Effects of vessel traffic on relative abundance and behaviour of cetaceans: the case of the bottlenose dolphins in the Archipelago de La Maddalena, north-western Mediterranean sea.

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Abstract

Many studies have shown that vessel traffic has both long and short term negative effects on marine mammals. Although there has been a great expansion of recreational vessel traffic in the Mediterranean Sea in recent decades, few studies focused on this problem. Here, Bayesian models were used to explore the influence of vessel traffic on behaviour and relative abundance patterns of bottlenose dolphin in the Archipelago de La Maddalena (Italy), a coastal area included within the Pelagos Sanctuary. Results showed that season, moon phase and presence of calves had an effect on the number of adult dolphins per sighting, and that there were differences in occurrence in the sub-areas. On the contrary, the number of vessels was negatively related to the number of adult dolphins and their mean dive intervals (MDI). In particular, when more than three recreational boats were present in the area, dolphins surfaced more frequently per unit time and behaviours such as feeding and socializing were not detected. On the contrary, longer mean dive were found when fishing boats were present. Our results provide additional support for the need to consider disturbance such as vessel traffic in management plans for cetacean conservation.

Keywords: Bayesian models; conservation; disturbance; Pelagos Cetacean Sanctuary; surfacing rate; *Tursiops truncatus.*

Introduction

Nowadays cetacean populations are facing several threats including depletion of resources (Stefánsson, 1997), interactions with commercial fisheries (Gilman et al. 2007), degradation of habitat (Simmonds & Nunny, 2002), diseases produced by pollution (Wafo et al. 2005), and physical and acoustic disturbance (Roussel, 2002) caused particularly by increased boating and shipping traffic.

Particularly, the bottlenose dolphin (*Tursiops truncatus*) is exposed to a wide variety of these threats, due to its occurrence in coastal waters. Its coastal ecotype is present in the ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic area) region (Notabartolo di Sciara, 2002). This species is protected by the EU Habitats Directive 92/43/EEC and it has recently been classified as vulnerable (VU A2cde) in Mediterranean waters (Bearzi et al. 2012).

Effects of vessel traffic on animals can be described by considering short-term responses and also their long-term ramifications. In particular, short-term responses are indicated by changes in respiration patterns, surface active behaviours, swimming velocity, inter-individual spacing, approach and avoidance, and displacement from the area of interaction (Nowacek & Wells, 2001; Lusseau, 2003; Buckstuff, 2004; Pirotta et al. 2015a; Campana et al. 2015). These responses have been suggested as being related to noise (Bejder et al. 1999) or a reaction to physical presence, or a combination of both (David, 2002).

Although there has been a great expansion of recreational vessel traffic and shipping in the Mediterranean in recent decades (Dobler, 2002), only three studies have focused on behavioural changes related to boat traffic in this area (David, 2002). Underhill (2006), Papale et al. (2001) and Rako et al. (2013) all reported modifications in the diving pattern of bottlenose dolphins, in Sardinian, Sicilian and Adriatic waters, respectively.

In the waters of Northern Sardinia, located in the Pelagos Cetacean Sanctuary, the bottlenose dolphin is one of the most common cetacean species (Notabartolo di Sciara, 2002). In particular, in the Archipelago de La Maddalena, Pennino et al. (2013) photo-identified 71 individuals, and defined 22 as resident (individuals sighted in all seasons during that one year and at least five times).

In this area, tourism is the main industry, with around 150,000 visitors each year and with traffic of about 5,000 leisure boats. Moreover, in the summer months (from June to September) boat traffic increases, prompting displacement of the resident animals to other areas (Pennino et al. 2015).

To interpret and mitigate potential impacts of vessel traffic on the local population of bottlenose dolphins, it is essential to assess short-term responses in terms of changes in the distribution and behaviours.

In this context, the primary goal of our study was to evaluate whether the interaction of vessel traffic with dolphins in the Archipelago de La Maddalena has an effect on the relative abundance of the local dolphin population. In order to do so we modelled the number of adult individuals sighted with respect to number and type of vessels, environmental, spatial and temporal covariates, using Bayesian methods.

