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Living on the edge: overlap between a marine predator's habitat use and fisheries in the Northeast Atlantic waters (NW Spain)

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ABSTRACT

The impact of commercial fisheries on marine top predators is currently the focus of considerable international concern. In spite of the recognition of the competition between fisheries and marine predators for the same resources, few comprehensive assessments of the level of overlap between marine predators and fisheries have been conducted. Data from 273 daily boat surveys over a period of 4 years along the northwestern coast of Spain were used to assess the environmental, topographic, and anthropogenic correlates of habitat use and relative density of short-beaked common dolphins. Moreover, the degree of vulnerability of this marine top predator to coastal fisheries was assessed by identifying the type of fisheries associated with the presence of common dolphins. Our results reported that common dolphin presents a fine-scale pattern of habitat use, with an unequal use of available habitat and varying relative abundance, which was mostly related to the variation in environmental, topographic, and anthropogenic variables. The high occurrence of common dolphins in zones characterized by a high bottom trawl fishing pressure was indirectly linked to the

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susceptibility of these marine predators to fishing activities. These findings can be used as a relevant indicator of the degree of vulnerability of common dolphins to human pressure providing comprehensive information on which to base conservation and management strategies.

Keywords: Marine predators, Fisheries, Cetaceans, *Delphinus delphis*, Atlantic Ocean, GAMs

INTRODUCTION

Anthropogenic pressure on the marine environment has significantly augmented over the last decades increasing the potential for areas of human and wildlife activity to overlap (Halpern et al., 2008). One of the most detrimental anthropogenic impacts on marine ecosystems is the effect of fishing activities (Pauly et al., 2005) and it is particularly evident on top predators such as sharks, sea birds, and marine mammals (Baum et al., 2003; Lewison et al., 2004; Rogan and Mackey, 2007; Read, 2008; Moore et al., 2009; Anderson et al., 2011). These species are directly affected by operational processes such as direct and incidental captures or collisions with fishing vessels, and by indirect biological effects (i.e. depletion of prey), which induce changes to the marine food web and competition for food resources (Tasker et al., 2000; Lewison et al., 2004; Northridge, 2009; Anderson et al., 2011; Díaz López, 2018).

Fisheries make certain areas more attractive to marine top predators, by concentrating food resources in particular zones. This indirectly modifies specific habitats that consequently become favorable for feeding (Bearzi et al., 2003; Díaz López 2006a, 2018; Guinet et al., 2014). As a result, marine top predators depredate their natural prey species from fishing nets because fish abundance and distribution have been altered by human activities (Bearzi et al., 2003; Guinet et al., 2007; Díaz López, 2018). By doing this, marine predators may come into physical contact with the fishing gear, which ultimately may result in bycatch or injury (Díaz López, 2006). Ecological studies are critical for the better understanding of the impact human activities on marine top predators (Díaz López, 2018). As information on both distribution and abundance of marine predator food resources is scarce,

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environmental and anthropogenic variables can be used as substitutes to assess the distribution of these potentially vulnerable species (Pirodda et al., 2011; Breen et al., 2016; Díaz López and Methion, 2017, 2018).

A number of marine mammal species are attracted to fishing vessels and have been observed to feed in association with fisheries (Bearzi et al., 2003, 2008; Díaz López 2006, 2018; Guinet et al., 2007, 2014). One species regularly present in studies about bycatch across different fisheries and regions is the short-beaked common dolphin (*Delphinus delphis*, Linnaeus 1758, hereafter referred to as common dolphin), a small cetacean widely distributed in temperate and tropical waters worldwide (Jefferson et al., 2009). In the North Atlantic there are two separate populations of common dolphins based on morphological and genetic characteristics: the northwestern and the northeastern Atlantic populations (Natoli et al., 2006; Westgate, 2007). The latter, found in waters off the western coast of Europe from southern Spain up to 65° of latitude in Norway (Mirimin et al., 2009), is one of the most abundant cetacean species in these waters and accounts for most of the fisheries bycatch in the area (López et al., 2003; Fernández-Contreras et al., 2010; De Boer et al., 2012). Although fluctuations in the common dolphin fine-scale use of habitat have been the subject of several studies in different parts of its range (Murphy et al., 2013), there is a lack of information available on interactions between this species and fishing operations (Bearzi et al., 2003). While common dolphin is known to interact with fisheries and to be sensitive to fisheries impact, few studies have included anthropogenic explanatory variables (such as the presence of different types of fisheries) in habitat models (Bearzi et al., 2003; Rogan and Mackey, 2007; Fernández-Contreras et al., 2010; De Boer et al., 2012; Marçalo et al., 2018). Furthermore, very few studies with long-term and year-round monitoring datasets on common dolphin habitat preferences and interaction with inshore fisheries are available. This lack of information is clearly evident along the northwestern coast of Spain (Galicia), a region that supports significant pelagic and demersal fisheries associated with coastal upwelling events (Pérez et al., 2010)

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and where previous studies have reported high rates of common dolphin bycatch (López et al., 2003; Fernández-Contreras et al., 2010; Goetz et al., 2013; Saavedra et al., 2017).

In this paper we present, for the first time, a year-round comprehensive investigation of common dolphin habitat use along the coastal and shelf waters of Galicia (northwestern Spain). This was achieved by examining the relationships between environmental, topographic, and anthropogenic variables and presence and relative density of common dolphins. We also assessed the degree of vulnerability of this marine top predator to coastal fisheries by identifying the type of fisheries associated with the presence of common dolphins.

