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Total number of authors:
12

Published in:
Biological Conservation

Link to article, DOI:
10.1016/j.biocon.2018.03.012

Publication date:
2018

Document Version
Peer reviewed version

Di Franco A., Plass-Johnson J., Di Lorenzo M., Claudet J., Gaines S.D., García-Charton J.A., Giakoumi S., Grorud-Colvert K., Werner Hackradt C., Micheli F., Guidetti P., 2018. Linking home ranges to protected area size: the case study of the Mediterranean Sea. *Biological Conservation* 221: 175–181. https://doi.org/10.1016/j.biocon.2018.03.012

Linking home ranges to protected area size: the case study of the Mediterranean Sea

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Abstract

Protected areas not allowing extractive activities (here called fully protected area) are a spatially explicit conservation management tool commonly used to ensure populations persistence. This is achieved when an adequate fraction of a species' population spends most of its time within the boundaries of the protected area. Within a marine context, home ranges represent a tractable metric to provide guidance and evaluation of fully protected areas. We compiled peer-reviewed literature specific to the home ranges of finfishes and invertebrates of ecological and/or commercial importance in the Mediterranean Sea and related this to the size of 184 Mediterranean fully protected areas. We also investigated the influence of fully protected areas size on fish density in contrast to fished areas with respect to home ranges. Home range estimations were available for 11 species (10 fishes and 1 lobster). The European spiny lobster *Palinurus elephas* had the smallest home range (0.0039±0.0014 km^2; mean±1 SE), while the painted comber *Serranus scriba* (1.1075±0.2040 km^2) had the largest. Approximately 25% of Mediterranean fully protected areas are larger than 2 times the size of the largest home range recorded. Fish densities were significantly higher when fully protected areas were larger than the home range, while no change in density occurred when home ranges were larger than fully protected areas. These results display a direct link between the effectiveness of fully protected areas and species' home range, suggesting that fully protected areas of at least 3.6 km^2 may increase the density of local populations of coastal marine species.

Keywords: fully protected areas, marine protected areas (MPA), marine protected area design, fish, coastal species, marine protected area size

1. Introduction

In an effort to reach the Aichi Target 11 of the Convention on Biological Diversity to effectively protect 10% of the ocean by implementing management measures by 2020, several countries have established very large (>30,000 km^2) marine protected areas (Singleton & Roberts 2014). Marine protected areas are places in the sea designed to protect marine species and ecosystems, while sometimes allowing for sustainable uses of marine resources within their boundaries (Pisco & UNS, 2016). Since 2006, the percentage of marine protected area designations has increased dramatically in the Pacific Ocean due to initiatives by small island countries (e.g. Kiribati, Cook Islands) or nations with territories in the area (e.g. USA, France, the UK) that take advantage of protecting remote areas with relatively little human dependency (Wilhelm *et al.*, 2014). Very large marine protected areas contribute significantly to conserving many aspects of natural marine systems that cannot be protected with small marine protected areas (e.g. wide ranging species, all habitats used during the entire life cycle of marine species including larval dispersing stages) (Wilhelm *et al.*, 2014). In areas far from population centres and markets, strict conservation objectives can prevail. However, in more densely populated areas where conflicting marine resource uses are at stake, conservation benefits must trade-off with fisheries objectives and other human uses, thus, establishing very large marine protected areas can be extremely challenging.

Marine protected areas can be multiple use areas containing a fully protected area (also called no-take zone), where all extractive activities are forbidden, and one or more types of partially protected areas, where a range of extractive uses are allowed. Fully protected areas are the most effective type of marine protected areas for protecting ecological systems (Sala and Giakoumi 2017, Giakoumi *et al.*, 2017) in which increased abundance, biomass, diversity, body size, and reproductive output of species have been observed within their borders (Claudet *et al.*, 2008; Sala *et al.*, 2012), which can also provide benefits to the surrounding, fished areas (Green *et al.*, 2015; Di Lorenzo *et al.*, 2016). The movement from inside to outside the fully protected area occurs when the density of species inside a fully protected area increase towards the carrying capacity and organisms spillover via density-dependent diffusion (Kellner *et al.*, 2007). However, there is contrasting evidence concerning the effect of habitat continuity on spillover. Some studies suggest that spillover of certain species can be facilitated by suitable habitat outside the fully protected area (e.g. Forcada *et al*., 2009), while a recent review demonstrated that fish also cross unsuitable habitats when competition pressure is strong (Di Lorenzo *et al.*, 2016). To effectively reduce fishing-related mortality, the entire home range of individuals must be located within a fully protected area (Kramer & Champman 1999). We define home range as the area in which an individual spends 95% of its time and engages in routine activities, such as foraging and resting; this generally does not include ontogenetic changes in habitat or reproductive migrations (Green *et al.*, 2015).

Home range is considered a tractable metric to inform the implementation and configuration of effective marine protected areas or networks of marine protected areas (Kramer & Champman 1999; Green *et al.*, 2015). Moreover, it is also a practical measurement to determine the adequacy of a marine protected area and it is an intelligible metric to communicate to stakeholders (Weeks *et al.*, 2016). Information on the home range of marine organisms, and how this varies within (e.g. related to ontogenetic phases and individual size) and among species and with changes in environmental factors (e.g. density, disturbances, habitat composition) is therefore pivotal to designing effective fully protected areas (Green *et al.*, 2015). Since home range sizes can vary dramatically across species, the multispecies impacts of fully protected area designs will depend upon the range of biological characteristics of target species. It is difficult to determine the adequacy of fully protected areas for protecting local populations of marine species across their home ranges because the available literature lacks syntheses that associate home ranges and fully protected area sizes (but see McCauley *et al.*, 2015 and Weeks *et al.*, 2016).

To better understand the relationship between fully protected area size and species home ranges we synthesised the available data from the Mediterranean Sea as a case study. The Mediterranean Sea is a densely populated coastal area and is one of the most exploited seas worldwide (Micheli *et al.*, 2013a). High coastal population densities, industrialisation, maritime traffic, and tourism-based economies, along with a marine area that is partitioned among many differing countries/regions, are only a few of the challenges that can prevent implementation of large-scale conservation plans for Mediterranean countries and territories. This has resulted in many Mediterranean marine protected areas that are quite small. Although well-enforced small Mediterranean marine protected areas are effective at local scales (Giakoumi *et al.*, 2017), these may be unable to protect adequate proportions of species populations at a regional scale (Guilhaumon *et al.*, 2015). Here we focus on the home range of coastal marine species of the Mediterranean Sea. It should be noted that depending on the source, “full protection” can have different definitions (e.g. no access, no extraction, etc.). However, for our purposes we use the term fully protected area for sites where no removal of biota as a minimum requirement (sensu Horta e Costa *et al.*, 2016).

