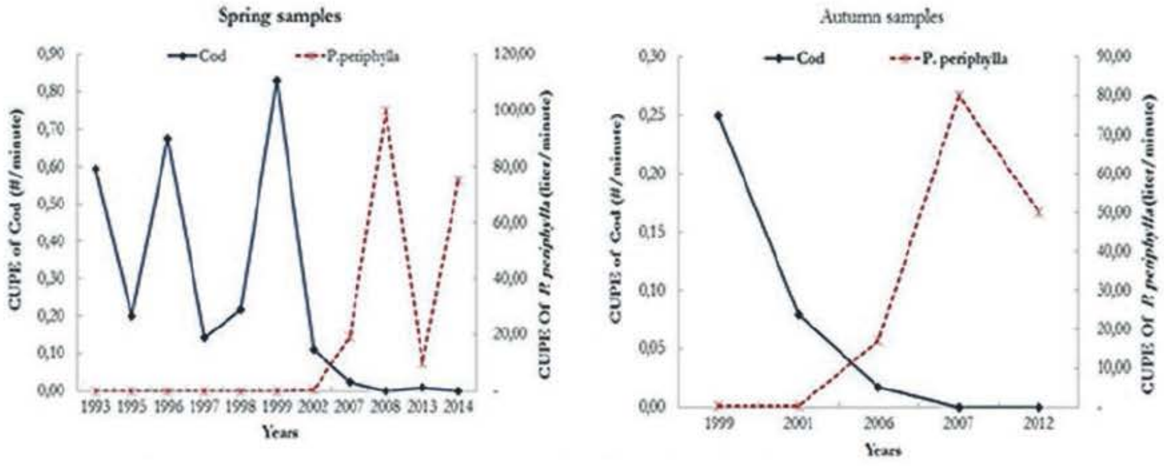

Figure 3. The catch per unit efforts (CPUE) of Cod vs. Periphylla.

In order to compare the data from the surveys, aggregated data from the National statistics for Trøndelag area (including Sør- and Nord-Trøndelag) and data from the questionnaire (e.g., fisher's logbook) were used to illustrate the changes in fisheries resources over the last decade. The catch composition of fishers' catch has changed substantially in the last decade (Fig. 4). The results indicated that cod and saithe are still the dominant species in terms of catch and value, although overall the cod catch has shown a rapid decline in the last few years (Fig. 4). For example, the catch of cod has halved from over 60% in 2000 to about 30% in 2012 while the catch of saithe has increased from 20% to 50% at the same period. Hake and Pollack have also shown increasing trend since they receive better price in the market due to increasing demand. However, according to the responses to the questionnaires in the current study cod is still the fishers' favourite species to catch although the price of cod has gradually declined.

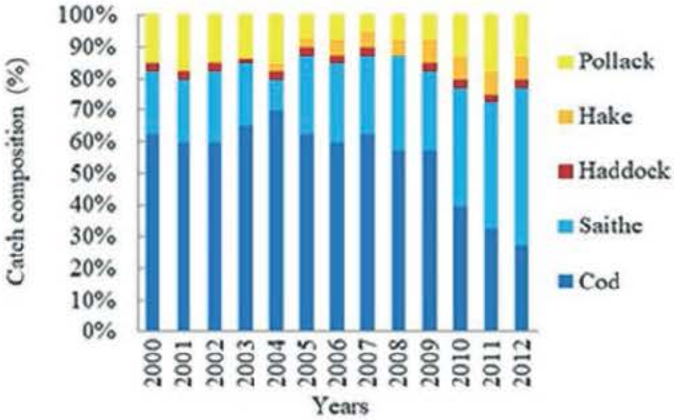

Figure 4. The catch composition from fisher's logbook.

The results from the two workshops are synthesized in Figure 5. The fishers at the workshop in the North Trøndelag had encountered *Periphylla* during their fishing occasionally while the fishers in Trondheim in the South Trøndelag just heard about *Periphylla* but had no personal experience with it. It, however, turns out that the both group fishers have shown the same concern about the ultimate effects of *Periphylla*, which is the decreased or lower income. Which is not surprising as fishing is the main source of their income. They also expressed their concerns about the direct effects of *Periphylla* on: 1) fish larvae mortality due to predation, 2) adult fish mortality due to stinging danger and predation, and 3) damaged catch by direct contact with fish in the net. Additional factors regarding *Periphylla* were also very similar for both groups of fishers.