Our secondary goal was to describe whether and how dolphin behaviour varied with the presence of vessel traffic. Firstly, we tested the impact of different levels of vessel traffic on the variation in dolphin behaviour, using an analysis of similarity (ANOSIM). This technique was implemented to identify differences in behaviour categories by combining permutation tests with the general Monte Carlo randomization approach. Secondly, Bayesian models were used to assess whether variation in the intersurfacing interval of dolphins were related to habitat features, vessel traffic or a combination of both effects.

Materials and methods

Study area

This study was carried out in waters within 3 miles of the coast of Archipelago de La Maddalena (41° 13′ 0″ N, 9° 24′ 0″ E) (*Figure 1*).

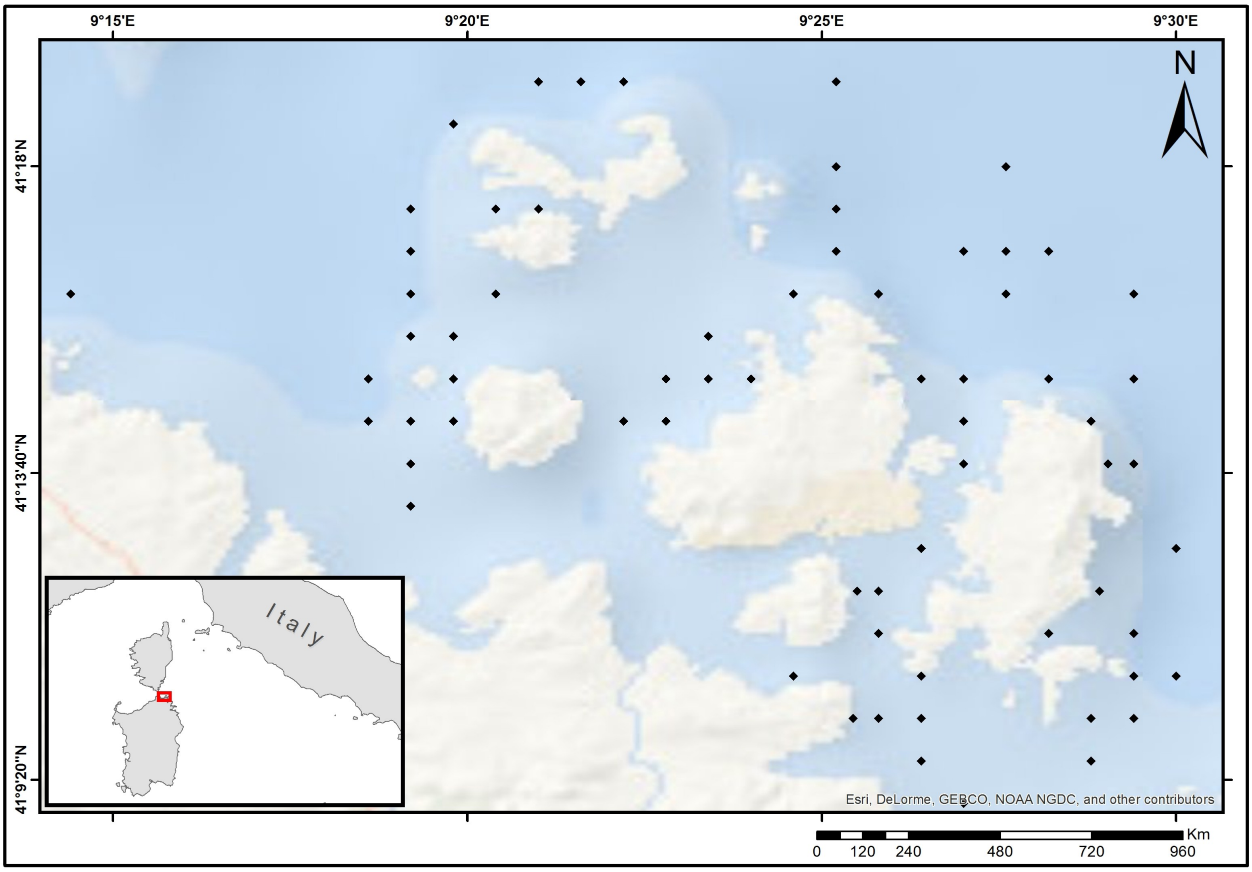

Figure 1: Map of the study area, the Archipelago de La Maddalena, Sardinia (Italy) with bottlenose dolphin sightings.

