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Environmental impacts of increasing leisure boating activity in Mediterranean coastal waters

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ABSTRACT

Leisure boating is an important economic activity which is increasing in popularity worldwide, and the Mediterranean Sea is one of the most popular nautical tourism destinations in the world. While the overall ecological impacts of recreational boating on freshwater ecosystems have been relatively well studied, very few works have assessed its impacts on marine ecosystems. This is the first holistic review of the ecological impacts of leisure boating in the Mediterranean Sea. Impacts are classified in different categories and rated following a risk assessment matrix. Major or high impacts include anchoring impacts on seagrass meadows (*Posidonia oceanica)*, motor noise disturbance, toxic antifouling products, and transport of exotic species. Moderate impacts include discharge of grey waters, air pollution, and fuel and oil leaks. Low impacts include sediment resuspension, discharge of black waters and marine litter, artificial light emissions, and animal feeding. The conclusion drawn is that there is an urgent need to raise awareness of the potential impacts of leisure boating in Mediterranean coastal environments. Greater research effort is required to monitor these ecological impacts and pressures, especially in marine protected areas (MPAs), with the aim of drawing up management measures to mitigate the identified impacts. Furthermore, a holistic approach involving marine scientists and engineers, policy makers, and the boating industry needs to be adopted to lower the impacts of recreational boating both in the Mediterranean and in other parts of the world.

1. Introduction

Leisure boating is an important economic activity which is increasing in popularity worldwide, with the Mediterranean Sea one of the most popular nautical tourism destination in the world (Venturini et al., 2016). The Mediterranean attracts all types of leisure boaters, not only because of its climate and landscape, but also because it is well provided with marinas, and manufacturing, refit and repair facilities (Cappato, 2011). As part of coastal tourism, leisure boating is one of the pillars of the EU Blue Economy (European Commission, 2018). There are around 400,000 berths in the Mediterranean, distributed in 940 marinas (Billé and Lowezanin, 2010; Cappato, 2011) with more than half of these concentrated in Italy (253), Spain (191), and France (124). According to the European Boating Industry (EBI, 2019), 36 million European citizens regularly participate in recreational boating activities, with the vessels used either owned by the participants themselves or chartered (DG Enterprise and Industry, 2015).

The leisure boating sector generates various economic benefits in European coastal areas, including jobs, investment, and infrastructure. The EU's nautical tourism sector creates up to 234,000 jobs and generates €28 billion in annual revenue, with 59% of its economic output coming from the Mediterranean, and the Northern Mediterranean region generating around half of the sector's economic output and employment (European Commission, 2017). Since the 2008 economic crisis, from which European sectors have recovered (ICOMIA, 2018), recreational boat production in European Mediterranean countries has shown an average annual growth rate of 10%.

Although leisure boating is one of the most important sources of income for coastal and insular economies, specific data on the size, type and capacities of the marinas and the leisure boating industry in Europe is scarce (European Commission, 2017). Existing data indicate that more than 90% of the total Mediterranean fleet of vessels are recreational boats of between 2.5 and 24m in length. Most of the leisure boat fleet is composed of motor boats (87%), compared to 11% for sail boats and 2% for other types of crafts (inflatable boats, canoes, etc.) (Cappato, 2011).

Leisure boats over 24 m in length (10% of the total Mediterranean recreational fleet) are also known as superyachts. 70% of the world's superyacht charter contracts are in the Mediterranean (Piante and Ody,

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2015). The Superyacht Migration Report (Superyacht Group, 2019) shows a 3.5% average annual growth in large yacht presence in the Mediterranean Sea. Although the number of these large yachts is relatively limited, they still make up a significant share of the nautical economy in the Mediterranean region, where Italy, Turkey and France make up half the global market share (Cappato, 2011). The services offered to yachts by coastal cities generate significant income, with many ports focusing their economy on the large yacht segments to rehabilitate and redevelop their infrastructure facilities (Cappato, 2011).

Considering the growth of the nautical sector in the Mediterranean, there is increasing concern about the detrimental impacts of leisure boating on the marine environment, and particularly in marine protected areas (MPAs). Surveys over the last 20 years have shown high density figures such as 4.5 boats per ha in the Cap de Creus MPA (Spain) (Lloret et al., 2008). While these densities relate to smaller vessels, the impacts of large yachts are even greater. More than 350 leisure boats and over a hundred superyachts were identified over one peak day in the Gulf of Saint Tropez (France) (AFB, 2019). The coastal and maritime tourism industry is reaching over-capacity in many popular Mediterranean destinations, bringing socio-economic and environmental challenges that threaten its contribution to economic growth (Lucrezi et al., 2017; UNWTO, 2018). In many EU Mediterranean countries such as Spain, France and Italy, marina port capacities in number of moorings per kilometre of coastline reach very high numbers of up to 100 moorings per kilometre, while large yacht (crafts > 24m), sailing and pleasure routes are extremely dense (i.e. over 100 h of super yacht presence per square km per year) in these areas of the western Mediterranean (Fig. 1).

Current knowledge on the effects of recreational boating on aquatic environments has been summarized in a number of regional reviews, but these have largely focused on freshwater ecosystems (e.g. Liddle and Scorgie, 1980; Mosisch and Arthington, 1998a) as opposed to marine ecosystems (e.g., Australian coastal waters, Burgin and Hardiman, 2011). All these regional reviews show that boating can have a number of different, potentially interacting effects on submerged aquatic vegetation and fauna. Regarding the Mediterranean, while there are some studies that assess specific ecological impacts such as anchoring, no comprehensive review has yet been carried out. Therefore, this paper is the first systematic and holistic review of the ecological impacts of leisure boating on the Mediterranean coastal marine environment, providing key recommendations for marine policy makers and managers to mitigate these impacts.

2. Material and methods

2.1. Literature review

The existing literature was systematically reviewed to retrieve information about the potential ecological impacts of leisure boating on the Mediterranean marine environment. The literature search was conducted primarily using the databases PubMed, ScienceDirect, PlosOne, Research Gate, and Google Scholar. These databases provide comprehensive results covering a broad range of dissertations, academic books and technical reports, in addition to scientific journals. The search for information on the environmental impacts of leisure boating was not limited by year. General keywords were searched for alone or in combination with other keywords such as “leisure boating”, “boating impacts”, “anchoring impacts”, and “coastal habitats”. More specific terms were then used to research each impact (i.e. antifouling, non-indigenous species, black waters, marine mammals, etc.). Although the review mainly focused on peer-reviewed scientific literature assessing leisure boating and its impacts in the Mediterranean, “grey literature” was also considered, given that these reports are often valuable sources of ecological and biological information. Among other sources, grey