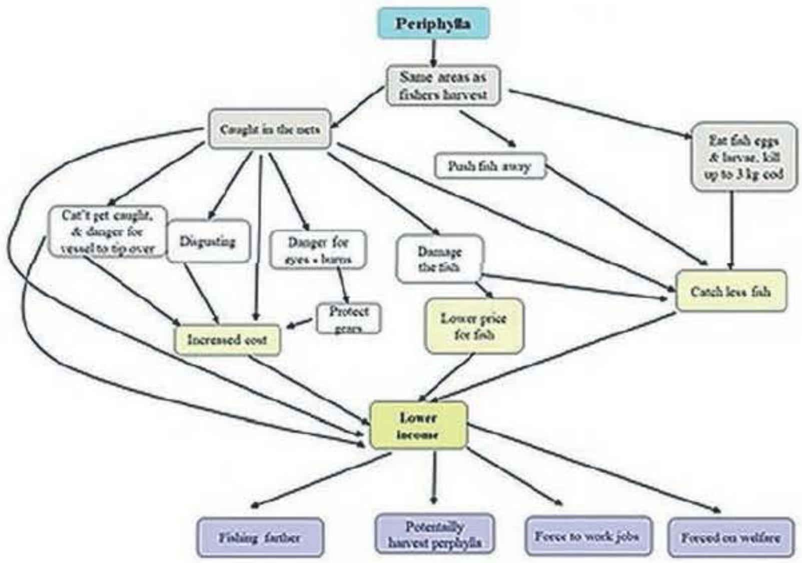

Figure 5. Traced tree summing up fishers' perception about *Periphylla*.

The results from the questionnaire revealed similar claims as those in the workshops. Overall effects of *Periphylla* on fishing are larger, in the magnitude of more than 3 on average with a scale 0 representing no effects and a scale of 5 strongest effects. The impacts in the Beitstadfjord is stronger than in other parts of the fjord (Fig. 6) as expected because the Beitstadfjord is where the 'mother population' comes from. The effects, however, vary in terms of fishing area, fishing gear and time used, and working hours for cleaning nets. Of which, fishing areas and fishing time have stronger effects than fishing gears and working hours for cleaning nets. The fishers further indicated that their total income from cod fishing was reduced over the last decade, but *Periphylla* is not the primary cause although the catch of cod was reduced. The fishers reported that the main factor causing income loss is, however, the market price of cod and increasing fishing costs of fuel and materials, especially for the fishers who are commercial fishers and have not encountered jellyfish yet. The data from the statistics clearly showed that the price of cod has declined in the last several years. Nevertheless, it is believed that the increasing fishing cost is partially due to *Periphylla* because fishers need to go farther out their fishing zones and spend longer hours in sea, and require more hours to clean the clogged nets and repair torn nets. This in turn could partially explain the declining CPUE for cod and the increasing CPUE for *Periphylla* (illustrated in Figure 3).

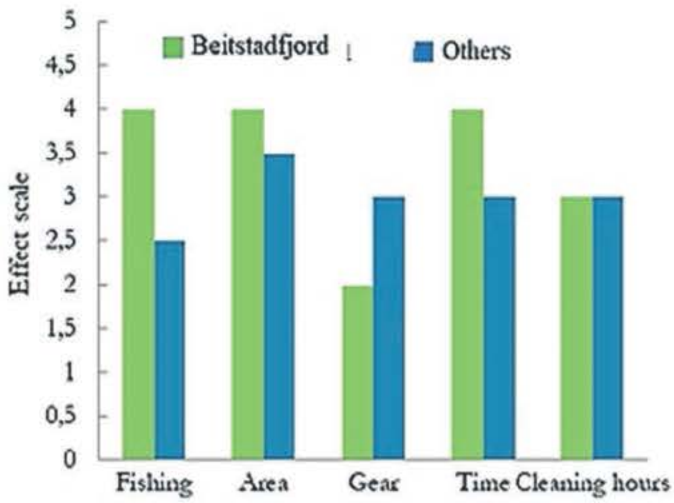

Figure 6. The effects of *Periphylla* on small-scale cod fishing.