METHODS

Study area

The present study was performed along the northwestern coast of the Iberian Peninsula, more particularly along the southern coast of Galicia (Spain), covering the entire continental shelf from Muros (42.79° N, 9.15° W) to Cíes Islands (42.36° N, 8.94° W) (Fig. 1). The study area encompassed 1 300 km², with 92% of the area corresponding to continental shelf and inshore waters (depth < 150 m) and the rest covering the continental slope down to a depth of 1 050 m. These waters are influenced by oceanographic processes associated with wind-driven coastal upwelling events that enhance primary production. This area is heavily affected by human activities, including but not limited to marine traffic, fisheries, and aquaculture (Méndez and Vilas, 2005). Galicia has the largest fishing fleet in Spain, which in 2016 consisted of 4 354 vessels representing 48% of the Spanish and 5.4% of the European fleets (Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente, 2016). The different cetacean species present along this highly productive locus are therefore vulnerable to a number of direct human impacts such as vessel collisions, by-catch, overfishing, oil spills, pollution and habitat modification (López et al., 2003; Vieites et al., 2004; Díaz López and Methion, 2017, 2018).

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Data collection

Data for this study were collected as part of a longitudinal study carried out by the Bottlenose Dolphin Research Institute BDRI (www.thebdri.com) on the ecology of cetacean species inhabiting the Galician waters (Díaz López and Methion, 2017, 2018; Methion and Díaz López, 2018). A 12 m fly-bridge research vessel was used to systematically monitor the study area, recording data on presence and number of common dolphins, anthropogenic and oceanographic variables following the methods described by Díaz López and Methion (2018). Boat-based observation surveys were carried out year-round from March 2014 until November 2017 with systematic transect lines adapted to match the specific conditions of the study area. At least three experienced observers were stationed on the flying bridge (situated at 4 m above the sea level), scanning 360 degrees of the sea surface in search of cetaceans (with the naked eye and 10x50 binoculars). The spatial distribution of the effort varied according to weather conditions and time constraints throughout the study period. Surveys were done when the sea conditions were up to 4 on the Beaufort wind force scale, wave height smaller than 1.5 m, and visibility was not reduced by rain or fog.

Following Díaz López and Methion (2018), on each survey, the time, position, vessel speed, presence of cetaceans (within a 1 nm radius of the boat's position), anthropogenic and environmental data were recorded as an instantaneous point sample every 20 minutes. The spatial resolution of this 20 min interval was 2 nm (given a 6 - 8 kt speed) and the visual detection/nondetection of common dolphins was recorded instantaneously for all 20 min sampling points. Upon sighting of common dolphins, searching effort (on effort time) ceased and the vessel slowly manoeuvred towards the animals in order to minimise disturbance during the approach. Group size and composition were estimated before and after common dolphins had been approached based on the total count of individuals observed at one time in the area. A group of common dolphins was defined as one or more dolphins observed within a 500 metres radius. Because the research vessel often stayed with the

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animals, we could observe animals at close ranges (<50 m) and for long periods of time (>45 min). At the end of an encounter, the searching effort continued along the previously planned route.

Environmental variables

Five environmental predictors were initially considered to have potential ecological significance and were available for each 20 min sample recorded:

- Date, time (UTC in hours), sea surface temperature (SST in ° Celsius), tidal cycle (rising with the flooding tide and falling with the ebbing tide), chlorophyll-a (in $\text{mg} \times \text{m}^{-3}$), and upwelling index ($\text{m}^3 \times \text{s}^{-1} \times \text{km}^{-1}$).

Tidal cycle (presence/absence of flood tide) was obtained for the harbour of Ribeira (42° 33' N, 008° 59' W), from the Galician weather service (<http://www.meteogalicia.gal>). Chlorophyll-a data were obtained as daily rasters, with a spatial resolution of 1 km x 1 km, for the position of each instantaneous sample from the COPERNICUS Marine Environment Monitoring Service website (<http://marine.copernicus.eu>). Upwelling index (Bakun, 1973) was obtained from the Instituto Español de Oceanografía (www.indicedeafloramiento.ieo.es) and was calculated using sea level pressure of the Meteogalicia WRF atmospheric model.

Topographic variables

Five topographic variables were initially considered to have potential ecological significance and were available for each 20 min sample recorded.

- Position (Latitude and longitude coordinates), depth (m), bottom slope gradient (expressed as percent slope), bottom slope aspect (the orientation of the slope with respect to true north in degrees), and distance to the coast (m).

Bottom slope gradient and slope aspect, were computed from the bottom depth obtained from a bathymetric chart data set, with a 500 m x 500 m resolution, digitized from two 1 : 50 000 scale nautical charts from the Instituto Hidrográfico de la Marina (Spain).

Anthropogenic variables

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Four anthropogenic variables were measured within a 1 nm visual range for each 20 min sample recorded:

- Number of bottom trawlers, number of purse-seines, number of motor boats (including recreational boats and cargo ships, representative of the marine traffic), and presence of fishing buoys (indicating the occurrence of bottom set gill-nets).

Data analysis and modelling framework

Overall, 3 114 samples were collected instantaneously every 20 min of which 1 207 were on effort (when searching for common dolphins). Of these on effort samples, 634 were in inshore waters (< 150 m depth) and 569 on the continental shelf (between 150 m and 300 m). All samples collected in waters deeper than 300 m were excluded for further analysis because there were unrepresented in the study (n = 20 samples).