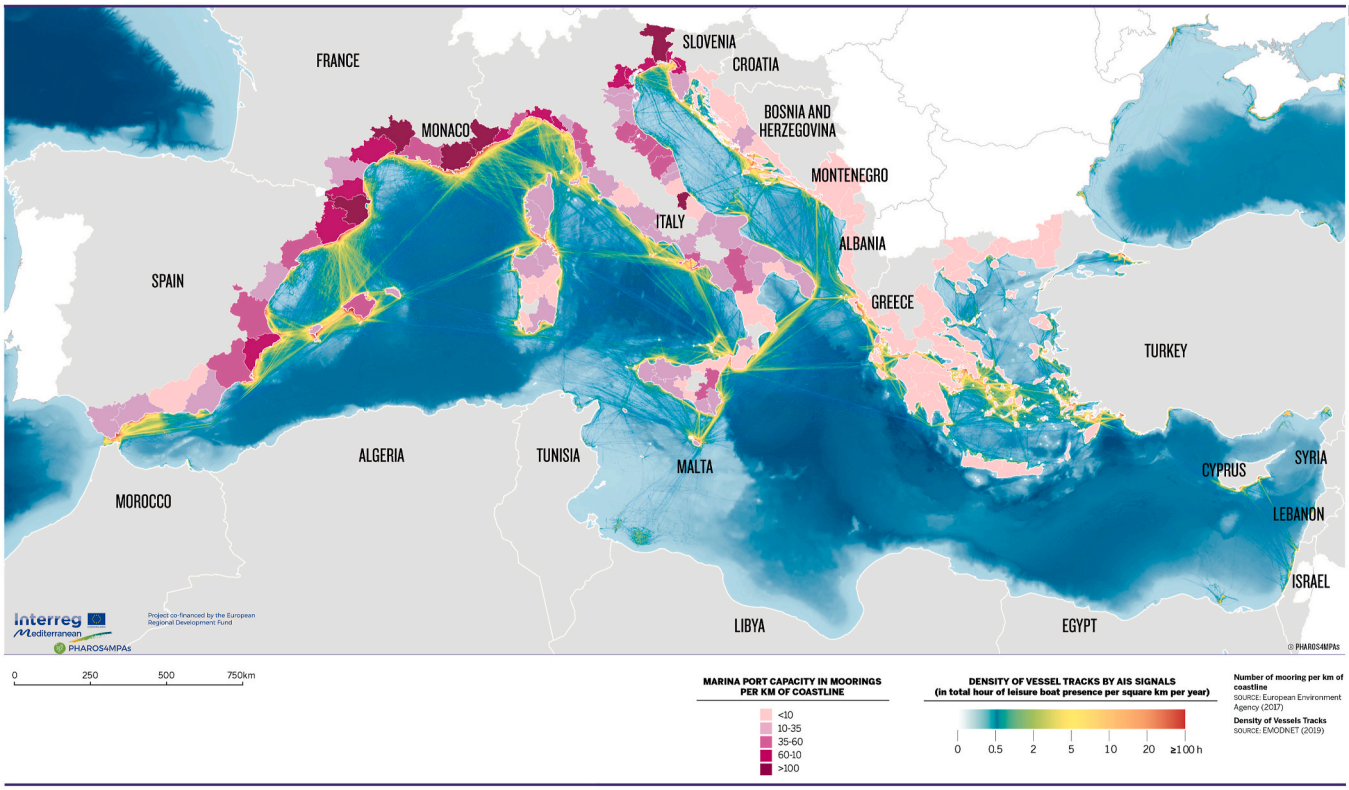


Fig. 1. Marina port capacities in number of moorings per km of coastline in EU countries (except Cyprus), and sailing and pleasure craft routes using Automatic Identification System (AIS) signals (crafts > 24m). Source: Interreg Pharos4MPAs; Alessandro Mulazzani. Adapted from the European Environment Agency (2017) and EMODNET (2019).

literature comprised EU reports on Blue Economy and Tourism, EU regulations, Leisure Boating Industry reports, and several projects assessing the ecological impacts of recreational boating such as Cruises and Recreational Boating Plan Bleu project (Cappato, 2011) and Interreg's Pharos4MPAs project (Carreño et al., 2019). Although this review mainly focused on studies carried out in the Mediterranean, where scarce or no information was available, other studies carried out in other parts of the world were taken into consideration. Furthermore, recommendations and measures introduced in other parts of the world were considered when novel, or when no similar approaches to mitigate certain environmental impacts in the Mediterranean were found.

2.2. Assessment of impacts

According to the scientific literature and expert opinion (Burgin and Hardiman, 2011; Sagerman et al., 2020), and following the qualitative model developed by Lewin et al. (2019) for assessing the environmental impacts of recreational fisheries, the impacts rating was adapted to leisure boating and established as high, moderate, and low in a risk assessment matrix (Table 1). The impacts assessment criteria were as follows; (i) the severity of the potential impact on the marine environment and communities; (ii) the spatial scale of the potential impact and the associated management measures; (iii) impact probability; (iv) the reversibility of the effects; and (v) the complexity or difficulty of the management measures required to mitigate the impact. Regarding the severity of the impact, the ranks were classified as high impact (severe effects on the marine environment), moderate impact (effects on the marine environment appear to be moderate), and low impact (there are some effects, but they are weak). Regarding the spatial scale, the ranks were classified as high (the impact affects the entire Mediterranean region), medium (the impact affects certain Mediterranean regions), and low (the impact affects certain local areas only). Regarding the non-reversibility of the impacts, the ranks were classified as high (impact is non-reversible or very difficult to reverse), medium (somewhat reversible), and low (reversible). The impact probability was classified as high (highly likely), medium (likely), and low (unlikely). The management complexity was classified as high (impact is difficult to manage or control), medium (solutions to tackle the impact are somewhat difficult to find or expensive), and low (solutions exist and are affordable). Last, an overall rank (high, moderate, and low) was estimated considering all the different ranks detailed above.

3. Results

3.1. Anchoring impacts

With regards to leisure boating, anchoring is the largest major human-related impact affecting marine protected areas. Overfrequentation of sensitive areas and a lack of artificial ecological mooring zones often leads to high intensity impacts on marine flora, fauna, and habitats (Font, 2014; Hereu et al., 2014; Lloret et al., 2008; Luciani, 2014; Milazzo et al., 2004; Oceana, 2010; Sagerman et al., 2020; Steiner and Feral, 2016; United Nations Environmental Programme, 2002). Depending on the type, shape and size of the anchor, the length and size of chains, and the characteristics of the area where boats are moored, different sensitive habitats such as seagrass meadows (*Posidonia oceanica)*, coralligenous assemblages and maërl bottoms can be heavily damaged (Boudouresque et al., 2012). Both Posidonia meadows and coralligenous assemblages are defined as priority natural habitats in Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora. Experiments conducted in Mediterranean MPAs such as Port-Cros (France) and Ustica Island (Italy) have revealed that depending on the anchor size (Milazzo et al., 2002, 2004), an average of between 6 and 34 Posidonia shoots are destroyed during an anchoring cycle (lock-in and retrieval). Apart from anchor size, the level of damage they inflict on seagrass meadows of this type differ depending

Table 1
Severity of environmental impacts of activities associated with leisure boating. The activities and their potential impacts were ranked as high (H), moderate (M), and low (L) following the risk assessment described in the text.