The entire area is included within a National Park located in the strait of Bonifacio, between the islands of Sardinia and Corsica, and is part of the Pelagos Cetacean Sanctuary established by Italy, France and Monaco in 1999. The Sanctuary is a vast marine protected area extending over 90,000 km^2 of sea surface in a portion of the north-western Mediterranean Sea comprised between south-eastern France, Monaco, north-western Italy and northern Sardinia, and encompassing Corsica and the Tuscan Archipelago (Notarbartolo di Sciara et al. 2008).

The Maddalena area is characterized by rocky and sandy bottoms extensively covered with

Posidonia (*Posidonia oceanica*) sea-grass beds, with water depth ranging from 0 to 70 *m*. The location of the Archipelago inside the "Bocche of Bonifacio" causes a high level of hydrodynamism that, associated with the shallow depth of the channel and limited tidal range, is responsible for the very clean water which characterizes the area (Pennino et al. 2013).

Only 18 fishing boats are authorized to practice artisanal fishing activities within the National Park. In accordance with park regulations, fishing is permitted throughout the year, except for a closure during 45 days every winter. Most fishing uses bottom-set fishing gear, such as trammel nets, whilst other gear, such as traps, is sporadically used. The net mesh size is chosen based on the main target species and on the season (Pennino et al. 2015).

Sampling methods

The study area was divided into four sub-areas of equal dimension (northern, western, southern, and eastern, see *Figure 2*) and each was monitored following systematic transects in a boat travelling at a speed of 8 to 10 kts. Surveys of five hours duration were performed always at set times, namely in the morning (6:00-10:00) and afternoon (16:00-20:00), on a 5.5 m Zodiac inflatable boat. In addition, to ensure that all behaviours were visible across the study area, surveys were only performed when the sea state was less than Douglas sea force 3 and in clear weather conditions with no precipitation.

Data collected included sighting date, location (the monitored sub-area), depth and type of seabed, number and type of vessels (sailing, fishing, recreational and ferry boats) present, dolphin school size, and dolphin behaviour. During monitoring, data on environmental variables and boat presence were collected every 15 minutes. Two expert observers conducted visual surveys concurrently on the same boat but on opposite sides. Data were included in the database only when there was an agreement between the two concurrent observers. Specifically, if the number of sighted dolphins was substantially different (i.e. more than 2 dolphins) the sighting was not included in the database, while in cases in which the difference was small (i.e. just 1 dolphin) the lower number of dolphins was included in the database. Similarly, if any difference was recorded in the behaviour, the dive time of the focal animal was used to confirm the selection of the behaviour category.

