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Large marine protected areas (LMPAs) in the Mediterranean Sea: The opportunity of the Adriatic Sea

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ABSTRACT

The aim of this paper is to highlight current opportunities and expected benefits of establishing a transboundary large marine protected area (LMPA)-specifically a no-trawl area – in one of the most exploited sectors of the Mediterranean, the Adriatic Sea. A no-trawl area is examined as a strategy to foster recovery of the local marine ecosystems and economies, and to meet international conservation targets and EU legal mandates. Based on a review of published studies documenting the positive outcomes of previous trawling bans in other regions, and of current initiatives and opportunities within the Mediterranean region, it is concluded that large-scale protection of the Adriatic with a no-trawl zone is a promising and feasible approach for reversing ecological and socioeconomic losses in this basin. In particular, ecosystem protection can be established in the Mediterranean through a proposal for a Fisheries Restricted Area (FRA) to the general Fisheries Commission for the Mediterranean (GFCM). The successful establishment and function of a FRA or LMPA will depend on its support by the governments of the surrounding countries, as well as involvement and participation of key user groups.

1. Introduction

In recent years numerous international conventions have recognised the need to increase protection of marine resources and to reform ocean management to balance the multitude of human marine uses. Significant efforts are taking place worldwide to reach the objective of protecting 10% of coastal and marine areas by 2020 (Aichi targets Convention for Biological Diversity (CBD) (https://www.cbd.int/2011-2020/goals/)). Very recently, some initiatives have been planned to expand ocean protection to deep and offshore areas (including Areas Beyond National Jurisdiction (ABNJ) or high seas; see Glossary) [1–3].

Progress towards the 10% target has accelerated in recent years through the establishment of several Large Marine Protected Areas (LMPAs, 1000s – 10,000 s Km^2 in surface area) and very LMPAs (VLMPAs, > 100,000 Km^2) ([4]; see Glossary, Fig. 1 and Table S1 in Suppl. materials). LMPAs and VLMPAs provide unique benefits, but also potential drawbacks and challenges, including the difficulty of limiting uses and of enforcing regulations over large areas of the ocean, particularly in intensely-used marine regions (Table 1).

The Mediterranean Sea is a prime example of the difficulty of establishing comprehensive, coordinated marine conservation and management. The Mediterranean has been exploited for centuries and currently is one of the most intensely-used and most impacted seas in the world [5,6]. Marine resource overexploitation poses major threats to biodiversity, resulting in the decline and loss of marine populations and habitats [7,8]. In turn, the consequences of biodiversity loss include decline in ecosystem function and flow of ecosystem services [9], a scenario that is complicated by climate change [10,11].

Mediterranean marine ecosystems are composed by diverse and ecologically valuable habitats such as seamounts, canyons, hydrothermal vents, cold seeps, mud volcanoes and unique and sensitive habitats (e.g. meadows of the endemic seagrass *Posidonia oceanica* and biogenic reefs) [12]. These habitats make the Mediterranean Sea one of world seas with the highest biodiversity [13,14]. Although the basin covers only 0.82% of the global ocean's surface, it hosts more than 17000 described marine species, contributing to an estimated 4–18% of the world's marine biodiversity [15,16]. These values are likely much higher if the hidden deep-sea biodiversity is included [13]. More than 20% of known Mediterranean marine species are endemic [17], and therefore at risk of global extinction from local extirpation.

As of 2012, 161 marine protected areas (MPAs) have been

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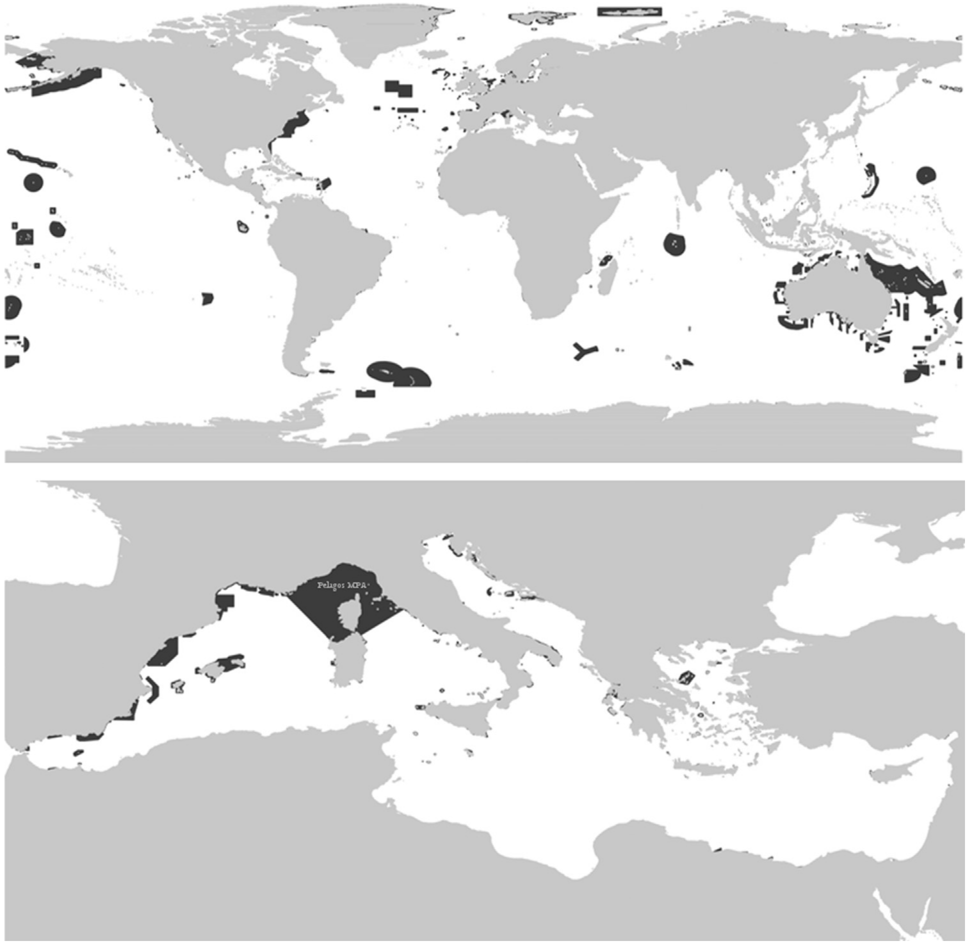

