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The impact of shellfish farming on common bottlenose dolphins' use of habitat

Running head: Impact of mussel farming on bottlenose dolphins

Bruno Díaz López[1] · Séverine Methion[1,2]

Abstract Shellfish farming is an expanding segment of marine aquaculture, but the impact of this industry on coastal cetacean species is only beginning to be considered. The interaction between mussel farming and coastal cetaceans in one of the world's leading producers of this bivalve (Galicia, NW Spain) was studied. Specifically, the habitat use of common bottlenose dolphins (*Tursiops truncatus*) was evaluated in relation to environmental, geographical, and anthropogenic variables. Over a period of 22 months spent in the field, 154 daily boat surveys and 353 common bottlenose dolphin encounters were done. Results of this study confirm that areas of mussel production are frequently utilized by common bottlenose dolphins. Of the investigated factors, shellfish farms appeared to have a clear effect, with increased bottlenose dolphin occurrence at mussel farm locations and in waters close to the aquaculture zones. These observations contrast with previous studies where the occurrence and distribution of coastal cetacean species decreased in association with shellfish aquaculture representing a source of habitat loss and causing potentially negative effects. These differences suggest that the interactions between shellfish aquaculture and cetaceans are affected by the culture method and cetacean species involved. The positive relationships between dolphins'

occurrence and mussel aquaculture zones are presumably the result of large aggregations of fish species around mussel rafts, which provide high densities of high-quality prey for dolphins. This study provides new insights into the understanding of how shellfish aquaculture influences coastal dolphins and hence support the design of policies aimed at implementing ecosystem management principles.

Keywords Aquaculture · Common bottlenose dolphin · *Tursiops truncatus* · Shellfish farm · Mussel rafts · GAMs

Introduction

Marine aquaculture, that is, the farming of plant and animal species from the sea, has shown a large worldwide expansion over the last years (FAO 2014). An increasing demand for seafood products, declining wild stocks, together with globalization of trade and economic incentives, have resulted in this rapid growth in fish and shellfish farming (Naylor et al. 2000; Bostock et al. 2010). According to the latest available statistics collected globally by FAO (2014), world aquaculture production attained an all-time high of 90.4 million tons in 2012 (US$144.4 billion).

Shellfish farming is an important sector of the industry (representing the 23% of the total production) and, like other forms of aquaculture, is expanding (FAO 2014). Consistent with this global trend, shellfish aquaculture has increased rapidly in Galician waters (Spain) since the 1940s (Miguez et al. 2009). Mussel production volume in Galician waters (300,000 tons annual production) represents 98% of the total Spanish production, approximately 50% of the European production and almost 13% of the world mussel production (FAO 2014). This Spanish region is the third largest mussel producer

in the world behind China and Thailand (Fuentes et al. 2000; Rodriguez et al. 2011).

The development of aquaculture industry has been accompanied by an increase in environmental impacts (reviewed by Pillay 2008). Concerns related to shellfish aquaculture have centred around the introduction of non-indigenous species, habitat alteration, changes to community structure or function (Chesney and Iglesias 1979; Iwama 1991; McKindsey et al. 2011), and effects on bird and mammal populations (Price and Nickum 1995; Würsig and Gailey 2002). Only a relatively small number of studies have evaluated the effects of shellfish aquaculture on cetacean species (Indo-Pacific bottlenose dolphin, *Tursiops aduncus* Watson-Capps and Mann 2005; Dusky dolphin, *Lagenorhynchus obscurus*; Markowitz et al. 2004; Pearson et al. 2012; Chilean dolphin, *Cephalorhynchus eutropia*; Ribeiro et al. 2007). These previous studies showed that shellfish farming restricts cetaceans from using the available space, reducing the extent of coastal areas used for potentially important biological and social activities.

Common bottlenose dolphins (*Tursiops truncatus*) are particularly likely to interact with human activities (Würsig and Gailey 2002; Díaz López 2006a, 2012, 2017; Bearzi et al. 2008). Most of the previous studies about bottlenose dolphins and aquaculture have been focused on the interaction with fin fish farms (Díaz López et al. 2005; Díaz López 2006b, 2012, 2017; Díaz López and Shirai 2008). However, there are no previous studies about the impact of shellfish aquaculture on this species. Likewise, the relationship between mussel cultivation in Galicia, which constitutes one of the world's leading producers of this bivalve (Fuentes et al. 2000), and habitat use by cetacean species has never been analysed. As observed in other cetacean species, shellfish aquaculture could negatively affect this species through habitat transformation or exclusion, entanglement risk, or by disturbance arising from farming activities and boat traffic (Würsig and Gailey 2002). As the hazards can already be identified, information on habitat use is a critical missing piece of the equation that can be used to determine the impact shellfish aquaculture may have on common bottlenose dolphins.

The aims of this study are (i) to assess the type of impact caused by shellfish aquaculture on bottlenose dolphins' presence and distribution and (ii) to describe habitat selection patterns of common bottlenose dolphins in this important area for shellfish farming, while identifying potential anthropogenic and environmental features responsible for fine-scale habitat use.

