

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

Valentin Lauret¹, H       Labach², L     David³, Matthieu Authier^{4,5}, Olivier Gimenez¹

(1) CEF  , Univ Montpellier, CNRS, EPHE, IRD, Montpellier, France

(2) MIRACETI, Connaissance et conservation des c  t  c  s, Place des traceurs de pierres, 13500 La Couronne, France

(3) EcoO       Institut, 18 rue des Hospices, 34090 Montpellier

(4) Observatoire Pelagis, UAR 3462, CNRS-La Rochelle Universit  , 17000 La Rochelle, France

(5) Adera, 162 Avenue Albert Schweitzer. CS 60040 – 33608 Pessac CEDEX, France

Abstract: In the Mediterranean Sea, interactions between marine species and human activities are prevalent. The coastal distribution of bottlenose dolphins (*Tursiops truncatus*) and the predation pressure they put on fishing stocks lead to regular interactions with fisheries. Multispecies occupancy models allow mapping co-occurrence between two (or more) species while accounting for false negatives and potential interspecific dependance. Here, we illustrated how to extend multispecies occupancy model to integrate multiple datasets 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 and map potential interactions. Possibility to integrate several datasources into multipsecies occupancy models opens promising avenues in the study of interactions between human activities and marine mammals that occur at large spatial scales.

Keywords: cetaceans, human-animal interaction, NIMBLE, odontocetes, trawlers

Introduction

The Mediterranean Sea, being on the busiest seaway 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 marine mammals, odontocetes frequently forage in the proximity of fishing vessels (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, including the Mediterranean Sea (Allen et al. 2017, Bonizzoni et al. 2022). Following mortality events that have been documented about bottlenose dolphins (Manlik et al. 2022), interactions have raised conservation concerns and mitigation measures trialed thus far have not proven effective (Snape et al. 2018, Bonizzoni et al. 2020). Interactions between bottlenose dolphins and fisheries have largely been studied via *in-situ* observations (Santana-Garcon et al. 2018), passive acoustic monitoring (Bonizzoni et al. 2022), and using trawlers data as covariate on dolphin distribution models (Pirotta et al. 2015), but not in multispecies modelling to our knowledge.

Mapping human-wildlife interactions is a preliminary step to better understand and manage conservation conflicts. This is usually achieved by calculating and mapping the overlap between the distribution of a species and human pressure(s). This overlapping approach raises two issues. First, when modelling species distributions, 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). In particular, one need to account for biotic effects when mapping potential interactions between marine mammals and fisheries as we know that cetaceans can forage in association to trawling vessels (Jourdain & Vongraven 2017, Allen et al. 2017). 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 or even inaccurate 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 for 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 aiming to study interactions between 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 while integrating multiple datasets.

Material and Methods

Data

We combined bottlenose dolphin and fisheries data extracted from two large-scale monitoring programs. First, we used Aerial Surveys of Marine Megafauna (SAMM in French) conducted in 2011 and 2012 in the French Mediterranean sea 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 data of bottlenose dolphins and of fishing trawlers from the 2011-2012 SAMM surveys. The second monitoring program targeted bottlenose dolphin habitats in the French Mediterranean Sea using a photo-identification protocol between 2013 and 2015 (Labach et al. 2021). We focused our attention on the Gulf of Lion and used data collected by EcoOcean Institut. We extracted detections of bottlenose dolphins and trawlers. We only used data on trawlers seen fishing as we focused on fishing areas and not traveling routes between harbour and fishing areas.

We divided the Gulf of Lion study area into 397 $5' \times 5'$ contiguous Madsen grid-cells (WGS 84) for statistical analysis. We calculated the sampling effort as the transect length (in km) of each

monitoring program for each grid-cell per time unit. To model spatial variation in occupancy of bottlenose dolphins and trawlers, we used depth as an environmental covariate.