The aims of this paper are to: 1) collate all available information on the home ranges of Mediterranean marine species to explore the relationship between body size and home range and identify evidence of overlapping home ranges; 2) evaluate current Mediterranean fully protected area sizes relative to the distribution of home ranges; 3) investigate the influence of fully protected area size on increased density of individuals of the species of interest in fully protected areas compared to fished areas with respect to home range size, and 4) provide information about benefits to local populations based on the size of Mediterranean fully protected areas. Although our focus is the Mediterranean Sea, the findings of this study may have implications for other regional seas.

2. Methods

2.1. Data collection, handling, and analyses

We conducted a comprehensive survey of the peer-reviewed literature to compile data on the home ranges of finfishes and invertebrates from the Mediterranean Sea (see Appendix A for details on search procedure). Studies had to utilise satellite, radio, or acoustic telemetry, because they are the most reliable methods to obtain home range size estimations (Green *et al.*, 2015). Species with large home ranges and individually legislated protection (i.e. cetaceans, sea turtles) were not included because these home ranges sizes are not feasibly encompassed by fully protected areas. A total of 15 studies met our criteria (Table 1).

We compiled information on movements of individuals as well as the study area (e.g. presence/absence of a marine protected area and protection level; See Table A.2 in Supporting Information). To provide home range estimates at the species level, the values for all individuals within a species were averaged (as in McCauley *et al.*, 2015). Individuals included in our dataset were those that provided reliable estimates of home ranges and were retained in each primary study based on specific quality control criteria defined by the those authors (see Table A1). Across all studies, approximately 22% (55 out 245) of monitored individuals were discarded by the primary authors (Table A1). Due to high variability in tracking time among the retained individuals (see Results and Table A1), we performed sensitivity analyses to determine whether tracking time affected home range estimations and if there was evidence of a threshold in tracking time below which home range estimates should be discarded due to high variability and therefore unreliable (see Appendix A and Fig

A1). Variability in home range estimates were not related to tracking time (Appendix A). Therefore all the individuals retained by the primary authors were also included in our dataset and analyses.

To test whether home range size varied among species in relation to body size (McCauley *et al.*, 2015), we assessed the relationship between the maximum size of a species (extracted from Fishbase with reference to Mediterranean samples) and its mean home range size.

Only 76 of the 1,231 marine protected areas designated in the Mediterranean include one or more fully protected areas, with a total of 184 individual fully protected areas (collated from MAPAMED 2016 following the fully protected area definition provided by Horta e Costa *et al.* 2016). To investigate the influence of fully protected area size on fish densities compared to external unprotected areas, we used data compiled by Giakoumi *et al.*, (2017) and a weighted meta-analytical approach for each of the 11 species (see Appendix A for details on analytic procedure). The effect size for each study was estimated by using the log-response ratio, ln (X_T /X_c), where X_T and X_c are the mean values of density inside (treatment site) and outside the fully protected area (control site), respectively. Density was selected as opposed to biomass due to the greater availability of studies and data. Only studies from highly enforced fully protected areas, (sensu Giakoumi et al. 2017) were considered because multiple studies have shown that the increase in density (or biomass) in marine protected areas is strongly linked to enforcement (Guidetti *et al*., 2008, Edgar *et al*., 2014, Giakoumi *et al*., 2017). Moreover, it would be impossible to disentangle the effects of inadequate enforcement and ineffective marine protected area size on density in our analyses. The effect sizes for all species were compiled into two groups: a) fully protected areas smaller than species home ranges and b) fully protected areas larger than species home ranges. We used the average estimated home range size for each species (see Results) compares to fully protected area size. This approach could show that fully protected areas larger than the home range size result in a greater density of fishes when compared to fully protected areas that do not encompass the entire home range.

Previous studies suggested, as a conservative guideline, that a fully protected area should be at least twice the size of the species' home range to provide significant benefits to a population (Kramer & Chapman 1999; Green *et al*., 2015). We applied this criterion to conservatively assess the potential for fully protected areas to protect local populations of each species. In fact, if fully protected areas larger than the average home range size of a species lead to significant increase in density (see previous paragraph and Results), implementing fully protected areas at least twice the size of target species' home ranges would further ensure ecological benefits at the local population scale. We calculated the percent of individual fully protected areas greater than twice the size of the largest individual home range assessed for a given species, thus accounting for intra-specific, inter-individual variability in home range estimates (Appendix A). This allowed us to estimate the fraction of current fully protected areas that could provide significant benefits to a particular species.

3. Results

Home range estimates were available for 11 species (10 fish and one lobster species) in nine study areas, with a total of 190 monitored individuals (Table A.1). Most of the 15 studies (86%) were conducted in marine protected areas and more than half (53%) contain home range estimates from fully protected areas (Table 1, Table A2). Individuals were monitored for periods ranging from three to 372 days, with an average (± 1 S.E.) and median tracking time of 158(±8) and 147 days, respectively. More than three-quarters (79%) of individuals were tracked for more than one month and 62% were tracked for more than 100 days (Table A.2). Individual home ranges varied in size between 10s of square meters (i.e. 0.00004 km^2, *Epinephelus marginatus* tracked for one year within the fully protected area of Cabo de Palos - Islas Hormigas, Spain) and a few square kilometres (1.874 km^2, *Sarpa salpa* tracked for 71 days in Medes Islands marine protected area and the surrounding fished area, Spain). Of the nine studies that released individuals within fully protected areas, six studies reported that all individuals stayed completely within the fully protected area throughout the study period, ranging from one month to one year (Table A1). A significant positive relationship between fish size and home range size was identified for only one species (*Epinephelus costae*) in one study (Table 1). All studies reported evidence of overlapping home ranges among conspecific individuals.

At the species level, the home range of the European spiny lobster *Palinurus elephas* was the smallest (0.0039±0.0014 km^2; mean± 1 SE). The painted comber *Serranus scriba* (1.1075±0.2040 km^2) had the largest home range and was the only species with a home range > 1 km^2 (Fig. 1).

When considering only the fish species, the relationship between maximum total length and average home range is well described by an exponentially decaying curve (Fig. 2). This relationship is highly significant ($F= 31.37$, $n=10$, $p= 0.0005$) and explains 79% of the variability in home range size.