Methods

Study area

Galicia is a region situated in the northwest of Spain with 1 195 km of coastline, on which there are a series of ancient drowned tectonic valleys taken over by the sea (also referred to as ''rías'') (Evans and Prego 2003). The rías are important areas for shellfish aquaculture, and more particularly for the production of mussels (*Mytilus galloprovincialis*) due to the high primary production enhanced by intense upwelling events in the area (Perez Camacho et al. 1991; Prego et al. 1999).

The Ría of Arousa (where the present study was performed; Fig. 1), located in southern Galicia (Spain), is the largest of the Galician rías (approximately 33.1 km long, 10 km wide at the mouth, and covering an area of 239 km^2) (Prego et al. 1999). The average depth of the ría is 19 m. The entire system is subjected to a semidiurnal and mesotidal tide regime, with a tidal range of 1.1 and 3.5 m during neap and spring tides, respectively (Alvarez et al. 2005).

The system of shellfish production employed in Galicia is the floating raft (named "batea"), which is in contrast with other traditional systems of production such as longlines, stake cultivation, or beach mussel farming (Perez Camacho et al. 1991). The rafts are floating mussel platform farms configured in a rectangular shape. They are usually made of eucalyptus trusses bound together, from which ropes are suspended for the mussel cultivation. The rafts keep afloat with a system of floating devices that are also bound by chains to a block of concrete resting on the sea floor. These rafts have a maximum surface area of about 500 m^2 and a maximum of 500 ropes with a length no longer than 12 m for the cultivation of mussels (Fuentes et al. 2000). There are 3,386 mussel cultivation rafts in the Galician rías, of which about 70% (2 000 floating rafts) are situated in the Ría of Arousa (Rodriguez et al. 2011).

While the use of habitat and the status of the common bottlenose dolphin population in Galician waters remain poorly known, this is the most frequent cetacean species along the coast, and more particularly inside of the Galician rías (López 2003; Pierce et al. 2010; Louis et al. 2014).

Data collection

Data for this study were collected as part of a longitudinal study of common bottlenose dolphins inhabiting the Galician coast. We conducted boat-based surveys in the Ría of Arousa between April 2014 and May 2016 using a 12-m vessel, powered by two 180 hp inboard engines. In all, 22 months were spent in the field. Because of poor
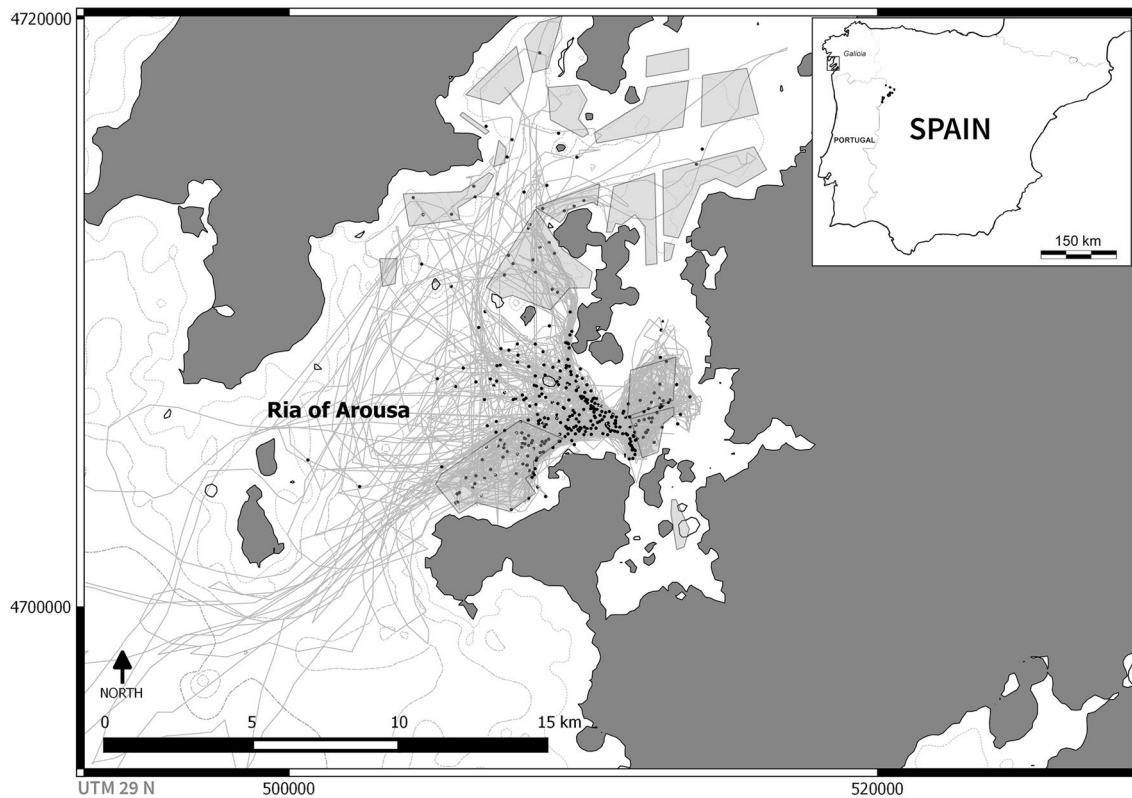
Fig. 1 Geographical location of the Ría of Arousa (Galicia, NW Spain) including 50 and 100 isobaths with index map of the Iberian Peninsula. Survey effort is indicated by *grey track lines*. Dolphin encounters are indicated by *small circles*. Filled polygons indicate the locations of mussel aquaculture zones

weather conditions during December, we were unable to complete surveys in this month.