Criteria	Anchoring	Collisions	Sediment resuspension	Noise disturbance	Air pollution	Fuel and oil leaks	Black waters	Grey waters	Marine litter	Antifouling paints	Transport of exotic species	Animal feeding	Artificial lights
Spatial scale	H	M	L	H	M	M	L	L	L	H	H	L	L
Non-reversibility	H	H	L	M	M	M	L	M	H	H	H	L	L
Impact probability	H	L	L	H	H	M	M	L	L	H	M	L	L
Management complexity	M	L	M	H	M	M	L	L	L	M	H	L	L
Ecosystem impact	H	M	M	M	L	L	L	M	M	H	H	L	M
Rating score	H	M	L	H	M	M	L	M	L	H	H	L	L

on the anchor type, the anchoring process, and the seagrass mat compactness. It is known that damage to Posidonia meadows is directly proportional to the size of the boat, with larger leisure boats (superyachts) doing the greatest damage (Milazzo et al., 2004). The damage is greater when inexperienced boaters like those without a navigation license who usually rent small boats or boaters with no ecological knowledge of the sea bottoms, try to anchor. To give an example, 76% of boat owners in Cape Creus MPA (Spain) declare that they do not know where the anchor is moored (in which habitat type) when visiting a marine protected area (Lloret et al., 2008).

It is estimated that the regression of Posidonia meadows in the Mediterranean area over the last 50 years is 34%. This generalised phenomenon is mainly ascribed to the cumulative effects of multiple local stressors, with the leisure boating sector a major influence (Telesca et al., 2015). The anchors and chains from vessels when mooring may affect sessile organisms inhabiting Posidonia meadows and coralligenous assemblages, especially those with slow growth and those that are very sensitive to pollution, such as Mediterranean noble pen shells (*Pinna nobilis*) and gorgonians (Benabdi et al., 2019; Flynn and Forrester, 2019; Hendriks et al., 2013). In a study carried out in Cabrera and Mallorca, Spain, it was found that the average density of noble pen in an area where anchoring was forbidden was significantly higher than in areas where anchoring was permitted, suggesting that noble pen shell density and growth is related to anchoring pressure (Hendriks et al., 2013).

Apart from anchoring, the impacts of traditional mooring buoys must also be considered because these can do even more damage than anchoring directly on Posidonia meadows (La Manna et al., 2015; Sagerman et al., 2020). Traditional mooring fields consist in a concrete block deployed on the seabed, linked to a heavy chain, ropes and floats, which hold the vessels in position. Studies suggest that the dump weight of traditional buoys may be displaced and dragged through the seabed following a strong wave episode or due to the misuse of the mooring sites, destroying the *Posidonia oceanica* meadows (La Manna et al., 2015).

3.2. Impacts related to motor engines

3.2.1. Collision with marine animals

Fish can change their behaviour depending of the size of the boat and exposure to high boat traffic (Whitfield and Becker, 2014). There is no regulated safe distance for most marine animals (excluding cetaceans) and the presence of recreational boats causes discomfort to animals, who can also be harmed when struck by a ship's hull or cut by its propellers (Steiner and Feral, 2016; United Nations Environmental Programme, 2002). Although no studies have been performed in the Mediterranean area, there is documented evidence from direct observation of lethal and non-lethal impacts on marine turtles and sunfish (*Mola mola*). Of the various threats at sea, including ghost gear and by-catch, which are the main causes of human-induced sea turtle mortality in the Mediterranean (Abdulla and Linden, 2008; Casale, 2011), ship strikes may be a minor cause of death, but they are becoming increasingly common and should not be ignored (Abdulla and Linden, 2008). Although most reports of collisions between cetaceans and vessels involve large whales and large commercial vessels or cruise ships, any type of vessel and species of cetacean can be potentially be involved (Schoeman et al., 2020; Wang et al., 2017). Animals can be injured or killed and vessels can sustain damage. According to the International Whaling Commission (International Whailing Commission, 2019), serious and even fatal injuries to passengers of hydrofoil ferries, whale watching vessels, and recreational craft have occurred. In the Mediterranean Sea, these collisions are more frequent in summer when the number of leisure vessels in the Mediterranean increases, as has been recorded in the Pelagos Sanctuary, where 82% of the collisions have been observed to occur between April and September (Panigada et al., 2006). In 24 of the cases the vessel involved could be identified and, while most of the fatal impacts were caused by large cruisers, 2 of the collisions (8.3%) were caused by large recreational yachts (from 15 to 80m long) (Panigada et al., 2006).

3.2.2. Sediment resuspension

The navigation of motor boats and jet skis with propeller engines over shallow, sandy or muddy sea beds may contribute to generating sediment resuspension, and certainly contributes to water turbidity thus decreasing the penetration of light, which may have adverse effects on marine algae and phanerogams (Ruiz and Romero, 2003). Suspended sediments may also affect fish directly given that it could affect their gills (Bruton, 1985). Turbidity also enhances the risk of eutrophication, which may promote the growth of blooms of toxic bacteria and the appearance of harmful algae due to the presence of more organic material to decompose (Ailstock et al., 2012; Alexander and Wigart, 2013). The high vessel speeds achieved by more powerful propeller engines are directly related to this sediment resuspension given that high speeds generally produce larger, more energetic waves (Hill and Younkin, 2005; Mcconchie and Toleman, 2003). The depth of the water also plays a critical role in resuspension as boats and jet skis create greater turbidity when travelling in shallower water, with the downward pressure of water created by the craft reaching the sediment with greater energy (Klein, 2007; Mosisch and Arthington, 1998b).

3.2.3. Motor noise disturbance

All the reviewed studies that have assessed how noise affects fish are inconclusive mainly because they are carried with fish in laboratories and not in their natural habitat. However, the continued passage of vessels in certain frequented areas suggests that the navigation of recreational motor boats and yachts causes recurring noise levels that can affect marine fauna (including birds and mammals), causing changes in their behaviour (Cominelli et al., 2018). In particular, there is growing concern that human-generated sounds may interfere with the ability of fish to detect biologically relevant sounds (Popper and Casper, 2017). An experimental study performed with damselfish has suggested that under constant noise these fish change their behaviour during the first 20 min, after which they return to their normal behaviour (Holmes et al., 2017). In damselfish *(Chromis chromis)*, brown meagre (*Sciaena umbra*), and red-mouthed goby (*Gobius cruentatus*), boat noise reduced auditory sensitivity and increased the time the fish spent in shelters (Codarin et al., 2009). In the Lusitanian toadfish (*Halobatrachus didactylus*), boat noise affected acoustic communication and decreased hearing sensitivity immediately after exposure to the boat noise stimulant (Vasconcelos et al., 2007). Boat noise also increased the metabolism and induced motility in European seabass (*Dicentrarchus labrax*) and gilt-head bream (*Sparus aurata*)(Bruintjes and Radford, 2013; Buscaino et al., 2010). Furthermore, one study suggests (de Jong et al., 2018) that the reproductive success of certain species of fish such as the two-spotted goby (*Gobiusculus flavescens*) and the painted goby (*Pomatoschistus pictus*) may be sensitive to noise pollution given that they use visual and acoustic signals during courtship. The negative effects of noise on acoustic communication and spawning success, which is crucial for reproduction, have been also found in laboratory conditions (de Jong et al., 2018).

