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

Antonio Di Franco[a,b,*,1], Jeremiah G. Plass-Johnson[a,c,1], Manfredi Di Lorenzo[d], Bruno Meola[e], Joachim Claudet[f,g], Steven D. Gaines[h], José Antonio García-Charton[i], Sylvaine Giakoumi[a,j], Kirsten Grorud-Colvert[k], Carlos Werner Hackradt[i,l], Fiorenza Micheli[m], Paolo Guidetti[a,b]

[a] Université Côte d'Azur, CNRS, FRE 3729 ECOMERS, Parc Valrose 28, Avenue Valrose, 06108 Nice, France
[b] Consorzio Interuniversitario per le Scienze del Mare, CoNISMa, Piazzale Flaminio 9, 00196 Rome, Italy
[c] Centre for Ocean Life, National Institute of Aquatic Resources (DTU-Aqua), Technical University of Denmark, Lyngby, Denmark
[d] CNR-IAMC, Mazara del Vallo, Via Vaccara 61, 91026 Mazara del Vallo, TP, Italy
[e] Network of Marine Protected Area Managers in the Mediterranean (MedPAN), Marseille, France
[f] National Center for Scientific Research, CRIOBE, USR 3278 CNRS-EPHE-UPVD, Perpignan, France
[g] Laboratoire d'Excellence CORAIL, France
[h] Bren School of Environmental Science and Management, University of California at Santa Barbara, Santa Barbara, CA 93117, USA
[i] Departamento de Ecología e Hidrología, Universidad de Murcia, Campus de Espinardo, 30100 Murcia, Spain
[j] ARC Centre of Excellence for Environmental Decisions, School of Biological Sciences, The University of Queensland, Brisbane, Queensland, Australia
[k] Department of Integrative Biology, Oregon State University, 3029 Cordley Hall, Corvallis, OR 97331, USA
[l] Centro de Formação em Ciências Ambientais, Universidade Federal do Sul da Bahia, Campus Sosígenes Costa, Porto Seguro 45810-000, Brazil
[m] Hopkins Marine Station, Stanford University, 120 Oceanview Blvd., Pacific Grove, CA 93950, USA

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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 these coastal marine species.

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 and 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 and 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,

* Corresponding author at: Université Côte d'Azur, CNRS, FRE 3729 ECOMERS, Parc Valrose 28, Avenue Valrose, 06108 Nice, France.
E-mail address: difry@libero.it (A. Di Franco).
[1] These authors contributed equally to this work.

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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 and Chapman, 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 and Chapman, 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 is 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 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 they are not directly related to ecological effects delivered by fully protected areas, and their home range sizes are not feasibly ecompassed 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 A2 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 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 section 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 of low reliability (see Appendix A and Fig. A1). Variability in home range estimates was 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 1231 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