Biological and ecological impacts derived from recreational fishing in Mediterranean coastal areas

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Short title (for running headlines): Mediterranean Recreational Fisheries

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Recreational fishing is a booming activity in Mediterranean coastal areas. Despite generating a variety of impacts on marine resources and ecosystems, there is much less research into recreational fishing than there is into commercial fishing. This is the first study to cover the diverse implications that derive from this activity in Mediterranean coastal areas, and is based on a review of different studies from 15 areas in Spain, France, Italy and Turkey. This study defines and compares the biological impact of the different recreational fishing methods on Mediterranean marine resources - particularly the most vulnerable and threatened coastal species, and characterizes the emerging and potential indirect ecological impacts on the marine ecosystem of certain aspects of this activity that have not, thus far, been taken into account (e.g. exotic species of bait, fishing gear loss and bycatch). The results highlight the importance of determining the actual impact resulting from recreational fishing in coastal areas, so that effective regulatory measures can be developed for each mode of fishing.

Keywords: vulnerable species, reproductive potential, exotic baits, bait digging, fishing gear loss, bycatch

1 INTRODUCTION

Of all the activities currently taking place in coastal areas worldwide, recreational fishing is one of the most common. Estimates from countries with reliable statistics, suggest that, on average, approximately 10% of their citizens participate in recreational fishing (Arlinghaus and Cooke, 2009). Global estimates on the number of recreational fishermen worldwide range from 220 million (World Bank, 2012) to 700 million (Cooke and Cowx, 2004) and their activities place a significant strain on resources (Cowx, 2002; Pitcher and Hollingworth, 2002; Westera et al., 2003; Lynch et al., 2004; Arlinghaus et al., 2013). Several studies support the idea that both commercial and recreational fishing can have similar environmental effects on fish (McPhee et al., 2002; Coleman et al., 2004; Cooke and Cowx, 2006, 2004; Lewin et al., 2006; Rangel and

Erzini, 2007). Recreational fishing is not as controlled nor as well investigated as commercial fishing. In fact, in the Mediterranean, recreational fishing is particularly important because it represents more than 10% of the total production of all fishing (EU, 2004) and yet, despite its importance, there are few studies that have investigated recreational fishing and even fewer in the Mediterranean itself (Coll et al., 1999, 2004; Morales-Nin et al., 2005). Concern about overfishing has been increasing in recent years and there is now greater emphasis on studying the impact of recreational fishing on marine resources and ecosystems (National Research Council, 1999, 2006; Lucy and Studholme, 2002; Coleman et al., 2004) including the use of innovative sampling techniques different to those used for commercial fisheries (Pitcher and Hollingworth, 2002; National Research Council, 2006). In the context of this study, recreational fishing in Mediterranean coastal waters is defined as all non-commercial fishing that is carried out mainly for pleasure, where the catch - the selling of which is illegal - is used for one's own consumption (or for one's family and friends). This definition does not include the following: i) people fishing in their free time for subsistence purposes (i.e. fishing for food rather than fishing for sport or pleasure); ii) the activity of retired professional fishermen who often continue fishing for pleasure or to get some extra income to complement their pensions; iii) charter fishing (which is a commercial activity carried out for profit with professional guides assisting recreational fishermen); iv) shellfish gathering (carried out on foot or by freediving and which involves gathering sea urchins, mussels, snails, etc. by hand); v) offshore fishing, which is highly focused on big game fishing and has a significant impact on large pelagic species (e.g. tuna, billfish, etc.) and vi) fishing competitions.

With reference to Mediterranean coastal areas, the main objectives of this study are twofold: a) to define and compare the biological impact of the different recreational fishing methods on marine resources, particularly the most vulnerable coastal species and those included in biodiversity conservation programmes or international conventions for the protection of flora and fauna (Barcelona Convention, Bern Convention, CITES and the IUCN Red List); and b) to summarize and characterize the emerging and potential indirect ecological impacts on the marine ecosystem of certain aspects of this activity that have not, thus far, been taken into account (e.g., exotic species of bait, fishing gear loss or bycatch).