On the other hand, the effects of motor noise on marine mammals are well-known (Wright et al., 2014). Typical observed behavioural responses include changes in direction of travel (Miller et al., 2008), increased dive duration (Janik and Thompson, 2006; Lusseau, 2003), changes in dolphin behavioural state (Constantine et al., 2004; Lusseau, 2003; Nowacek et al., 2001), increased group cohesion (Bejder et al., 1999; Nowacek et al., 2001), and increased breathing synchrony (Hastie et al., 2003), responses that are all associated with evasion (Miller et al., 2008; Saayman et al., 1972). Conversely, some dolphins have been observed to approach boats (Ansmann et al., 2012; Constantine et al., 2004). Cumulative short-term responses to vessels, be they positive or negative, could have impacts on long-term dolphin survival (Miller et al., 2008) given that by either approaching or avoiding boats they may reduce the time spent socializing, feeding or resting, causing

decreased energy acquisition and increased energy expenditure (Miller et al., 2008), potentially leading to lower individual fitness, reproductive success, and thus a less viable population (Bejder et al., 2006). Dolphins inhabiting disturbed areas have shown more moderate responses to noise disturbance, but some individuals have been found to completely leave a disturbed area in favour of a non-disturbed area. A similar effect has been noted for bottlenose dolphins in the coastal waters of Croatia's Cres–Lošinj archipelago (northern Adriatic Sea,) where permanent or temporary avoidance of one area of the Mediterranean was observed in response to seasonal increases in boat traffic (Rako et al., 2013; Richardson, 2012).

3.2.4. Air pollution emissions/Hydrocarbon release

Although recreational craft engines are a minor source of the hydrocarbons released into the environment (only 1% of total marine pollution is caused by recreational crafts), these emissions can be significant at a local level (Moreau, 2009). Apart from directly affecting the marine environment by polluting the air and the water, they also contribute to climate change by promoting global warming effects (Pitana et al., 2010). Another serious threat arising from air pollution emissions is ocean acidification (Harrop, 2002). Chemical reactions in the atmosphere can convert emitted NO_x and SO_x hydrocarbon components into nitric and sulphuric acids, respectively (Lacoue-Labarthe et al., 2016), which are related to ocean acidification (Turner et al., 2018). However, there are currently no existing estimates for the specific CO_2 and NO_x emissions generated by recreational craft in the Mediterranean (estimates are only available for general ship-generated CO_2 emissions). However, a recent study modelling leisure boating activities and emissions in the Baltic Sea found that fuel consumption, NOx and PM2.5 of leisure boats are significantly lower (1.2%, 0.4% and 2.7% respectively) than those of commercial shipping vessels (Johansson et al., 2020). In contrast, levels of non-methane volatile organic compounds (NMVOCs) emitted by leisure boats are 52% (annual average) and 500% higher (peak boating season in summer). On the other hand, the average CO emissions annual of leisure boats, compared to commercial shipping, are 38% lower, rising to 140% higher during peak boating season in summer (Johansson et al., 2020). Given that the number of leisure boaters has been increasing since the year 2000 and is expected to continue increasing (IMO, 2000), this impact is also expected to worsen.

3.2.5. Fuel and oil leaks, including bilge waters

Bilge water is the waste water generated in the engine room and released into the sea water, which may contain fuel, oil, and other toxic substances. Moreover, sourcing fuel out of sites authorised to do so (ports and marinas) can cause highly polluting small spills. The scale of this problem has not been assessed in terms of leisure boating. However, the environmental impact is visible and needs to be addressed (Abdulla and Linden, 2008; Moreau, 2009; Steiner and Feral, 2016; United Nations Environmental Programme, 2002).

Fuel contains heavy metals and polycyclic aromatic hydrocarbons, which are highly harmful to organisms, bioaccumulating and biomagnifying throughout the trophic chain to finally reach humans through the consumption of seafood (Egardt et al., 2018). Several studies have shown that Polycyclic Aromatic Hydrocarbons (PAHs) may induce genetic damage in all living organisms, even at environmentally low concentrations (Bolognesi et al., 2006; Cavallo et al., 2006; Cebulska-Wasilewska et al., 2005). Such damage includes DNA base modification, strand breaks, depurination, and cross-linkages. It has been shown that the water-soluble fraction of PAHs preferentially accumulates in membrane lipids and other lipidic compartments (Di Toro et al., 2001), and in so doing has the potential to disrupt the biochemical and physiological properties of cell membranes, causing toxic effects (Lavarías et al., 2007). Teleost hepatic lesions, including neoplastic, preneoplastic, focal, and necrotic lesions resembling those experimentally induced in fish by chronic exposure to PAH-contaminated sediments and diets are commonly detected in sea bottom fish from contaminated environments (Myers et al., 1998).

The old two-stroke engines used by many leisure boats are one of the major sources of air and water pollution in coastal areas frequented by these boats (Vermont Agency of Natural Resources, 1999). The main cause of the high hydrocarbon emissions from old two-stroke engines is the design of the motor, which is less fuel efficient and has an improper combustion, leading to fuel wastage and more pollution. It is estimated that 20–30% of the fuel and added oil used by these two-stroke engines are emitted unburned directly into the water (KIMO, 2019; Long, 1997). Moreover, two-stroke engines require an oil mix to be added to the air-fuel mixture to lubricate the crankshaft. The combustion of the oil in the mixture creates a lot of smoke, leading to air pollution (MechStuff, 2015).

3.3. Impacts of human waste

3.3.1. Black waters

Black water discharge (i.e. toilet waste, which will often contain harmful bacteria and viruses) from recreational craft is both a health and an environmental issue in confined waters such as inland waterways, creeks, and marinas (Moreau, 2009). While some EU Member States have enacted national legislation limiting access to certain areas to recreational craft equipped with a sewage holding tank, there is no consistency on this issue at the European level (Ellis, 2009). Moreover, there is no international agreement requiring private pleasure craft to fit a holding tank, with only vessels exceeding 400 GT and carrying more than 15 passengers obligated to do so (IMO, 2003).