Following Díaz López and Methion (2018), a dataset was generated by randomly selecting 35% of the samples (n = 422 samples) searching for common dolphins. By arbitrarily down-sampling the number of on effort 20 min sets, the lack of independence arising from consecutive samplings was limited, avoiding the influence of variation in the spatial distribution of the observation effort, and limiting pseudo-replication. Date and time were not included as covariates in further analysis, because they were related with other variables (i.e. sea surface temperature and chlorophyll a) which were included instead due to their biological interpretability (Díaz López and Methion, 2018) and to prevent over-parameterization (Forney, 2000). Likewise, latitude and longitude (GPS position) and distance to the coast were not included in further analysis, because they were highly correlated with water depth (Spearman rho > 0.9, p < 0.001).

Generalized additive models (GAMs, Hastie and Tibshirani, 1990) were used to explore the environmental, topographic and anthropogenic variables that might have affected the distribution and density of common dolphins. A GAM is a non-parametric generalization of multiple linear regressions, widely-used for interpreting ecological interactions, which enables the estimation of both

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linear trends as well as non-monotonic responses, within the same model framework (Hastie and Tibshirani, 1990). The GAMs results and diagnostic information about the fitting procedure were implemented from the *mgcv* package (Wood, 2006) in v. 1.8.1. of the statistics and graphics tool R (R Development Core Team, 2011). To choose the most appropriate presence-absence model to address an apparently zero-inflated dataset, three different models such as GAMs with logistic link function, Tweedie or Negative Binomial distributions were compared using the Akaike Information Criterion (AIC) (Virgili et al., 2017). The number of common dolphins seen (given presence) was modelled using a GAM with a negative binomial distribution and logarithmic link function. Even though the best presence-absence model selected did not completely accommodate the elevated number of absences, the use of two types of GAMs in this study, with abundance data and presence-absence data, allowed an accurate prediction of the response variables (Howard et al., 2014). The smooth functions were constructed as cubic splines and their optimal shape was estimated by minimizing the general cross validation (GCV) criterion (Wood, 2006). To limit relationships to plausible simple forms and limit the risk of overfitting we reduced the number of knots in the smooth functions to 5. Model assumptions were checked by visual inspection of the residuals and regression fits were examined using plots of residuals against fitted values. The Variance Inflation Factor (VIFs) was calculated to reveal no signs of collinearity among the explanatory variables, with all values below a cut-off level of 3. To find a set of explanatory variables that does not contain collinearity, variables were removed one at a time and then the VIF values were recalculated. This process was repeated until all VIF values were smaller than 3. The Durbin-Watson test (from the R package “*lmtest*”, Zeileis and Hothorn, 2002) and auto-correlation functions (ACF) were used to check for serial correlation, both in our raw data and in the residuals from the models.

Because of the large number of potential combinations of predictor variables, and as an additional improvement, GAMs simplification and selection were performed using a multi-model inference approach based on the methods and recommendations of Burnham and Anderson (2002) and Grueber

et al. (2011). Model averaging can lead to robust predictions accounting for uncertainty in model selection by making inferences from an ensemble of possible solutions (Burnham and Anderson, 2002). This multi-model inference approach enables the response variable (presence or number of common dolphins) to vary as a linear or nonlinear function of the selected model covariates, while accounting for the non-normality.

As a first step in the analysis, an ensemble of competing GAMs to explain the response variable was selected using the R package 'MuMIn' (Barton, 2011). To ensure that the most parsimonious models were maintained within the best supported model set, models were compared based on their Akaike information criterion corrected for small sample sizes (AICc) (Grueber et al., 2011). The models with a $\Delta AICc < 2$ (the difference in AICc of each model in comparison to the model with the lowest AICc) were selected to identify the relative importance of each model term in predicting the response variable and to estimate the effect sizes of the predictors (Burnham and Anderson, 2002). Ecological conclusions were drawn from the direct comparison of this set of models that provided substantial support. Models were ranked from best to worst using the $\Delta AICc$ and the Akaike weights (w_i) to give the relative support for a given model compared with the others (Grueber et al., 2011). Furthermore, the relative importance of a predictor variable (RVI) was calculated as the sum of the Akaike weights overall of the models in which the predictor appears (Burnham and Anderson, 2002). Partial predictions with 95% confidence intervals were plotted for each covariate included within the best supported model set.

RESULTS

Survey effort and presence of common dolphins

Overall, 273 daily boat surveys over a period of 38 months and covering 9 417 km were undertaken between March 2014 and November 2017. In total, 1 015 hours were spent in satisfactory conditions (up to 4 on the Beaufort wind force scale, wave height smaller than 1.5 m, and absence of rain or fog).

During the study, 91 sightings of common dolphin groups were recorded (average sighting distance = 341 ± 60 m) (Figure 2). A total number of 4 963 common dolphins were seen on 28 different days at sea (10% of total number of daily surveys) over 14 different months. This species was encountered along the shelf and inshore waters throughout the study area and in all seasons of the year. The size and composition of common dolphin aggregations were examined for the observed groups. Group size ranged from 1 to 700 dolphins (mean = 54.5 ± 11 , $n = 91$) with the majority (73 % of the groups) having 40 or less individuals. Group composition showed that 81% of the observed common dolphins were considered adults; thus the remaining 19% were categorized as dependent calves, of which 4% were new-borns. Dependent calves were present in 69% of the observed groups. Group size was significantly related with the number of dependent calves in the group (Spearman $\rho = 0.88$, $p < 0.001$). Likewise, the size of the aggregations was significantly higher in presence of dependent calves (mean_{with calves} = 75.7 ± 15 vs. mean_{without calves} = 6.9 ± 1.4 ; Mann-Whitney, $p < 0.001$). During the study period common dolphins have not been observed in mixed feeding aggregations with other dolphin species.