Fig. 1. Existing MPAs and LMPAs. Top: the world LMPAs (black polygons) generated by UNEP World Conservation Monitoring Centre (UNEP WCMC) using data from the World Database on Protected Areas (WDPA). Bottom: Mediterranean MPAs (black polygons), including Pelagos, in the northern Tyrrhenian Sea.

established in the Mediterranean, covering 4.6% of its surface [18] (Fig. 1). Most MPAs are small (66% of Mediterranean MPAs are smaller than 50 Km^2; [18,19]) and concentrated along its northern and western coasts. The only Mediterranean LMPA is the Pelagos Sanctuary for Marine Mammals, which encompasses 87,500 Km^2 [6,20] (Fig. 1) and accounts for 76% of the Mediterranean total protected area (3.5% of the total Mediterranean MPAs surface; [5]). If Pelagos is excluded, only 1% of the Mediterranean Sea surface is in MPAs, and less than 0.1% is in fully protected areas that exclude all extractive uses [1,17]. Thus, it is necessary to increase conservation efforts throughout the Mediterranean basin to reach the CBD protection target of 10% in MPAs by 2020 and achieve more effective protection of marine biodiversity and management of multiple marine uses. This goal could be achieved through the establishment of LMPAs.

Among the Mediterranean ecoregions, the Adriatic Sea represents a top priority and opportunity for expanding spatial protection through MPAs [6]. This region has undergone major fisheries overexploitation, causing the widespread degradation of marine habitats, decline of target and non-target species, food-web alterations [7,21–24], and major losses of ecosystem services [25]. The yields of several important commercial fisheries have sharply declined in the last 6–7 decades [26–28]. The basin-scale management of the Adriatic Sea and its resources is challenging because of the presence of a large array of multiple interacting pressures, in addition to fishing [56]. Moreover, marine resource management and ecosystem restoration are also complicated by the exceptional proximity of the various countries bordering the Adriatic Sea, each with their own economic interests and cultural and legal approaches to marine management.

Recognition of these peculiar environmental and geo-political constraints has motivated the development of the European Strategy for the Adriatic Ionian Macroregion (EUSAIR) (http://www.ai-macroregion.eu/), whose objective is to increase co-operation among the countries bordering the Adriatic Sea. The initiative is built upon four main pillars (Table 2), including the quality of marine environment, in line with the ecosystem approach of the CBD. The Adriatic Ionian Macroregion initiative could represent a political opportunity for the establishment of a transboundary LMPA, in particular a no-trawl area aimed at recovering biodiversity and reversing fisheries decline in the Adriatic Sea. An Adriatic LMPA could promote biological and socio-economic benefits and effectively address the political and management challenges of large-scale protection of the basin, as reported from other areas of the world's oceans (Table 1).

This work presents the rationale for, as well as the risks and uncertainties of, establishing a transboundary LMPA in the Adriatic Sea as an option to meet international conservation targets and promote recovery of depleted fish stocks and habitats. First, the ecological basis for such an initiative, by assessing key ecosystem services (with a focus on fisheries) that are expected to benefit from the establishment of an Adriatic LMPA it is analysed. Then, the political opportunities and the national and international legal frameworks that may enable the establishment of a LMPA in the Adriatic Sea it is examined. Finally, a possible process by which the LMPA may be implement and identify the remaining challenges,

Table 1
Benefits and limitations of large and very large MPAs (LMPAs and VLMPAs).

Benefits
LMPAs may comprise the entire home range of threatened species or overexploited commercial stocks, thereby effectively protecting or recovering these populations [29,30]
By protecting larger portions of the ocean than MPAs, LMPAs ensure connectivity through the dispersal of larvae and early life stages of marine species [31]
LMPAs are effective in protection of migratory species, in addition to sedentary organisms [31–33]
LMPAs have potential economic benefits including enhancement of local fisheries [34], increased sustainable tourism [34,35], and maintenance of ecosystem services [25,34]; LMPAs are expected to provide these benefits and are less expensive per unit area than smaller MPAs [36,37]
LMPAs constitute a mechanism for preventing future overexploitation and degradation of currently remote and near-pristine ecosystems (e.g., Global Ocean Legacy, http://www.pewtrusts.org/en/projects/global-ocean-legacy)
LMPAs allow for expansion of globally protected areas, thereby achieving the conservation targets of international agreements (e.g., CBD) [38–40]
Transboundary LMPAs provide opportunities for international cooperation among States [2,38,41]
Limitations and uncertainties
It is difficult to ensure adequate surveillance and enforcement, and therefore effective protection of LMPAs [31]. New control technologies are needed before LMPAs can become an effective conservation and management tool [41–43]
Reaching agreements between multiple states adds a further layer of complexity in the establishment of LMPAs, if they are transboundary [45]
Empirical evidence that LMPAs effectively protect exploited populations within their boundaries is still limited [46,47]
Creation of LMPAs redirects fishing effort in other areas that are perhaps less effectively managed than where closure is planned [47]
Because of the large extent of protection, larvae and early life stages will benefit only the area under protection without any benefit for adjacent areas because larval and juvenile export across the MPA boundary is limited [46]
LMPAs are typically established in remote areas and may take resources and political support away from areas where protection is most urgently needed (e.g., densely populated coastal areas) and may provide economic benefits [48,49]
LMPAs can be established only in remote and unpopulated areas where marine ecosystems are in the least need of protection [44]

information gaps and uncertainties of this proposed process it is delineated.

2. The Adriatic Sea: needs and opportunities for large-scale protection

2.1. Marine biodiversity and economies under threat

The Adriatic Sea (Fig. 2) covers 5% (138,600 Km^2) of the total area of the Mediterranean and 1% (35,000 km^3) of its total volume. It is one of the most productive areas of the Mediterranean Sea, supporting a wide diversity of habitats, including rocky and extensive soft bottoms, large estuaries and lagoons, seagrass meadows, and deep water environments [50–52]. This richness of habitats is mirrored by a high level of biodiversity, with high species richness of marine invertebrates, seabirds, marine mammals [5,7], and 18% of the endemic fish species of the Mediterranean [16,24,53].