The Ría of Arousa was surveyed during daylight hours at a constant speed, between 6 and 8 knots, with at least three experienced observers, stationed on the flying bridge, scanning 360° of the sea surface in search of bottlenose dolphins (with the naked eye and/or 10×50 binoculars). The minimum number of observers and vessel speed remained constant during the study period, making data suitable for the comparative analysis of encounter rates. Boat-based observations were done when the visibility was not reduced by rain or fog, and sea conditions were <3 on the Douglas sea scale (approximately equivalent to the Beaufort wind force scale). The survey area and track were selected based on sea conditions and time constraints on each day. Surveys were attempted to equally cover all parts of the study area, although the geographic distribution of effort could vary according to weather conditions. Upon sighting a group of bottlenose dolphins, searching effort ceased and the vessel slowly manoeuvred towards the group in order to minimize disturbance during the approach. During observation sessions, bottlenose dolphin groups were monitored for extended periods of time, often during the course of

several hours. After the end of an encounter, the searching effort generally continued along the previously planned route.

On each boat survey, the time, position, speed (knots), presence of dolphins, and environmental and anthropogenic data were recorded every 20 min (following Díaz López [2017]). These 20-min sets were used to summarize field conditions and distribution of the survey effort irrespective of dolphins' presence. Sets were designed to collect records for dolphin groups using one-zero sampling (Altmann [1974]), for which an observer records the presence or absence of bottlenose dolphins at the beginning of each 20-min sample. We also recorded potentially confounding variables that were beyond the control of the observers but which may have influenced the presence or sightability of the bottlenose dolphins.

The environmental variables used to predict bottlenose dolphin presence comprised date, time, position, bathymetry, bottom slope gradient (the maximum rate of change in depth in a given grid cell and expressed as percent slope), bottom slope aspect (the compass orientation of the slope, ranging from −180° to +180° with respect to true north), tide level, sea surface temperature (SST), sea surface salinity (SSS), wind speed and direction, and distance to the

coast (metres). The anthropogenic variables comprised distance to mussel aquaculture zones (metres, value zero when the group of dolphins was inside the aquaculture zone), number of recreational vessels, number of fishing vessels, and number of mussel farm boats in the area.

The date, time (UTC), position (UTM coordinates), bathymetry (depth in metres), speed of travel (knots), and SST (in degrees Celsius) were obtained by a GPS-Plotter Map Sounder (Garmin) associated with an echo-sounder. The wind speed (m/s) and direction (degrees) were measured, when the vessel was stationary, by a cup anemometer and compass situated 4 m above the sea level. Tide level (metres) was obtained for the harbour of Vilagarcia de Arousa from the Galician weather service: http://www.meteogalicia.gal. Bottom slope gradient and slope aspect were computed from the bottom depth obtained from the General Bathymetric Chart of the Oceans (GEBCO08, http://www.gebco.net) dataset. This dataset was converted to a raster format and then interpolated using QGIS software (http://www.qgis.org) terrain analysis tools. All distances to coast and mussel aquaculture zones were minimum distances from the GPS position of each 20-min point sample to the perimeter of the feature, taking into account the coastal and shellfish aquaculture zones' profile and calculated via spatial analyst tools using QGIS software.

A group of bottlenose dolphins was defined as one or more common bottlenose dolphins observed within a radius of 100 metres. When a group of dolphins was sighted, dolphin aggregations and composition were estimated based on the initial count of individuals observed at one time in the area. Individual dolphins were classified according to age within each group at the time of the sighting (Scott et al. 1990). Age class definitions followed those by Mann and Smuts (1998), Mann et al. (2000), and Díaz López (2006a), where bottlenose dolphins were classified as follows: (1) Newborns are dependent dolphins smaller than 1.5 m (in relation to the mother) with foetal folds or lines. Newborns were also determined on the basis of uncoordinated surfacing behaviour and swimming in infant position (underneath the mother lightly touching her abdomen). (2) Immatures are dolphins with few rake marks and skin lesions and two-thirds or less the length of adults, often observed in close association with an adult but never observed in the infant position. (3) Adults are full-grown (longer than 2.5 metres) marked or unmarked animals with darker skin colouration.

Data analysis and modelling framework

The target sample size was arbitrarily set at 50 randomly selected instantaneous 20-min sets searching for dolphins (on-effort) for each season across the study period. During the study, four seasons were defined (Díaz López and

Shirai 2007): Winter (January to March), Spring (April to June), Summer (July to September), and Autumn (October to December). By selecting data at random, the lack of independence arising from consecutive samplings was limited, avoiding the influence of variations in the observation effort and limiting any pseudoreplication problems.

