Using integrated multispecies occupancy models to map co-occurrence between bottlenose dolphins and fisheries in the Gulf of Lion, French Mediterranean Sea.

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Abstract

In the Mediterranean Sea, interactions between marine species and human activities are prevalent. The coastal ecology of bottlenose dolphins and the depredation pressure they put on fishing stocks lead to regular interactions with fisheries. Mapping the risks of interactions is a preliminary step in managing this human-wildlife conflict. However, quantifying interactions is hampered by the issue of false negatives whereby dolphins and trawlers may go undetected despite being present and co-occurring. Here, we develop an integrated multispecies occupancy model to quantify spatial co-occurrence between trawlers and bottlenose dolphins in the Gulf of Lion, French Mediterranean Sea. We combined bottlenose dolphin and trawler detections and non-detections from both aerial surveys and boat surveys in the Gulf of Lion. Multispecies occupancy modelling opens promising avenues in the study of interactions between human activities and marine mammals.

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1 Introduction

Identifying threats to marine ecosystems and species is one of the objectives of ecological monitoring programs (Lindenmayer & Likens 2010). The Mediterranean Sea, being the busiest on Earth, is especially affected by anthropic pressures (Coll et al. 2012, Giakoumi et al. 2017). In particular, there are increasing interactions between marine species and human activities. Among other species, marine mammals frequently forage in the proximity of fisheries (Bonizzoni et al. 2022). Despite facilitating access to prey, foraging behind trawlers leads to depredation or by-catch interactions that pose conservation concerns (Lewison et al. 2004, Snape et al. 2018, Santana-Garcon et al. 2018, Bonizzoni et al. 2020, 2022). The coastal ecology of common bottlenose dolphins (*Tursiops truncatus*, hereafter bottlenose dolphins) and the depredation pressure they put on fishing stocks lead to regular interactions with human recreational activities and fisheries (Bearzi et al. 2009, Queiros et al. 2018, Leone et al. 2019). Bottlenose dolphins are often reported in close proximity to fishing activities, and are known to forage behind trawlers in multiple locations worldwide and including the Mediterranean Sea (Bonizzoni et al. 2022). Even though few mortality events have been documented in bottlenose dolphins, interactions have raised conservation conflicts and mitigation measures have been tested without significant outcomes (Snape et al. 2018, Bonizzoni et al. 2020). At large, interactions between bottlenose dolphins and fisheries have been studied via in-situ observations (Santana-Garcon et al. 2018), passive acoustic (Bonizzoni et al. 2022), and the trawlers effect on dolphin distribution has been accounted for (Pirotta et al. 2015).

Mapping interactions is a preliminary step to better understand and manage human-animal interactions. This is usually achieved by calculating the overlap between a species distribution map and a map of human pressure. This overlapping approach raises two issues. First, when modelling species distribution, failure to account for interspecific interactions between co-occurring species may lead to biased inference, which arises when modelling only abiotic and habitat associations (Rota et al. 2016b). Second, another challenge when quantifying species interactions is to account for imperfect detection, e.g. when species do co-occur but one or several of the species involved go undetected by sampling (Rota et al. 2016a, Fidino et al. 2019). Ignoring imperfect detection leads to the underestimation of species distribution and imprecise quantification of species interactions (MacKenzie 2006). To account for these issues, multispecies occupancy models have been developed to estimate occupancy probabilities of two or more interacting species while accounting for imperfect detection (Rota et al. 2016b, Fidino et al. 2019). One caveat of multispecies models is that they require substantial data to produce robust ecological inference (Clipp et al. 2021). To overcome data scarcity, several authors have suggested to combine multiple datasets into an integrated modelling framework (see Kéry & Royle (2020), Chapter 10, for a review). In that spirit, we previously developed a single-species integrated occupancy model to map the distribution of bottlenose dolphins over the Northwestern Mediterranean Sea (Lauret et al. 2021).