The peculiar geomorphology of Adriatic seafloor in its northern and central area has historically created favourable conditions for intense exploitation, providing easy access to fishing ground. The Adriatic Sea has been exploited for centuries by a variety of fishing activities, ranging from small-scale artisanal fisheries and recreational fishing, to industrial fisheries using hydraulic and trawled dredges for clams and scallops, otter and mid-water trawling for exploiting ground and small pelagic fishes, and pelagic long-lines for tunas [7,26,54–56]. In 2013, there were 3590 trawlers (dredges, demersal and beam trawlers) fishing in the Adriatic. Of these, 3,105 were Italian, while 485 (mainly smaller than 12 m) where from Slovenia and Croatia (http://stecf.jrc.ec.europa.eu/data-reports). Adriatic fisheries account for 51% of the total capture fish production (landings) in Italy, and 40% of its total value [57]. The main exploited stocks by the Italian fleet are small pelagics such as anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) respectively contributing to 22% and 10% of Italian total landings. European hake (*Merluccius merluccius*) and red mullet (*Mullus barbatus*) are the most important demersal species fished, and together with Norway lobster (*Nephrops norvegicus*), are the next most landed species (together they represent around 4-5% of total landings) [58].

The Adriatic marine ecosystems and the services they provide are affected by a suite of natural and anthropogenic threats [5,59], which have resulted in historical species declines, food web changes, extensive ecosystem degradation, and, more recently, severe regime shifts [7,21,23,25,60–62]. Among all human activities and pressures, fisheries exploitation, in particularly bottom trawling and dredging, has been identified as the major threat [8,59,63]. Impacts of fishing are compounded and exacerbated by other stressors and pressures. Eutrophication, for example, is an important stressor in the north and western Adriatic sectors, which are influenced by high nutrient discharge from the Po River (the Po River, 673 km long, is the 3rd largest Italian freshwater riverine input throughout the Mediterranean Sea and supplies over the 28% into the entire Adriatic Sea and 50% into its northern part [64]). Nutrient input combined with alteration in water circulation have caused hypoxia and anoxia events, resulting in episodic mortalities of the Adriatic benthos [62,65,66]. Maritime traffic is also very intense inside the Adriatic basin, causing a significant risk of accidents and spills of oil and other contaminants [67,68]. From 1990 to 2013, the commercial marine traffic of the north Adriatic ports (Koper, Trieste, Venice, Ravenna and Rijeka), increased with an average of 7% per year [69] with a total throughput cargo of 106 million of tonnes in 2014

Table 2
Pillars and topics of the European Strategy for the Adriatic Ionian Macroregion (EUSAIR) initiative (http://www.adriatic-ionian.eu/about/pillars).

	TOPICS
PILLAR 1: BLUE GROWTH	1) Promote research and development of blue technologies 2) Promote sustainable seafood production and consumption (fishery and aquaculture) 3) Improve maritime and marine governance and services
PILLAR 2: CONNECTING THE REGION	1) Strengthen maritime safety and security (maritime transport) 2) Intermodal connections to the hinterland 3) Energy networks
PILLAR 3: ENVIRONMENTAL QUALITY	1) Reach Good Environmental Status (GES) by 2020, halt the loss of biodiversity and degradation of the ecosystem services and restore them (marine environment) 2) Transnational terrestrial habitats and biodiversity
PILLAR 4: SUSTAINABLE TOURISM	1) Diversified tourism offer (products and services) 2) Sustainable and responsible tourism management (innovation and quality)

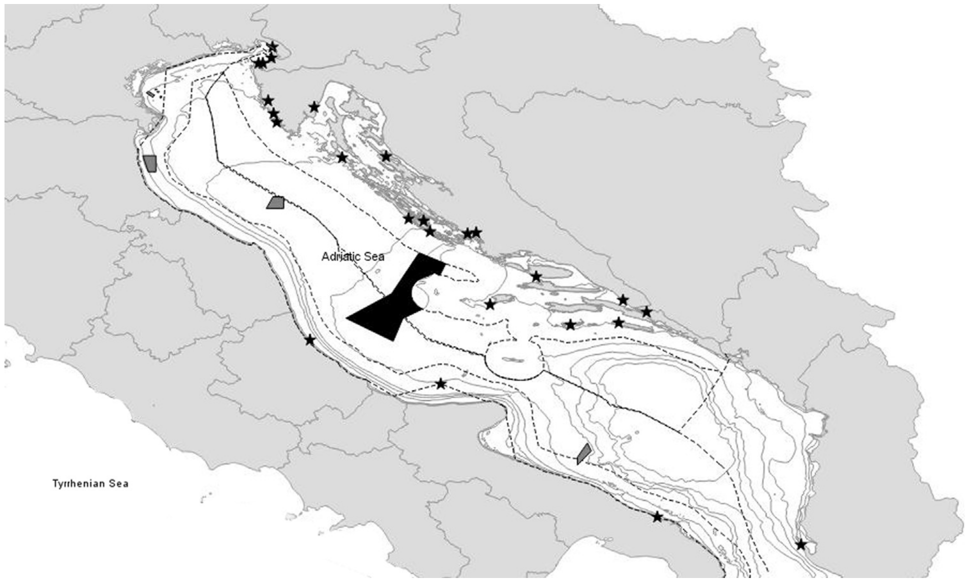

Fig. 2. Current protection of the marine environment in the Adriatic Sea (February 2016). The picture shows the current distribution of Adriatic MPAs (black stars), of the temporal closure areas (grey polygons) and the temporary no-trawl areas of Jabuka-Pomo Pit (the big black polygon). The dashed lines show the territorial sea boundaries of Italy and Croatia and the limit of the continental shelf.