Environmental, topographic, and anthropogenic factors affecting common dolphin presence

Due to restricted habitat use, low density and poor detection even in good sea state conditions the absence of common dolphins in the dataset was large (78.7%). We found that a GAM with a logistic link function was the most appropriate model to fit the data (lowest AIC), the GAMs with a negative binomial and Tweedie distributions showed similar predictions but higher AIC scores. A global GAM with a logistic link function was created with 11 selected environmental, topographic, and anthropogenic variables that did not contain collinearity: SST, CHL-a, upwelling index, tidal cycle, depth, slope, aspect, number of bottom trawlers, number of purse seine fishing boats, and presence of gill-nets. The GAM explained 21.3% of the variation in common dolphin presence ($R\text{-sq} = 0.18$, $UBRE = -0.10$, $AICc = 379.6$). We produced a candidate model set consisting of all 2 048 simplified versions

of the global model and compared them based on their AICc. Five models with $\Delta AICc < 2$ were used to produce model averaged parameter estimates (Table 1).

Depth, water temperature, and presence/absence of gill-nets were retained in each model within the candidate model set having a relative variable importance (RVI) of 1 in the final average model. Concentration of chlorophyll-a had a RVI of 0.61 in the final averaged model. Number of bottom set trawlers and bottom slope gradient had a relative variable importance RVI of 0.32 and 0.15 respectively in the final averaged model. Number of purse seine fishing boats, tidal cycle, number of motor boats (as a measure of the marine traffic), upwelling index, and bottom slope aspect, however, were not present in the top model set, indicating that these covariates were not important predictors of the presence of common dolphins.

Common dolphin occurrence was predicted to be more likely at the edge of the continental slope (at 150 – 200 m depth and strong bottom slope gradient), during moderate sea surface water temperatures (around 16°C), in absence of bottom set gill-nets, low concentration of chlorophyll-a, and with a high number of bottom trawlers (Figure 3, Table 2).

Effects of environmental, topographic, and anthropogenic factors on the size of the aggregations of common dolphins

Nine explanatory variables were used to create the GAMs since aspect and number of motor boats were considered collinear and therefore were dropped before starting the analyses. The global GAM explained 39.3% of the variation in the number of common dolphins ($R^2 = 0.393$, $AICc = 833.91$, $n = 89$). Out of 1 024 simplified versions of the global model, four models with $\Delta AICc < 2$ were used to generate model averaged parameter estimates (Table 3).

Slope gradient and upwelling index were both retained in each model within the candidate model set having a relative variable importance (RVI) of 1 in the final average model. Tidal cycle and presence of fishing nets had a RVI of 0.80 and 0.69 respectively in the final averaged model. Depth and number of purse seine fishing boats had a RVI of 0.43 in the final averaged model. CHL-a and SST were only

present in one model within the candidate model set and had a RVI of 0.23 and 0.20, respectively in the final averaged model. The anthropogenic variable number of bottom trawlers, however, was not present in the top model set, indicating that this covariate was not an important predictor of the size of the aggregations of common dolphins.

The number of common dolphins was predicted to be mostly influenced by the tidal cycle and upwelling events. Common dolphin aggregations were predicted to increase during flood tide and upwelling periods at the edge of the continental slope. Moreover, the size of the aggregations of common dolphins was predicted to increase in absence of gill-nets and with a higher number of purse seines (Figure 4, Table 4).

DISCUSSION

Marine top predators, such as common dolphins, can serve as indicators of ecosystem health and are exposed to different levels of anthropogenic impacts (Halpern et al., 2008; Maxwell et al., 2013). A good understanding of the level of interaction between common dolphins and commercial fisheries is critical for marine conservation and management. In this context, our study provides relevant information to assess the common dolphin habitat preferences and its degree of interaction with commercial fishing activities along the northwestern coast of the Iberian Peninsula. At the same time these findings highlight the importance of considering the interaction of multiple variables in ecological studies on fine temporal and spatial scales.

Our results report that common dolphins present a fine-scale pattern of habitat use along the northwestern coast of Spain, with an unequal use of available habitat and varying relative abundance, which is mostly related to the variation in environmental, topographic, and anthropogenic drivers. These findings are consistent with previous studies in the region which used data collected from observers on-board fishing vessels (Spyrakos et al., 2011). Furthermore, the boat-based research surveys of this study provide additional information than fishing vessel observer programs by providing data about common dolphin occurrence from areas not covered by the fishing vessels.

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Given the oceanographic characteristics of the northwestern coast of Spain, variability in common dolphin responses to the environmental and topographic stressors is likely a result of the complex and dynamic interactions of these factors with prey availability. Along this coastal region, the species shows a preference for blue whiting (*Micromesistius poutassou*), sardine (*Sardina pilchardus*) and to a lesser extent, Atlantic horse mackerel (*Trachurus trachurus*) (Santos et al., 2013, 2014). Therefore, the observed influence of oceanographic parameters such as the sea surface temperature on the fluctuations in presence and relative density of common dolphins may be related to seasonal changes in abundance of these demersal and pelagic fish species (Tenore et al., 1995). It is likely distribution aspects of these fish species, not primary productivity aspects, that influence common dolphin presence in the area. Likewise, the relationship with depth could also be associated with the availability of demersal or pelagic fish species (Spirakos et al., 2011).