There have been some reviews on recreational fisheries in the scientific literature, but these are mainly based on angling in freshwater ecosystems (see e.g. Lewin et al., 2006). Moreover, most of the studies found in the bibliography relating to fishing in marine ecosystems often focus on recreational fishing as a whole and do not consider separately the various modes of fishing involved. It is important to consider that each mode of fishing (boat fishing, shore fishing and spearfishing) is implicated in a variety of biological and ecological impacts that are specific to each one (Lloret and Font, 2013). We believe, therefore, that this is the first study that looks into the variety of impacts and imbalances generated by recreational fishing in Mediterranean coastal areas.

2 METHODOLOGY

For this study, we have reviewed a selection of existing studies from different coastal areas in four Mediterranean countries: Spain, France, Italy and Turkey. The sources used were scientific literature and *grey* literature (unpublished reports and documents that are not easily accessible through online searches). It is worth underlining that the bulk of the information considered for this review comes from unpublished studies provided by managers of coastal marine protected areas (MPAs), where most of the research regarding recreational fishing in the Mediterranean has been carried out. There are some kinds of recreational fishing carried out in coastal waters that could not be included in this review because of a lack of information or very little data. This includes activities involving, for example, retired professional fishermen, charter fishing, shellfish gathering, fishing competitions and offshore fishing.

In total, 24 studies from 15 different areas (Fig. 1) in the Mediterranean have been reviewed (Table 1). In order to determine, in general terms, which species face the greatest fishing pressure, we have chosen the most-caught species (those that accounted for over 10% of the total number of species caught) in each of the studies for which quantitative information was available. It should be noted that there will be a certain bias caused by the differences in the sampling periods in each study. This is because each study was based on data that was gathered at various different times of the year (Table 1).). Independently of the fishing method involved, most of the studies gathered data in spring and summer; other studies gathered data throughout the year and some studies were limited to one season only. Obviously, some fishing methods target particular species at particular times of the year when they are more accessible (or when it is legal to catch them). Therefore, any conclusions regarding the possible impacts of recreational fishing derived from a comparison of data from these different studies will be affected by the seasons in which the sampling was carried out in each study.

Particular attention was paid to vulnerable species, i.e. those species included in international conventions for the protection of biodiversity such as those of Barcelona, Bern and Washington (CITES), in the IUCN Red List or in the Habitats Directive. But we also included species with a high Intrinsic Vulnerability Index (IV). This index is calculated using fuzzy logic expert systems and is based on the life history and ecological characteristics of marine fish, such as maximum body length, age at first maturity, the von Bertalanffy growth parameter K, natural mortality rate, maximum age, geographic range, annual fecundity and the strength of aggregation behaviour (Cheung et al., 2005). The most vulnerable fish are deemed to be long-lived and slow-growing species with low reproductive potential and a narrow geographic range. The index values range from 1 to 100, with 100 being the most vulnerable. With regard to the IUCN Red List, we have only taken into account the species classified in the following categories: *critically endangered*, *endangered*, *vulnerable*, *near threatened*, and *least concern*, but not those in the category *data deficient*.

Where the data obtained has allowed, the different types of fishing (boat, shore and underwater fishing) have been analyzed separately and comparatively because, as we pointed out in the introduction, previous studies (for example, Lloret and Font 2013) have given sound reasons for investigating each type of fishing separately. However, it was not possible to carry out a separate analysis of bait types according to fishing method since most of the data did not distinguish between the types of bait used for boat fishing and those used for shore fishing. The fact that a large number of studies did not give any measurement of variability (e.g. standard deviation or standard error) makes it impossible to show any measurement of this kind.

3 DIRECT IMPACTS ON COASTAL MARINE RESOURCES

3.1 Catch composition

Taking into account all modes of fishing, the mean number of different species caught in the areas reviewed was 46; (maximum=78 in Côte Bleue; minimum=23 in Cap d'Agde). However, the number of different species caught in a particular area depends on a number of factors:

i. **The type of fishing that takes place in the area**: a comparison of the number of different species caught *from boats* (mean=43; max=65; min=22), *from shore* (mean=32; max=53; min=10) and *by spearfishing* (mean=24; max=31; min=12), shows that boat fishing affects a higher number of different species than the other types of fishing, while spear fishing is the most selective (i.e. fewer different fish species caught).