(http://www.portsofnapa.com/about-napa). Collective tonnage passing through the Adriatic ports is expected to increase by 227% by 2030 [70]. In ten years, since 2002, Mediterranean cruise tourism increased by 162%, and Venice and Dubrovnik in the Adriatic Sea were prime destination. The mass tourism related with large ship cruises (more than 4000 passengers and crew), may determine heavy environmental impacts, in particular in a region where effective environmental monitoring and management system for pollution are poor [71]. As a consequence, considering the expected increase in maritime traffics, container traffic, new touristic routes in the Adriatic Sea, an effective integrated coastal zone management (ICZM) is urgent [72]. In this regard, Croatia is currently the unique Adriatic country with an existing legislation for coastal protection, while the ICZM implementation by Slovenia and Italy is in progress [72]. Finally, climate change is also expected to significantly affect these ecosystems [7,73]. The Adriatic Sea counts more than 190 non-indigenous species [74]. In the Italian northern Adriatic 51 invasive species (39 of which in the Lagoon of Venice) have been recorded since 1945 [75], while 61 alien species (due to aquaculture activities and shipping) and 52 introduced (due to climate change) were recorded in Croatian waters [76]. Some invasive species, such as the green grape algae *Caulerpa cylindracea* and the red algae *Womersleyella setacea*, are known as habitat modifiers, reducing diversity and changing community structure in invaded areas compared to non-invaded sites [77]. The introduction of non-indigenous and invasive species carried by human vectors (mainly maritime traffic and aquaculture), together with the natural shifts of marine habitats caused by global environmental changes contribute to the modification of marine ecosystems.

2.2. Existing MPAs and other forms of spatial marine management

Currently, there are 25 coastal MPAs (including all coastal protected areas with a marine component, Table S2 in Suppl. materials) in the Adriatic Sea, altogether covering less than 1% of its surface. Four additional MPAs are planned: two in Albania (Kepi i Rodonit and Porto Palermo) [67], and two in central Italy (Costa del Monte Conero and Costa del Piceno) [72].

The current siting of Adriatic MPAs is not homogeneously distributed: 21 of the 25 existing MPAs are along the eastern coast of the basin, 17 of these in Croatia (though only six of these are managed MPAs [72]) (Fig. 2). Adriatic MPAs are also widely heterogeneous in their regime of legal protection. There are national parks (Briuni, Croatia), nature reserves (Miramare, Italy) and natural monuments (Debeli Rtic, Slovenia) (see the Glossary for their definitions).

Outside of the 12 nautical miles limit of national territorial waters, there is no permanent spatial protection and management of human activities. Current, management of Adriatic trawl fisheries calls for temporal closures (i.e. closing sectors to fishing for a few months, seasons or years; Tremiti Island, Tenue areas, Miramare, area off Ravenna, the area around the Barbara gas platform, a no-trawl area off Apulia region, and the Jabuka-Pomo Pit [79] are examples of existing temporal closures within the Adriatic, see below). Seasonal closures (e.g. for 30-45 days, as commonly done in Italy) are likely too short to recover demersal and benthic species with long-term life cycles [78]. The Croatian fleet operating on offshore areas is mainly composed by large pelagic purse-seines, particular involved in Bluefin tuna fishery [79]. In Croatia, temporal closures of purse-seine fisheries go from December 1st (with interruption between December 14th and 24th) to January 31st throughout the national territorial waters. With the ordinance on spatial and temporal closures regarding purse-seine fisheries in 2015, the temporal restriction covers also the month of May for the objective to protect anchovy during its spawning period [80].

Fouzai et al. [24] modelled the efficacy of different fisheries' management strategies applied in the Adriatic from 1975 to 2020, including the limitation of the number of fishing licenses, the introduction of closed fishing seasons, the establishment of spatial and temporal closures for all or a subset of fishing gears (e.g. seasonal closure of mid-water and bottom trawl fisheries; see the Glossary for the definitions of these fisheries). Their results demonstrate that past fisheries management has not been effective in ensuring a sustainable use of marine resources, and that the current management regime is not expected to promote recovery of depleted fish stocks unless is augmented with new options, including the establishment of MPAs and an overall reduction of fishing effort [24].

Areas outside territorial waters include important and sensitive fishery areas [81,82]. The Jabuka-Pomo Pit (240 m of maximum depth), for example, is considered a nursery area for some of the most economically important fished Adriatic species, such as the European hake, *Merluccius merluccius*, and the Norway lobster *Nephrops norvegicus* [83–85], and consequently this area is regularly and intensively trawled [86]. Due to the importance of this area, there is an ongoing debate on the need to establish here a permanent no-trawl area [82,87]. In July 26th 2015, a temporary no-trawl area covering approx. 2700 Km^2 was established in the international waters of the Jabuka-Pomo Pit to promote the recovery of *M. merluccius* and *N. norvegicus* [88] (Fig. 2). The closure is planned for only one year and it includes a fraction of the nursery and spawning areas identified for these and other commercially important species [85].

3. Ecological, economic and political benefits of no-trawl areas

3.1. Benefits for target stocks, non-target species, and fisheries

Empirical assessments of the effects of large no-trawl zones from other marine regions, particularly the few established in intensely exploited regions, are valuable references for anticipating the benefits of establishing no-trawl zone in the Adriatic (Table 3). Several studies report evidence that limiting or banning bottom trawling from large areas can provide some of the positive economic and biological effects expected for LMPAs (Table 1), as well as additional benefits specific to benthic and demersal communities. In particular, no-trawl zones are expected to promote recovery of depleted target populations and benefit adjacent fishing grounds and fisheries through larval, juvenile and adult spillover. In addition, no-trawl zones are expected to increase diversity of benthic and demersal assemblages, and increase complexity of benthic habitats, thereby restoring processes and interactions lost in intensely fished marine ecosystems [89–91]. A trawl-ban will also reduce by-catch of marine megafauna. Research has linked trawl fishing with sea turtle strandings [92,93]. It is estimated that more than 132,000 turtles are incidentally caught annually by Mediterranean fisheries and more than 4000 are taken in the north Adriatic [94,95]. Similar figures have been recorded for cetaceans [53].