3.3.2. Grey waters

Vessel grey water is generally what is left over from accommodation facilities (e.g. shower, bath, laundry, kitchen, dishwasher, etc.). This is not a major issue in terms of the smallest leisure boats since most of them do not have such facilities on board, but superyacht, large boat/sailboat and cruise ship grey water can constitute 90% of the liquid waste generated on board (IMO, 2018). Grey water is technically more difficult to treat than black water given that it typically contains a wide range of chemicals and fats such as oil and grease, detergent and soap residue, metals (e.g. copper, lead, mercury), bacteria, pathogens, hair, food particles, organic matter, oxygen-depleting substances, suspended solids, bleach, pesticides, and phosphates (EPA, 2011).

As with black waters, the discharge of grey water into confined waters can be an issue with the associated water clouding and foam clearly visible, but it can also be a threat in areas where a high number of superyachts are moored (EU Commission, 2007; Şanlıer, 2018; Steiner and Feral, 2016). Pollutants in grey water can contribute to adverse environmental effects such as shellfish contamination, the proliferation of toxic microorganisms and microalgae (algal blooms), hypoxic waters, the smothering of benthic biota (e.g. reef-building organisms), and the introduction of invasive species (Czub et al., 2018; Perić et al., 2016). Moreover, soap-based detergents can prevent the work of filtering organisms, inducing their mortality (Zahn et al., 1977). Grey water discharges can impair phytoplankton, which are the basis of the food chain for higher trophic level species (IMO, 2018). Grey waters can also contain traces of Persistent Organic Pollutants (POPs), which are organic compounds that persist in the environment and are resistant to degradation by biological or chemical processes. Due to this resistance, POPs bioaccumulate in flora and fauna, and especially in large predator fish, cetaceans, and turtles, and may be biomagnified through the trophic chain causing impacts to human health, especially at the endocrine level (Abdulla and Linden, 2008).

3.3.3. Marine litter dropping

Litter is dropped into the sea by many recreational boat users and this is becoming a serious pollution threat in marine protected areas (UNEP, 2015). Most of the plastics generated by recreational craft users

come from various kinds of food packaging (Sheavly, 2005). While there is no existing data on the amount of plastics generated by leisure boat users, and the figure is probably tiny compared to the total amount of plastics that come from other sources of pollution (landfills, cities, beaches, etc.), this source of contamination is becoming a major concern for wildlife (de Carvalho-Souza et al., 2018). Litter can accumulate on the surface of many marine species from algae to animals, inhibiting their growth and causing many different threats such as tissue necrosis, strangulation, asphyxia, and so on. (Law, 2017). Plastics can also accumulate on filtering organisms causing their death (Law, 2017). Furthermore, they can be decomposed by microorganisms or by the action of time, becoming micro-plastics, which can be ingested by other organisms and bio accumulated through the trophic chain (Bordbar et al., 2018; Derraik, 2002).

3.3.4. Antifouling paints

Anti-fouling paints based on tributyltin (TBT) are highly damaging to both the environment and to organisms, and can be dissolved in water over time. Although the use of TBT on all type of ships, including leisure boats, has been banned by European legislation since 2003, traces of this product have been found in some areas such as the Iroise Marine Natural Park during water quality monitoring (Abdulla and Linden, 2008). TBT and its degradation products, mono- (MBT) and dibutyltin (DBT), and triphenyltin (TPT) have been recognised as the most toxic materials intentionally introduced into the sea and confirmed as harmful to a wide range of organism. Their eco-toxicological impacts have been amply documented (Abdulla and Linden, 2008; Adelman et al., 1990; Gabrielides et al., 1990; Seligman et al., 1986, 1988). Despite the banning of TBT, some current paints may still be harmful given that they may contain heavy metals, which are highly detrimental to organisms and may bioaccumulate and biomagnify throughout the food chain, reaching humans through seafood consumption (Egardt et al., 2018; Moreau, 2009; Steiner and Feral, 2016; United Nations Environmental Programme, 2002; Ytreberg et al., 2016). Zinc and copper are examples of toxic heavy metals contained in some antifouling paints. Waterborne zinc toxicity disrupts the absorption of calcium, resulting in hypocalcaemia, and eventually causing fish death (McRae et al., 2016). High levels of zinc cause branchial mucus secretion, a mechanism of toxicity that impairs vital gill-based processes such as oxygen uptake and ion regulation (McRae et al., 2016). Copper from antifouling paints has been found to impair the behaviour of fish inhabiting other ecosystems by affecting their olfactory system, thus blunting their ability to sense predators and prey (Baldwin et al., 2011; Scholz et al., 2012; TECHLAW, 2017). Although no examples concerning the Mediterranean were found, a recent study estimated antifouling pollutant emissions from leisure boat activity in the Baltic Sea and concluded that the amounts of zinc and copper emitted from the antifouling paints from leisure boating sector were 19% and 81% lower, respectively, than those emitted by all commercial shipping (Johansson et al., 2020). Nevertheless, these values increase during the peak season for leisure boating (July): rising to levels 89% higher than those emitted by all commercial shipping in the case of zinc. Although levels also increase for copper, they remain 56% lower than levels emitted by all commercial shipping (Johansson et al., 2020).

3.4. Transport of exotic species

Shipping has been implicated in the dispersal of numerous neritic organisms, ranging from micro-organisms and macrophytes to fish (Katsanevakis et al., 2014; REMPEC, 2017). Recreational shipping can transport alien species on their anchors, as hull fouling or as solid ballast (i.e. with sand, rocks, soil, etc.), thus contributing to their spread, as shown in samples from over 600 recreational boat hulls in 25 marinas across the Mediterranean (from France to Cyprus) (Ferrario et al., 2019; Ulman et al., 2017, 2019). 71% of leisure vessels carried at least one non-indigenous species whose richness was strongly correlated with that of highly exotic species in home marinas. Over half of the vessels carried species not yet present in the marinas they were visiting (Ulman et al., 2019). Hull fouling on ships was recognised as a vector for alien introductions when non-native serpulid polychaetes were found for the first time in the Mediterranean (Otero et al., 2013; Quelin et al., 2008). By way of example, leisure boat anchors are a vector of expansion of *Caulerpa taxifolia*, an invasive algae found in the Mediterranean which is very resistant to desiccation and also responsible for the regression of Posidonia meadows (Katsanevakis et al., 2010; Molenaar et al., 2006; West et al., 2007). A recent study by Ulman et al. (2017) showed that western Mediterranean ports and marinas are where most non-indigenous species are found, concurring with Abdulla and Linden (2008), who stated that their primary introduction was through the Suez Canal (Katsanevakis et al., 2010).