The relative frequency of occurrence of common bottlenose dolphins (ER) was computed as ER = Ns/Eff, where Ns is the number of 20-min sets (on-effort) with the presence of *T. truncatus* and Eff is the total number of 20-min sets searching for dolphins as a measure of the effort. A non-parametric Mann–Whitney test was used to investigate the equality of medians of group size samples (i.e. groups observed inside and outside the shellfish aquaculture zones).

Since the shapes of relationships with explanatory variables were unknown, a generalized additive modelling (GAM) framework was used to investigate the factors affecting the occurrence of common bottlenose dolphins throughout the Ría of Arousa. GAMs allow for flexible relationships between the response variable (presence/absence of common bottlenose dolphins) and explanatory variables (Hastie and Tibshirani 1990). The GAMs were implemented from the library mgcv (Wood 2006) in v. 1.8.1. of the computer package R (R Development Core Team 2012).

We initially attempted to model the presence–absence of common bottlenose dolphins as a binomial GAM with a logistic link function. For the binomial model, the following hypotheses of control were tested: environment-based (persistent and non-persistent environment), geographical, and anthropogenic variables. Therefore, four different models—each with a set of related variables—were generated. To reduce multicollinearity and eliminate redundant information, we selected a set of explanatory variables to enter in the GAM analysis by eliminating those variables that were highly correlated with each other ($r > 0.70$) and exhibited low tolerance statistics (<0.3) in ordinary least squares regression analysis (OLS) (Dormann et al. 2013). Multicollinearity between model terms was tested by means of variance inflation factors (VIF; Neter et al. 1990).

Environment-based models (persistent and non-persistent environment) aim to relate observations of dolphin's presence to various attributes of the marine environment. Persistent environment models initially included depth, bottom slope gradient, bottom slope aspect, and distance to the coast. Non-persistent environment models initially included time of the day, month, season, wind speed and direction, SST, tide level, and SSS. Geographical models initially included continuous geographical coordinates (UTM longitude and UTM latitude). Anthropogenic models initially included distance to mussel farms, number of recreational vessels, number of fishing vessels, and number of mussel

farm boats in the area. To account for a different probability of encountering common bottlenose dolphins depending on different survey efforts, a relative sampling effort index was included in all four models. This index was generated by calculating the number of 20-min sampling sets (on-effort) within stratified grid cells of 1 km^2 throughout the study area. This effort index was then simplified into a factor variable at the quartiles of the resulting values, generating categories of 'low', 'medium', 'high', and 'very high' survey effort (Bonizzoni et al. 2014). All four models also included initially the wind speed as a measure of the sea conditions to account for sampling bias and error.

The outcome of this multimodel inference may not always be the identification of a unique solution ("best model") but rather an ensemble of likely solutions (Planque et al. 2011). The technique, if used appropriately, can lead to robust predictions without the need to identify a unique best model (Araújo and New 2007). Akaike information criteria (AIC) with forward stepwise selection was used to obtain the optimal set of predictor variables, where the lowest AIC value for every possible combination of explanatory variables was chosen (Pan 2001). To assist with the selection process, we used the 'basis = cs' option for fitting smoothers, which allows degrees of freedom for individual smoothers to fall to zero (a good indication of non-significance). We conservatively removed a variable in the model if it was clearly non-significant ($P >> 0.05$). Partial predictions for significant predictors were plotted, and 95% confidence bands were constructed.

Results

Survey effort and presence of common bottlenose dolphins

The field effort within the coastal waters off the Ría of Arousa entailed two consecutive years of fieldwork from April 2014 to May 2016. The total area monitored was around 410 km^2. In all, 154 daily boat surveys over a period of 22 months were spent in the field, totalling 466 h

and 3 788 km (Table 1). During this period, 1 428 instantaneous sets were recorded every 20 min (795 sets searching for dolphins (on-effort) and 633 with the group of dolphins (off-effort)).

During this time, there were 369 small cetacean encounters (353 with common bottlenose dolphins, 11 with harbour porpoises (*Phocoena phocoena*), 4 with common dolphins (*Delphinus delphis*), and 1 with Risso's dolphins (*Grampus griseus*)). Common bottlenose dolphins were the most commonly observed cetacean species in the area, seen on 141 days at sea (92% of total number of daily surveys). This species was encountered throughout the whole study area and in all months of the year. Bottlenose dolphins were the only cetacean species encountered inside of the aquaculture zones.

In order to limit the lack of independence arising from consecutive 20-min instantaneous set sampling and to control for seasonal variation, a total of 200 randomly selected samples were used. The relative frequency of occurrence (ER) of bottlenose dolphins in relation to the spatial distribution inside or outside of the aquaculture polygons is summarized in Table 2.