Integrated multispecies occupancy model

Several assumptions need to be met to safely apply multispecies occupancy models: i) geographic and demographic closure of grid-cells and of the study area (i.e. individuals do not move in and out the grid-cell, and no birth or death event occur during the sampling period), ii) independence of the detections over space and time, iii) accurate identification (i.e. no misidentification) (Rota et al. 2016b). In our case study, dolphins and trawlers moved in and out grid-cells during the sampling period making the geographic closure unlikely to be respected. Thus, we interpreted occupancy as “space-use”, that is the probability that the species uses the grid-cell given it is present in the study area. In this article, we presented an extension of multispecies occupancy models to integrate multiple datasets. Then, to ensure clarity of the integrated multispecies occupancy model we did not perform a deep investigation of ecological predictors.

Latent ecological process

We followed Rota et al. (2016a) to formulate the ecological model describing the occupancy process. Ignoring the grid-cell index, 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 corresponds to the probability that none of the previous events occurs, with $\psi_3 + \psi_2 + \psi_1 + \psi_0 = 1$.

We modeled the occupancy state of each grid-cell z as a multinomial draw in vector $\pi = (\psi_0, \psi_1, \psi_2, \psi_3)$:

$$z \sim \text{Multinomial}(1, \pi)$$

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

$$\text{logit}(\psi) = \alpha_0 + \alpha_1 \text{ depth} + s(X,Y)$$

where $s(\cdot)$ is a smooth function (see Supplementary Information), and α_0 and α_1 were to be estimated.

Observation process

We considered 4 sampling occasions j 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” had a different detection probability depending on the monitoring program considered, which led to four different detection probabilities:

- p_d^B that is the probability of detecting dolphins by boat photo-id surveys;
- p_d^A that is the probability of detecting dolphins by aerial surveys;
- p_t^B that is the probability of detecting trawlers by boat photo-id surveys;
- p_t^A that is the probability of detecting trawlers by aerial surveys.

For each grid-cell i and each sampling occasion j , we modeled the detection probability $p_{i,j}$ as a logit-linear function of sampling effort. For example :

$$\text{logit}(p_d^B(i,j)) = \beta_{0d}^B + \beta_{1d}^B \text{ sampling effort}_{i,j}^B$$

where β_{0d}^B , and β_{1d}^B were to be estimated for the probability of detectiong bottlenose dolphins by boat photo-id surveys.

From the four detection probabilities, 16 observation ‘events’ y can occur. We coded them as follow:

- 1 for none “species” detected neither by B nor A
- 2 for dolphins detected by B, nothing by A
- 3 for trawlers detected by B, nothing by A
- 4 for both “species” detected by B, nothing by A

- 138 • 5 for none “species” detected by B, dolphins detected by A
- 139 • 6 for dolphins detected by B and by A
- 140 • 7 for trawlers detected by B, dolphins detected by A
- 141 • 8 for both “species” detected by B, dolphins detected by A
- 142 • 9 for none “species” detected by B, trawlers detected by A
- 143 • 10 for dolphins detected by B, trawlers detected by A
- 144 • 11 for trawlers detected by B, trawlers detected by A
- 145 • 12 for both “species” detected by B, trawlers detected by A
- 146 • 13 for none “species” detected by B, both “species” detected by A
- 147 • 14 for dolphins detected by B, both “species” detected by A
- 148 • 15 for trawlers detected by B, both “species” detected by A
- 149 • 16 for both “species” detected by B, both “species” detected by A.

150 Then, with 4 ecological states (in columns) and 16 observation events (in rows), we got the
 151 observation process with the following (transposed) 4x16 matrix.