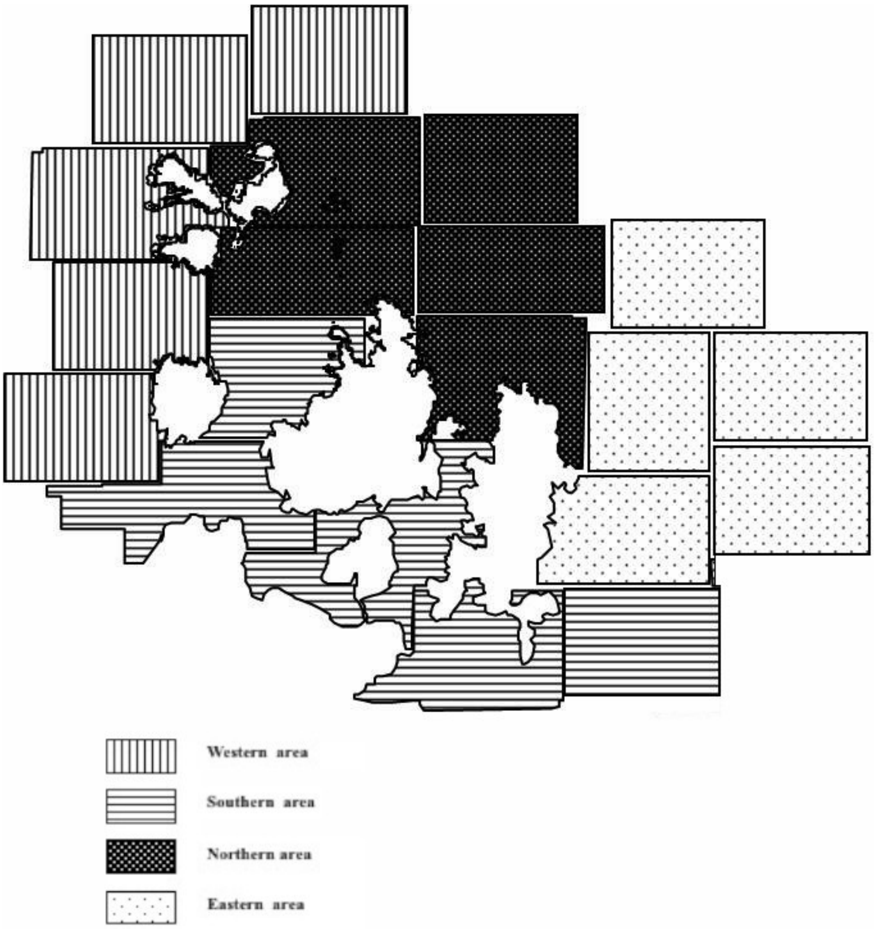

Figure 2: Map of the study area divided into four sub-areas of equal dimension (northern, western, southern, and eastern).

A school was defined as a group of bottlenose dolphins sighted within an approximate 100 m radius (Wells et al. 1987). Individuals were identified as belonging to three arbitrary age classes based on visual assessment using the average adult size: (1) adult (a bottlenose dolphin approximately 3 to 4.5 m long), (2) juvenile (about two thirds of an adult), and (3) calf (newborn with evident fetal folds or individual about one-half the size of an adult in constant association with a single adult –

presumably its mother) (Bearzi et al. 1997). Behavioural data were collected using the predominant group activity sampling method (Mann, 1999), with the group activity being scored every 5 minutes. To standardize data collection, behavioural activity was sampled for at least 45 minutes unless contact with the group was lost before that time.

The behaviour of dolphins was classified in the field into one of four exclusionary categories, according to Mann & Smuts (1999), and Chilvers & Corkeron (2001):

1. *Foraging* – Rapid surfaces, frequent direction changes, fast swimming, chasing fish, and observed fish catches.

2. *Socializing* – Physical contact, splashing, chases, pokes, and play, with little consistent directional progress.

3. *Travelling* – Swimming in a constant direction with regular surfacing intervals.

4. *Surface activities* – Acceleration on the sea surface, breaching and tail slap.

In addition, the dive time (mean time between breaths) of a focal animal was recorded during each survey. The selection of the focal animal was carefully conducted each time to ensure reliability of re-sighting the individual within a survey session. We chose focal animals that would not be confused easily with other members of the group and that were therefore likely to be consistently re-sighted. A focal animal typically had a distinctive dorsal fin and saddle patch (Ford et al. 1994). Animals were followed for a minimum of 15 minutes, because earlier work has shown that shorter surveys tend to bias estimates of respiration rate (Kriete, 1995).

In order to avoid harassment of bottlenose dolphins, we observed them from a safe and respectful distance, avoiding approaching them closer than 10 m. If bottlenose dolphins approached the boat, we maintained its course, avoiding abrupt changes in direction or speed to prevent running over or injuring the animals.