Common bottlenose dolphin group size and composition were examined for 353 independent groups monitored during 245 h (corresponding to 1 270 km). Each group was observed during an average of 42 ± 2 min (3.7 ± 2 km). Group size ranged from 1 to 64 individuals (mean = 13.0 ± 0.6; Table 3). The most observed were aggregations of three dolphins (8% of the encounters)

Table 2 Frequency of occurrence of common bottlenose dolphins (ER) with respect to whether or not dolphins were present inside the mussel aquaculture zones

	Total number of randomly selected (on-effort) 20-min sets	Number of randomly selected (on-effort) 20-min sets with the presence of *T. truncatus*	ER
Inside	45	22	0.49
Outside	155	47	0.30
Total	200	69	0.35

Table 1 Seasonal observation effort, bottlenose dolphin encounters, and number of 20-min samples collected in relation to the 2 years of research

Seasons	Days	Observation effort (h)	Distance surveyed (km)	Number of bottlenose dolphin encounters	Total 20-min sets	On-effort 20-min sets	Off-effort 20-min sets
Winter	31	94	763	85	289	165	124
Spring	47	138	1 129	99	423	234	189
Summer	61	200	1 661	146	613	336	277
Autumn	15	34	235	23	103	60	43
Total	154	466	3 788	353	1 428	795	633

Table 3 Mean number of dolphins ± standard error with respect to whether or not bottlenose dolphins were present inside the mussel aquaculture zones

Presence	Number of encounters	Group size	Adults	Immatures	Newborns
Inside	106	13.2 ± 1.1	11.7 ± 1.0	1.3 ± 0.1	0.10 ± 0.04
Outside	247	13.0 ± 0.7	11.3 ± 0.6	1.5 ± 0.1	0.18 ± 0.04
Total	353	13.0 ± 0.6	11.4 ± 0.6	1.5 ± 0.1	0.16 ± 0.03

followed by couple of individuals (7%), and with most encountered groups (81%) containing less than 20 animals. Group composition showed that 87% of the observed common bottlenose dolphins were considered adults; thus, the remaining 13% were categorized as dependent calves (here considered together as immature dolphins (12%) and newborn dolphins (1%)). Group size did not exhibit any spatial variations between groups observed inside and outside the mussel farm zones (Mann–Whitney test, $p > 0.05$). Likewise, the number of dolphins of a given age category did not show spatial fluctuations between inside and outside the mussel farm zones (Mann–Whitney test, $p > 0.05$).

Models output: environmental (persistent and non-persistent), geographical, and anthropogenic variables

The summary of the values of the selected variables in the presence and absence of common bottlenose dolphins is given in Table 4. For all four final models, the effect of sea state and the effect of relative sampling effort were never significant. Therefore, these variables did not affect the probability of bottlenose dolphin encounters.

Once these results were taken into account, within the final persistent environment model only depth was retained as a predictor of *T. truncatus* presence (Fig. 2). The persistent environment model explained 21.5% of deviance in bottlenose dolphin presence. In this case, the model can be considered satisfactory. The response curve for depth indicates that dolphin presence was higher in waters shallower than 30 m. Within the non-persistent environment model, all the variables were non-significant. Within the geographic model, longitude was retained as a predictor of *T.*

truncatus presence (Fig. 3). The response curve for longitude indicates that dolphin occurrence was lower in western portions of the Ría of Arousa (at the mouth of the ría). This model explained 20.3% of deviance in bottlenose dolphin presence and is thus relatively good. For the anthropogenic model, the distance to mussel farms affects the probability of bottlenose dolphin encounters. Bottlenose dolphin occurrence was higher in areas within 1 km of mussel farms and lower at distances greater than 6 km (Fig. 4). The explanatory power of the distance to mussel farms (19% of deviance, not accounted for the effects of variables related to observation effort and efficiency) can be considered satisfactory.

Discussion

The interaction between top predators and aquaculture, and the consequences of this interaction, is of great importance for coastal and aquaculture management (Díaz López 2012). Since marine aquaculture activities are restricted to shallow, near-shore waters, there is an important overlap with the distribution of coastal cetacean species in several areas around the world (Würsig and Gailey 2002; Jefferson and Hung 2004; Markowitz et al. 2004; Watson-Capps and Mann 2005; Visser 2007; Ribeiro et al. 2007; Pearson 2009; Pearson et al. 2012; Díaz López 2012, 2017; Díaz López et al. 2013; Bonizzoni et al. 2014).

Observations during this study suggest that areas of shellfish production are frequently utilized by common bottlenose dolphins. These results contribute to extend the scant information available about the impact of aquaculture on marine top predators. The unequal use of available habitat, concentrated in the vicinity of shellfish aquaculture zones, and in shallow waters inside of the Ría of Arousa, showed that bottlenose dolphins presented a fine-scale pattern of habitat selection. Of the investigated factors, shellfish farm appeared to have a clear effect, with increased bottlenose dolphin occurrence at shellfish farm locations and in waters close to the farm zones. While mussel farms comprised just around 17% of the total area in the Ría of

Table 4 Summary of the variables retained by the final selected models (persistent environment, geographical, and anthropogenic models) for the presence and absence of common bottlenose dolphins. In all cases, the sample size (N) corresponds with the number of randomly selected on-effort 20-min sets