3.5. Impacts related to bad practices

3.5.1. Animal feeding from leisure boaters

Feeding animals may change their alimentation habits and provisioning patterns, and make them potentially aggressive towards humans (Clua, 2018). Marine mammals that accept fish, shrimp, or squid from humans run the potential risk of ingesting contaminated or inappropriate food (Barros and Wells, 1998) or foreign objects associated with recreational fishing, including hooks and rod and reel fishing tackle. Dolphins have been reported ingesting baited hooks for fishing (Bryant, 1994), and the ingestion of fishing tackle has been reported to be a cause of mortality in dolphins (Gorzelany, 1998). These animals are also at increased risk of entanglement in fishing gear as they lose their natural fear of human beings and their activities (Powell and Wells, 2011; Wells et al., 1998). Furthermore, wild dolphins have been reported engaging in aggressive or “pushy” behaviour, and there have been incidents of them biting humans for food (Cunningham-Smith et al., 2006; Hazelkorn et al., 2016; Orams, 1994, 1996; Samuels et al., 2000).

3.5.2. Impact from artificial light emissions

Light pollution can affect marine organisms in many different ways (Longcore and Rich, 2004) and although this issue has not yet been assessed in the Mediterranean, it is favoured by the high numbers of vessels moored in coastal waters (Hölker et al., 2010). Recreational boats are usually allowed to stay overnight in many areas. Light from these boats, which is getting more powerful as the years pass, may contribute to disturbing or modifying the behaviour of marine fauna.

Light pollution is a growing threat to many animals guided by daylight or its absence (night), such as sea turtles. Hatchlings are particularly affected during their first crawl to the ocean, exhibiting phototaxis and moving towards or being disoriented by artificial lights, even after reaching the water (Cruz et al., 2018). Adults also have difficulties finding a suitable place to lay their eggs (Brei et al., 2016) and there is a negative association between night-time light pollution and sea turtle nest densities for three sea turtle species (green turtles, loggerheads, and leatherbacks) (Hu et al., 2018). Moreover, the use of artificial light at night can lead to massive mortality episodes for nocturnally active petrels, one of the most threatened avian groups. Some fledglings can be attracted to or disoriented by artificial light on their first flights, although studies are still inconclusive (Rodríguez, A. et al., 2017). Altered night-time lighting may lead to altered circadian rhythms (Brüning et al., 2015) and an inhibition of sexual maturation in various species of fish (Davie et al., 2007; García-López et al., 2006; Migaud et al., 2006; Porter et al., 1998; Rodríguez et al., 2005). Light pollution may affect fish that communicate by visual signals in many ways, disturbing colour patterns and negatively affecting their behaviour (Newport et al., 2017). Day-time and night-time pattern disruption by light pollution may also affect fish in their resource gathering (Brüning et al., 2015).

4. Discussion

This study summarizes the existing information on the ecological impacts derived from the leisure boating sector, which can have direct and indirect physical, chemical, and biotic impacts on Mediterranean coastal waters. These impacts can be grouped in 13 broad typologies that fall under three different risk categories (high medium and low). These categories can be used by policy makers to prioritize management actions for each impact typology. This paper provides new insights into the magnitude of these impacts in the Mediterranean and serves as a basis for the scientific community, MPA managers, policy makers and public authorities to introduce new or updated management measures targeting the leisure boating sector. These policy makers and public authorities have a significant role to play in mitigating the impacts of this sector on the Mediterranean, as well as setting up environmental monitoring programmes for recreational boating which can track its environmental impact along the national coastline, and define a recreational boating strategy at both national coastline and MPA level. In the following sections, recommendations for better management of recreational boating are proposed based on the three risk categories needing 1) government support to guide, engage and educate boaters with the aim of lessening the impacts of recreational boating; 2) introduce suitable legal tools for the protection of the marine environment from the impacts of leisure boating; and 3) design and develop more environmentally benign products and boats which minimise the impact of recreational boating on the marine environment. Nevertheless, more research is still needed to deepen our understanding of the environmental problems arising from recreational boating so we can provide tools to better manage it. Substantial gaps in knowledge exist with regards to the impact of crafts and boaters. For example, boaters who hire leisure boats not requiring a navigation license or permit have a potentially higher environmental impact due to insufficient navigation experience. They often lack essential knowledge of MPA navigation and anchoring rules and may be responsible for more accidents and environmental impacts (Carreño et al., 2019; GEAS, pers. comm. 2020). Furthermore, the number of recreational craft purchases (including superyachts, saltwater fishing boats and jet boats) and yacht charters rose during Covid-19 as wealthy citizens considered new ways to travel and vacation which avoid the crowds and interactions associated with conventional travel (Grossman, 2020). This highlights the urgency of using the results of our study to implement new management tools.

4.1. High impacts/risks and management measures on a broad spatial scale

'Anchoring', 'engine noise disturbance', and 'antifouling paints' impact typologies were ranked overall as high-risk impacts. These impacts are very likely to occur in all Mediterranean coastal regions, strongly affecting fragile organisms and habitats that have already received the cumulative impacts of other human activities, such as land based pollution, pollution from marine shipping, impact of fishing gear, etc. (Boudouresque et al., 2012). In addition, these impacts are not easily reversible and solutions are very expensive or difficult to implement.

The overall impact of anchors on *Posidonia* meadows was classified as high because of the risks associated with the destruction of this organism. There is a high probability of damage to *Posidonia* meadows during an anchoring cycle. *Posidonia* meadows have an average horizontal growth of just 1 cm–7 cm per year. Consequently, they do not regenerate easily when damaged, causing the area to become sandy or muddy, promoting water turbidity and the displacement of the natural fauna inhabitants (Abadie et al., 2016; Montefalcone et al., 2007). Appropriate management measures should address this risk on a broad, transnational scale. The monitoring and protection of seagrass beds of *Posidonia oceanica* and other phanerogam species and the species that live in them, such as the noble pen shell (*Pinna nobilis*), must be the first priority considering the major decline faced by these habitats and species over the last 50 years (Boudouresque et al., 2012; Natalotto et al., 2015) Mooring prohibitions and restrictions in seagrass beds for all ships must be applied, as is currently the case in the Balearic Islands (BOIB, 2016). These strict measures should at least be implemented in MPAs and should particularly address the most potentially damaging vessels, the superyachts (Carreño et al., 2019). This is already the case in the Scandola MPA (France), where the navigation and mooring of vessels of over 45m in length is forbidden, and in Portofino MPA, where the navigation and mooring of boats of more than 24m in length is prohibited (Venturini et al., 2016, 2018).

On the other hand, small leisure boats need to be allowed to moor safely, and to this effect ecological mooring buoy fields need to be installed in line with the monitoring studies carried out and the carrying capacity of the site. They have already been installed in several MPAs, such as Portofino, Egadi Islands, Cabrera, and Cap d'Agde, among others. While most of these mooring buoy fields require previous booking of the facilities and the payment of a small fee depending on the typology of vessel, they are well accepted among leisure boat users and the funds raised designated for reinvestment to protect the MPA's ecosystem (Agence Française pour la Biodiversité, 2017; Donati, 2016). Furthermore, boat renting should be strictly regulated, at least in MPAs, given that these boats are often rented by inexperienced users with no license, who tend to do more damage to ecosystems, especially when mooring (Carreño et al., 2019).