In the Gulf of Castellammare, a previously intensely-bottom trawled area off Sicily [96], a significant increase in catch of eleven target species (9 finfish and 2 cephalopods) was reported after only a 4-years trawl ban covering approximately 200 Km^2 (corresponding to about 50% of the total surface area of the gulf). Artisanal and recreational fishing are allowed inside the gulf, while all towed bottom and pelagic fishing gears are forbidden. The trawl ban promoted recovery of benthic habitats and increased habitat complexity. Areas with no bottom trawling show structured three-dimensional benthic communities [97] with higher diversity and density of invertebrates (e.g. sponges and seapens) than heavily trawled grounds [98,99]. The recovery of large epifauna, such as sponges, hydroids, bryozoan and tube-dwelling polychaetes in undisturbed areas results in complex biogenic habitats that provide refuges and food to benthic and neritic species, including larval and juvenile stages that are key to the recovery of over-exploited species [100]. Similar positive effects on benthic diversity and habitat complexity were observed at lightly or no-bottom trawled areas of eastern Florida, USA (Table 3). Demersal and pelagic species are linked to benthic assemblages, exploiting them both as food source, as refuge and/or reproduction/nursery areas [101], highlighting the importance of an ecosystem approach to the management of fisheries, including the protection of habitats and food-web interactions.

The fishing closures on Georges Bank, USA, are other clear examples of the beneficial effects of large no-trawl areas. The Georges Bank is a shallow, mainly sandy submarine plateau with high level of primary productivity that has been one of the most important fishing grounds of the North West Atlantic. The increase of fishing effort since 1960 caused the decline of over 50% of total fish biomass [102]. After the collapse of cod stocks in the 1990 s, five large areas, together covering 22,000 Km^2, were closed year-round to all gears targeting groundfish, including bottom trawlers and scallop dredges [103]. Monitoring of these no-trawl areas highlighted the importance of long-term spatial closures for meeting the multiple management objectives of recovering depleted fisheries, protecting benthic habitats, and restoring ecosystem structure and function. Protection of spawning stocks and juvenile haddock and cod has contributed to increase the abundance of these populations [32,102]. Scientific trawl surveys demonstrated that in four years since the closure (between 1994 and 1998), scallop total biomass and harvestable biomass increased by a factor of 14 and 15 respectively in the closed areas, and catches outside the closure boundaries increased through larval spillover from the no-trawl zones [32].

In addition to examples of recovery of individual size and abundance of fished stocks within the no/lightly trawled areas, and increased catches in adjacent fishing grounds, trawl bans can results in economic benefits through increased value of the catch (Table 3). In the Gulf of Castellamare no-trawl area, fishes reached larger sizes compared to adjacent fished areas, resulting in greater commercial value and increased reproductive output [104,105]. Increased catch of high value species, such as scallop, shrimp and crab has resulted in an increase of income for the Georges Banks fisheries [32,106]. Benefits can extend to other sectors and users groups. The absence of competition from trawling inside the Gulf of Castellammare, for example, ensured a sustainable artisanal fishery, which benefited from the increase of fish stocks promoted by the trawl ban [107].

Spatial gradients in fishing pressure across the Adriatic basin provide an opportunity to examine the past and current impacts of trawling and make predictions about the possible future effects of its spatial management in areas that are currently intensely fished [23]. Along the western (Italian) Adriatic coasts, fishing effort has historically been greater whereas along the eastern (Croatian) side, fisheries have developed more slowly and in a less industrialized fashion. As an effect of this historical fishing pressure, in the last 60 years catch rates and landings of elasmobranchs have declined by $>94\%$ and 80-89% respectively in the central and northern Adriatic Sea [23,108]. However, these declines were not homogeneous throughout the basin. Comparing catch rates between the two sides of the basin, Ferretti et al. (2013) found that a greater species richness and abundance of sharks and rays persisted on the eastern side of the Adriatic, reflecting the less intense fishing pressure on the Croatian side both historically and recently. Thus, the Croatian jurisdictional waters acted as a refuge from intense fishing pressure. Data also indicate that mobile species like spurdogs, eagle rays and smooth-hounds that maintained higher abundances on the eastern side may have replenished the more intensely exploited western side and supported catches within this region [23].

3.2. Expected benefits for ecosystem functions and services

Recovery of marine ecosystems from trawling impacts may provide additional benefits, beyond fisheries. The importance of soft bottom habitats, the most widespread bottom type in the Adriatic, is increasingly recognised [114]. Soft bottom benthos play important ecosystem functions such as controlling eutrophication and algal blooms by filtering large water volumes and stabilizing sediments [115–118]. Soft-bottom macrofauna can have profound influences on organic matter deposited on marine sediments [119]. Large-bodied species, such as sea urchins, influence sediment

Table 3
Examples of documented biological and economic effects of no-trawl zones.

Location	Size of closure	Year of establishment	Type of management	Documented effects on fisheries	Effects on habitat/community	Economic effects	Reference
Georges Bank and in Southern New England	22,000 Km^2	1994	Trawl ban in the 3 areas and complementary fishery regulation in the waters outside the closed areas (reduced effort, trip limits and increased mesh size)	– After about 4 years of closure, increase of spawning- stock biomass of cod, haddock, yellowtail flounder and other components of groundfish community – Increase of total biomass of scallops – Reduction in fishing mortality of the stocks	– Higher abundance of organisms, biomass and species diversity – More complex habitat in undisturbed areas, formed by higher presence of fragile epifauna organisms (tube-dwelling polychaetes, bryozoans, hydroids)		[32,101]
Gulf of Castellammare (NW Sicily, coastal)	200 Km^2	1990	Trawl ban	-Increase in biomass of eleven target demersal species (9 finfish and 2 cephalopods) – Increase in total catches	Not reported	Improved financial returns for the artisanal fishermen	[96,109]
Malacca Straits and the north coast of Java	Not reported	1980	Trawl ban	– Increase of demersal stocks	Not reported	Increase in the employment of the small-scale fishery	[110]
Eastern Florida (Deep-water *Oculina* coral reefs)	315 Km^2 passed to 1029 km^2	First ban in 1984; expansion in 2000	Ban of trawling, dredging, bottom longlines and anchoring	– Fish populations have yet to recover from overfishing in the 1980s and 1990s	Healthier coral communities in no-trawl areas compared to areas where fishing is still present		[111]
Isle of Man	≈ 2 Km^2	1989	Trawl ban	– The density of scallops above the minimum legal landing size (110 mm SL) was more than 7 times higher in the closed area than in the fished area by 2003 – Shift towards much older and larger scallops in the closed area and, lower estimates of total mortality			[112]
Great Barrier Reef Marine Park (GBRMP), Australia	$\approx 33\%$ of the area of the Marine Park (that covers a total area of about 344,400 Km^2)	2004	Trawling prohibited, large mesh gill netting allowed	– Increase mean size and abundance of fish (e.g. coral trout and stripey seaperch (*Lutjanus carponotatus*)) and reef sharks – Provide ecosystem-wide larval supply – $>20\%$ predicted increase of biomass of seabed species	– Decrease in the frequency of starfish outbreaks, with positive effects on coral populations – Increased abundance of corals	Economic value of a healthy GBR to Australia is estimated to be about A$5.5 billion annually; 53,800 full time jobs	[113]

biogeochemistry through their burrowing activity [116]. Bioturbation, the disturbance of sedimentary deposits by living organisms, has a major influence on column fluxes of nutrients and oxygen between sediments and the water column by increasing nutrient remineralization [114,116].