Mediterranean fully protected areas range from 0.01 to 153.94 km^2, with approximately 50% between 0.01 and 1 km^2 (Fig. A2). A further 13% of the fully protected areas are between 1 and 2 km^2. Only 8.7% of Mediterranean fully protected areas are larger than 10 km^2 (Fig. A2).

When considering the combined effect of multiple species, we found density was significantly affected by fully protected area size. Fully protected areas larger than the species' home ranges resulted in higher densities of that species (log-response ratio: E=-0.39±1.01, 95% CI, n=7) (Fig. 3).

Combining information about fish home ranges and the size of individual fully protected areas, we found that 24.5% of Mediterranean fully protected areas are larger than two times the largest home range size recorded of the investigated species (that of the salema, *S. salpa*, Table 1) (Fig. 1, Table A3). Approximately 36% of fully protected areas are larger than twice the home range size of most species considered in this analysis (8 out the 11 species, Table A4).

4. Discussion

Conservation practices in densely populated and highly used areas such as the Mediterranean Sea are constrained by multiple social, economic, and political considerations. Thus, it is unlikely that fully protected areas will be implemented at sizes large enough to protect individuals and populations of wide ranging species (e.g. sharks, Heupel *et al.*, 2004, carangids, Brown *et al.*, 2010, or turtles, Schofield *et al*., 2013), or that they will encompass the entire range of ecological requirements (e.g., spawning grounds) of even small-ranging species. These constraints, however, do not preclude marine protected areas from meeting other important conservation goals such as effectively protecting an area that contains most of the ecological requirements of species with smaller home ranges. Although very large marine protected areas protect a wider range of species during their varied life histories, small marine protected areas can lead to positive effects for coastal species with high economic value like those considered in the present study. Here, we found that about one-third of the Mediterranean fully protected areas are large enough to encompass twice the size of the home ranges of most of the 11 studied species (10 finfishes and one lobster), despite the small average size of Mediterranean fully protected areas. The 10 fish species on average (±1 S.E.) accounted for 31.1(±0.7)% of species richness and 40(±2.0)% of total coastal fish biomass in the 13 Mediterranean marine protected areas investigated by Guidetti *et al.*, (2014). The 10 fish species in the present study include two high trophic level predators (*E. marginatus* and *E. costae*), two keystone species that feed on sea urchins, a group responsible for the creation of barrens in the Western Mediterranean Sea (*D. sargus* and *D. vulgaris*), and the only two autochthonous herbivorous fishes in the Mediterranean Sea (*S. salpa* and *S. cretense*). In addition, six of the 11 species (*E. marginatus*, *E. costae*, *D. sargus*, *D. vulgaris*, *Sciaena umbra*, *Palinurus elephas*) are commercially important across the Mediterranean (Guidetti *et al.*, 2014). Despite the existence of tracking studies for only 11 species, they are highly ecologically and economically important when determining the effectiveness of Mediterranean marine protected areas. However, the interpretation of our results could be made more robust by increasing the number of studied species and the number of tracked individuals of each species. Including more species and habitat-specific information both within the fully protected area and the surrounding area would allow for comparative analyses (inside vs. outside marine protected area) both at the level of the individual and the community, further increasing application to assist the design/management of fully protected areas relative to species' movements.

Although biodiversity conservation is commonly the objective of marine protected areas and their fully protected areas at the global level (Watson *et al.*, 2014; Sala and Giakoumi 2017), fisheries interests can strongly offset these objectives in densely populated regions such as the Mediterranean Sea. In the Mediterranean, coastal fisheries are mostly small-scale and multispecific (Di Franco *et al.*, 2016), suggesting that optimal fully protected area size should be a compromise between the inclusion of the home ranges of most species and the optimal size for spillover to neighbouring areas (Di Lorenzo *et al.*, 2016), which are often partially protected (Di Franco *et al.*, 2016).

Here, we highlight the potential of enforced fully protected areas to produce significant increases in fish densities when the fully protected areas are larger than the average home range sizes of each target species. Conversely, fish abundances did not show any response to protection in highly enforced fully protected areas smaller than the species' home ranges. This, however, does not necessarily transfer to the species level. Protection of a population, or ultimately species, within fully protected areas can only occur when a viable and sustaining proportion of the species' population is protected. Local protection of species can also be achieved through a large network of marine protected areas that protect a significant portion of a population (Guilhaumon *et al.*, 2015; Giakoumi *et al.*, 2017).

Among the 11 species studied, *Epinephelus marginatus* and *E. costae* are two of the most important high-level coastal predators because they have important effects on ecosystem functioning (Prato *et al.*, 2013). Globally, high-level predators with large home ranges (>100 km^2) are primarily sharks (McCauley *et al.*, 2015), which have mostly disappeared along Mediterranean coasts due to overfishing (Sala *et al.*, 2012). The two Mediterranean high-level predators for which home range estimates were available had very small home ranges; these contribute to the negative relationship between species size and home range. This suggests that within small fully protected areas, integral ecological functions mediated by specific large-sized, high-level predators with low mobility may be conserved or recovered.

Many of the movements compiled here were performed within the boundaries of effective marine protected areas (Claudet *et al.*, 2008; Guidetti *et al.*, 2014). By protecting populations of exploited species and habitats, marine protected areas also preserve and re-establish species interactions. Provided the age of a well-managed marine protected area is sufficient to allow the complete response of species to protection, some populations within a fully protected area may approach their carrying capacity (García-Rubies *et al.,* 2013). Due to the need to forage further to find resources, fishes associated with fully protected areas may have larger home ranges than those at fished sites. Few studies (all conducted outside the Mediterranean Sea) have concurrently tagged individuals of the same species both inside and outside marine protected areas, and those that did so reported no clear effect due to high variability among individual movements (Parson *et al*., 2010 and references therein). Despite the lack of within-study comparisons in our dataset, the home ranges of *D. sargus, D. vulgaris*, and *S. salpa* (the three species for which we had information from both marine protected areas and fished areas) from the fully protected areas were larger than their conspecifics from fished areas. These studies also showed that some individuals from the fully protected areas moved into fished areas, supporting goals to augment fisheries with the implementation of fully protected areas. This evidence supports the concept that within fully protected areas increased density-dependence can drive spillover. However, this cannot be applied generally because specific studies comparing home ranges in protected and unprotected conditions are scarce, and further research is needed to clarify this process. Likewise, information specific to environmental factors (e.g. habitat coverage and spatial distribution, depth; Topping et al., 2005) are needed to determine home range variability between marine protected areas and fished areas.