ii. **The fishing technique employed**: *Serranus cabrilla* and *Coris julis* are two species under significantly more fishing pressure than other species from both boat and shore fishermen. This may be because the commonest technique used by boat and shore fishermen is *bottom fishing with rods* - a technique which primarily results in catches of these two species. Expressed as a percentage of the total number of fish landed by boat fishermen, a maximum of 72% (Cerbère-Banyuls) and a minimum of 47% (in Plemmirio) consisted of these two species. Similarly, in Porquerolles, boat fishermen declared during interviews that *C. julis* and *S. cabrilla* were, by some distance, the species most often caught (over 90% of fishermen admitted that they regularly landed these two species). Among shore fishermen, a similar pattern emerged. The two species represented up to 65% of the total shore fishing catch in Cap de Creus, with the lowest percentage being 26% in Cerbère-Banyuls. In contrast, the species caught most often (as a percentage of the total catch) by spearfishing techniques are from the genus *Diplodus* (especially *D. sargus* and *D. vulgaris*) and the species *Dicentrarchus labrax* and *Octopus vulgaris*. These represented 43% of total catches in Cap de Creus, 35% in Archipel de Riou and 25% in Côte Bleue.

iii. **The time of year the data was gathered**: the sampling effort in some studies is concentrated at particular times of the year (Table 1). This may lead to errors in annual estimates of the catches of certain species when, for example, a particular fishing activity takes place during a particular period of the year to coincide with the peak presence of certain species or to coincide with the open season when a particular species can be fished legally: any data gathered within this period will be different from data gathered at other times of the year.

iv. **The expertise of the fishermen:** in spearfishing, for example, *O. vulgaris* is captured more often by less experienced spearfishers (Bonhomme, unpubl. res.; Chavoin and Boudouresque, unpubl. res.), while *D. labrax, Dentex dentex* or *Epinephelus marginatus* are caught by more experienced spearfishers.

In general, with regard to boat fishing and shore fishing, the species most often caught belong to the *Sparidae* and *Serranidae* families by some distance to the rest, although there were also Labridae species. With regard to spearfishers, the species most often caught also belong to the *Sparidae* family. This is further confirmation that spearfishing is the most selective fishing method in terms of taxa caught.

3.2 Yields: catch per unit effort (CPUE)

According to the data collected from the studies, it seems that, in general terms, boat fishing and spearfishing both obtain higher CPUE values than shore fishing (though there is no clear pattern when comparing boat and spearfishing). The highest CPUE value found was for the Çanakkale Strait, in Turkey (Ünal et al., 2010), with 2770 g/hour/fisherman for boat fishing and the highest value for spearfishing was 1347 g/hour/fisherman in Cap de Creus (Lloret et al., 2008b); in contrast, the highest CPUE for shore fishing was 970 g/hour/fisherman, also in the Çanakkale Strait (Ünal et al., 2010) (Fig. 2). In addition, considering each type of fishing separately, some estimates of total catches in different areas of the Mediterranean (Bernard et al., unpubl. res.; Charbonnel, unpubl. res.; Lloret and Font, 2013; Luna-Pérez, unpubl. res.) suggest that boat fishing has the largest extractive potential (followed by spearfishing and shore fishing).

Yields not only depend on the type of fishing, but also on a particular technique. For example, in the case of boat fishing, we can distinguish two sub-modalities: trolling, essentially targeting large and heavy pelagic species (hence increasing CPUEs which focus on weight), and bottom fishing with rods, targeting benthic species which are usually smaller in size and weight (leading to lower CPUEs) (Lloret et al., 2008a; Sacanell, unpubl. res.). Despite the fact that bottom fishing is the most popular fishing activity, involving between 65% and 80% of the fishermen active in the MPAs of the

Cap de Creus and Medes Islands, trolling clearly has the greatest impact in terms of biomass removed. It should be noted here that species such as *S. cabrilla* and *C. julis* which were mentioned in the previous section as being the species most often caught in terms of number, would register a much lower presence in CPUE data in terms of weight. In any case, the data regarding weight was not abundant enough to perform the relevant analyses.