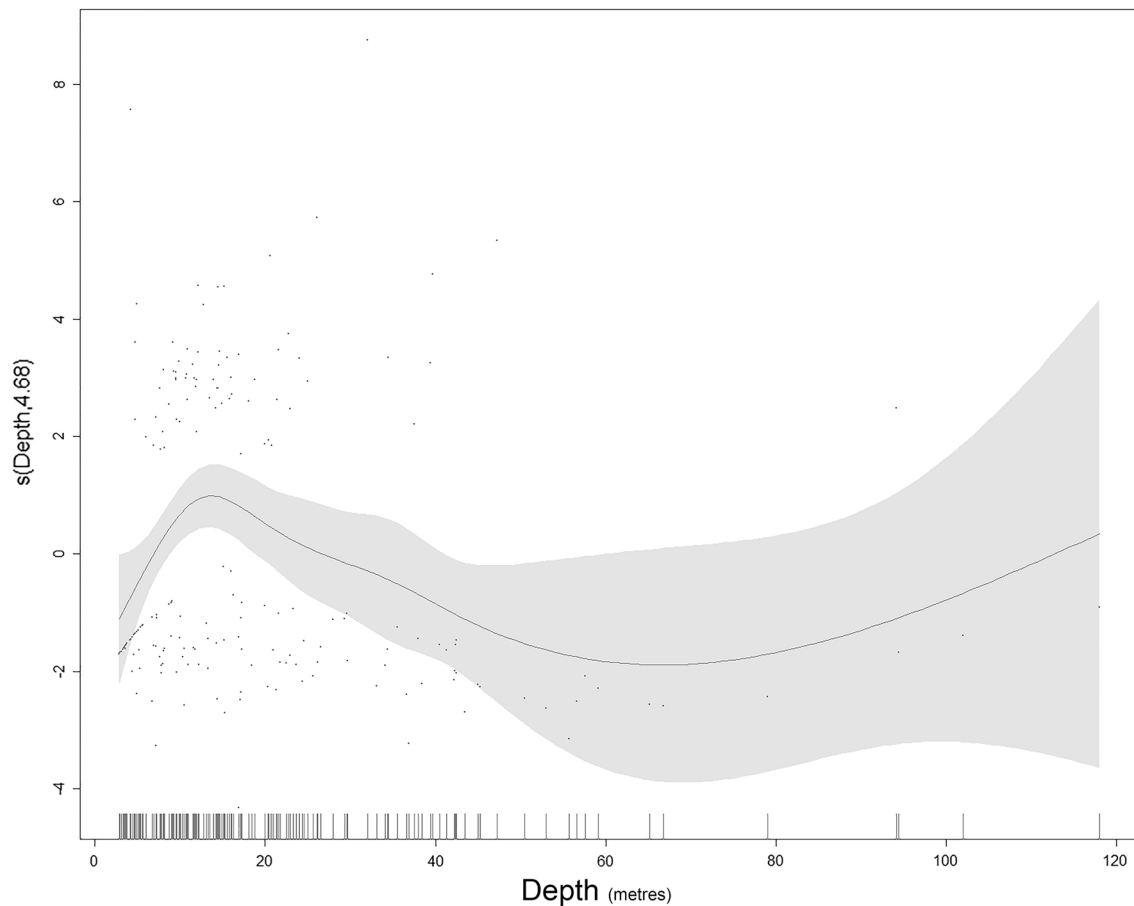| Model/significant variable	Presence			Absence			Overall		
	N	Mean ± SE	Min–max	N	Mean ± SE	Min–max	N	Mean ± SE	Min–max
Persistent environment/depth (m)	69	16.7 ± 1.6	4.2–94.1	131	20.7 ± 1.8	2.9–118	200	19.3 ± 1.3	2.9–118
Geographical/longitude (UTM X) (km)	69	509.8 ± 0.4	491–514	131	508.7 ± 0.4	491–516	200	509.1 ± 0.3	491–516
Anthropogenic/distance from mussel rafts (km)	69	0.73 ± 0.2	0–14	131	1.33 ± 0.2	0–17.9	200	1.12 ± 0.16	0–17.9

Fig. 2 Common bottlenose dolphin presence modelled as a smooth function of depth. The AIC of the best permanent environment model was 230 (corresponding $R^2 = 0.2$) and $P < 0.01$. *Shaded areas* represent 95% CIs. A rug plot with the actual data values is also shown

Arousa, they appear to represent a preferred area of distribution for *T. truncatus*.