The use of the '2 × home range' criterion within this study is applied from Kramer & Chapman (1999) and Green *et al.,* (2015). These studies and the present one recognise that this value is a minimal threshold. Other information concerning habitat requirements and individual distribution is needed to fully characterise movement of species throughout their life cycle to ensure the protection of individuals and populations (D'Aloia *et al*., 2017). Although we used the largest home range recorded for a species as a conservative estimate, extreme movements during stages of high vulnerability such as spawning aggregations often occur beyond fully protected area boundaries (Di Lorenzo *et al.*, 2014) and are likely not reflected in these reviewed studies. Furthermore, this study lacks information on the habitat requirements of Mediterranean fishes at different spatial scales, as well as habitat distribution maps beyond marine protected area boundaries. Suitable habitat outside the studied marine protected areas or at greater depths may have impacted home range observations as individuals would have moved more, or less, according to specific requirements. Therefore, when assessing the ability of marine protected areas to afford protection to particular species there is a strong need to assess the habitat requirements of species at every phase of their life cycle, their specific needs during crucial phases (i.e. spawning and nursery areas), and the degree of overlap of individual home ranges. At the same time, extensive habitat mapping efforts and concomitant species distribution and abundance studies are required within and outside marine protected areas to assess habitat discontinuities that impact observed home ranges.

Of the 76 Mediterranean marine protected areas that are either fully protected s, or include at least one fully protected area, only 10 were implemented after 2006; the year of the first home range study (Jadot *et al*., 2006, Tables 1). This suggests that species' home ranges were not considered in the design of the majority (87%) of Mediterranean marine protected areas, even for those where fish/invertebrate protection was a primary conservation goal. Furthermore, existing conservation planning studies identifying priority areas for conservation in the Mediterranean Sea, either at local scales or at the regional scale, have not considered multiple species' home ranges (Micheli *et al.*, 2013b).

In summary, we demonstrated that one fourth of Mediterranean fully protected areas are large enough to provide protection to local populations of 11 ecologically and commercially important species (with these species representing a considerable proportion of

Mediterranean coastal fish assemblages). However, the strong protection offered by fully protected areas is only ensured by appropriate design and effective enforcement (Guidetti *et al.*, 2014). Recent work has shown that small Mediterranean marine protected areas tend to have higher levels of enforcement, underscoring their value as a marine conservation tool in this crowded region (Giakoumi *et al.*, 2017). Mediterranean fully protected areas of at least 3.6 km^2 may have increased density of local populations of the species investigated in the present study.

Although the species covered in this study include a relevant set of economically important and targeted species in the Mediterranean (Guidetti *et al*., 2014), a spatial area of 3.6 km2 should be considered a minimal threshold and augmented when new home range data are available, thus ensuring benefits to as many species as possible. The transfer of protection benefits from single populations (inhabiting marine protected areas) to meta-populations and species depends on the aggregate benefits from all protected areas (Grorud-Colvert *et al*., 2014).

Even though our analyses, coupled with recent Mediterranean-wide analyses (Giakoumi *et al*., 2017), suggest that many of the small existing marine protected areas are individually providing benefits to the local populations of these 11 species, the overall benefits (i.e. at meta-population and species level) could be small because the total coverage of marine protected areas is cumulatively small. Currently only 0.04% of the Mediterranean Sea is declared as fully protected from fishing (PISCO & UNS, 2016). By linking these spatial requirements of fully protected areas to recent studies on connectivity among protected areas, we can extrapolate minimal requirements needed to implement beneficial marine protection. Taking the entire Mediterranean coastline as a practical example and conservatively allowing for no more than 50 km between marine protected areas (based on recent connectivity estimates for a few Mediterranean coastal fishes, Di Franco *et al.*, 2015 and reference therein, and for other species from outside the Mediterranea sea, Almany *et al*., 2017 and reference therein), at least 1.7% of the coastal area between 0 and 50 meters of depth (the area where most coastal fishes live) should be protected from any form of fishing through a network of fully protected areas. This recommendation is in line with the recent call to fully protect 2% of the Mediterranean Sea issued in the Tangier Declaration (https://drive.google.com/file/d/0Bw8D-TFFFccxUHVMTFdQMElPOVU/view) by researchers and conservation practitioners. Much more progress is needed to increase spatial coverage and the effective implementation of management measures to benefit species while meeting international targets for marine protection and also benefiting resource users. Here, we provide a synthesis of the home ranges of Mediterranean marine species, providing powerful, empirically-based information that can be used to inform marine spatial planning.

Acknowledgments

The study was supported by the Prince Albert II of Monaco Foundation, Total Corporate Foundation, MedPAN, RAC-SPA, French MPA Agency, WWF, DG MARE (SafeNet, Mantis) , BiodivERsA (BUFFER), FBBVA (ECOMERO), and Interreg MED Programme (FishMPABlue2 co-financed by European Regional Development Fund – ERDF).

We thank the Editor Amanda Bates and two anonymous reviewers for their useful comments on the manuscript.

References

Almany, G.R., et al, 2017. Larval fish dispersal in a coral-reef seascape. Nat. Ecol. Evol. 1, 0148.

Alós, J., March, D., Palmer, M., Grau, A., Morales-Nin, B., 2011. Spatial and temporal patterns in *Serranus cabrilla* habitat use in the NW Mediterranean revealed by acoustic telemetry. Mar. Ecol. Prog. Ser. 427, 173–186.

Alós, J., Cabanellas-Reboredo, M., 2012. Experimental acoustic telemetry experiment reveals strong site fidelity during the sexual resting period of wild brown meagre, *Sciaena umbra*. J. Appl. Ichthyol 1, 6.

Alós, J., Cabanellas-Reboredo, M., Lowerre-Barbieri, S., 2012a. Diel behaviour and habitat utilisation by the pearly razorfish during the spawning season. Mar. Ecol. Prog. Ser. 460, 207–220.

Alós, J., Cabanellas-Reboredo, M., March, D., 2012b. Spatial and temporal patterns in the movement of adult two-banded sea *bream Diplodus vulgaris* (Saint-Hilaire, 1817). Fish. Res. 115–116, 82–88.

Aspillaga E., Bartumeus F., Linares C., Starr R.M., López-Sanz À., Díaz D., *et al.*, Ordinary and Extraordinary Movement Behaviour of Small Resident Fish within a Mediterranean Marine Protected Area. PLoS ONE. 2016;11(7):e0159813. doi: 10.1371/journal.pone.0159813. pmid:27437692

Brown, H., Benfield, M.C., Keenan, S.F. & Powers, S.P. (2010). Movement patterns and home ranges of a pelagic carangid fish, Caranx crysos, around a petroleum platform complex. Mar. Ecol. Prog. Ser. 403, 205–218.