There is also great disparity in the CPUE values depending on the seasons in which the studies were carried out. This is because the diversity of species caught in each season varies greatly and this has a direct effect on the CPUE values (Bernard et al., unpubl. res.; Bonhomme, unpubl. res.; Luna-Pérez, unpubl. res.; Chavoin and Boudouresque, unpubl. res.). The data also indicates that CPUEs can vary considerably depending on the expertise of the fisherman (Bonhomme et al., unpubl. res.), as shown in a study in the French Riviera (Chavoin and Boudouresque, unpubl. res.) which examined spearfishing competition data and found that the mean mass caught per fisherman showed substantial differences between more-skilled spear fishermen, who caught between 10 and 30kg/day, and less skilled fishermen who did not catch anything. A similar situation occurred in Mallorca, with *E. marginatus* being the largest specimen caught only by the more skilled spearfishing competitors (Coll et al., 2004). This may be because less skilled divers cannot fish at greater depths. Also, they may not have sufficient experience to correctly identify the microhabitats of the target species (Lincoln Smith et al., 1989). Further studies are needed to evaluate the effects of the fishermen's skills and experience on catch composition and CPUEs; such data may be much more significant in recreational fisheries than in commercial fisheries.

In general, the level of biomass removed in many Mediterranean areas is considerable, especially when compared with artisanal fishing, thus confirming the seriousness of the impact on marine resources caused by recreational fishing. Recreational fishing's *share* of total catches ranges from 10% up to 50% of the total commercial fishing catch (Lloret and Font, 2013; Ünal et al., 2010; Morales-Nin et al., 2005; Colella, unpubl. res.; Hussein et al., 2011; Leleu, unpubl. res.).

It should be noted once again that this study does not take into account several kinds of recreational fishing (such as the activity of retired professional fishermen; charter fishing; shellfish gathering and fishing competitions) because the data on such activities is poor or non-existent. Furthermore, this study does not take into account subsistence fishing, which involves people fishing for food rather than for sport or pleasure. Subsistence fishing appears to be increasing in some areas of the Mediterranean due to the current economic crisis and it is becoming increasingly difficult to distinguish between people who fish for pleasure and people who fish for food. Including data on subsistence fishing would certainly lead to higher estimations of the fishing pressure on Mediterranean coastal resources than those given in this paper.

3.3 Impact on the reproductive potential

The *reproductive potential* represents the ability of a fish stock to produce viable offspring that may recruit to the adult population or fishery (Trippel, 1999). Age and size at sexual maturity are fundamental variables that influence the reproductive potential of a fish stock (Trippel et al. 1997; Marteinsdottir and Begg, 2002). In the Mediterranean, some of the studies reviewed show that the size of the individuals captured is below the minimum landing size (MLS), which means that some recreational fishermen are landing immature fish, which is illegal. For example, in the Côte Bleue (Charbonnel, unpubl. res.), 81% of *D. sargus* and 16% of *D. vulgaris* were smaller than the legal minimum; in the Cap de Creus (Font and Lloret, 2011), 33% of *P. pagrus*, 90% of *D. vulgaris* and 66% of *D. sargus* caught from shore were below the MLS, as were 31% of *P. pagrus*, 43% *D. vulgaris* and 49% of *D. sargus* caught from boats (Lloret et al., 2008a). In contrast, in Cerbère-Banyuls (Claisse, unpubl. res.), from a total of 1753 individuals measured, only 5.2% were below the MLS.

Furthermore, when comparing the MLS of 17 species that are targeted in recreational fishing to their corresponding *size at maturity* (based on data provided in *www.fishbase.org* and Lloret et al., 2012), we found that only four species (*D. annularis*, *D. sargus*, *L. mormyrus* and *P. bogaraveo*) have an MLS that is greater than their *size at maturity*. Of the remaining 13 species, three have an MLS below size at maturity of either the male or female (♀*D. labrax*, ♂*E. marginatus* and ♀*P. acarne*) while the MLS of the other ten are below the *size at maturity* for both sexes. This raises the question of whether the MLS of certain species is high enough to ensure sustainability. For this reason, it is essential to adjust MLS values so that they are larger than size at maturity, especially in the most vulnerable species. Such action has also been suggested in areas outside the Mediterranean (e.g. in Portuguese Atlantic waters; Guerreiro et al., 2011).