Here, we extend this single-species integrated occupancy model to an integrated multispecies occupancy model and several co-occuring species, with the aim to study interactions between common bottlenose dolphins and fisheries in the Gulf of Lion (French Mediterranean Sea). Our objective was to provide a statistical framework for mapping co-occurrence between fisheries and bottlenose dolphins.

2 Material and Methods

2.1 Data

We combined bottlenose dolphin and fisheries data extracted from two large-scale monitoring programs. First, Aerial Surveys of Marine Megafauna (SAMM in French) conducted in 2011 and 2012 in the French Mediterranean and Italian waters of the Pelagos Sanctuary (Laran et al. 2017). These aerial surveys aimed to collect data on human activities, seabirds, fish, and marine mammals (Baudrier et al. 2018, Lambert et al. 2020). We used detections and non-detections of bottlenose dolphins and of fishing trawlers from the 2011-2012 SAMM project. The second monitoring program targeted bottlenose dolphin habitats in the French Mediterranean Sea using a photo-identification protocol in the Gulf of Lion between 2013 and 2015 (Labach et al. 2021). We extracted detections of bottlenose dolphins, and that of trawlers which we considered as a proxy of fisheries. We used data on fishing trawlers only as we focused on fishing areas and not traveling routes between harbour and fishing areas.

We restricted aerial surveys and boat photo-id data to the Gulf of Lion. We divided the study area into 397 contiguous grid-cells for statistical analysis. We calculated the sampling effort as the transect length (in km) of each monitoring program for each grid-cell. To model spatial variation in occupancy of bottlenose dolphins and trawlers, we used depth as an environmental covariate (see Supplementary Information).

2.2 Integrated multispecies occupancy model

Several assumptions need to be valid to safely apply multispecies occupancy models: i) geographic and demographic closure of grid-cells and of the study area, ii) independence of the detections over space and time, iii) accurate identification (i.e. no misidentification). In our case study, dolphins and trawlers obviously moved in and out grid-cells during the sampling period making the geographic closure unlikely to be respected. Thus, we interpret occupancy as "space-use", that is the probability that the species uses the grid-cell given it is present in the study area.

2.2.1 Latent ecological process

We follow Rota et al. (2016a) to formulate the ecological model describing occupancy process. Our multispecies occupancy model estimated 4 occupancy probabilities.

- ψ_3 is the probability that both dolphins and trawlers use the grid-cell;
- ψ_2 is the probability that trawlers use the grid-cell and dolphins do not;
- ψ_1 is the probability that dolphins use the grid-cell and trawlers do not;
- ψ_0 is the probability that neither dolphins nor trawlers use the grid-cell, which correspond to the probability that none of the previous events occurs, with $\psi_3 + \psi_2 + \psi_1 + \psi_0 = 1$.

We modeled occupancy probabilities ψ_1, ψ_2, and ψ_3 as non-parametric functions of depth and geographical coordinates X and Y with Generalized Additive Models (GAMs, Wood (2006)):

$$\text{logit}(\psi) = s(\text{depth}) + t(\text{X,Y})$$

where $s(.)$ and $t(.)$ are smooth functions (see Supplementary Information).

2.2.2 Observation process

We considered 4 sampling occasions with similar sampling effort for each monitoring program (winter, spring, summer, and autumn). We extended the observation process of the multispecies occupancy model of Rota et al. (2016a) to integrate two datasets in the spirit of Lauret et al. (2021). We considered dataset A (i.e. aerial line transects), and dataset B (i.e. boat photo-id surveys). In both monitoring programs, detection and non-detection data on bottlenose dolphins and trawlers were collected. Each “species” has a different detection probability depending on the monitoring program considered, which leads to four different detection probabilities:

- $p^B_{dolphins}$ is the probability of detecting dolphins by boat photo-id surveys;
- $p^A_{dolphins}$ is the probability of detecting dolphins by aerial surveys;
- $p^B_{trawlers}$ is the probability of detecting trawlers by boat photo-id surveys;
- $p^A_{trawlers}$ is the probability of detecting trawlers by aerial surveys.

We modeled each detection probability as a logit-linear function of sampling effort.

$$\text{logit}(p) = \beta_0 + \beta_1 \text{sampling effort}$$

where β_0, and β_1 are to be estimated (see Supplementary Information).