Statistical analysis

A total of nine potential fixed-effects have been considered to explain the relative abundance of bottlenose dolphins and these are listed in *Table 1*.

Except for the variables “depth” and “number of vessels”, which are continuous, the other explanatory variables are all categorical: season, sub-area, time of day (morning, afternoon), moon phase, type of seabed, type of vessel (sailing, fishing, recreational and ferry boats) and presence of calves (*Table 1*).

Table 1. *Summary of variables included in Bayesian models as potential fixed-effects influencing the relative abundance of bottlenose dolphin (Tursiops truncatus) excluding calves.*

Variable	Description	Units
Season	Season when the sighting was performed	Winter, spring, summer, autumn
Location	Sub-area where the sighting was performed	Northern, western, southern, eastern
Time	Time when the sighting was perfomed	Sunrise, morning, afternoon, sunset
Presence of calves	Occurrence of calves during the sighting	Yes/no
Number of vessels	Number of vessels sighted during the sighting	1, 2, 3, 4, 5, 6, 7
Type of vessel	Typology of the vessel sighted	Sailing, fishing, recreational, ferry boats
Moon phase	Moon phase of the sighting day	crescent, full moon, waning, new moon
Type of seabed	Seabed substrate at the survey location	Sand, mud, rock, gravel
Depth	Mean depth of the sighting location	In metres

Collinearity between explanatory variables was checked using a draftsman's plot and the Pearson correlation index. Variables were not highly correlated ($r < 0.6$), and thus all have been considered in further analyses.

Modelling relative abundance of dolphins

The variation of the relative abundance of dolphins was modeled by a hierarchical Bayesian approach, specifically a Poisson model with log-linear intensity. We used a Bayesian approach, as it allows both the observed data and model parameters to be considered as random variables, resulting in a more realistic and accurate estimation of uncertainty (Banerjee et al. 2004).

Specifically, the expected number of adult dolphins in each sighting (i.e., excluding calves) was modelled with respect to the variables mentioned in *Table 1*. In addition, a random factor that represents the observer's effect for each sighting was included as possible predictor. Indeed, the remaining potential source of variation in the number of dolphins sighted could be due to the observers themselves. These differences can be caused by observer's behaviour (caused by random aspects, such as the personal experience) or unobserved survey characteristics. Ignoring such non-independence of the data may lead to invalid statistical inference. Then, in order to remove this bias a random observer effect was included.

Following the Bayesian reasoning, once the model has been determined, the next step is to estimate its parameters, and assign to them a prior distribution. In particular, for the parameters involved in the fixed effects, we use non-informative Gaussian distributions $N(0, 100)$, where 0 is the mean and 100 the standard deviation.

All possible combinations of variables described in *Table 1* were tested using both backwards and forwards approaches to select relevant variables. Specifically, we used the Deviance Information Criterion (DIC), a well-known Bayesian model-choice criterion for comparing complex hierarchical models (Spiegelhalter et al. 2002). DIC is inversely related to the compromise between fit and parsimony.

Bayesian models were fitted using the integrated nested Laplace approximation (INLA) methodology and software (Rue et al. 2009) implemented in R software (R Development Team, 2015).

Identifying changes in dolphin behaviour

In order to assess if there are differences in the type of behaviour observed with respect to the number of boats we performed an analyses of similarity (ANOSIM). Firstly, the number of boats was split in three different categories: low (0-2), medium (3-5) and high (6-8). Secondly, we created a matrix for each category of behaviour (foraging, socializing, traveling, surface activities) standardized per hour, for each survey. Specifically, we count how many times a particular behaviour was recored for each hour of a sighting, as well the number of boats. Dissimilarity matrices were computed with the Morisita index (Morisita, 1959), that is commonly used for count data, with the "*vegdist*" function of the "*vegan*" package (Oksanen et al. 2014) of the R software.