Apart from the impact of recreational fishing on juveniles, the impact on large spawners must also be noted. Trippel et al. (1997) observed that the depletion of large fish may seriously lower a stock's egg production, but stock reproductive potential is further diminished if poorer gamete quality is exhibited by younger compared with older members. In Cap de Creus, for example, a study highlighted the pressure spearfishing exerts on the reproductive potential of fish species in rocky habitats along the Mediterranean coast (Lloret et al., 2008b), and a later comparative analysis in the same area also identified spearfishing as the recreational fishing technique that raises the most environmental concern among all fishing techniques considered (Lloret and Font, 2013). The removal of large individuals by spearfishing can adversely affect the reproductive potential of vulnerable fish populations because larger females are proportionally more fecund, reproduce over an extended period and spawn bigger eggs and larvae with better survival rates (reviewed by Birkeland and Dayton, 2005). Finally, for sequential hermaphrodites such as *D. sargus* and *E. marginatus*, where all the larger individuals may be of the same sex, significant removal of large fish may prejudice the spawning success of the population (Alonzo and Mangel, 2005; Molloy et al., 2008). Spear fishing competition data also support these facts because spear fishing competitions are often based on the catch of a maximum number of fish and a maximum weight in a particular number of hours (e.g. 5 and 6 hours in Mallorca, Coll et al., 2004). This means each participant tries to catch the highest number of individuals but preferably the largest ones, thus impacting on the reproductive potential of certain species, generally those that are most vulnerable (Dalzell,1996).

3.4 Vulnerable species

In total, it was found that 45 vulnerable species were being caught by recreational fishermen (Table 2). In general terms, the average proportion of vulnerable species in the catch (in each area) is about 30% of the total. Among those, there are two large decapods (*P. elephas* and *S. latus*), a bivalve (*L. lithophaga*), two sharks (*A. vulpinus* and *M. mustelus*), in addition to a large variety of fish species. Thirteen of these species have been captured via all three fishing methods; 21 are captured by only one method: 3 via spearfishing, 6 via shore fishing and 12 via boat fishing (Table 2). Boat fishing would therefore seem, a priori, to have the greatest impact on vulnerable species, affecting a total of 36 species (versus 26 by shore fishing and 20 by spearfishing; Table 2). This is consistent with the fact that boat fishermen use a greater diversity of techniques, catch a greater number of fish on average and can move from one area to another quite freely - thus going from one habitat to another. However, when the average *intrinsic vulnerability index* of fish in the catch (calculated from the arithmetic mean of the intrinsic vulnerability index of fish taxa weighted by their catch) is used, it appears that spear fishing has the greatest potential impact on vulnerable species. The average IV of the spearfishing catch in Cap de Creus (54.15) is higher than that of the shore fishing catch (52.2) and the boat fishing catch (41.22) in the same area (Lloret et al., 2008a,b; Font and Lloret, 2011); it is also higher than that of the shore fishing catch in Tabarca (49.2; Luna-Pérez, unpubl. res.). The most commonly caught vulnerable species are classified in the IUCN Red List as being of "Least Concern" followed by the species in the categories "Endangered" and "Vulnerable". There are only two cases of species from the "Near Threatened" category and two from the "Critically Endangered" category. Of the areas we reviewed, the highest number of vulnerable species were caught in the Cap de Creus with a total of 19. This was followed by Cerbère-Banyuls with 18 species. The proportion of vulnerable species caught with respect to the total number of species caught, was highest in the Medes Islands (up to 48%), and lowest in the Côte Bleue (around 10%) (Font et al., 2012).

Nevertheless, it should be noted that most of the fishing pressure on vulnerable species falls on those in the category of "least concern", i.e., the lowest degree of vulnerability on the scale of the IUCN Red List (just above the "data deficient" category). The most noteworthy case is that of *C. julis*, which is caught in very high numbers compared with other species (comprising over 50% of the total catch of vulnerable species in several areas). *C. julis* is not as vulnerable as, for example, *E. marginatus* and *S. umbra* but, on the other hand, it has an IV value of 60, which is considered high. When the vulnerable species listed as being of "least concern" are excluded from the results, we get a much lower proportion of vulnerable species in the total catch with the highest value being 5% and the lowest being reduced to zero. This, at least, indicates that the greatest fishing pressure is not exerted on the most highly vulnerable species.