2.2.3 Implementation in NIMBLE

We used the `jagam()` function in the `mgcv` R package to implement GAMs in a BUGS model (Wood 2019). We ran all models with three Markov Chain Monte Carlo chains with 100,000 iterations and 10,000 burnin each in the NIMBLE R package (Valpine et al. 2017). We reported posterior mean and 80% credible intervals (CI) for each parameter. Data and codes are available on GitHub at https://github.com/valentinlauret/fisheries-tursiops-multispeciesoccupancy.

3 Results

We detected 60 trawlers, and 18 bottlenose dolphins by aerial surveys, while we detected 71 trawlers and 30 bottlenose dolphins by boat photo-id surveys.

Overall, the probability that trawlers only use the grid-cell was lower than the probability that only dolphins used the grid-cell. The probability of having neither species using the grid-cell did not depend on depth, while co-occurrence probability increased with decreasing depth (Figure 1 & 2). Subsequently, the probability that only dolphins used the grid-cell decreased with decreasing depth. We also found that trawlers used the coastal space more than dolphins (Figure 1, and Supplementary Information).

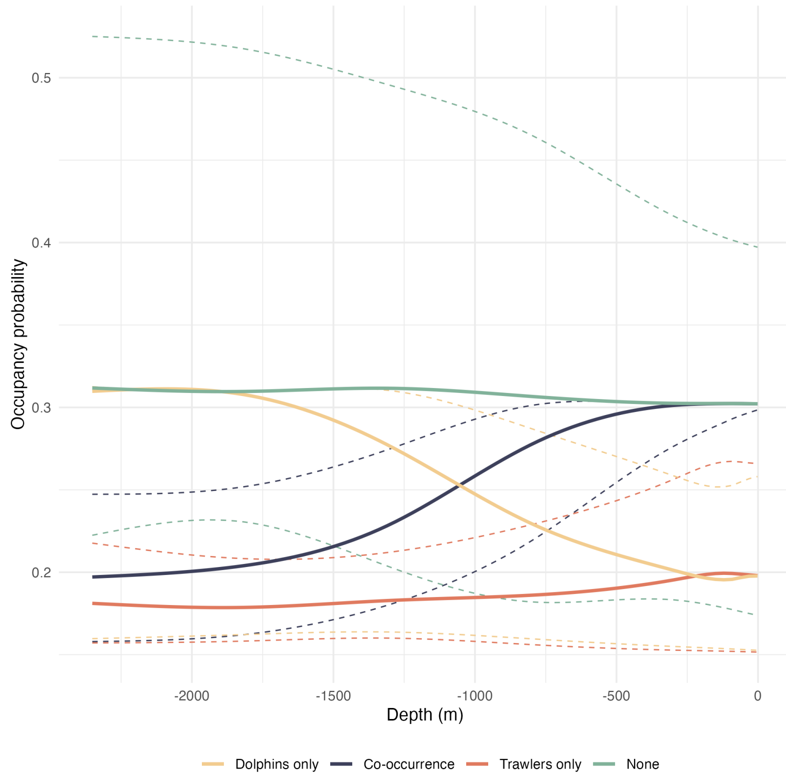

Figure 1: Occupancy probabilities estimated from the integrated multispecies model as function of depth (in meters) We represented 80% credible interval in dashed lines. Yellow lines represent Psi1, the probability that only bottlenose dolphins used the space. Orange lines represent Psi2, the probability that only fishing trawlers used the space. Blue lines represent Psi3, the probability that both bottlenose dolphins and fishing trawlers used the space. Green lines represent Psi0, the probability that neither bottlenose dolphins nor fishing trawlers used the space.

Both dolphins and trawlers detection probabilities increased with increasing sampling effort. Boat photo-id monitoring had higher detection probabilities than aerial surveys (Figure 3). Trawlers were more easily detected than bottlenose dolphins for both monitoring programs.