These observations contrast with previous studies where the occurrence and distribution of cetacean species decreased in association with shellfish aquaculture representing a source of habitat loss by excluding cetacean species and causing potentially negative effects. In Admiralty Bay, New Zealand, dusky dolphins spent significantly less time than expected inside shellfish farm zones (Markowitz et al. 2004; Pearson et al. 2012). In Shark Bay, Australia, Indo-Pacific bottlenose dolphins used habitat inside shellfish farms significantly less than they used an ecologically similar habitat without shellfish farms (Watson-Capps and Mann 2005). In Yaldad Bay, Chile, Chilean dolphins avoided using areas that were covered by shellfish farms (Ribeiro et al. 2007). In the Marlborough Sounds, New Zealand, killer whales (*Orcinus orca*) avoid entering shellfish farm areas (Visser 2007). In Chinese waters, Indo-Pacific humpback dolphins' (*Sousa chinensis*) use of habitat was also influenced negatively by the presence of shellfish farms (Jefferson and Hung 2004). These differences

suggest that the interactions between shellfish aquaculture and cetaceans seem to be affected very significantly by the culture method and cetacean species involved, being fundamental to study the impacts on a case-by-case basis in more detail. The type of bivalve culture technique used in Galician waters, characterized by mussel rafts (Perez Camacho et al. 1991), differs from the longline system described in the previous studies about interactions between cetaceans and shellfish aquaculture.

Although predator avoidance, interspecific competition, and reproductive strategies all play a key role in cetacean distribution to some extent, habitat preference is assumed to be determined primarily by food availability (Stevick et al. 2002). The positive relationships between dolphins' occurrence and mussel aquaculture zones are presumably the result of large aggregations of fish species around mussel rafts, which in turn provide higher densities of higher quality prey for dolphins than in areas outside the mussel farm zones. Bottlenose dolphins in Galicia eat a wide range of fish species, the most important numerically and in terms of biomass being pelagic and demersal fish
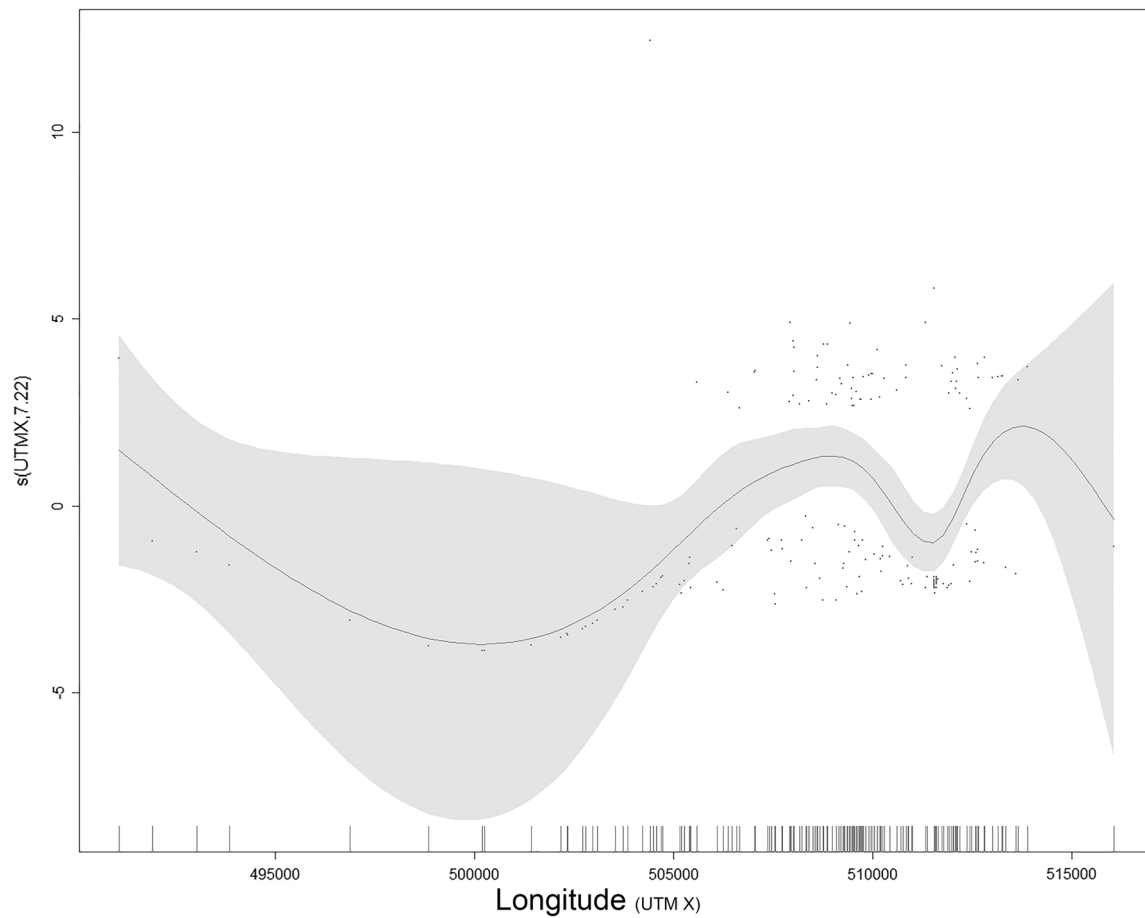
Fig. 3 Common bottlenose dolphin presence modelled as a smooth function of longitude (UTM X, grid 29 N). The AIC of the best geographic model was 229 (corresponding $R^2 = 0.19$) and $P < 0.01$. *Shaded areas* represent 95% CIs. A rug plot with the actual data values is also shown
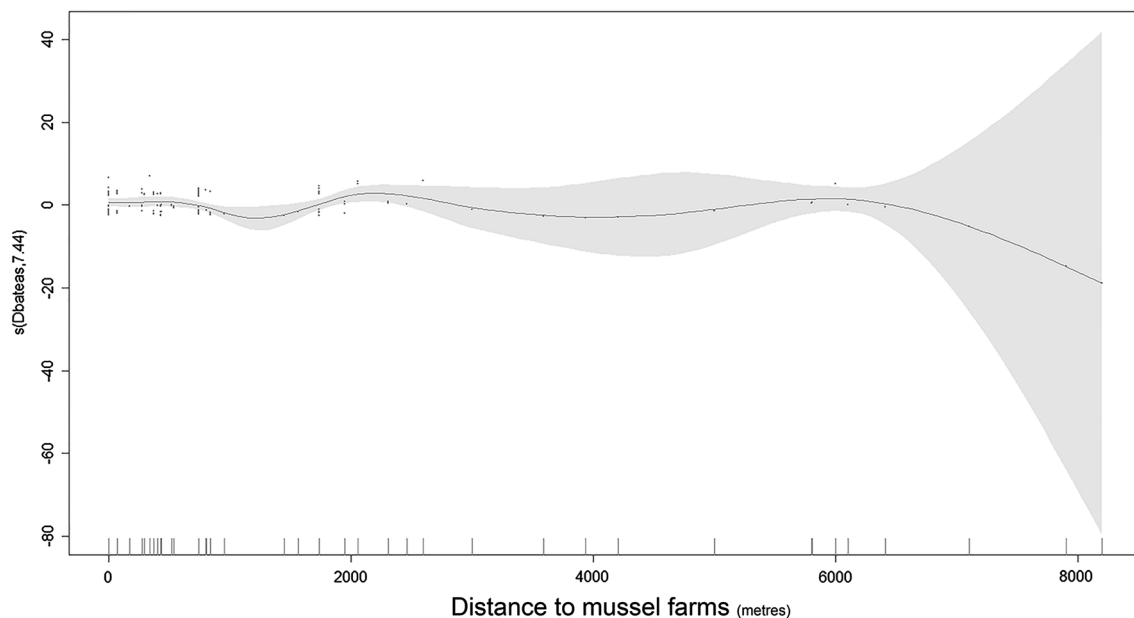