Benthic filter feeders improve water quality through water filtration. They are involved in benthic-pelagic coupling, the cycling of nutrients between sediments and the overlaying water column [120], nutrient regeneration [117], and facilitation of surrounding communities by providing refuges from predation [121]. Bivalve filtration, in particular, can have a fundamental role in controlling phytoplankton communities and water quality. The filtering activity of bivalves and other filter feeders can control phytoplankton abundance, reducing algal blooms and consequent anoxic or hypoxic events [122]. For example, it was calculated that in oyster beds of Chesapeake Bay, USA, around 188,000 t (dry tissue) of the oyster *Crassostrea virginica* would filter the whole water volume of the bay (around 70×10^9 m^3) in less than 1 week. The depletion of these oyster populations and reefs that have occurred from the beginning of 19th century has caused an estimated 50-fold decrease in filtering activity [115,122]. These results raise the question of whether the once abundant population of filters feeders in the Adriatic may have similarly contributed to maintain its water quality.

The recent dramatic reduction in the Adriatic Sea of filter feeding organisms, such as clams [28], oysters [123], and sponges [124] due to intense fishing, habitat loss from bottom trawling, dredging, hypoxia, and climate change may have produced a functional loss similar to that documented in Chesapeake Bay. The disappearance or decrease of ecologically important filter feeders may in turn have led to dramatic ecosystem shifts [125], e.g. favouring the outbreaks of gelatinous plankton that impacts the communities in the water column by removing zooplankton and fish larvae [125]. The overexploitation of the north Adriatic *Ostrea edulis* reefs, whose landings decreased from ca. 57 t in 2002–1.5 t in 2012 [56], eventually caused their local extinction [126] and the consequent loss of their filtration efficiency in the basin, ultimately resulting in an ecological extinction (i.e., loss of their ecological function [127]). This decline, however, may be the tail end of a much larger historical reduction of any oyster species in the region. Lotze et al. (2006), estimated a reduction of oysters of around 90% since Roman time [128].

Another bivalve that is currently present and harvested in the Adriatic is the clam *Chamelea gallina.* Based on laboratory estimates, the filtration rate *of C. gallina* is 0.42 $L\,h^{-1}$ [129] (a lower value than those measured for *Ostrea edulis* – 2.83 $L\,h^{-1}\,g^{-1}$ [130]- and sponges –1–6 $L\,h^{-1}$ [131]). It is estimated that to filter the entire Adriatic water volume, the currently depleted population of *C. gallina* would take 7 years longer than the clam population present in the 1950s (Bastari, unpublished data). Bottom trawling and dredging have radically altered many epibenthic communities of the central and northern Adriatic Sea [132]. The consequences of this change in terms of filtration capacity have never been considered, but are expected to be important. Field and laboratory measurements, modelling, and historical reconstructions of ecosystem change are needed to assess and quantify changes in ecosystem function and services due to bottom trawling, and make predictions about what might be recovered in LMPAs. While LMPAs regulating fisheries alone cannot directly address additional pressures (such as climate changes, marine pollution), they are expected to increase population and ecosystem resilience to global change by decreasing cumulative impacts and recovering diversity and functional redundancy [133–135].

3.3. Expected economic and political benefits

A suite of marine sectors supports the marine economies of the Adriatic region. The most valuable sectors include coastal and maritime tourism (8 billion euros), transport (5.2 billion euros), fisheries (2.9 billion euros), offshore oil and gas activities (2.2 billion euros), ship building and repair (1.5 billion euros) and, finally aquaculture (0.3 billion euros in 2012). In terms of employment, tourism (198,760 jobs) is the most important sector, followed by fisheries (95,420 jobs), transport (55,860 jobs), shipbuilding and repair (48,610 jobs), offshore oil and gas (5,970 jobs) and aquaculture (4,030 jobs) [136].

The Adriatic region is one of the most visited sectors of the Mediterranean for tourism. In Italy, Adriatic tourism is worth almost 2.5 times the value generated by fisheries [136]. The environmental status of the sea is one of the most important factors influencing tourists' choices to vacation in Croatia [137]. A transboundary Adriatic LMPA could thus provide new opportunities to bolster this economic sector. An example could be well-regulated fishing activities where tourists can conduct a limited amount of fishing within the protected area for immediate consumption (charter fishing trips) with economic benefits and job opportunities for coastal communities in all neighbouring countries (transportation, accommodations, meals) [138,139]. In California, USA, recreational fishing within the four marine sanctuaries of the state generated more than $200 million in annual economic output and supported nearly 1400 jobs (http://sanctuaries.noaa.gov/news/press/2015/rec-fishing-california.html). Marine mammals, such as dolphins, whales, seals, as well as sea turtles and sharks, were abundant in the Adriatic basin in the past [7,23]. A no-trawl zone, could promote recovery of these species, which are important attractions for tourists interested in nature-related activities. It has been calculated that more than $300 millions per year are being spent by shark-watchers, supporting 10,000 jobs [140]. The whale watching industry is now a billion dollar business. The current global estimates are of over 2.5 billion USD in yearly revenue with the production of around 19,000 jobs around the world [141].

There are also potential political benefits derived from the creation of a shared no-trawl area [41,142]. A transboundary no-trawl area is expected to produce international cooperation between bordering countries, and may simplify the definition of their maritime boundaries (Table 1). A clear delimitation of marine regions will define responsibilities of each country in the management and surveillance of their areas of jurisdiction [142]. LMPAs in general could act as 'peace parks' [45] and create an important dialogue between states [41].