4 Discussion

4.1 Bottlenose dolphins co-occurrence with fisheries in the Gulf of Lion

We predicted a high co-occurrence probability throughout the continental shelf of the Gulf of Lion (Figure 2). Our model highlighted the critical importance of the Gulf of Lion waters for French fisheries and bottlenose dolphins. We emphasized a high probability of co-occurrence between dolphins and trawlers, which supports the assumption of depredation pressure in the Gulf of Lion (Queiros et al. 2018). Integrating multiple data sources helped to overcome data scarcity when datasets are used in isolation (Zipkin et al. 2019, Lauret et al. 2021). Additional presence-absence data, e.g. from scientific fishing campaigns or aerial surveys for tuna stock assessment (Bauer et al.

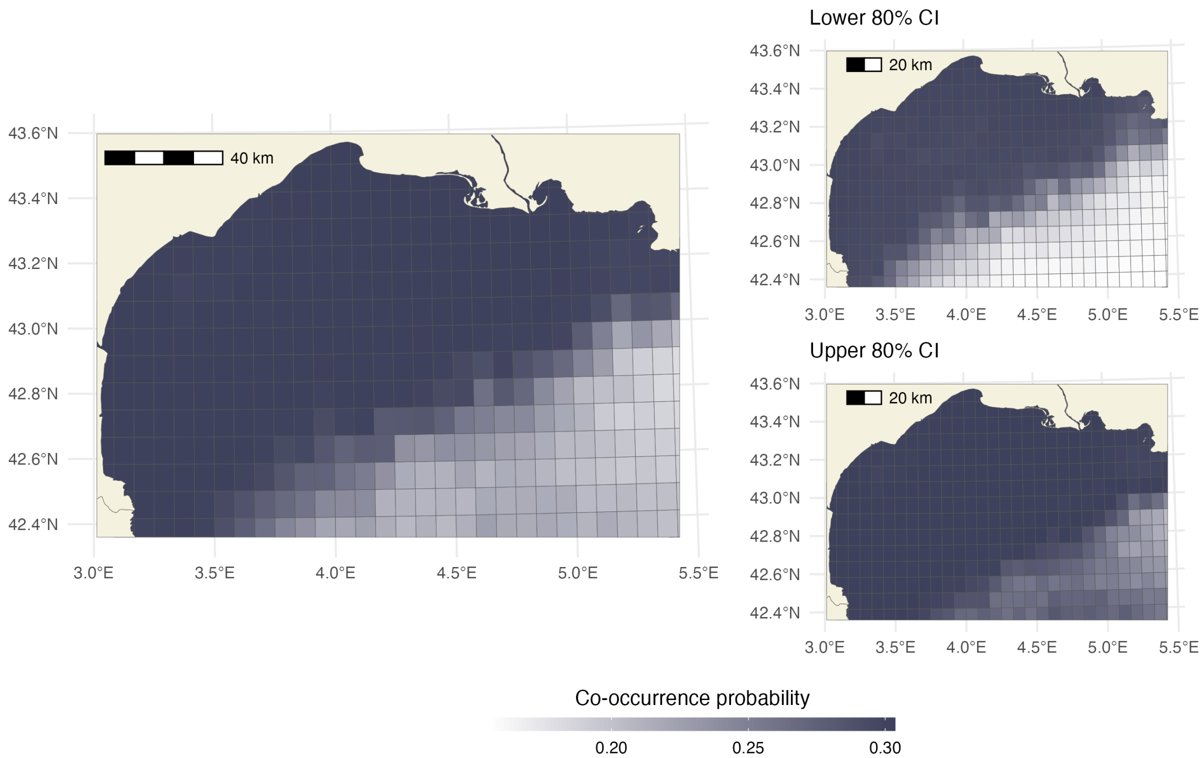

Figure 2: Co-occurrence probability Psi3 between dolphins and trawlers in the Gulf of Lion (Northwestern Mediterranean Sea). Left panel shows estimated probability and right panels display lower and upper bounds of 80% credible intervals.