Fig. 4 Common bottlenose dolphin presence modelled as a smooth function of distance to mussel farms. The AIC of the best anthropogenic model was 237 (corresponding $R^2 = 0.14$) and $P < 0.05$. *Shaded areas* represent 95% CIs. A rug plot with the actual data values is also shown

species (Santos et al. 2007). The physical structure of mussel rafts, acting as "fish aggregation devices" (Rountree 1989), together with the cascading effect from the presence of an associated high epifaunal biomass (Mckindsey et al. 2011), enhances the biomass of bottlenose dolphin preys. Effects on wild fish species have been investigated in the Ría of Arousa, indicating a considerable increase in pelagic and demersal fish species abundance and biomass in the immediate vicinity and inside of mussel aquaculture zones (Chesney and Iglesias 1979). Many of these fish species (i.e. families Gadidae, Mullidae, and Carangidae) were described as the most important prey species of *T. truncatus* in Galician waters (Santos et al. 2007). Behavioural observations of groups of bottlenose dolphins conducted during this study were consistent with the hypothesis of mussel rafts playing a key role in their distribution, as dolphin groups were repeatedly observed catching fish and performing long dives around the floating platforms. By reducing the time spent searching for prey, common bottlenose dolphins reduce the energy required to feed and possibly increase the quantity and quality of the food consumed (Díaz López 2006b). This effect has been associated in other *T. truncatus* populations with opportunistic feeding due to concentrated resource of food in a coastal environment characterized by a patched distribution of food resources (Díaz López 2012, 2017).

Management of shellfish farms with regard to how they affect marine mammals is currently a pressing issue. Modelling cetaceans' distribution is a valuable tool for conservation, in particular in terms of identifying relationships between the environment and species habitat selection (Pirotta et al. 2011). In essence, distribution models are restricted to modelling species response to the environment but environmental forcing alone cannot be expected to fully explain the spatial distribution of bottlenose dolphin populations, unless such forcing is so strong that it over-rides all other drivers. This study suggests that other mechanisms such as the impact of human activities, and more particular shellfish farming, affect the spatial distribution of common bottlenose dolphin populations.

This study provides new insights into the understanding of how shellfish aquaculture influences common bottlenose dolphins' ecology, and hence supports the design of policies aimed at implementing ecosystem management principles. This also contributes to the growing body of literature addressing environmental consequences of suspended shellfish aquaculture, particularly the effects on coastal cetaceans, which have rarely been evaluated. A better understanding of the preferred behaviour associated with the observed habitat preferences will improve management and conservation efforts by providing a context for interpreting the present and future anthropogenic effects on bottlenose dolphin populations and their distribution.

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