The third pillar of the Adriatic Ionian Macroregion EU Strategy for the Adriatic and Ionian Region (EUSAIR) focuses on environmental quality. One of the main goals is to reach a good environmental and ecological status of marine ecosystems, as also requested by the Marine Strategy Framework Directive (2008/56/EC). A transboundary no-trawl area would help to tackle the following ecological targets of Good Environmental Status (GES): (i) the maintenance of sea-floor integrity, by restoring benthic communities and preserving sensitive species and their ecological functions (Descriptor 6, MSFD); (ii) the maintenance of biological diversity, through the protection of the habitats and species of the sandy bottoms (Descriptor 1, MSFD); (iii) ensure the long-term abundance of species and all the food webs elements (Descriptor 4, MSFD). The establishment of a no-trawl zone, with a reduction of fishing effort on a big area of the Adriatic basin, may also contribute to the reduction of the chronic exposure of marine organisms to marine litter (Descriptor 10, MSFD) and ambient noise (Descriptor 11, MSFD).

4. Political opportunities and legal mechanisms for establishing a transboundary no-trawl area in the Adriatic Sea

There are historical precedents, current political opportunities and legal instruments for establishing a transboundary LMPA in the Adriatic Sea. In 2003, Croatia proposed the establishment of a 23,870 Km^2 Ecological and Fisheries Protection Zone (EFPZ) for marine biodiversity and fisheries conservation [143]. The EFPZ was approved by the Croatian government and enforced in January 2008. However, due to harsh opposition by Italy and Slovenia, fisheries restrictions within this area were applied only to non-European fleets [144]. In 2013, Croatia became a new member of the European Union. This membership has produced new opportunities to start negotiations for the establishment of an Adriatic transboundary LMPA between the two main Adriatic countries (Italy and Croatia) that could co-manage the area. The former European Commission's President Jose' Manuel Barroso has declared that the EU is willing to consider a special protection zone in the middle of the Adriatic [143], thereby demonstrating the Commission's intention to expand marine protection in this region. The EU is also currently funding a plethora of scientific projects on spatial planning within the Adriatic Sea [145–149], further highlighting the EU current effort to support spatial management aimed at promoting the recovery of Adriatic marine resources and economic sectors, and reduce conflicts among user groups.

Despite difficulties in international dialogue and possible stakeholder conflicts (Table 1), international laws provide the legal authority and support for establishing a transboundary LMPA in the Adriatic Sea that would protect its ecosystems and marine resources from bottom trawling, the main driver of their degradation [7,23,59]. The Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (the Barcelona Convention), adopted in 1995 by all Mediterranean States, mandates the selection of Specially Protected Areas of Mediterranean Importance (SPAMIs) by each nation. In addition, more recently a list of Ecologically or Biologically Significant Marine Areas (EBSAs), including several of the existing SPAMIs, was identified and approved at the Extraordinary Meeting of the Focal Points for Specially Protected Areas (UNEP(DEPI)MED WG. 348/5 June 2010). In 2012, the Contracting Parties of the CBD have been asked by UNEP/MAP to present the work carried out for the identification of the Mediterranean EBSAs. The description of the proposed EBSAs was produced during a workshop hosted in Spain from 7 to 11 April 2014 [150]. The scientific criteria for the identification of the EBSAs, defined by the ninth Conference of the Parties to the CBD, are based on areas' uniqueness or rarity, special importance for life-history stages of species, importance for threatened, endangered or declining species and/or habitats, vulnerability, fragility, sensibility or slow recovery potential, biological productivity, biological diversity and naturalness [151]. The definition of the EBSAs has led to the identification of areas in offshore pelagic and deep-sea habitats in need of protection that are not included in established MPAs. The EBSAs have been endorsed by all the contracting parties of the Barcelona Convention [152].

In the Adriatic Sea, EBSAs have been identified in the northern, central and southern basins (Fig. 3), making these areas priorities for improved marine management and conservation [150]. The EBSA in the northern Adriatic basin, encompassing the area above the straight line linking Ancona (Italy) and the island of Ilovik (Croatia), was selected because of its high productivity, richness of benthic habitats, and the presence of breeding or feeding areas for dolphin and turtle populations. The central area encompasses the Jabuka-Pomo Pit, but it is larger than the temporary no-trawl zone established in the Jabuka-Pomo Pit in July 2015 (see above). Finally, the southern Adriatic-Ionian EBSA comprises particular features such as cold-water corals and sponge gardens [52,153,154].

Adriatic areas outside of the current EBSAs were identified as priorities for conservation by a suite of analyses and conservation plans [6,53]. Selection was based on information on the distribution of critical benthic habitats, importance to marine mammals and seabirds, and current distribution and intensity of threats to