3.5 Bycatch and Catch & Release

Unlike in other parts of the world where *catch and release* is a common practice (Cooke & Schramm, 2007; Cooke et al., 2006; Henderson, 2009; Danylchuk et al, 2007) and where it is estimated that approximately 60% of recreational fishing catches are returned to the sea (Cooke and Cowx, 2004), in the Mediterranean, the practice is not widespread, probably because most species caught are for human consumption (Gaudin and De Young, 2007). An exception would be the tagging programmes for bluefin tuna organized in the south of France and in some parts of the Spanish Mediterranean, and other initiatives organized by fishing associations or federations, as well as by individual fishermen (through private websites and bloggers), where special emphasis is placed on the importance of responsible recreational fishing practices. Obtaining data on *catch & release* of species is problematic because (in the absence of onboard observers) it relies on the ability of fishermen to recall and identify the species they have handled and obviously this implies a substantial potential for error. According to a review of recreational fisheries survey methods, some of the specific issues related to *catch & release* fisheries include the following: the released catch cannot be inspected in an onsite survey, unlike the kept catch; rounding errors are common; exaggeration or under reporting due to memory problems are possible and species identification errors may occur (National Research Council, 2006; Pollock and Pine, 2007). In six areas (Table 3) where studies analyzed this type of data, no clear pattern was observed. However, it appears that in some cases, the percentage of fishermen who returned some of their catch to the sea is substantial (up to 74% in Porquerolles; Bonhomme, unpubl. res.).

Nevertheless, in the Mediterranean, in many cases this practice cannot be classified, strictly speaking, as catch & release because it involves catching specimens that are considered to be too small or not worth eating and it is for this reason they are thrown back into the sea. Hence, it would be more accurate to classify them as discards or bycatch. Given the high level of fishing activity, bycatch can be significant in recreational fisheries, if species that are unwanted or protected by minimum size limits - or simply too small to eat or too big to land - are released after capture (Cooke and Cowx, 2004). Non-target species in the Mediterranean can include certain sharks and rays, but there are other non-valuable species such as *Chromis chromis* and *Synodus saurus* (among others). Discards have an unnecessary impact on the environment and should be minimized and monitored by fisheries management organisations involved in recreational fishing (FAO, 2012). According to the studies reviewed, spearfishing has the lowest level of bycatch. This is because spearfishers are highly selective and usually avoid capturing unwanted species and sizes, thus minimizing discards and even eliminating them altogether. Obviously, catch & release is not a feasible practice for spearfishers since, once a fish is speared, the damage is usually irreversible.

Although *catch & release* may appear to cause little harm, in reality it has many negative effects on fish, as shown by numerous studies on the subject (reviewed by Cooke and Schramm, 2007; Lewin et al., 2006). According to Bartholomew and Bohnsack (2005), the factors found to affect post-release mortality can be divided into five categories: i) intrinsic factors (e.g. fish size, maturation, behaviour); ii) terminal fishing gear (e.g. hook type, hook size, bait type); iii) fishing, handling, and release techniques (e.g. deep hook removal, playing time and handling time); iv) environmental conditions (e.g. temperature, dissolved oxygen); and v) other factors (e.g. indirect mortality due to multiple *catch & release* events). The question to resolve is: do fish returned to the sea always survive? It is thought that certain handling techniques can cause great stress and subsequent death among fish that are caught and then released. Other studies, for example Arlinghaus et al. (2007), focus on providing an alternative perspective in relation to fish welfare and establish (with reference to other studies) that with proper handling, many of the harmful effects can be avoided by taking into account factors such as minimizing the duration of the activity, minimizing or eliminating handling and exposure to air, using gear that reduces damage, stress or mortality (artificial lures versus organic baits, barbless hooks versus barbed hooks, etc.). The FAO Code (FAO, 2008) provides a set of principles by which fishermen should act in order to minimize the negative impact on catches.