The ANOSIM technique tests for differences in behaviour frequency by combining permutation tests with the general Monte Carlo randomization approach (Hope, 1968). The null hypothesis (H_0) was that there are no differences in behaviour frequency between traffic boat categories. To test the null hypothesis, a test statistic, *R*, that contrasts the variation between pre-defined categories of number of boats with variation within categories, is computed. The *R* value is compared to a predicted permutation distribution, given H_0 is true. This distribution is calculated by a chosen number of random permutations of the samples; in this study we used 10,000. If H_0 is true, the observed *R* value will fall within the range of the computed permuted distribution. The *R* values fall between 0 and 1, such that a value close to 1 indicates high separation between levels of the grouping factor, while a value close to 0 indicate no separation between levels of the grouping factor. For this purpose the "*anosim*" function of the "*vegan*" package of the R software was used.

Assessing changes in dolphin mean dive intervals

Dive intervals were defined as the time elapsed between 2 surfacings of the focal animal, e.g. the time between 2 breaths. One mean value for dive intervals (hereafter MDI) of the focal animal was calculated for each survey. In order to assess whether dolphin MDI variability was related to habitat features and/or to the vessel traffic, we modelled the MDI (μ_i) using a Bayesian General Linear Model. In particular, the expected values of μ_i in each survey were related to the independent variables: number of vessels, type of vessel, depth of the location, moon phase, zone, season and time, according to the general formulation:

$$\mu_i = \alpha + X\beta$$

where α is the intercept and β is the vector of the regression coefficients and X is the matrix of covariates for each survey i.

Vague Gaussian distributions for the parameters involved in the fixed effects were used, in order to allow empirically derived distributions. As for the other Bayesian GLMs, this model was fitted using both backwards and forwards stepwise procedures and the goodness-of-fit of each model was also assessed using the DIC.

Results

Between July 2007 and July 2009 a total of 207 surveys was performed and 93 sightings were recorded (*Figure 1*). In particular, 47 out 206 surveys were conducted in the western area, 56 in the northern, 48 in the eastern and 55 in the southern area.

Relationships between dolphin relative abundance and variables

The Bayesian model of the dolphin relative abundance selected for its best fit (based on the lowest DIC) includes season, moon phase, sub-area, number of vessels, type of vessels and presence of calves.

The observer random effect, depth, type of the seabed and time of the sighting were not retained in the final model. *Table 2* presents a numerical summary of the posterior distributions of the fixed effects for this final model.

Table 2. *Numerical summary of the posterior distributions of the fixed effects for the best model of dolphin relative abundance. This summary contains the mean, the standard deviation and a 95% credible interval, which is a central interval containing 95% of the probability under the posterior distribution.*

Variable	**Mean**	**Sd**	$\mathbf{Q_{0.25}}$	$\mathbf{Q_{0.95}}$
Intercept	1.61	1.13	1.23	2.11
Season(Summer)	-1.29	1.58	-3.22	-1.04
Season(Winter)	1.32	1.08	1.10	1.78
Season(Spring)	-1.63	1.27	-2.61	-1.02
Zone(Eastern)	-1.68	1.29	-2.82	-1.06
Zone(Northern)	-1.49	1.18	-2.09	-1.05
Zone(Western)	1.22	1.13	1.05	1.59
Moon(Full)	1.75	1.16	1.29	2.41
Moon(New)	1.09	1.29	1.01	1.36
Moon(Waning)	1.59	1.17	1.03	2.61
Number of vessel	-1.53	1.10	-1.84	-1.06
Type of vessel (Fishing)	1.40	1.13	1.06	1.75
Type of vessel (Recreational)	-1.75	1.10	-1.41	-1.10
Type of vessel (Ferry)	1.10	1.12	-1.37	1.12
Number of calves	1.59	1.12	1.25	2.03

Results showed that winter is the season with the highest estimated dolphin relative abundance (posterior mean = 1.32; 95% CI = [1.10, 1.78]) with respect to the reference level (autumn season). Conversely, summer and spring seasons show lower estimated dolphin relative abundance than the reference level (respectively, posterior mean = -1.29; 95% CI = [-3.22, -1.04] and posterior mean = -1.63; 95% CI = [-2.61, -1.02]).