Claudet, J., Osenberg, C.W., Benedetti-Cecchi, L., Domenici, P., García-Charton, J.A., Pérez-Ruzafa, Á., Badalamenti, F., Bayle-Sempere, J., Brito, A., Bulleri, F., Culioli, J.M., Dimech, M., Falcón, J.M., Guala, I., Milazzo, M., Sánchez-Meca, J., Somerfield, P.J., Stobart, B., Vandeperre, F., Valle, C. & Planes, S. (2008). Marine reserves: Size and age do matter. Ecol. Lett., 11, 481–489.

D'Aloia, C., Daigle, R.M., Cote, I.M., Curtis, J.M.R., Guichard, F., Fortin. M.J., 2017. A multiple-species framework for integrating movement processes across life stages into the design of marine protected areas. Biol. Conserv. 216: 93-100

D'Anna, G., Giacalone, V.M., Pipitone, C., Badalamenti, F., 2011. Movement pattern of white seabream, *Diplodus sargus* (L., 1758) (Osteichthyes, Sparidae) acoustically tracked in an artificial reef area. Ita. J. Zool. 78, 255e263.

Di Franco, A., Calò, A., Pennetta, A., De Benedetto, G., Planes, S., Guidetti, P., 2015. Dispersal of larval and juvenile seabream: Implications for Mediterranean marine protected areas. Biol. Cons. 192, 361–368. Doi: 10.1016/j.biocon.2015.10.015

Di Franco, A., Thiriet, P., Di Carlo, G., Dimitriadis, C., Francour, P., Guitiérrez, N., de Grissac, A., Koutsoubas, D., Milazzo, M., del Mar Otero, M., Piante, C., Plass-Johnson, J., Sainz-Trapaga, S., Santarossa, L., Tudela, S., Guidetti, P., 2016. Five key attributes can increase marine protected areas performance for small small-scale fisheries management. Sci. Rep. 1–9.

Di Lorenzo, M., D'Anna, G., Badalamenti, F., Giacalone, V.M., Starr, R., Guidetti, P., 2014. Fitting the size of marine reserves to movement patterns of protected species: a case study on the white seabream (*Diplodus sargus sargus*) in the Mediterranean Sea. Mar. Ecol. Prog. Ser. 502, 245–255.

Di Lorenzo, M., Claudet, J. & Guidetti, P., 2016. Spillover from marine protected areas to adjacent fisheries has an ecological and a fishery component. J. Nat. Cons. 32, 62–66.

Edgar, G.J., Stuart-Smith, R.D. , Willis, T.J., Kininmonth, S., Baker, S.C., Banks, S., Barrett, N.S., Becerro, M.A., Bernard, A.T.F., Berkhout, J., Buxton, C.D., Campbell, S.J., Cooper, A.T., Davey, M., Edgar, S.C., Försterra, G., Galván, D.E., Irigoyen, A.J., Kushner, D.J., Moura, R., Parnell, P.E., Shears, N.T., Soler, G., Strain, E.M.A., Thomson, R.J., 2014. Global conservation outcomes depend on marine protected areas with five key features. Nature 506, 216–220.

Forcada, A., Valle, C., Bonhomme, P., Criquet, G., Cadiou, G., Lenfant, P., Sánchez-Lizaso, J. L., 2009. Effects of habitat on spillover from marine protected areas to artisanal fisheries. Mar. Ecol. Prog. Ser. 379, 197–211.

García-Rubies, A., Hereu, B. & Zabala, M., 2013. Long-Term Recovery Patterns and Limited Spillover of Large Predatory Fish in a Mediterranean MPA. PLoS One, 8(9), e73922.

Giacalone V.M., Barausse A., Gristina M., Pipitone C., Visconti V., Badalamenti F., D'Anna G. 2015 Diel activity and short-distance movement pattern of the European spiny lobster, *Palinurus elephas*, acoustically tracked. Mar. Ecol. 36, 389−399.

Giakoumi S., Scianna C., Plass-Johnson J., Micheli F., Grorud-Colvert K., Thiriet P., Claudet J., Di Carlo G., Di Franco A., Gaines S.D., García-Charton J.A., Lubchenco J., Reimer J., Sala E., Guidetti P. 2017. Ecological effects of full and partial protection in the crowded Mediterranean Sea: a regional meta-analysis. Sci. Rep. 7, 8940; doi:10.1038/s41598-017-08850-w

Green, A.L., Maypa, A.P., Almany, G.R., Rhodes, K.L., Weeks, R., Abesamis, R.A., Gleason, M.G., Mumby, P.J. & White, A.T. (2015). Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. Biol.

Rev. 90, 1215–1247.

Grorud-Colvert, K., Claudet, J., Tissot, B.N., Caselle, J.E., Carr, M.H., Day, J.C., Friedlander, A.M., Lester, S.E., De Loma, T.L., Malone, D. & Walsh, W.J., 2014. Marine protected area networks: Assessing whether the whole is greater than the sum of its parts. PLoS One 9, 1–7.

Guidetti, P., Milazzo, M., Bussotti, S., Molinari, A., Murenu, M., Pais, A., Spanò, N., Balzano, R., Agardy, T., Boero, F., Carrada, G., Cattaneo-Vietti, R., Cau, A., Chemello, R., Greco, S., Manganaro, A., Notarbartolo di Sciara, G., Russo, G. F., Tunesi, L., 2008 Italian marine reserve effectiveness: Does enforcement matter? Biol. Conserv. 141, 699−709.

Guidetti, P., Baiata, P., Ballesteros, E., Di Franco, A., Hereu, B., Macpherson, E., Micheli, F., Pais, A., Panzalis, P., Rosenberg, A.A., Zabala, M. & Sala, E., 2014. Large-scale assessment of mediterranean marine protected areas effects on fish assemblages. PLoS One 9(4), e91841.

Guilhaumon, F., Albouy, C., Claudet, J., Velez, L., Ben Rais Lasram, F., Tomasini, J.A., Douzery, E.J.P., Meynard, C.N., Mouquet, N., Troussellier, M., Araújo, M.B. & Mouillot, D., 2015. Representing taxonomic, phylogenetic and functional diversity: New challenges for Mediterranean marine-protected areas. Diversity and Distribution, 21, 175–187.