To continue fishing in a jellyfish infested fjord, the fishers have to mitigate and/or adapt the situation while minimize the negative impacts. From the workshops and surveys, the fishers indicated some alternatives. For instance, if the infestation is very severe, the fishers may leave the jelly affected fishing areas to go somewhere else if they have access to them. If they have to stay at the affected fishing ground, they then may have to do something else to compensate the lost income, like farming instead fishing. Some of them further mentioned that they have thought to sell their fishing vessels and permits if *Periphylla* continues to be the problem and alternatives become less available. They stressed that if *Periphylla* can be explored and used for commercial values, they would be willing to harvest them. This is how fishers have gradually adapted to the situation if they cannot mitigate the jellyfish problem.

Discussion

Over the last decade, the ecological structure and abundance of species in the fjord have been altered due to a combination of factors including climate change, darkening waters, pollution and jellyfish infestation, increased fishing pressure and market demand. These combined factors have led to changes in fishing behavior and patterns. *Periphylla* has negative effects on fishing activities and fisheries, and has the potential to profoundly affect the marine ecosystem in term of taking over as a top predator and competitor, not only in Trondheimsfjord, but also in other Norwegian coastal areas (Tiller *et al*., 2016).

This paper demonstrates that the jellyfish proliferation in the Trondheimsfjord has become a growing concern to the small-scale fishers.
As species distributions change in response to climate change and other environmental shifts, small-scale fishers are more vulnerable, and may be less able to adapt because of limited mobility and fishing capacity. Traditional area-based access rights institutions will become strained by the loss or relocation of local marine resources. However, while some fishers will see the disappearance of their target fish species, others could see an opportunity in the landings of species of high commercial value. The fishers did, however, see some hope in the possibility in harvesting *Periphylla* for income generation, given that certain conditions were met.

The direct loss resulting from fishing these species is not detrimental to the fishers' livelihood at the moment. Overall fishers have maintained their income level because the income loss from cod fishing has been compensated by the income from other activities like increasing opportunities for emerging species, like crab and pollack or farming, as well as financial support from the government (thanks for the good welfare system in Norway). For instance, some fishers indicated that only half of their incomes came from fishing and the other half from other activities. Since fishing is their lifestyle, they prefer fishing as long as they can sustain their livelihood. However, the fishers in general perceived the future fishing in the Trondheimsfjord as not very promising due to the reduced income from fishing. They believe that policy and management can help improve their fishing situation, but they are against new fishing regulations that may potentially restrict their fishing activities such as fishing areas and seasons. These contradictory claims show that the fishers do not totally believe that policy and management can change the jellyfish situation, but they do need financial support for maintaining their fishing activities.

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Jellyfish bloom impacts on human welfare: what do we know is happening vs what do we think is happening.

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Abstract

Changes in marine foodwebs, raise various concerns, raise various concerns, for instance that an increase in the numbers of jellyfish may lead to a "jellification" of the oceans. While changing foodwebs can have significant impacts on the ecology of the oceans, they are also negatively impacting on fishermen and tourists in the affected areas. This work, focused primarily on the Mediterranean Sea, is considering the perceptions of the stakeholders who have been impacted by the increase in jellyfish blooms. These stakeholder studies can help verify whether an increase in the density and frequency of jellyfish blooms is occurring, and investigate the effects that these blooms can have on human welfare. The work suggested utilises an ecosystem services approach to examine whether jellyfish blooms affect human welfare benefits directly or indirectly through the impact on ecosystem services. Suggestions are provided to identify whether the appearance of alien species could be considered a challenge to reducing welfare impacts, or an opportunity to be explored for additional gain. In all cases, the integration of science and stakeholder knowledges and understandings reduces uncertainty in the approach to the issue.

Introduction

Jellyfish outbreaks may be regarded as a natural phenomenon (CIESM 2001; Boero *et al*., 2008; Condon *et al*., 2012), but there is now a growing awareness that jellyfish blooms, both alien and native, are on the increase, though there is great uncertainty on the scale of the issue and the extent of the jellification of coastal and marine waters (Lynam *et al*., 2006; Attrill *et al*., 2007; Richardson *et al*., 2009). Jellyfish blooms can have a large impact on the ecosystem, with devastating environmental and economic costs. Palmieri *et al*. (2015) report several worldwide examples of alien and native jellyfish blooms presence and their impacts on human welfare and related loss of benefits, including fisheries and aquaculture, human health, recreation, and coastal power plant operations (Purcell *et al*., 2007; Fenner and Williamson, 1996; Burnett, 2001; Mariottini and Pane, 2010). Conversely, there are also recognised benefits of jellyfish blooms such as use in human consumption, cosmetics, drugs, or education and recreation and aquaria (Palmieri *et al*., 2015), though quantifying these economic opportunities has been explored.