The eastern area is the zone that shows the lowest dolphin relative abundance (posterior mean = -1.68; 95% CI = [-2.82, -1.06]) with respect to the reference level (southern area), while the western zone has the highest estimated relative abundance (posterior mean = 1.22; 95% CI = [1.05, 1.59]).

The full moon is the phase associated with the highest estimated relative abundance (posterior mean = 1.75; 95% CI = [1.29, 2.41]) with respect to the reference level (crescent moon), which is the phase that presents the lowest estimated relative abundance.

Presence of calves was associated with a higher estimated number of adult dolphins than the reference level (No calves presence) (posterior mean 1.59; 95% CI = [1.29, 2.03]), while the number of vessels showed a negative relationship with the estimated dolphin relative abundance (posterior mean -1.53; 95% CI = [-1.84, -1.06]).

Finally, the fishing boat is the type of vessels associated with the highest estimated dolphin relative abundance (posterior mean = 1.40; 95% CI = [1.06, 0.75]) with respect to the reference level (sailing boats). On the contrary, recreational boats show the lowest estimated dolphin relative abundance (posterior mean = -1.75; 95% CI = [-3.85, -1.10]). Ferry boats were associated with higher estimated dolphin relative abundance compared to the reference level, but (to follow the Bayesian terminology) this difference was not relevant (i.e. the CI spanned zero; posterior mean = 1.10; 95% CI = [-1.37, 1.12]).

Changes in dolphin behaviour

The analysis of the four different categories of behaviour (foraging, socializing, traveling, surface activities) shows a clear difference in behaviour between vessel traffic categories (low, medium, high). The largest differences among vessel traffic categories were found for the foraging (R = 0.83 $p < 0.0001$) and socializing (R = 0.94 $p<0.0001$) behaviours. In both cases, 0 out of 10,000 permutations exceeded the observed value.

In particular when more than three recreational vessels were present in the area, these kinds of behaviour were not recorded (*Figure 3*).