Hackradt C.M., 2012. Population ecology and mobility patterns of groupers (Serranidae: Epinephelinae) on temperate rocky reefs on south-western Mediterranean. Sea: Implications for their conservation. PhD thesis pp 160

Heupel, M.R., Simpfendorfer, C. & Hueter, R.E., 2004. Estimation of Shark Home Ranges using Passive Monitoring Techniques.Environ. Biol. Fish. 71, 135–142.

Horta e Costa, B., Claudet, J., Franco, G., Erzini, K., Caro, A. & Goncalves, E.J., 2016. A regulation-based classification system for Marine Protected Areas (MPAs). Mar. Pol. 72, 192–198.

Jadot, C., Donnay, A., Acolas, M.L., Cornet, Y., Begout Anras, M.L., 2006. Activity patterns, home-range size, and habitat utilization of *Sarpa salpa* (Teleostei: Sparidae) in the Mediterranean Sea. ICES J. Mar. Sci. 63, 128–139.

Kellner, J.B., Tetreault, I., Gaines, S.D. & Nisbet, R.M., 2007. Fishing the Line Near Marine Reserves in Single and multispecies fisheries. Ecol. Appl. 17, 1039–1054.

Kramer, D. & Champman, M., 1999. Implications of fish home range size and relocation for marine reserve function. Environ.Biol.Fish- 55, 65–79.

La Mesa G, Consalvo I, Annunziatellis A, Canese S. 2012. Movement patterns of the parrotfish *Sparisoma cretense* in a Mediterranean marine protected area. Mar. Environ. Res. 82, 59–68

La Mesa, G., Consalvo, I., Annunziatellis, A., Canese, S., 2013. Spatio-temporal movement patterns of *Diplodus vulgaris* (Actinopterygii, Sparidae) in a temperate marine reserve (Lampedusa, Mediterranean Sea). Hydrobiologia 20, 129–144.

March, D., Palmer, M.,Alós, J., Grau,A., Cardona, F., 2010. Short-term residence, home range size and diel patterns ofthe painted comber *Serranus scriba* in a temperate marine reserve. Mar. Ecol. Prog. Ser. 400, 195–206.

McCauley, D.J., Pinsky, M., Palumbi, S.R., Estes, J.A., Joyce, F. & Warner, R.R., 2015. Marine defaunation: Animal loss in the global ocean. Science. 80, 347.

MedPAN & UNEP-MAP-RAC/SPA 2016. MAPAMED, the database on sites of interest for the conservation of marine environment in the Mediterranean Sea. October 2016 release. http://www.mapamed.org

Micheli, F., Halpern, B.S., Walbridge, S., Ciriaco, S., Ferretti, F., Fraschetti, S., Lewison, R., Nykjaer, L. & Rosenberg, A.A., 2013a. Cumulative human impacts on Mediterranean and Black Sea marine ecosystems: Assessing current pressures and opportunities. PLoS One. 8(12), e79889.

Micheli, F., Levin, N., Giakoumi, S., Katsanevakis, S., Abdulla, A., Coll, M., Fraschetti, S., Kark, S., Koutsoubas, D., Mackelworth, P., Maiorano, L. & Possingham, H.P., 2013b. Setting Priorities for Regional Conservation Planning in the Mediterranean Sea. PLoS One. 8(4), e59038.

Pages JF, Bartumeus F, Hereu B, López-Sanz À, Romero J, Alcoverro T., 2013 Evaluating a key herbivorous fish as a mobile link: a Brownian bridge approach. Mar. Ecol. Prog. Ser. 492, 199–210

Pastor, J., Verdoit-Jarrayaa, M., Astrucha, P., Dalias, N., Pasquala, J.-S., Saragonia, G., Lenfant, P., 2009. Acoustic telemetry survey of the dusky grouper (*Epinephelus marginatus*) in the Marine Reserve of Cerbère-Banyuls: infirmations on the territoriality of this emblematic species. C. R. Biol. 332, 732–740.

PISCO (Partnership for Interdisciplinary Studies of Coastal Oceans) & UNS (University of Nice Sophia Antipolis) (2016). The Science of Marine Protected Areas (3rd edition, Mediterranean). www.piscoweb.org. 22 pages.

Prato, G., Guidetti, P., Bartolini, F., Mangialajo, L. & Francour, P. (2013). The importance of high-level predators in marine protected area management: Consequences of their decline and their potential recovery in the Mediterranean context. Adv. Oceanogr.

Limnol. 4, 176–193.

Sala, E., Ballesteros, E., Dendrinos, P., Di Franco, A., Ferretti, F., Foley, D., Fraschetti, S., Friedlander, A., Garrabou, J., Güçlüsoy, H., Guidetti, P., Halpern, B.S., Hereu, B., Karamanlidis, A. a., Kizilkaya, Z., Macpherson, E., Mangialajo, L., Mariani, S., Micheli, F., Pais, A., Riser, K., Rosenberg, A., Sales, M., Selkoe, K., Starr, R., Tomas, F., Zabala, M., 2012. The structure of mediterranean rocky reef ecosystems across environmental and human gradients, and conservation implications. PLoS One, **7**.

Sala, E., Giakoumi, S., 2017. No-take marine reserves are the most effective protected areas in the ocean. ICES J Mar Sci; doi:10.1093/icesjms/fsx059.

Schofield, G., Dimadi, A., Fossette, S., Katselidis, K.A., Koutsoubas, D., Lilley, M.K.S., Luckman, A., Pantis, J.D., Karagouni, A.D., Hays, G.C., 2013. Satellite tracking large numbers of individuals to infer population level dispersal and core areas for the protection of an endangered species. Divers. Distrib. 19(7): 834-844

Singleton, R.L., Roberts, C.M., 2014. The contribution of very large marine protected areas to marine conservation: Giant leaps or smoke and mirrors? Mar. Pol. Bull. 87, 7–10.

Topping, D.T., Lowe, C.G., Caselle, J.E., 2005. Home range and habitat utilization of adult California sheephead, *Semicossyphus pulcher* (Labridae), in a temperate no-take marine reserve. Mar. Biol. 147:301–311

Watson, J.E.M., Dudley, N., Segan, D.B., Hockings, M., 2014. The performance and potential of protected areas. Nature 515, 67–73.

Weeks, R., Green, A.L., Joseph, E., Peterson, N., Terk, E. 2016. Using reef fish movement to inform marine reserve design. J. Appl. Ecol. 54, 145–152.