Wind driven coastal upwelling events along the northwestern coast of Spain take nutrient-rich waters into the photic layer, enhancing primary and secondary productivity and so, after some time, supporting plankton-feeding fish species in shelf waters (Pérez et al., 2010). The availability of these fish species is an important driver for both common dolphins and fisheries presence and distribution. The relatively low chlorophyll-a concentration reported in presence of common dolphins could be interpreted as a period of phytoplankton decay mediated by zooplankton grazing and therefore an abundance of zooplanctivorous fish species. The results of our analysis predicted higher aggregations of common dolphins in deeper waters, in periods of upwelling, and during flood phases, which may be related to the abundance of large aggregations of fish species in offshore waters (Pérez et al., 2010). Indeed, the upwelling events together with strong tidal streams make the study area a suitable foraging habitat for common dolphins, by supporting high prey densities.

Many dolphin species can be both harmed by and benefit from anthropogenic fishing activities and some of the effects of this interaction operate at the population level (Díaz López 2006, 2018; Bearzi et al., 2008; Guinet et al., 2014). While dolphin species deplete on fisheries because the catch is

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part of their natural diet, the lower probability to find common dolphins in presence of gill-nets supports the idea that this species does not exploit this anthropogenic food source. These observations could be explained by the fact that gill-net fisheries operate mostly in coastal waters targeting demersal, benthic and benthopelagic organisms, which are not main prey items in the diet of common dolphins (Santos et al., 2013). This lack of direct interaction between common dolphins and gill-net fisheries does not exclude the existence of incidental captures in this type of fishery. For example, López et al., (2013) estimated an annual mortality of 87 small dolphin species (most of them probably common dolphins) in gill-net fisheries in Galician waters, derived from interview data and observations from fishing vessels.

In addition to incidental captures in gill-net fisheries, common dolphins are also caught in trawl and purse seine fisheries (Morizur et al., 1999; Murphy et al., 2013). In fact, the main fisheries responsible for common dolphin bycatch in Galician waters are bottom trawlers, with estimations ranging from 394 to 900 common dolphins captured per year (López et al., 2003; Fernández-Contreras et al., 2010). Our findings support the idea that the by-catch is related to the frequency of common dolphin interaction with fishing vessels. Indeed, our results predict a higher presence of common dolphins in areas where the trawl fisheries mainly operate. While common dolphins have been reported to feed both on discards and directly from trawl nets (Murphy et al., 2013), the link between the number of bottom trawlers and common dolphin presence does not necessarily imply a direct relationship. Their association may also be due to trawlers and common dolphin sharing the same resources since bottom trawl fisheries target blue whiting, Atlantic horse mackerel and hake (*Merluccius merluccius*) (Fernández-Contreras et al., 2010).

Although purse-seine fisheries target sardine, one of the main prey species of common dolphins in the region (Méndez Fernández et al., 2012; Santos et al., 2013; Marçalo et al., 2018), this type of fisheries was not an important predictor of the presence of common dolphins in the area. Common dolphins could target sardine aggregations irrespectively of the presence of purse seiners, as suggested in

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recent studies along the Portuguese shelf waters (Marçalo et al. 2018). Galician purse seine fishermen claim that common dolphins negatively affect their harvests, so fishers often avoid dropping their nets in presence of common dolphins (Goetz et al. 2013). This operational change could help explain the lack of overlap between common dolphins and purse seine fisheries in the region. Another explanation for the low association between purse seines and common dolphins is the fact that purse seines mainly operate in shallower waters, due to a decline in sardine stocks (Pérez et al., 2010), and therefore target less important common dolphin prey species.

Findings of this study may help concentrate conservation efforts on the interaction of common dolphins with fisheries in areas of highest concern. The observed fine-scale pattern of habitat use of common dolphins in zones characterized by a high bottom trawl fishing pressure supports the idea that this type of fishery is more likely to “attract” common dolphins. As the likelihood of fisheries by-catch is related to opportunity and selectivity of the fishing gear, these results can indirectly be linked to the susceptibility of these marine predators to fisheries. Indeed, trawl fisheries affect common dolphins in a number of ways: (1) increased mortality from entanglement in fishing gear that could compromise common dolphin survival in the region (López et al., 2003; Fernández-Contreras et al., 2010; De Boer et al., 2012; Saavedra et al., 2017) and (2) competition for the same fish species (Bearzi et al. 2003). The latter may represent a subtle and scarcely noticeable threat, as fisheries could reduce the availability of common dolphin prey and this impact may go unobserved given insufficient research effort (e.g. fish abundance estimations, changes in common dolphin survival rates and migration patterns).

Thanks to these findings, we can conclude that common dolphins are more vulnerable to bottom trawl than to purse-seine and gill-net fisheries along the northwestern coast of the Iberian Peninsula. With an increase of 16% of the bottom trawl catches along the continental shelf in the last 10 years (official catches from Ribeira harbour, Galician Institute for Statistics, 2018), current harvesting regimes along the study area might exacerbate both fishery-induced by-catch mortalities and fishing pressure on

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dolphin prey availability, increasing the risk of extinction of this marine predator. Previous studies in the region showed that the percentage of stranded common dolphins due to fishery interactions has increased approximately 18% during the last 20 years (Murphy et al., 2013). From such a perspective, a restriction of bottom trawl fisheries in waters shallower than 250 - 300 m (suggested by Fernández-Contreras et al. (2010) and Goetz et al. (2013)), combined with a reduction of nocturnal trawling (suggested by López et al. (2003)), could ameliorate adverse effects critical for the conservation of this marine top predator in the region.