$$152 \quad t(\theta) = \begin{bmatrix} 1 & (1 - p_D^B)(1 - p_D^A) & (1 - p_T^B)(1 - p_T^A) & (1 - p_T^B)(1 - p_T^A)(1 - p_D^A)(1 - p_D^B) \\ 0 & p_D^B(1 - p_D^A) & 0 & (1 - p_T^A)(1 - p_D^A)p_D^B(1 - p_T^B) \\ 0 & 0 & p_T^B(1 - p_T^A) & (1 - p_T^A)(1 - p_D^A)p_T^B(1 - p_D^B) \\ 0 & 0 & 0 & (1 - p_T^A)(1 - p_D^A)p_D^Bp_T^B \\ 0 & p_D^A(1 - p_D^B) & 0 & p_D^A(1 - p_T^A)(1 - p_D^B)(1 - p_T^B) \\ 0 & p_D^Bp_D^A & 0 & p_D^A(1 - p_T^A)p_D^B(1 - p_T^B) \\ 0 & 0 & 0 & p_D^A(1 - p_T^A)p_T^B(1 - p_D^B) \\ 0 & 0 & 0 & p_D^A(1 - p_T^A)p_D^Bp_T^B \\ 0 & 0 & 0 & p_T^A(1 - p_D^A)(1 - p_D^B)(1 - p_T^B) \\ 0 & 0 & p_T^Bp_T^A & p_T^A(1 - p_D^A)p_D^B(1 - p_T^B) \\ 0 & 0 & 0 & p_T^A(1 - p_D^A)p_T^B(1 - p_D^B) \\ 0 & 0 & 0 & p_T^A(1 - p_D^A)p_T^Bp_D^B \\ 0 & 0 & 0 & p_D^Ap_T^A(1 - p_T^B)(1 - p_D^B) \\ 0 & 0 & 0 & p_D^Ap_T^Ap_D^B(1 - p_T^B) \\ 0 & 0 & 0 & p_D^Ap_T^Ap_T^B(1 - p_D^B) \\ 0 & 0 & 0 & p_T^Bp_T^Ap_D^Bp_D^A \end{bmatrix}$$

153 Each observation y was linked to the ecological state z via a Categorical distribution in vector of
154 length 16, $\theta_z = (Pr(y = 1), Pr(y = 2), \dots, Pr(y = 16))$, where θ_z also corresponded in the θ
155 matrix to the 16 columns of the row referring to the ecological state z .

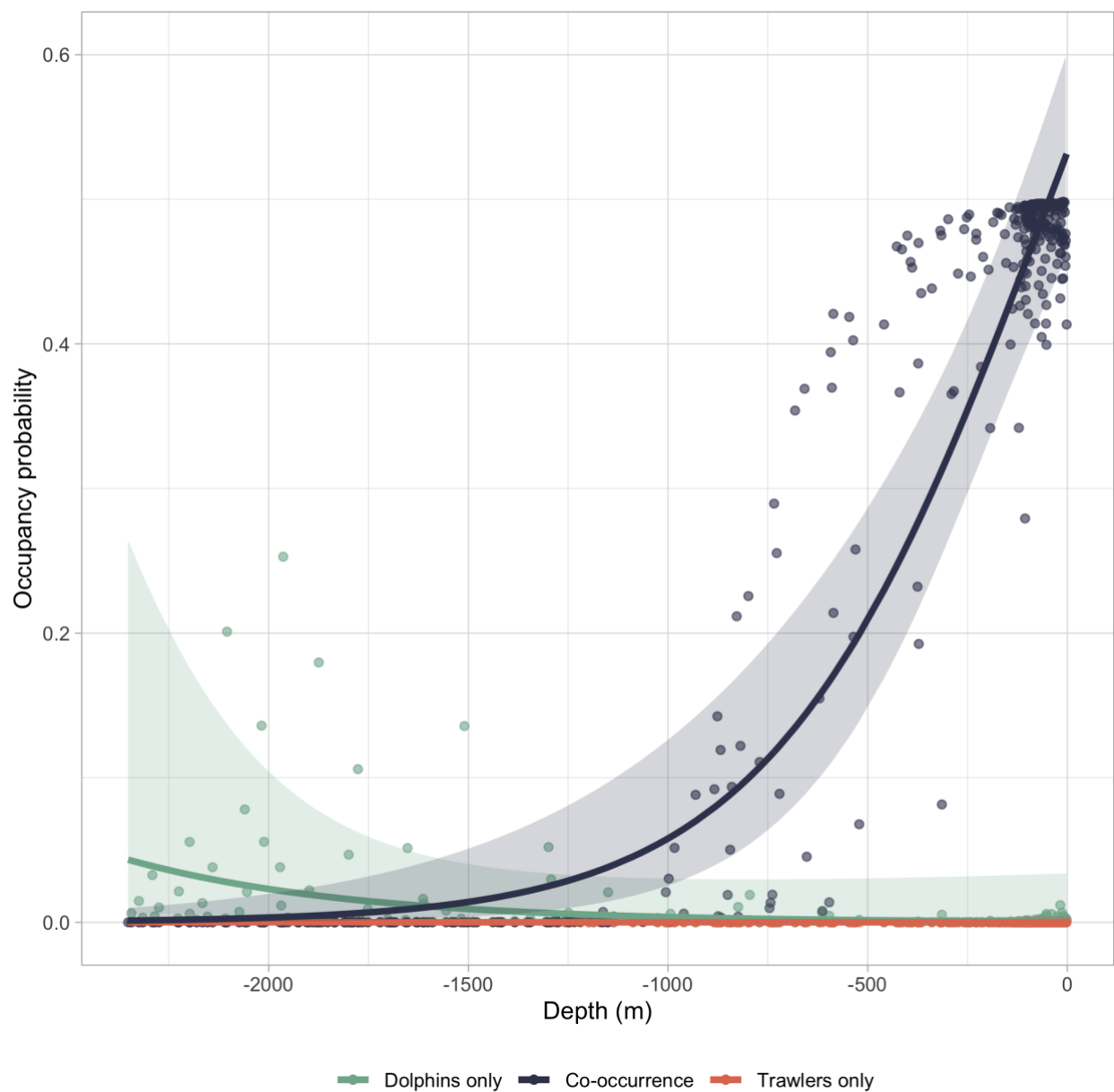
156 $y|z \sim \text{Categorical}(\theta_z)$