The CIESM Jellywatch Program, with over 50 stations around the Mediterranean Sea, systematically records the presence/absence of jellyfish blooms, allowing the collection of data on the frequency and extent of jellyfish outbreaks across the Mediterranean Sea. The geographical and temporal scale of the outbreaks as well as the ability to forecast short-term jellyfish blooms can be accessed from the data collected with the Program. The collection of these data, coupled with environmental data, over longer time periods will improve the predictions of jellyfish outbreaks.

Since jellyfish blooms may cause a shock to the ecosystems in which they appear (Blenkner *et al.*, 2015), an ecosystem services approach can help identify where they may occur and conceive alternative measures to address resulting issues. For example, the impact on fisheries can be multifold with jellyfish predating on fish eggs and juveniles, as happened in the Black Sea (Shiganova *et al.*, 2001), or interfering with fishing operations during fish capture (Purcell *et al.*, 2007). An ecosystem services approach can also help identify measures to tackle the pathways of non-native jellyfish to enter an area and provide guidance to limit their introduction, spreading and related impacts of non-native species.

Due to the level of uncertainty related to a potential increase of jellyfish blooms, Palmieri *et al.* (2015), for example, adopted a scenario analysis to estimate losses in fisheries provision within the Mediterranean Sea and to recreational opportunities along the North Sea coastline. Scenario analysis can be used to deal with non-linear effects and explore potential consequences on human welfare (Blenkner *et al.*, 2015), providing an initial assessment of the issues emerging and inform policy and decision makers in making choices related to measures to prevent or mitigate the jellyfish blooms.

What are the present costs, and what could be the future costs, of jellyfish blooms?
In this paper, we propose that an ecosystem services approach be used to identify the goods and benefits, or the related ecosystem services, impacted by jellyfish blooms. We illustrate this in relation to the tourism and the fisheries sectors (both wild and farmed) (see Figure 1). Here we are interested in investigating the impacts of both native and non-indigenous species (NIS) of jellyfish blooms, as their impacts on welfare, from an economic point of you, would be treated similarly. As reported by Ojaveer *et al.* (2014), non-indigenous species (NIS) do not include natural shifts in distribution ranges that could be due, for example, to climate change or dispersal by ocean currents.

Fig. 1 shows the impacts that jellyfish can have on marine and coastal ecosystem services and goods/benefits, but also on the built and human capital. Straight lines represent the direct impacts that jellyfish blooms can have on intermediate services (blue lines) such as on fish eggs and juveniles and on final services (blue lines) like fish and shellfish and/or seascapes (e.g. jellyfish blooms may make a beach unsafe or aesthetically unpleasant). Orange straight lines show the impact that jellyfish blooms can have (a) directly on built capital, such as when jellyfish are found in fishing nets and damage them, or when they clog the cooling system of power plants, and (b) on the human capital, such as when jellyfish sting bathers. The green straight lines indicate when blooms impact goods/benefits directly, e.g. when they enter aquaculture pens. These direct impacts may in turn have indirect effects on tourism and enjoyment of nature (dotted lines). This differentiation of impact is useful because it enables a more thorough examination of possible causes of ecosystem changes and the complex relationships that underpin these. For example, we might observe declining tourism numbers, but the causes could be different (e.g. smell on beach which is a direct impact on the seascape rather than stinging jellyfish in the sea as a direct impact on human capital – altering the health benefits), for which different management measures may be considered and applied.