This study can therefore be used as a relevant indicator of the degree of vulnerability of common dolphins to human pressure providing comprehensive information on which to base conservation and management strategies. Furthermore, the identification of hotspots with the greatest potential for overlap between fisheries and common dolphins might suggest specific areas and conditions in which to concentrate management strategies to protect this vulnerable species.

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Table 1. Most likely models explaining the variation in presence of short-beaked common dolphins in relation to environmental, topographic, and anthropogenic variables. Depth, CHL = concentration of chlorophyll-a, SST = sea surface temperature, Slope = bottom slope gradient, FN = presence/absence of gill-nets, Trawlers = number of bottom set trawlers.

Model	df	logLik	AICc	Δ_i	wi
FN/CHL/Depth/SST	8.20	-175.38	367.52	0.00	0.29
FN/Depth/SST	6.99	-176.76	367.84	0.31	0.24
FN/CHL/Depth/SST/Trawlers	9.26	-174.77	368.53	1.01	0.17
FN/CHL/Depth/SST/Slope	9.56	-174.57	368.75	1.23	0.15
FN/Depth/Trawlers/SST	8.34	-175.92	368.91	1.39	0.14

Only five most candidate models ($\Delta_i \leq 2$) of the 2048 are presented, df degrees of freedom, Δ_i difference between the particular model and the best model, wi Akaike weight showing the relative support of a given model compared to the others.

Table 2. Examples of the predicted effect of variables included in the model-averaged model on the presence of short-beaked common dolphins, with the other predictors held at their mean (N=422). SE = standard error. RVI = relative variable importance, N models = number of containing models. SST = sea surface temperature, CHL = concentration of chlorophyll-a, Trawlers = number of bottom set trawlers, Slope = bottom slope gradient.

Predictor		Estimated presence (%) of short-beaked common dolphins		RVI	N models
Depth	50m	15.66	SE = 3.78	1	5
	100 m	28.84	SE = 4.66		
	150 m	39.96	SE = 7.38		
	200 m	45.60	SE = 12.31		
	250 m	47.38	SE = 19.95		
Gill-nets	Presence	12.65	SE = 5.13	1	5
	Absence	28.05	SE = 4.90		
SST	12	0.26	SE = 0.77	1	5
	14	4.78	SE = 3.25		
	16	23.70	SE = 4.03		
	18	8.94	SE = 3.22		
	20	20.76	SE = 12.35		
CHL	0	32.35	SE = 7.05	0.61	3
	5	19.16	SE = 4.70		
	10	13.90	SE = 6.94		
	15	11.99	SE = 12.04		
Trawlers	0	22.79	SE = 4.16	0.32	2

	4	28.20	SE = 7.58		
	8	36.97	SE = 15.93		
Slope	0	24.97	SE = 4.89	0.15	1
	4	22.44	SE = 8.42		
	8	30.62	SE = 16.43		

Table 3. Most likely models explaining the variation in number of short-beaked common dolphins in relation to environmental, topographic and anthropogenic variables. Depth, CHL = concentration of chlorophyll-a, SST = sea surface temperature, Slope = bottom slope gradient, FN = presence/absence of gill-nets, Seines = number of seines, UI = upwelling index.

Model	df	logLik	AICc	Δ_i	wi
Slope/UI/Tidal cycle	9.43	-402.07	825.50	0.00	0.31
FN/Slope/UI/Tidal cycle	10.41	-400.97	825.82	0.31	0.26
FN/CHL/Depth/Seines/Slope/UI/Tidal cycle	16.65	-392.29	826.13	0.63	0.23
FN/Depth/Seines/Slope/UI/SST	17.20	-391.55	826.35	0.85	0.20

Only four most candidate models ($\Delta_i \leq 2$) of the 1 024 are presented, df degrees of freedom, Δ_i difference between the particular model and the best model, wi Akaike weight showing the relative support of a given model compared to the others.

Table 4. Examples of the predicted effect of variables included in the model-averaged model on the size of the aggregations of short-beaked common dolphins, with the other predictors held at their mean (N=89). SE = standard error. RVI = relative variable importance, N models = number of containing models. SST = sea surface temperature, CHL = concentration of chlorophyll-a, Trawlers = number of bottom set trawlers, Slope = bottom slope gradient.

Predictor		Estimated number of short-beaked common dolphins		RVI	N models
Slope	0	33.31	SE = 24.84	1	4
	4	277.62	SE = 225.65		
	8	134.39	SE = 109.20		
UI	-2000	23.35	SE = 7.64	1	4
	0	26.04	SE = 7.46		
	2000	33.71	SE = 13.21		
	4000	53.62	SE = 34.19		
Tidal cycle	Ebb	21.23	SE = 6.44		
	Flood	36.78	SE = 12.17		
Gill-nets	Presence	12.65	SE = 5.13	1	5
	Absence	28.08	SE = 8.15		
Depth	50m	9.47	SE = 3.80	1	5
	100 m	23.98	SE = 7.04		
	150 m	38.63	SE = 12.51		
	200 m	39.26	SE = 18.56		
	250 m	23.16	SE = 18.61		
Seines	0	25.35	SE = 7.32	0.32	2

	1	88.95	SE = 60.49		
	2	312.26	SE = 399.34		
CHL	0	16.87	SE = 6.09	0.61	3
	5	45.12	SE = 20.51		
	10	68.24	SE = 51.04		
	15	87.82	SE = 114.83		
SST	12	0.35	SE = 0.69	1	5
	14	3.55	SE = 3.01		
	16	23.09	SE = 6.41		
	18	19.94	SE = 7.92		
	20	5.99	SE = 4.05		