Wilhelm, T.A., Sheppard, C.R.C., Sheppard, A.L.S., Gaymer, C.F., Parks, J., Wagner, D., Lewis, N., 2014. Large marine protected areas - advantages and challenges of going big. Aquat. Conserv. 24, 24–30.

Table 1. Summary of home ranges (HR) of Mediterranean fish species and one invertebrate. Information is reported for each species in each study. UD 95% was used as home range descriptor in all the studies, except in Giacalone *et al.,* 2015 where authors adopted MCP 100%. “Protection level” indicates if the study was carried out in fully protected area (FPA), Partially protected (Buffer) and/or fished area (f.a.); “HR” reports estimated home range in km^2 (mean± 1 SE); “# individuals (in FPA)” indicates the number of individuals for which HR was estimated (within parenthesis the number of individuals released within FPA); “% HR in FPA” indicates the percentage of tagged individuals showing HR within the FPA; “TL/HR” indicates if the authors detected a significant relationship between fish length (or weight) and HR; “Overlapping” indicates if authors detected evidence of overlapping home ranges among conspecific individuals. Ref= reference (appended below the table), N/A= not applicable, NA= not assessed. .

Species	Protection level	HR	# individuals (in FPA)	% HR in FPA	TL/HR	Overlapping	Ref
Diplodus sargus	Buffer	0.13±0.035	3	N/A	No	Yes	1
Diplodus sargus	FPA, buffer, f.a.	0.48±0.26	31 (20)	100	No	Yes	2
Diplodus sargus	FPA	0.36±0.27	20 (20)	100	No	Yes	3
Diplodus vulgaris	FPA, buffer	0.041±0.01	8 (8)	37.5	No	Yes	4
Diplodus vulgaris	F.a.	0.58±0.15	8	N/A	No	Yes	5
Epinephelus costae	FPA, Buffer	0.029±0.21	13 (1)	100	Yes	Yes	6
E. marginatus	FPA and Buffer	0.034±0.19	37 (15)	100	No	Yes	6
E. marginatus	FPA	0.013+0.001	6 (6)	100	No	Yes	7
Palinurus elephas	FPA	0.0039±0.0031	5 (5)	100	No	NA	8
Sarpa salpa	F.a., buffer	0.049±0.02	14	N/A	No	Yes	9
Sarpa salpa	FPA, buffer, f.a.	1.337+0.10	10	28	No	Yes	10
Sciaena umbra	F.a.	0.57±0.20	2	N/A	NA	Yes	11
Serranus cabrilla	Buffer	0.76±0.17	12	N/A	No	Yes	12
Serranus scriba	Buffer	1.10+0.08	6	NA	No	Yes	13
Sparisoma cretense	FPA, buffer	0.125±0.03	5 (5)	0	NA	Yes	14
Xyrichthys novacula	Buffer	0.32±0.13	10	N/A	No	Yes	15

References: 1= D’Anna *et al.*, 2011, 2= Aspillaga *et al.*, 2016, 3= Di Lorenzo *et al.*, 2014, 4= La Mesa *et al.*, 2013, 5= Alos *et al.*, 2012b, 6= Hackradt 2012, 7= Pastor *et al.*, 2009, 8= Giacalone *et al.*, 2015, 9= Jadot *et al.*,, 2006, 10= Pages *et al.*, 2013, 11= Alos and Cabanellas-Reboredo 2012, 12= Alos *et al.*, 2011, 13= March *et al.*, 2010, 14= La Mesa *et al.*, 2012, 15= Alos *et al.*, 2012a

Figures

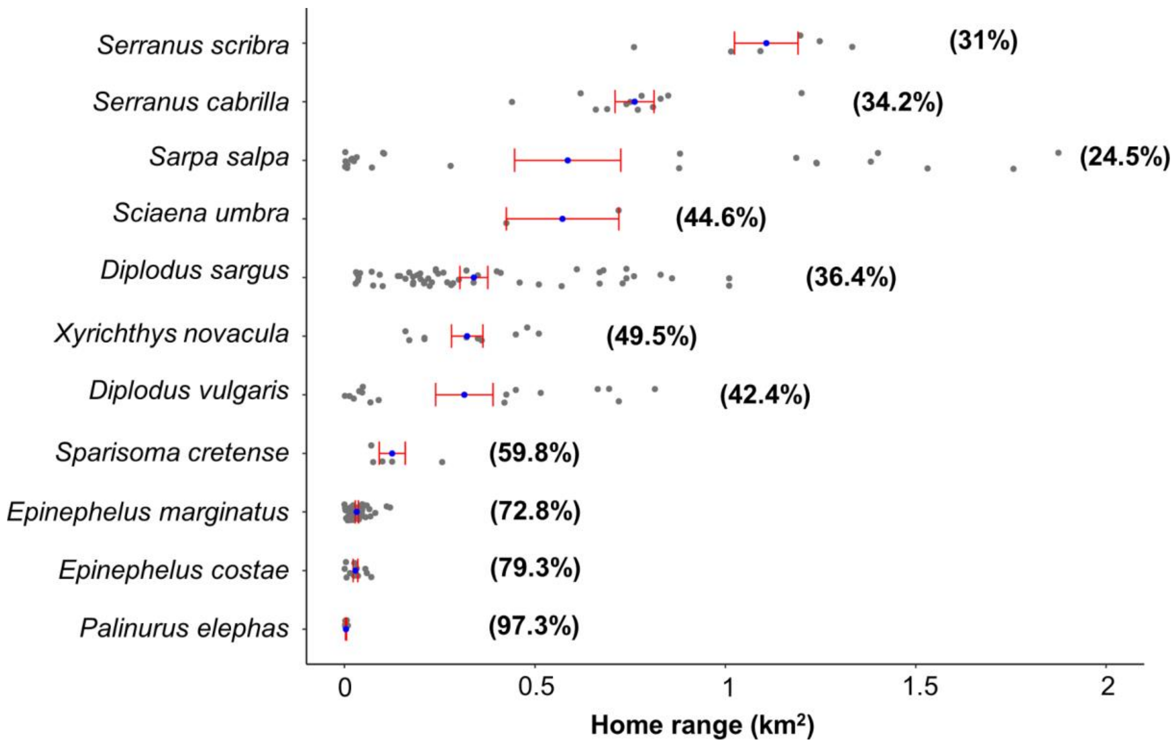

Figure 1. Home range for each individual (grey dots) of 11 Mediterranean marine species. Blue dots and red bars represent, respectively, mean ± 1 SE for each species. Species are listed from largest to smallest average home range. Values within parenthesis indicate the percent of fully protected areas greater than twice the size of the largest individual home range assessed for a given species.