Regarding motor noise, almost every type of vessel (excluding sailboats and modern electric engines) is involved in this impact. Underwater noise can harass marine fauna, and especially cetaceans, in many different ways, producing changes in their behaviour, reducing auditory sensitivity and damaging hearing, which are highly irreversible (Codarin et al., 2009; de Jong et al., 2018; Holmes et al., 2017). Underwater noise is somewhat difficult to manage, given that sound propagates faster and farther in water than in air, and can even reach areas that are not visited by leisure boats (Farcas et al., 2016). Underwater sound propagation mapping and prediction is a good first step to limit sound levels in MPAs and boundaries. There are currently several validated sound propagation models (Christ and WernliSr, 2014), but the field of underwater noise assessment is still relatively new and uncertainties in assessing risk to marine life are high due to the complexity of animal responses to noise pollution (Farcas et al., 2016). Traffic separation schemes could be implemented in sensitive areas where marine leisure traffic is heavy, as has been done with marine shipping in some areas, such as Cabo de Gata-Níjar, Spain (Ministerio de Fomento, 2006). Furthermore, the use of speakers by recreational boaters could be prohibited, as has been done in the Calanques MPA (Parc national des Calanques, 2020).

Regarding the toxic antifouling products used to impede organisms attaching to the hull, although the use of TBT-based antifouling products are banned in Europe, other products on sale still contain compounds such as heavy metals that are harmful to the environment, with copper-based products being especially toxic (Baldwin et al., 2011; Scholz et al., 2012; TECHLAW, 2017). These zinc and copper-containing antifouling products are approved by the EU, but can build up on many boats when used in enclosed areas and lead to zinc and copper pollution. This is evident in the Baltic Sea, where levels of these antifouling compounds emitted by leisure boating activity during peak season are similar to, or even higher than those emitted by commercial shipping (Johansson et al., 2020). Heavy metals have not only been shown to affect marine animals, but they may also compromise human health due to their neurotoxicity, among other factors, via the incorporation of these metals in the trophic chain until species are consumed by humans (Egardt et al., 2018; Green and Planchart, 2018; Ivanković et al., 2016; Wright and Baccarelli, 2007). The use of products that contain heavy metals should be strictly regulated and campaigns to promote the use of eco-friendly antifouling paints should be promoted. Nowadays, there are several options of heavy metal-free antifouling paints (EU Commission, 2018; Pettit, 2020).

Compared to cargo boats, which may transport non-indigenous species in their ballast waters, leisure boats are probably not major vectors transporting exotic species over large distances (Murray et al., 2011). However, leisure boats are a highly unregulated expansion and dissemination vector, given that leisure boats travelling to other areas or marinas may transport exotic species attached to their hull or anchors (Ferrario et al., 2019; Murray et al., 2011; Ulman et al., 2019; West et al., 2007). Further scientific research is required to monitor the presence of exotic species in places where leisure boating is popular (Abdulla and Linden, 2008; Otero et al., 2013). A new Mediterranean-level protocol is needed that is specifically aimed at preventing not only the potential effects of commercial shipping as a vector of introductions, but also leisure boating as a vector of expansion.

4.2. Moderate risks/impacts and management measures on a regional spatial scale

'Air pollution', 'fuel and oil leaks', 'collisions' and 'grey waters' typologies were overall classified as moderate impacts. Although these are not a major issue at the global Mediterranean level, but only in some regions, almost every type of leisure boat can be involved and the impacts can be severe (species and habitats affected can also suffer the cumulated effect of impacts from other sources such as land-based pollution, shipping, and cruises) and difficult to manage or reverse in certain frequented areas or confined zones.

While leisure boat exhausts contain similar compounds to gasoil and gasoline cars, to date there has been no systematic monitoring of air and water quality by either public authorities or by managers in the sites most frequented by leisure boats. Air and water pollution from cargo and cruise ship exhausts is a widely discussed topic internationally. For years, there have been concerns about the contribution made by ships to local and global air quality, health, and environmental problems. In 2013, more than 2500 tonnes of nitrogen oxides (NOx), sulphur dioxide (SO_2), and particulate matter with a diameter of less than 2.5 μm (PM2.5) were released by cruise ships in the five busiest Greek cruise ports. Regarding potential health impacts, this pollution is estimated as being responsible for 60,000 annual deaths each year (Caric et al., 2019; Maragkogianni and Papaefthimiou, 2015). While leisure boating and large ship exhausts cannot be compared because they do not contain the same compounds, regular monitoring studies on the presence of water and air pollutants in marinas and areas frequented by leisure boats need to be carried out, taking the status of benthic communities into account, given that these are very sensitive to this pollution (MMMPA Supervisory Board, 2016).

Establishing speed limits for vessels is the single main measure that could result in the reduction of emissions from exhausts, vessel collisions with marine animals, and noise pollution. There are many examples in the Mediterranean, such as in the Port-Cros MPA (France) and Portofino MPA (Italy) where speed limits are applied (Parc national de Port-Cros et Porquerolles, 2020; Nautica report, 2020). In Spain, there is a maximum speed limit but only within the 100 m from the coastline (BOE, 2011).

The requirement of entry permits to MPAs may be one of the most efficient ways to limit the number of vessels and their related impacts. This has already been done in Cabrera National Park, Spain, where a maximum number of permits are issued per day according to the estimated carrying capacity of the site. Furthermore, similar measures involving those currently being applied inland with the most polluting vehicles could be applied to leisure vehicles in certain areas. Limiting the access of old two-stroke engines, superyachts and speedboats to fragile areas such as MPAs should be considered if monitoring studies show excessive pollutant levels in the air and the sea, while priority authorisations should be given to boats equipped with eco-friendly engines, not only electric engines and sailboats but also hybrid and hydrogen engines, in addition to vessels fully equipped to avoid all waste discharge at sea, as is promoted in Port-Cros (Parc national de Port-Cros et Porquerolles, 2018). This would not only avoid air and water pollution but also reduce the levels of excessive noise.

Collisions with marine animals is almost unassessed issue in the Mediterranean. There are evidences in other parts of the world of collisions between small leisure boats and jet skis and marine animals other than cetaceans, as has been reported in Australian estuaries with green turtles (*Chelonia mydas*) and dugongs (*Dugong dugon*) (Davenport and Davenport, 2006). Informative campaigns targeting leisure boat users need to be launched by public administrations, MPA bodies, the leisure boating industry and other stakeholders to raise awareness of the importance of being alert when piloting the boat, respecting the security distance regarding cetaceans, and keeping a safe distance from other marine animals.