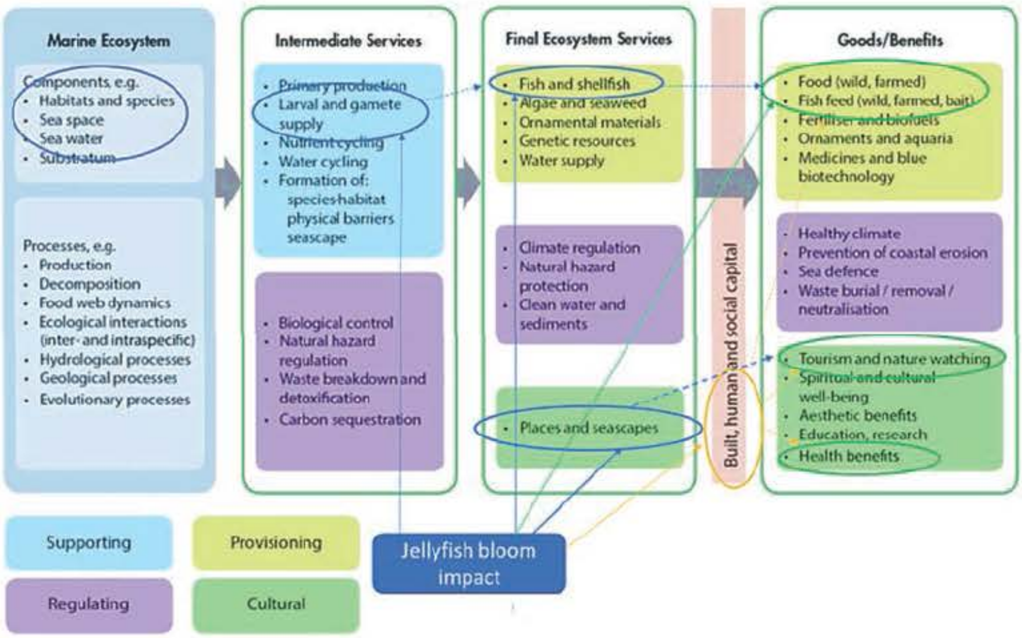

Figure 1. Jellyfish bloom impacts on ecosystem services and goods/benefits. Modified and adapted from figure 4.5 'classification of ecosystem services and goods and benefits for coastal and marine ecosystems' of the UKNA-FO 2014 (Turner *et al.,* 2014). Straight lines indicate direct impacts; dotted lines indicate indirect impacts. Blue circles indicate impacts on ecosystem services, either intermediate or final; orange circles indicate impacts on built or human capital (e.g. Infrastructures or humans respectively); green circles refer to impacts on goods/benefits. The diagram does not show the effects of triggering jellyfish blooms that anthropogenic activities may have.

It could be argued that jellyfish blooms may be regarded as an externality when the bloom is triggered by anthropogenic activities (i.e. overfishing); however, given the uncertainty on the drivers and specific causes of blooms, it is conceptually feasible to consider and treat blooms as internal sudden changes ('shocks') from within an ecosystem (Palmieri *et al*., 2015). Also, jellyfish blooms vary spatially and temporally. For example, due to non-linearities in ecosystem functioning and ecosystem services provision, a shock or a disturbance may create a non-linear response in the ecosystem. This may result in gradual incremental changes in the ecosystem, or in 'step' changes leading rapidly to a turning point in which a new steady state is reached (threshold effect) (Morse-Jones *et al*., 2011). Spatially, depending on the relationship between ecosystem service production area and benefit production area (Fisher *et al*., 2009), the impact of a disturbance can either have a direct or indirect effect on human welfare (see Blenkner *et al*., 2015), with possible knock-on effects and feedback loops. Monitoring programs such as the CIESM Jelly Watch can help understand disturbances and shocks and how these may be addressed in policy and practice.

Gourguet *et al*. (in this volume) provide a visualisation of the economic impacts of harmful algal blooms (HABs) on different economic activities. Although HABs and jellyfish blooms are very different in nature, an economic analysis of damages caused reveals some similarities. Similarly, in Figure 1 above, the last column represents goods and benefits linked to specific economic activities (e.g. as food is linked to fisheries, spiritual and cultural well-being and nature watching are linked to tourism).

The impacts on welfare, in other words the damage costs on welfare, can be estimated with different methodologies depending on the data available. For example, Palmieri *et al*. (2014) provide some worldwide figures of costs for fisheries operations disturbed by jellyfish blooms. Reported costs range between US$ 200,000 and 20 million depending on the country, the fishery industry, and the operations impacted. Palmieri *et al*. also provide some new estimates for the Adriatic Sea: they calculate that for the North Adriatic (NA) trawling fleet, economic losses due to reduction in fish catches could amount to as much as €8.2 million per year. A mixed approach was adopted to estimate the revenues lost due to jellyfish blooms related impacts, drawing upon data collected with a face-to-face semi-structured questionnaire survey and the price per kg of fish landed by the Italian NA vessels.