4. INDIRECT IMPACTS ON COASTAL MARINE RESOURCES

4.1 Bait used: potential effects of exotic baits

A total of 11 groups of baits were found being used in the Mediterranean, with a great diversity within each group. Polychaeta, which includes a large number of different worm species such as, for example, the Korean blue ragworm (*Nereis aibuhitensis*, *Perinereis vancaurica* and *P. cultrifera*), the red-gilled rockworm (*Marphysa sanguinea*), the north American bloodworm (*Glycera dibranchiata*), the lugworm (*Arenicola* spp.), the bobbit worm (*Eunice aphroditois*), and other species of the genus *Nereis* such as *N. succinta, N. cultrifera* and *N. diversicolor,* were used as live bait in more than 90% of the Mediterranean coastal areas considered (Font et al., 2012).

Table 4 shows the proportion of potentially exotic bait (basically consisting of species within the polychaete and sipunculid groups) in each area. In general, the estimated use of this type of bait is high, reaching 74% in the Côte Bleue MPA (Charbonnel, unpubl. res.) and up to 86% in non-MPA areas such as the Archipel de Riou (Bonhomme, unpubl. res.; Bernard, unpubl. res.). It is not absolutely certain what proportion of the polychaetes used as bait are exotic species (given that there are also Mediterranean polychaetes) but it is unlikely to be a small proportion. Some of the polychaete species, including the Korean ragworm, the American bloodworm and some lugworms have been produced or harvested in waters outside the Mediterranean, in countries such as China, Vietnam, Korea, Britain, the Netherlands and Canada (Font and Lloret, 2011). Other species, such as the sipunculid *Sipunculus nudus* are also often imported from outside the Mediterranean (Font and Lloret, 2011). Although it is difficult to estimate the real percentage of total exotic bait, a study carried out in the Cap de Creus (Font and Lloret, 2011), revealed that at least 43% of bait used was made up of species that were not native to the Mediterranean, mainly polychaetes and sipunculids. Furthermore, it should be noted that up to 80% of the bait sold in specialty shops catering for recreational fishermen are species from outside the Mediterranean, according to a survey of several Spanish wholesalers (Font and Lloret, 2011).

The use of exotic species as bait by recreational fishermen can be a threat to the coastal ecosystem. The introduction of exotic species resulting from the release of certain baits in aquatic ecosystems has been well documented in other aquatic ecosystems around the world (Carlton, 1992; Courtenay 2007; Di Stefano et al., 2009; Ludwig and Leitch, 1996). Furthermore, in order to keep them alive and moist, live bait is often packaged with living substrates (e.g., live algae) which fishermen commonly discard into the sea. These exotic algae and other substrates may contain other living organisms, such as small crustaceans, snails and worms. This may result in these exotic small invertebrates establishing themselves in the new ecosystem (Cohen et al., 1995, 2001; Lau 1995; Weigle et al., 2005). Along with the risks of unwanted introductions, it has also been shown that the bait (live or dead) can transfer viruses that can significantly affect stocks of wild fish (Goodwin et al., 2004). With this in mind, the

Code of Practice for Recreational Fisheries (FAO, 2008; Arlinghaus et al., 2010) recommends the use of aquatic organisms only in waters from which they have been extracted and never to transfer live bait or its substrates from one area to another. In some Italian MPAs, the use of these Polychaeta species is strictly prohibited, given the environmental implications. Outside the Mediterranean, a study recently carried out in California (Cohen, 2012), has summarized and analyzed the risk of the trade in live saltwater bait, in terms of introducing, establishing and spreading non-native species in California waters.

4.2 Bait collection

Since many recreational fishermen dedicate a certain amount of time to collecting their own bait before the day's fishing begins (mussels, limpets, etc.), as is the case, for example, in Bouches de Bonifacio, Côte Bleue, Port-Cros and Cap d'Agde (in France) as well as in Cinque Terre, Capo Carbonara and Bergeggi (in Italy) (Font et al., 2012), it is important to discuss the possible adverse effects of collecting bait from its natural home. Recreational fishing is an expanding activity around the world and, consequently, so is the bait industry. Bait digging can locally influence the littoral fauna and affect the abundance and size structure of the benthic organisms that are harvested (e.g., reviewed by Lewin et al. 2006). An intensive harvest affects not only the harvested species but other components of the macro and meio-fauna, as well as bacteria and algae. The bait digging or 'pumping' and the associated trampling can involve a considerable disturbance to the sediment and affect taxa that are sensitive to disturbance of the sediment structure (Lewin et al., 2006).