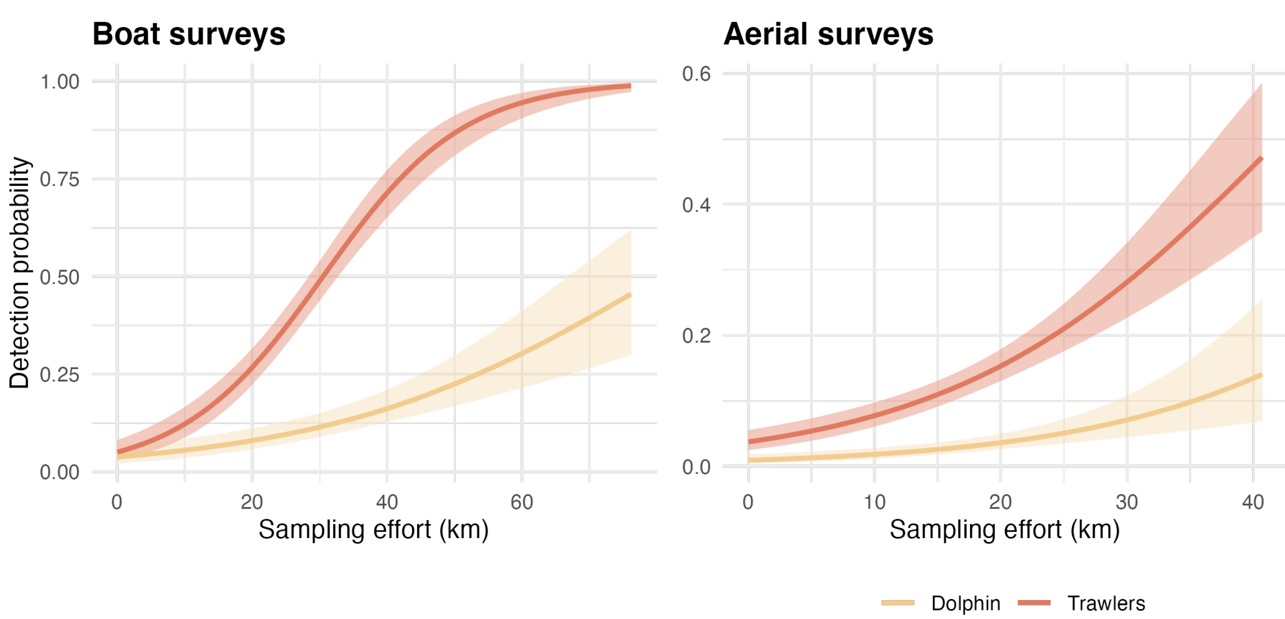

Figure 3: Estimated detection probability of dolphins and trawlers as a function of sampling effort for each monitoring program. We provide posterior medians (solid line) and 80% credible intervals (shaded area).

2015), would further allow to better delineate fishing areas.

4.2 Mapping human-cetaceans co-occurrences for conservation

Our approach echoes recent work integrating human activities into multispecies occupancy models to identify and quantify threats of anthropic pressures on the environment (Marescot et al. 2020). The main advantage of these models is that they explicitly account for imperfect species detection and biotic co-occurrence between animals and human activities. The ability to predict areas of human-wildlife interactions is of critical importance to implement conservation measures. To mitigate marine mammals depredations, acoustic deterrents are implemented worldwide along with ethical and conservation concerns (Santana-Garcon et al. 2018, Bonizzoni et al. 2022). Mapping co-occurrence and identifying hotspots of depredation risk may help to reduce the deployment of acoustic deterrents and minimize the associated negative impacts (Estabrook et al. 2016, Snape et al. 2018). At the other side of the Northwestern Mediterranean Sea, fin whales are at high risk of collision with ferries in the Pelagos Sanctuary Marine Protected Area. Mapping collision risk can ultimately direct the measures of speed limitation or help to warn onboard marine mammals observers (Ham et al. 2021). Overall, integrated multispecies occupancy models are promising tools to understand and map human-cetacean interactions hotspots, with the aim to help in designing areas of particular conservation focus and directing specific mitigation measures.

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