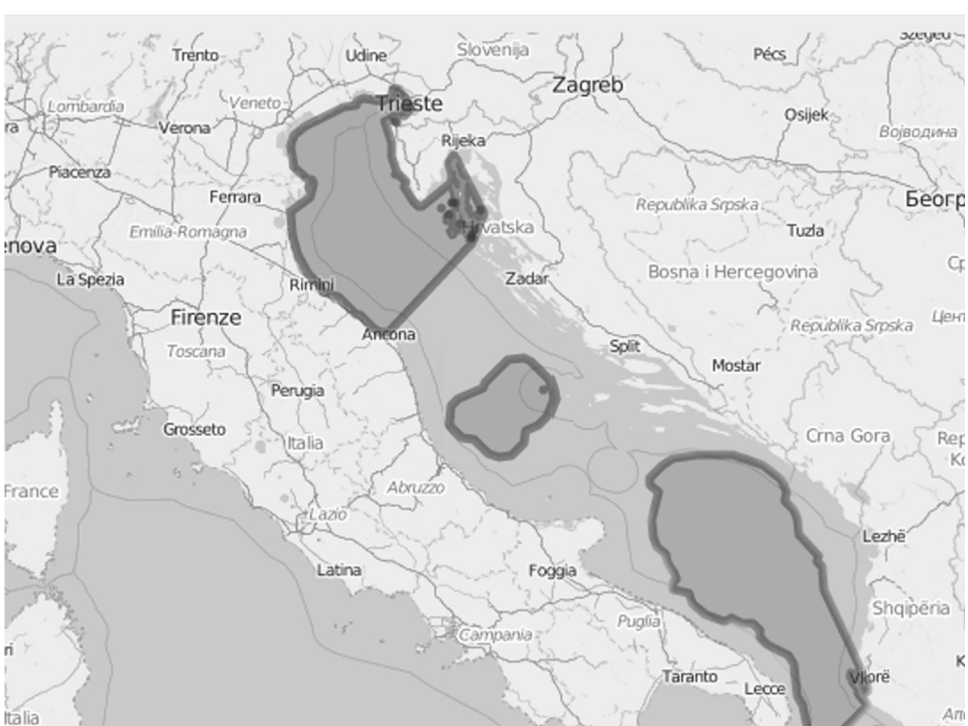

Fig. 3. Adriatic Sea EBSAs. The delimited polygons show the proposed EBSAs of the Adriatic Sea (as reported by https://www.cbd.int/ebsa/).

these ecosystem components [5]. Depending on the specific goals, data, and approaches, different areas were selected as top priorities, though areas within the central Adriatic emerge as priorities in most plans [5]. Systematic analyses, e.g. utilizing GIS approaches and MPA site selection algorithms, are needed to objectively and transparently identify candidate areas for the establishment of one or multiple no-trawl areas in the Adriatic, addressing and balancing different objectives and goals. The priority areas should include the protection of nursery habitats for demersal fish species, spawning areas for small pelagic, biogenic habitats, such as sponge and hydroid beds that support high biodiversity and important ecosystem functions, and foraging areas for marine mammals, sea turtles and birds. The large amounts of data available for this region and numerous previous threat analyses and conservation planning exercises [6,59,85,87,147,155] provide a unique opportunity to inform the siting and configuration of a no-trawl area with sound scientific information.

Organizations such as the International Maritime Organization (IMO), or the General Fisheries Commission for the Mediterranean (GFCM) have specific mandates to regulate human uses of deep or offshore habitats, selected through the EBSAs process or independently, by NGOs or other stakeholders. In particular, the GFCM has the authority to adopt spatial management measures to effectively manage fisheries. In this role, GFCM has already declared four Fishery Restricted Areas (FRAs) covering a total area of 26,248 Km^2 or 0.15% of the Mediterranean Sea surface: the *Lophelia* reef off Capo Santa Maria di Leuca; the Nile delta area; the Eratosthenes Seamount; the Gulf of Lion. In these areas, the use of towed dredges and bottom trawl nets is prohibited. Following the GFCM's FRA protocol, a LMPA banning trawling could be established in the Adriatic Sea as well. Finally, the European Union has legal responsibility for fishery management in European waters. A no-trawl zone could also be implemented based on emergency measures foreseen by the Common Fishery Policy (CFP) [38]. Subsequent to the establishment of a FRA or a fish recovery area under the CFP, additional ecosystems conservation measures could be implemented through the establishment of SPAMI areas, thereby expanding regulation of activities from fishing, as in a FRA, to other marine uses.

5. Remaining challenges: governance and compliance

Establishing effective MPAs, including LMPAs, requires clear management objectives and the involvement and support of marine users, in particular fishers who generally are the category most directly affected by MPA establishment. The experience with the Pelagos Sanctuary (established in 1999 and entered into force on 2002 as an agreement between Italy, France and Monaco in the northern Tyrrhenian Sea to protect cetaceans, Fig. 1) [20] highlights the importance of setting processes and necessary resources for enforcement of regulations and stakeholder involvement [156]. In fact, since its establishment, Pelagos still lacks a management plan, systematic monitoring or enforcement measures, and there is no evidence that human threats to marine mammals have decreased within the area [157]. Cetaceans living in the sanctuary are toxicologically stressed, and still affected by fishing and potentially harmful military activities [156,158]. The absence of a governance and enforcement body are major reasons for Pelagos' lack of efficacy as a cetacean sanctuary [156].

Governance of a transboundary Adriatic LMPA presents unique challenges but also new opportunities. The Adriatic-Ionian Macroregion initiative provides a robust political and economic platform to promote cooperation among Adriatic countries in managing marine uses, and could represent the shared governance body for an Adriatic LMPA. The already existing Adriatic Protected Areas Network (AdriaPAN), a sub-regional network included in the broader MedPAN network, represents an encouraging precedent of the willingness to develop a collaborative strategy among MPAs in the Adriatic region. This operational network of MPAs may serve as a facilitator of the process towards a shared governance body for an offshore Adriatic LMPA.

Monitoring and enforcement of regulations within large offshore managed areas require high economic investment [42,44]. New technologies and tools that are currently being developed and tested, such as the use of satellite imagery to counteract illegal fishing [159], will provide new opportunities for real-time, cost-effective surveillance and control of human activities in LMPAs. Involvement and participation of stakeholders such as fishers, tourism operators, and supporters of the LMPA is crucial for enforcement and compliance [160].

6. Conclusion

The establishment of one or more no-trawl areas in the Adriatic Sea, possibly in the form of a Fisheries Restricted Areas, could provide an unprecedented opportunity to promote the recovery of degraded Mediterranean marine ecosystems and fisheries, and to meet international commitments to expand marine conservation and improve fisheries management. The recognised limitations described for several LMPAs already established around the world could be overcome in the Adriatic basin. The available scientific knowledge identifies the central basin as representative of the main features of the whole Adriatic Sea including both ecological and biological important areas and overexploited bottoms. One of the main obstacles for the establishment of the no-trawl LMPA may derive from the different objectives and priorities of resource use and management of its bordering nations (most importantly Italy and Croatia). However, the critical status of the Adriatic marine resources and ecosystems, and the inefficient results of their current management highlight the urgent need of implementing new conservation actions. The EUSAIR process will provide a robust framework for the development of political, management and governance collaboration needed to establish an effective transboundary LMPA in the Adriatic Sea. One or more Adriatic no-trawl areas could benefit multiple marine users and economic sectors, in addition to fisheries. If successful, it is foreseen that the Adriatic process would provide an important precedent and a model for scaling up protection in other intensely used marine regions worldwide.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.marpol.2016.03.010.

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