The ecological impact on the benthic community of the growing business of collecting invertebrates for use as bait is well documented (McPhee et al., 2002). The use of aquatic species as bait needs to be monitored in the Mediterranean, particularly in Marine Protected Areas and especially with regard to species in danger of overexploitation (FAO, 2012). A new law approved in Croatia in 2006 which prohibited fishing with live bait illustrates the concern on this issue (Segedin, unpubl. res.).

4.3 Lost or abandoned fishing gear

It is common for recreational fishermen to lose, or throw away, all kinds of fishing gear, such as lead weights, lines and hooks, which can cause significant impacts on the marine ecosystem (Lewin et al., 2006; Chiappone et al., 2005). In other parts of the world (outside the Mediterranean) several studies have looked into the impacts caused by lost or abandoned fishing gear, such as, for example: (i) the effects of the ingestion of lead weights and other gear on waterfowl (e.g. Ferris and Ferris, 2004); (ii) the impact of lead in natural systems (Scheuhammer et al., 2003; Michael, 2006; Rattner et al., 2008; Goddard et al. 2008), though it is considered that lead derived from fishing gear has a lower impact on aquatic organisms than lead introduced by atmospheric deposition and discharges; (iii) the effects of fishing lines on sessile invertebrates (e.g. Asoh et al., 2004) causing abrasions, strangulation and reduced sunlight with a consequent weakening effect on the organisms; and (iv) the effects on marine fauna of the ingestion of plastic (Possatto et al., 2011), which is one of the most commonly used and commonly discarded materials in our seas and oceans.

Specifically in the Mediterranean, there appears to be very little scientific research into the effects of discarded fishing gear. To our knowledge, there are only two studies carried out in the Mediterranean. The first, very recently carried out in the Costa Brava, Catalonia, Spain (Lloret et al. *in press*), evaluated the loss of recreational fishing gear in a Mediterranean coastal area and discusses the potential biological impacts on fish and other wildlife of exposure to lead, plastic and other toxic materials from recreational fishing. Overall, the presence of a multitude of potentially harmful materials in the study area, particularly in shallow waters, demonstrated the importance of conducting studies to determine the actual impact resulting from recreational fishing so that effective regulatory measures can be developed for this activity. In the second study, which took place in the Isole Ciclopi MPA in 2006 (Toscano, unpubl. res.), an underwater survey was carried out by divers in an area highly popular with shore fishermen. They found high densities of materials such as lead weights and lines, which were clearly causing damage to fauna on the seabed. Currently there are no regulations governing the materials used for recreational fishing and their loss at the European or national level (Gaudin and De Young, 2007).

4.4 Other effects

Another indirect impact of recreational fishing involves anchoring and mooring which can affect marine habitats, particularly *Posidonia oceanica* meadows and coralligenous reef. Much of the impact is generated by recreational boating in busy boating areas (Lloret et al., 2008b), but since boat fishermen sometimes carry out their activities while at anchor (rather than adrift), the mechanical damage they cause to the seabed can also become a significant problem. Another impact involves the trampling of organisms on the rocks. Shore fishermen and shellfish collectors walking on the Mediterranean littoral rocky areas can damage the community of the erect algae inhabiting there, particularly *Cystoseira* assemblages, as has occurred in the Albères coast (Thibault et al., 2005) and Cap de Creus (Lloret and Riera, 2008).

5 CONCLUSION

Overall, this study shows there is an urgent need for further research and proactive management with regard to the direct and indirect impacts generated by the different modalities of recreational fishing in Mediterranean coastal areas. The impact of certain factors (among others, the catch of vulnerable species, alterations to the reproductive potential of fish, by-catch, the use of exotic species as bait, how local bait is gathered and the loss of fishing gear) has not yet been sufficiently investigated. It is essential that more studies are carried out to determine the actual impact resulting from recreational fishing in Mediterranean coastal areas, so that effective regulatory measures can be developed for each fishing modality.

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