157 ### Assessing the benefit of data integration

158 To investigate the benefit of the integrated model, we ran multispecies occupancy models with
159 each dataset separately. We compared the precision associated with occupancy probabilities for
160 each model (See supplementary materials).

161 **Implementation in NIMBLE**

162 We used the `jagam()` function in the `mgcv` R package to implement GAM (Wood 2019). We ran
163 all models using three Markov Chain Monte Carlo chains with 200,000 iterations and 20,000 burnin
164 each in the NIMBLE R package (Valpine et al. 2017). We reported posterior mean and 80%
165 credible intervals (CI) for each parameter. Data and codes are available on GitHub at
166 <https://github.com/valentinlauret/fisheries-tursiops-multispeciesoccupancy>.



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Figure 1.1: Occupancy probabilities estimated from the integrated multispecies model as function of depth (in meters) Green points and lines represent Ψ_1 , the probability that only bottlenose dolphins used the space. Orange points and lines represent Ψ_2 , the probability that only fishing trawlers used the space. Blue points and lines represent Ψ_3 , the probability that both bottlenose dolphins and fishing trawlers used the space, i.e. co-occurrence. We represented 95% credible interval in shaded areas

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

Overall, the probability that trawlers only or that trawlers only use the grid-cell was lower than the co-occurrence probability (Figure 1). Co-occurrence probability increased with decreasing depth (Figure 1 & 2), and both trawlers and dolphins used the coastal space more than the pelagic seas (Figure 2, and Supplementary Information). Although, dolphins space-use probability in pelagic seas appeared to be higher than trawlers space-use probability in Figure 1, the difference is not significant.