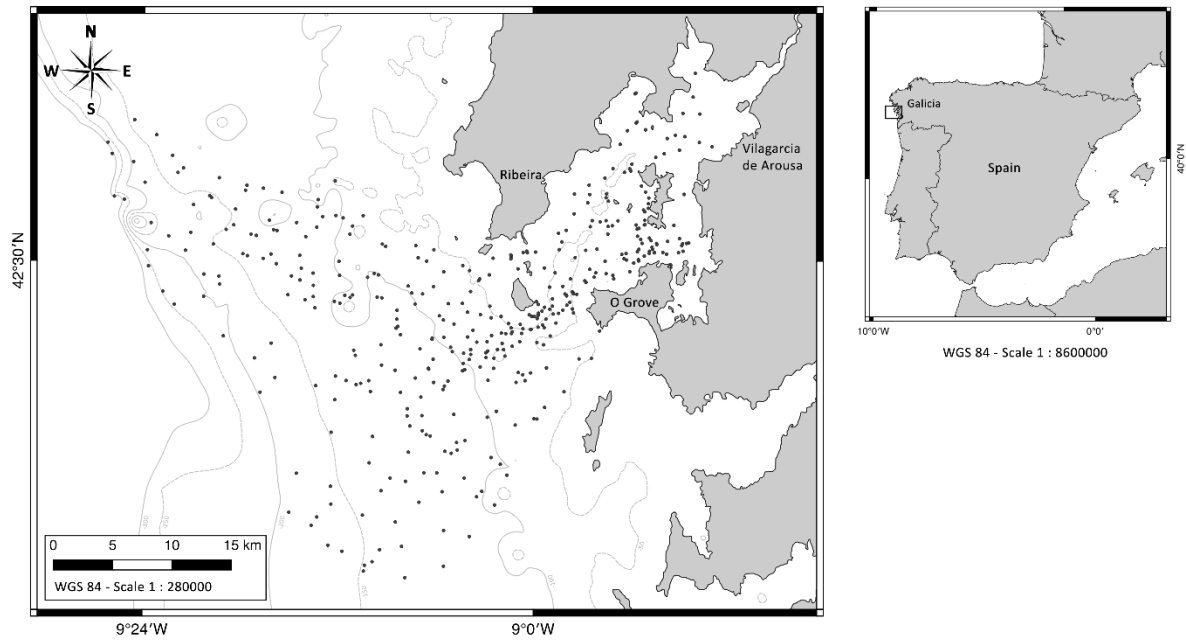


Figure 1. Map of the study area surveyed along the Northwestern coast of Spain, showing the randomly selected samples collected instantaneously every 20 min.

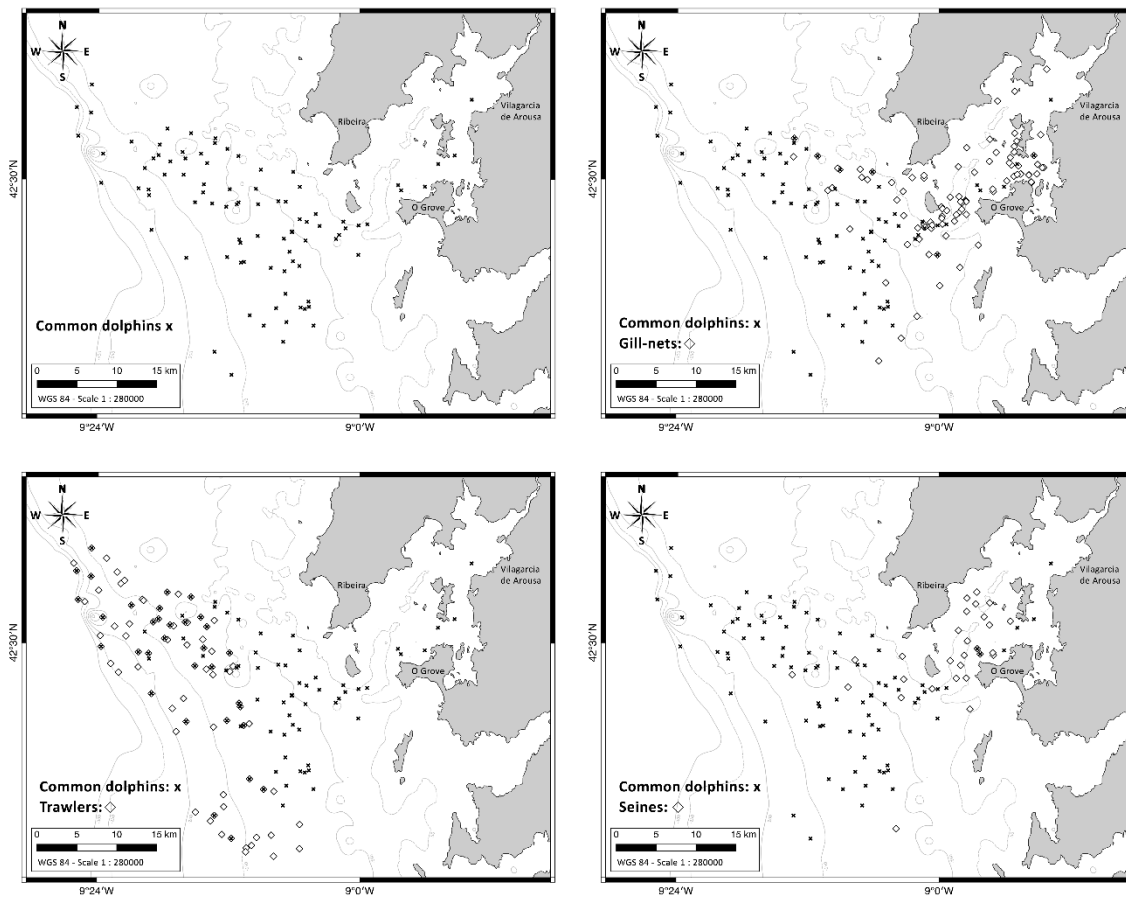


Figure 2. Distribution of common dolphin sightings (crosses) and distribution of commercial fisheries (squares). When sightings were in presence of fisheries crosses were included within the squares.