Although most leisure boats do not produce grey waters, this impact can be severe due to cumulated effects in popular areas, mainly confined bays, ports and marinas, where there are large accumulations of superyachts and big boats/sailboats. Sustainable solutions that are currently under development, such as on-board treatment systems, should be promoted by policy makers. Only the larger recreational craft currently have such on-board facilities. This issue has been recognised by the industry and has been included in the EU Waterborne Technology Platform's Strategic Research Agenda as an area requiring urgent research and development (DG Environment News Alert Service, 2007; EU Commission, 2007; United Nations Environmental Programme, 2002). In the meantime, informative campaigns about the ecological impacts of grey waters and motor engines should be launched to raise awareness among leisure boat users and to encourage good engine, propeller and hull maintenance to avoid malfunctioning, pollution, excessive noise or cavitation effects, and strikes to marine fauna. All the relevant stakeholders involved in the leisure boating sector (policy makers, managers, the boating industry, etc.) also need to work together with engineers to design new ecological ships powered with renewable energy and more fuel efficient engines, with a special emphasis on reducing both water and air emissions and engine noise.

4.3. Low impacts/risks and management measures on a broad spatial scale

'Sediment resuspension', 'black waters', 'marine litter', 'animal feeding' and 'artificial lights' are impact typologies that were ranked as low impacts in the Mediterranean, either because the impact to the ecosystem is low or very confined at a local level, or it is not a usual impact regarding leisure boating, is reversible, or easily managed.

While in other seas and oceans the issue of sediment resuspension and the scarring of seagrass are problems linked to the propellers of motor boats and jet skis in shallow waters (Barry et al., 2020), it seems that there is a low probability of this occurring in the Mediterranean because the bays in the Mediterranean Sea are generally deep enough for sediment resuspension or propeller scarring not to occur in most of the areas (Soukissian et al., 2017). However, these are unassessed impacts in the Mediterranean and may still occur in some frequented shallow areas. Managing this impact in a confined area would be easy by prohibiting leisure boat access to that area (Barry et al., 2020).

Severe impacts of black waters only occur in small confined areas such as ports and marinas, combined with the cumulated effect of other black water sources. While most leisure boats potentially discharge their black waters at sea, several Mediterranean countries such as Spain, France and Turkey do require boats built after a certain year to have a holding tank for black waters (Holding Tank Regulations | Tek-Tanks, 2020). This issue can be easily managed through prohibiting boats without holding tanks from entering MPAs, as is the case in Port-Cros in France (Parc national de Port-Cros, 2020).

Litter from leisure boating is an unassessed issue in the Mediterranean and is not comparable to other sources of litter such as land-based litter reaching the marine environment through river discharges. This issue needs to be addressed given its cumulated impacts affecting the whole of the Mediterranean basin. Since it is an impact that is difficult to

control and regulate, information campaigns about not throwing litter at sea and recycling need to be launched. Port and marina disposal facilities also need to be improved to facilitate waste recycling.

Animal feeding from leisure boaters usually has a low impact that is generally highly reversible, but certain animals such as dolphins can become very dependent on feeding by humans (Cunningham-Smith et al., 2006), creating the need to manage this practice. The number of leisure boats from which marine animals are fed is an unassessed issue in the Mediterranean, but it may affect the whole of the Mediterranean basin. While many campaigns have been launched in the USA telling the population not to feed marine mammals, no large information campaigns have been set in motion in the Mediterranean. Attempting to feed marine mammals in the wild is illegal in the USA (NOAA, 2017a,b). Similar measures prohibiting cetacean feeding need to be applied at the Mediterranean level.

Artificial light emissions from leisure boats are ranked as a low impact because only large boats may have enough lighting power to disturb marine animals. Moreover, this impact is very confined to areas where these large boats can stay overnight (mostly in ports and marinas, but also in MPAs). Although leisure boats are not a major contributor of artificial light emissions, this is a cause for increasing concern given the upward tendency along the coastline in recent years, and the cumulated impacts cannot be ignored. Although this is an unassessed issue worldwide regarding leisure boating, it can be easily managed. For example, prohibiting lights from leisure boats at night is under consideration in the Calanques MPA, France (Julien Tavernier, pers. comm.). Similar measures should be adopted in other popular areas frequented by large boats.

4.4. Limitations of the study

A first limitation of the study is that literature reviews may be subject to positive bias, as studies finding no impacts are less likely to be reported or to appear in the literature (Fanelli, 2012). Also, the methodology used to determine the intensity of the impact is based on evidence in the existing literature, so some impacts may be underestimated if not recorded in the literature.

A second limitation is the risk assessment method used in this research. This is based in a review of the scientific literature and expert opinion, following the qualitative model developed by Lewin et al. (2019). This method was chosen due to the broad scope of this paper in assessing the environmental impacts of leisure boating in the Mediterranean. However, other methods of assessing the environmental impact of human activities exist and are available to public authorities or policy makers within the quantitative scope, or on a narrower/local scale (Lonsdale et al., 2020). For example, the ODEMM Pressure assessment tool (Robinson et al., 2013) uses a linkage framework, pressure assessment, ecological risk assessment, cost-benefit analyses and governance models to provide a solid base of evidence and capture the complexity of ecosystems in a way that enables management options to be compared. In addition, the CUMULEO-RAM Model (Vries et al., 2011) uses a peer-reviewed approach as a basis to quantify the pressure human activities exert on marine environments and translate these pressures into effects on ecosystem indicators. This model combines visual aspects and speed of calculation, making it a powerful tool to support discussions with experts. It can also guide or focus future research in the leisure boating sector, or support decisions made by policy makers.

5. Conclusions

The risks associated with different typologies of impact arising from recreational boating in the Mediterranean can potentially occur in other seas and oceans, such as Australia (Burgin and Hardiman, 2011) and the USA (Barry et al., 2020). However, policy makers tend to ignore the impacts of recreational boating impacts on coastal waters, or they are not well managed. Moreover, due to the economic importance of leisure boating in many Mediterranean countries, the implementation of regulations in areas where this sector is very developed, especially in MPAs, is difficult. Given the recorded and projected increasing demand for recreational boats in the Mediterranean and world-wide (EBI, 2019; Venturini et al., 2016), associated with increased leisure time and demand for marine-based recreation, there is an urgent need to raise awareness of the potential impacts of leisure boating in coastal environments. This requires greater research efforts to monitor the ecological impacts and pressures, especially in MPAs, and to provide new tools to better manage recreational boating in the Mediterranean. Currently, there are models within the Mediterranean, such as the Pharos4MPAs project (Carreño et al., 2019) and the European Confederation of Nautical Industries (ECNI) (Moreau, 2009), and in other parts of the world (see the experiences in Australia, Burgin and Hardiman, 2011) where scientists, policy makers, engineers and boating industry work together to produce best practices guides and environmental voluntary actions. These examples show that engaging and educating the leisure boating industry and boaters may contribute to lowering the impacts of recreational boating. These engagement activities should, however, be accompanied by new legislative actions and the financial resources required for their enforcement, in addition to research into and the use of more environmentally benign boats (paints, engines, boat equipment, design, and reutilization) and associated infrastructure (ports, marinas). Only a holistic approach that considers all these different actions will enable the impacts of recreational boating in the Mediterranean and in other parts of the world to be lowered.

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