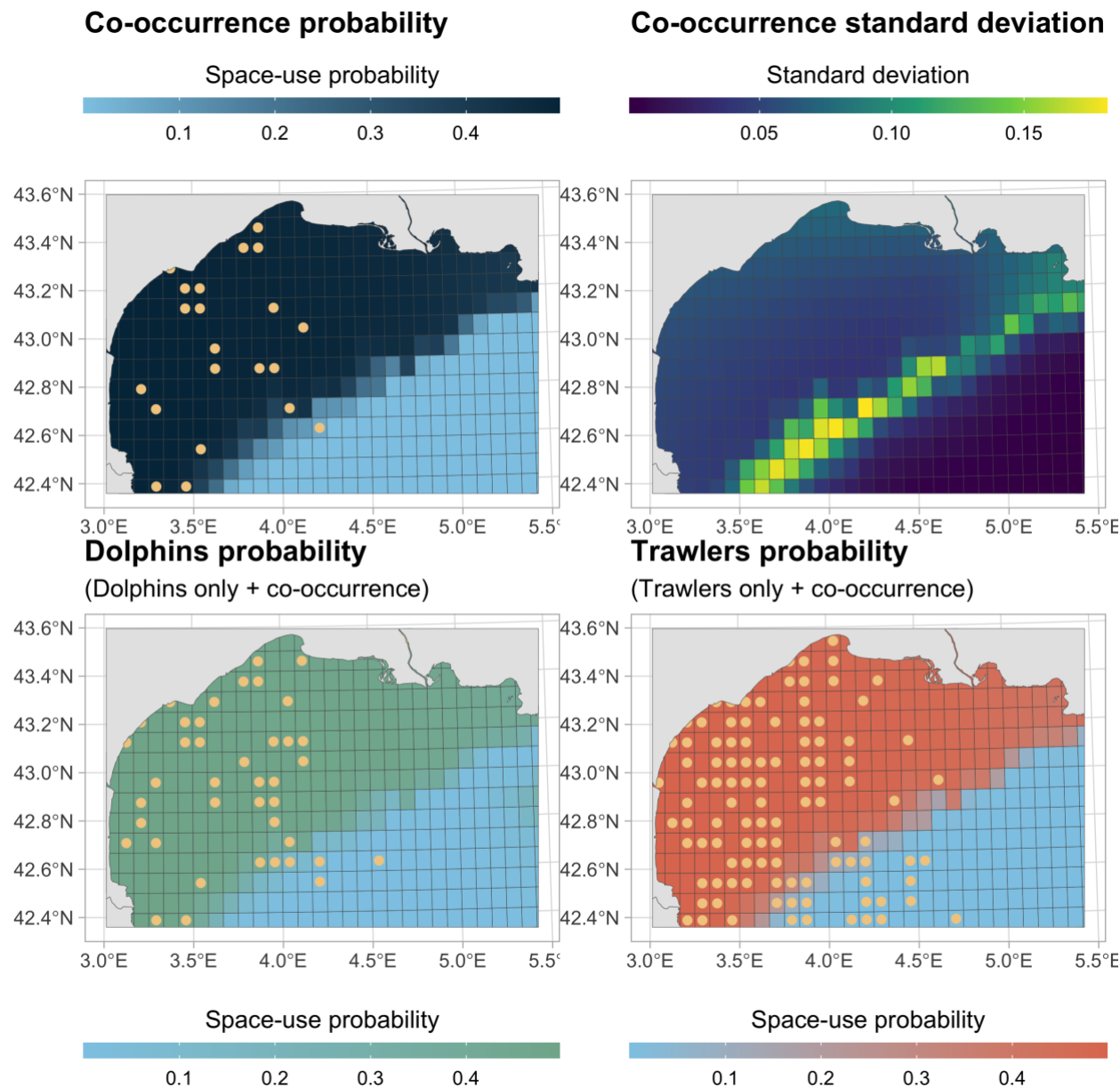


Figure 1.2: Probability of co-occurrence between dolphins and trawlers in the Gulf of Lion (Northwestern Mediterranean Sea) and associated standard deviation (upper panel). Lower

panel shows dolphins and trawlers space-use probabilities. Yellow dots reflect locations of detections of trawlers, dolphins, or both in the case of co-occurrence.

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.