Bosch-Belmar *et al*. (2017) report two main impactful jellyfish blooms in the Mediterranean Basin: one in 2009 in Tunisia where economic losses led an aquaculture company almost to bankruptcy; the other one in 2011 affected a Spanish aquaculture company that lost approximately €50,000. The authors also report average costs for changing a generic cage at around €4,000, and at about €3,000 for a formalin bath treatment. Bosch-Belmar *et al*. highlight that due to the increase of both caged aquaculture and other marine activities development and jellyfish densities, the economic impact of jellyfish blooms for the aquaculture sector in the Mediterranean may worsen. According to Bosch-Belmar *et al*. (2017) to date, the jellyfish blooms impacts recorded in the aquaculture sector are much lower for Mediterranean farms than in Northern European countries.

In the UK, Palmieri *et al*. (2015) investigated the potential costs on tourism and nature watching of a hypothetical jellyfish bloom off the English coasts lasting two weeks; they assumed the putrid smells of stranded jellyfish mass would affect recreation/tourism. A spatial model was used to predict the number of visitors at the coast and the results were combined with a meta-analysis on the value of recreational trips to the coast. Depending on the month when the jellyfish bloom was considered to occur (sometimes between May and August in 2011) the economic value of the recreational benefits lost was estimated to range between €1.7 to 3.4 million.

Ghermandi *et al* (2015) revealed and stated preference techniques to estimate the impact of jellyfish blooms on recreation in the coasts of Tel Aviv (Israel). The travel cost method analysis provided estimates of the monetary losses associated with jellyfish booms in the range €1.8 to 6.2 million. The contingent valuation results suggest that there is an interest equal to €14.8 million for introducing daily information systems for visitors about the abundance and location of jellyfish a long the Israeli coastline.

Jellyfish blooms increase: different locations, different perceptions.

There is anecdotal and science-based evidence reporting that different stakeholders (e.g. tourists, fishermen) perceive jellyfish blooms to be on the increase. For example, Palmieri *et al*. (2014), who interviewed Italian fishermen on the issue of jellyfish blooms, found that about 70% of the interviewees felt that jellyfish blooms were on the increase, especially in the last 10-20 years. It is worth noting that 83% of the respondents had experienced jellyfish blooms during their fishing activity.

On recreation, for example, Ghermandi *et al*. (2015) found that the experience of a bloom affected attitudes towards bathing in the sea; individuals were more reluctant to go into the sea before having experienced a bloom than after that experience.

Bosch-Belmar *et al*.'s (2017) aquaculture study found that, even if most of the respondents showed concern about the increase, both in density and in frequency, of jellyfish blooms in the last decade, their perception about their impacts on aquaculture differs depending on the country, the facilities, and the fish species considered. For example, in Malta aquaculture focuses exclusively on cage bluefin tuna. These are strong swimmers. When kept in cages of bigger size than those of sea bass and sea bream grown in the other countries sampled, this results in a reduced likelihood of jellyfish clogging the cages.

Two important, and related, ways in which stakeholder understandings of jellyfish can be considered are: the local ecological knowledge (LEK), which is often distinguishable from fishers' ecological knowledge (FEK). LEK refers to the knowledge gained by individuals over their lifetime living in close contact with nature (see Azzurro in this volume). LEK is characterised by traditional ecological knowledge that is based on information and understandings passed down through generations to preserve a historical memory of knowledge and beliefs. LEK can be elicited and understood with different methods from individual semi-structured interviews to focus-group discussions. Similar methodologies have been employed by Pita *et al.* (this volume) integrating FEK with scientific knowledge, showing how this practice can help managers and policy makers; for example, when participatory processes are used to co-design and co-manage marine protected areas and self-regulation of the fishing sector. FEK, as interpreted by Pita *et al.*, is closer to traditional ecological knowledge (TEK) rather than to LEK because it considers the history of the transmitted fishing practices and the history of the understanding of the environment in which fishermen operate, so that know-how and environment are strictly linked. The reported development of the Marine Protected Area (MPA) 'Os Minarzos' in Spain is an example of a bottom-up approach promoted by fishers based on the belief that the MPA is the solution for the continuation of the local fishery sector. Post-observation of the MPA development after ten years has shown the effectiveness of fishers and scientists collaborative work, which had improved both institutional trust and biological biodiversity, and it is now taken as an example by other fishing communities in the region. Pita *et al.* also report the use of FEK for the creation of maps to identify the distribution of the fishing grounds of the common octopus in Galicia (Spain), which were validated with the recording of fisheries monitoring in the area with low-cost GPS data-loggers providing the position of the vessels. FEK could therefore also be useful to map trends of jellyfish blooms, which could be validated, for example, with the data collected within programs such as the CIESM Jellywatch.