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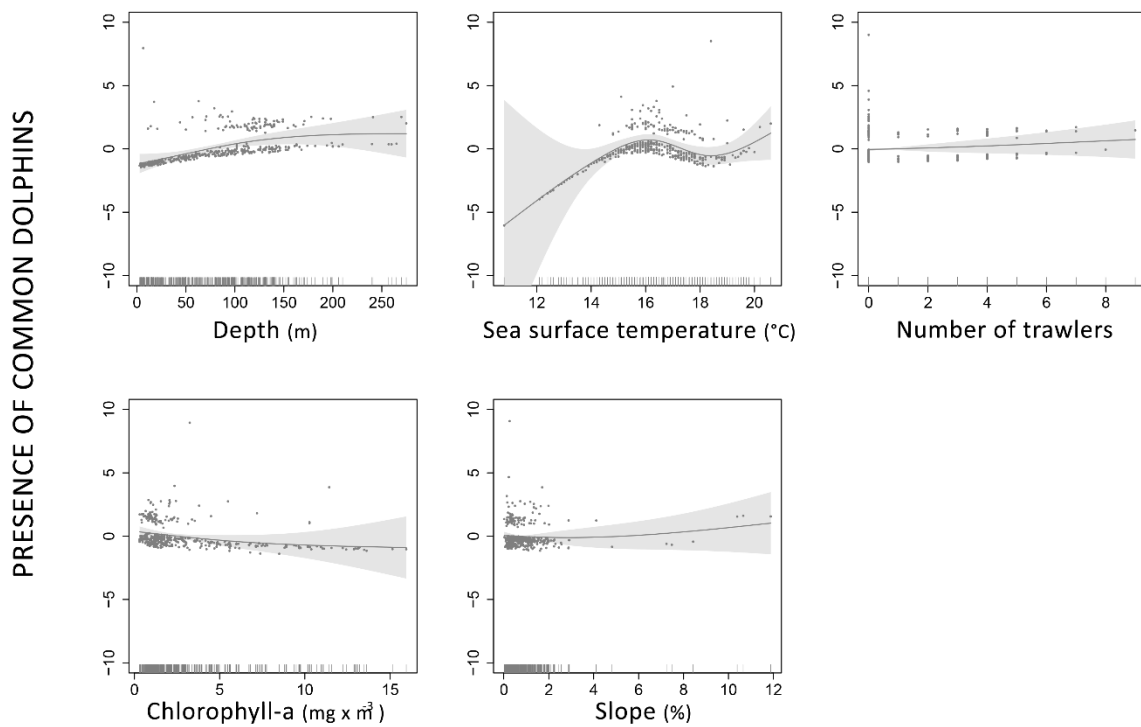


Figure 3. Averaged predictions of common dolphins' presence for each covariate present in the confidence set of models and their 95% confidence limits when all other variables are fixed to their mean value.

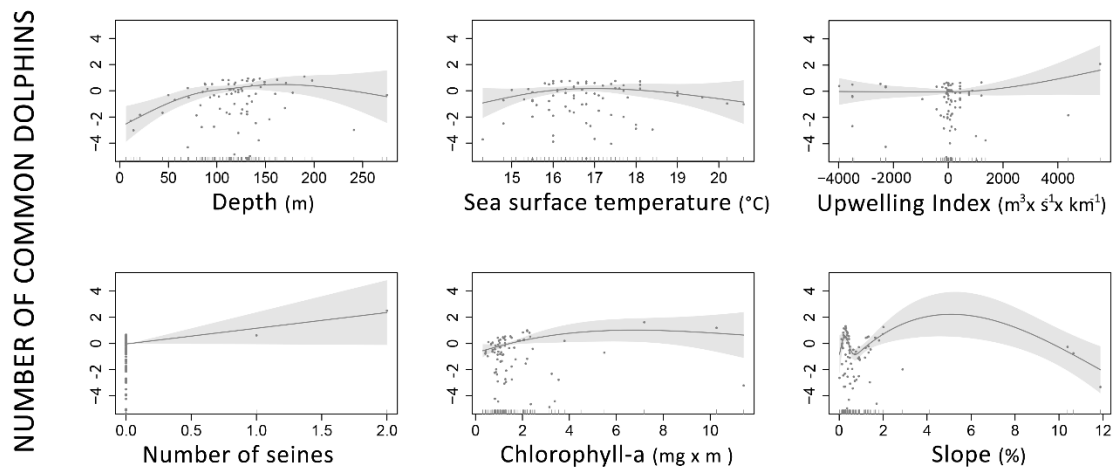


Figure 4. Averaged predictions of number of common dolphins (given presence) for each significant covariate in the confidence set of models and their 95% confidence limits when all other variables are fixed on their mean value.