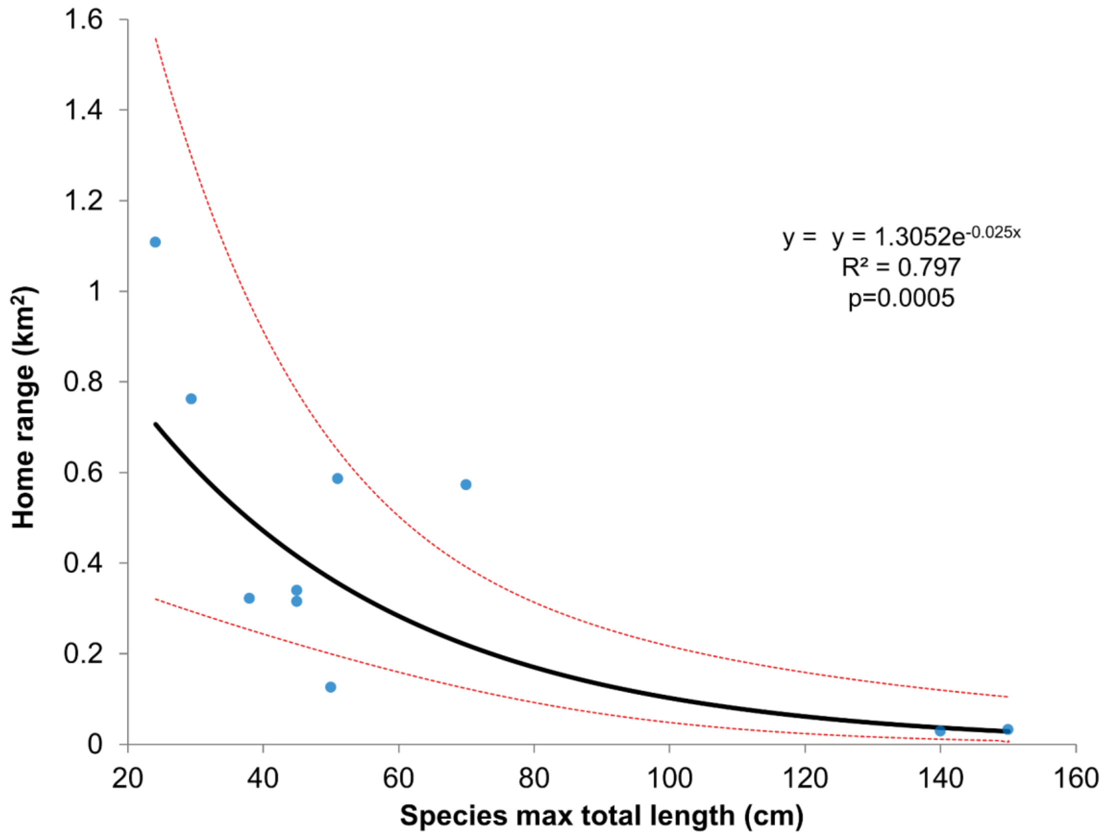

Figure 2. Exponential relationship between maximum total length and average home range of 10 Mediterranean fishes. Red dotted lines show the 95% confidence intervals calculated by using the simultaneous Working–Hotelling procedure.

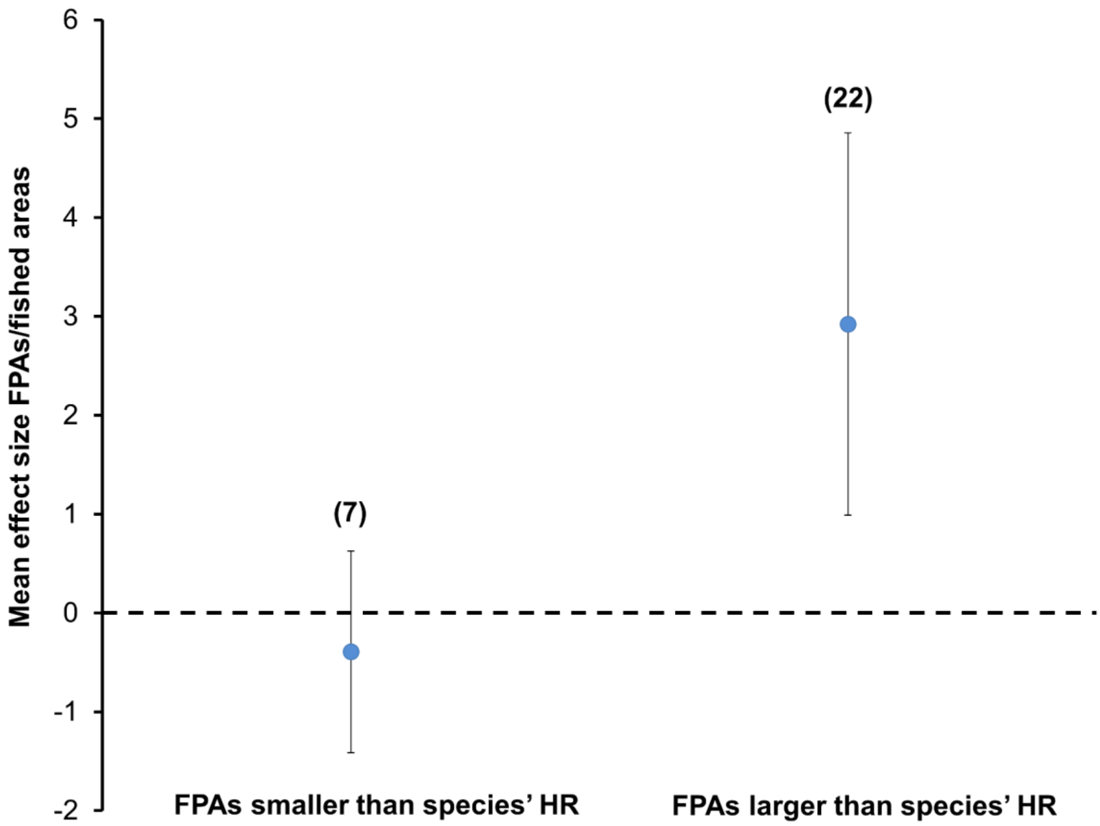

Figure 3. Effect of fully protected area on fish density as the mean of effect sizes across species calculated between the fully protected areas (FPAs) and fished areas in fully protected areas smaller and larger than species home range (HR). The graph displays the weighted ratio and 95% Confidence Interval (CI) in and out of the fully protected areas