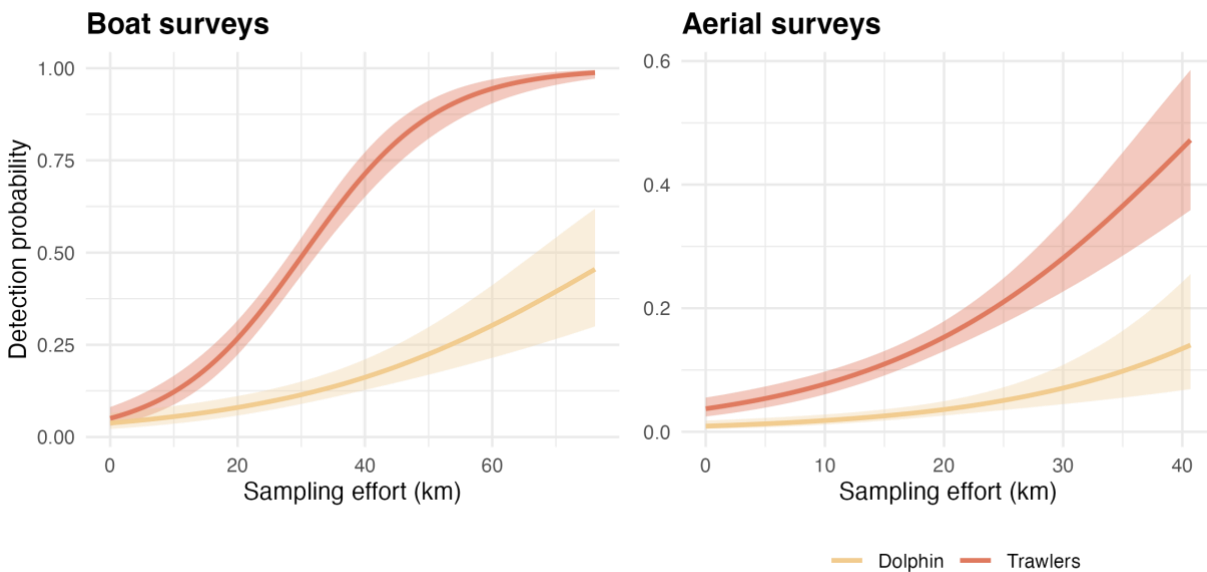


Figure 1.3: Estimated detection probability of dolphins and trawlers as a function of sampling effort for each monitoring program. We provide posterior medians (solid line) and 80% credible intervals (shaded area).

Integrated multispecies occupancy model estimated more precise co-occurrence probability than multispecies occupancy models using datasets in isolation (Supplementary materials).

Discussion

We showcase an integrated multispecies occupancy models to map the probability of co-occurrence between French fisheries and bottlenose dolphins in the Gulf of Lion waters (Figure 2). Our integrated multispecies occupancy models estimated a 0.40 probability of co-occurrence between trawlers and bottlenose dolphins in the coastal seas of the Gulf of Lion. However, we emphasize that we inferred co-occurrence probability and not interactions between dolphins and trawlers. This means that, despite the fact that interactions can occur, dolphins and trawlers also use the same

space without interacting. Mapping co-occurrence, we include potential interactions such as depredations or bycatch, and co-occurrence without interactions.

Mutlispecies occupancy models require substantial amount of data to precisely estimate co-occurrence (Clipp et al. 2021) and integrated approaches provide stronger inferences compared to an analysis of each dataset in isolation (Zipkin et al. 2019, Lauret et al. 2021). While having a limited amount of data, our integrated multispecies occupancy model helped to overcome data scarcity and provided more precise estimation of co-occurrence probabilities than multispecies models with sparated datasets (Supplementary materials). Through our integrated approach, we emphasized that integrated extension can be particularly promising for multispecies occupancy models.

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). Beyond the Gulf of Lion case study, integrated multispecies occupancy models can be leveraged to provide robust maps of co-occurrence between marine megafauna and anthropogenic activities while integrating several data sources. Additional presence-absence data, e.g. from scientific fishing campaigns, aerial surveys for tuna stock assessment (Bauer et al. 2015), or Automatic Indentification System for fishing vessels would further allow to better delineate fishing areas and hence areas of potential interactions.

The ability to predict areas of human-wildlife potential interactions is of critical importance to implement conservation measures as required under conservation legislation (e.g. the European Union Marine Strategy Framework Directive). To mitigate marine mammal depredation and/or bycatch, acoustic deterrents are implemented worldwide despite raising ethical and conservation concerns (Santana-Garcon et al. 2018, Bonizzoni et al. 2022). Using multispecies occupancy models to map potential hotspots of depredation may help to reduce the deployment of acoustic deterrents and minimize the associated negative impacts (Estabrook et al. 2016, Snape et al. 2018). Similarly, fin whales (*Balaenoptera physalus*) and sperm whales (*Physeter macrocephalus*) are at high risk of collision with ferries in the Northwestern Mediterranean Sea and in particular in the Pelagos Sanctuary Marine Protected Area (Ham et al. 2021, David et al. 2022). Mapping collision risk with mutlispecies occupancy models can ultimately direct the measures of speed limitation. 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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