The studies summarised here are based in Mediterranean locations where respondents are more familiar with the issue of jellyfish blooms. Palmieri *et al.* (2015) sampled in the Northern Adriatic, Germandi *et al.*'s (2015) work is based in Israel, Bosch-Belmar *et al.* (2017) in several locations (i.e. Italy, Spain, Tunisia, and Malta), and Pita *et al.* (in this volume) refer to examples from Galicia (Spain). However, it is important to consider the generalisability of these findings: it could be argued that similar studies in other European seas where jellyfish blooms may also increase in the future, and where respondents are as not familiar with the issue as the respondents in the South of Europe, may propose different findings (see for example Yajie Liu in this volume). Furthermore, stakeholders' perceptions of the impact of jellyfish blooms will affect the type of impact (i.e. if the impact is direct or indirect). The ecosystem services approach, in fact, is based on an anthropocentric view. Therefore, if stakeholders do not indicate that jellyfish have a direct impact on their welfare, adopting the ES approach assumes there will be an indirect effect only, if any.

Jellyfish blooms impact mitigation options and opportunities

Although, as reported by Ojaveer *et al.* (2014), natural shifts in distribution ranges do not qualify a species as a non-indigenous species (NIS), outbreaks of some species, of jellyfish for example, can still have an important impact on human welfare. Ojaveer *et al.* (2014) set guidelines for the assessment and management of NIS in marine ecosystems. However, it might be argued that some of Ojaveer *et al.*'s ten recommendations, which include NIS identification, standardisation of sampling and data, and indicators, may also be applicable to all species that might have an adverse impact on ecosystems, and the related ecosystem services, where they may suddenly appear. Biosecurity practices could also help limit the introduction and spread of species (Anderson *et al.*, 2014). Furthermore, understanding and monitoring of pathways (e.g. human activities that will determine introductions such as shipping, recreational boating, and live animal aquaculture) that may lead to adverse impacts are important components of any strategy aiming to mitigate, for example, jellyfish outbreaks effects (Tidbury *et al*., 2016).

The sudden appearance of alien species might also bring about opportunities, which Katsanevakis and Rilov (in this volume) argue could include: new commodities; new food sources for fish; biological control; and new habitats. However, Graham *et al* (2014) undertook a modelling analysis, under a scenario of increasing jellyfish abundance, in which a faster increase of impacts than ecosystem services is assumed, and argue, despite the limitations of the model, that the value of the benefits jellyfish may provide are likely to increase at a lower rate than the costs of the impacts the jellyfish abundance will generate.

Mitigation of invasive or alien species (e.g. removal of jellyfish blooms) may not always be possible and a range of adaptation options, which could also be considered as opportunities, should be taken into account. As mentioned in a previous section, the perception of stakeholders is also important to understand whether a bloom should be considered an opportunity or not. Further, it could be argued that an impact could also be transformed into an opportunity. For example, let us imagine a future in which an alien invasive species, say Species A, has entered a geographical area where it was unknown before (e.g. Area 1), where it has to be eradicated due to the damage it causes. Imagine also that at the same time there is another geographical area (e.g. Area 2) where Species A is considered a native species, but is declining. The two areas in relation to each other could be interpreted as a demand/supply problem. A potential solution would be for international agreements within a global framework, as well as direct agreements in between countries, to be developed to use the supply from Area 1 to meet the demand of Species A in Area 2, providing this does not cause any other effects or feedbacks to other geographical areas.

Conclusion

This short review of jellyfish impacts has shown that integrating scientific and local knowledge can provide significant insights on the issue of the potential increase of jellyfish blooms. Stakeholder perceptions are also important to consider whether a jellyfish bloom may be viewed either as an impact or as an opportunity. It is important to know what the costs of the current jellyfish blooms to society have been to date in order to explore mitigation measures. Therefore, there is a need to investigate which factors trigger jellyfish blooms and the pathways to limit future damages to coastal and marine ecosystems and the ecosystem services they provide, including potential threshold changes. We explored the opportunities that jellyfish may provide in the future. The pursuit of new opportunities in this area requires a good understanding of the natural sciences involved with the different options available, examined through an ecosystems services approach, to reduce the possibility of catastrophic damages. Finally, we also emphasized that to deal with uncertainties, non-linear effects, and explore potential consequences on human welfare; scenario analysis can play an important role for decision-making.

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