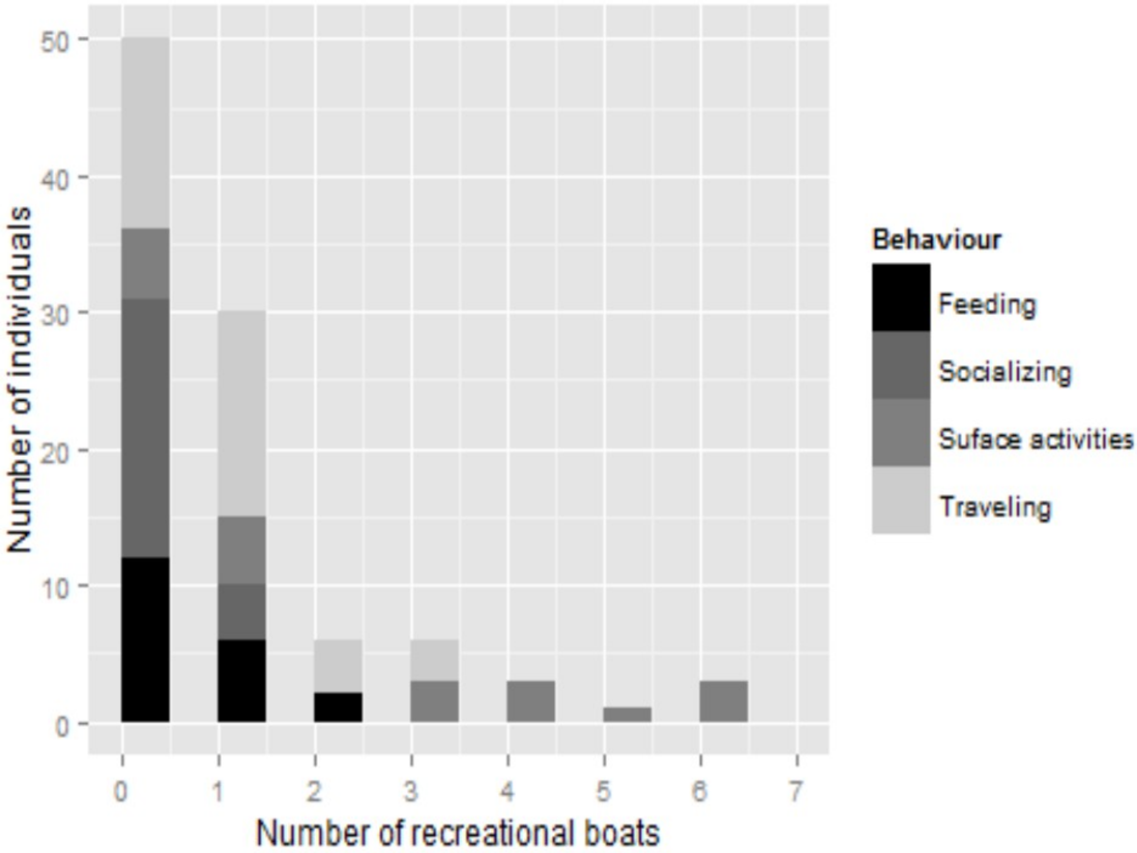

Figure 3: Number of individuals of bottlenose dolphin *(Tursiops truncatus)* sighted during surveys with respect to the number of recreational vessels recorded and dolphin behaviours observed.

The *R*-values for the traveling (R = 0.65) and surface activities (R = 0.72) also show differences, though lesser, among the vessel traffic categories, all with a significance level of $p < 0.001$.

Changes in dolphin mean dive intervals

The selected model for the MDI included as final relevant predictors the depth of seabed, the number of vessels and type of vessel (*Table 3*). Depth of the seabed shows an increasing effect with the MDI of dolphins (posterior mean = 0.35; 95% CI = [0.05, 0.75]); *i.e*. dolphins surfaced more frequently, per unit time in shallower water than in deeper waters.

Conversely, the number of vessels shows a negative effect with the MDI of dolphins (posterior mean = -0.45; 95% CI = [-0.65, -0.11]), which means that as the number of boats increased, dolphins surfaced less frequently (*Table 3*).

Table 3. *Numerical summary of the posterior distributions of the fixed effects for the best model of mean dive interval (MDI) of dolphins. This summary contains the mean, the standard deviation and a 95% credible interval, which is a central interval containing 95% of the probability under the posterior distribution.*

Variable	Mean	Sd	$Q_{0.25}$	$Q_{0.95}$
Intercept	0.28	0.23	0.11	0.85
Number of vessel	-0.45	0.22	-0.65	-0.11
Type of vessel (Fishing)	0.44	0.11	0.14	0.66
Type of vessel (Recreational)	-0.36	0.09	-1.15	-0.09
Type of vessel (Ferry)	0.08	0.02	-0.22	0.12
Depth of the seabed	0.35	0.06	0.05	0.75

Fishing boat is the type of vessel associated with the highest estimated MDI (posterior mean = 0.44; 95% CI = [0.14, 0.66]) with respect to the reference level (sailing boats). On the contrary, recreational boats show the lowest estimated MDI (posterior mean = -0.36; 95% CI = [-1.15, -0.09]) with respect to the other type of vessels. Ferry boats were higher estimated MDI compared to sailing boats, but the difference was not relevant (*i.e*. the CI spanned zero; posterior mean = 0.08; 95% CI = [-0.22, 0.12]).

Discussion

This study revealed strong short-term responses from bottlenose dolphins both in terms of relative abundance and changes in behaviour.

In particular, results of this study indicate that the estimated number of dolphins relative abundance is negatively affected by the increasing number of vessels in the area. However, the typology of the vessels also influences the number of the dolphins. Indeed, positive relationships were found between numbers of sailing and fishing boats and numbers of dolphins, while a negative relationship was seen with recreational boats. Larger vessels, such as ferry boats may be positively related to the relative abundance of this species but, because of the low number of recorded sightings the difference was not relevant in the Bayesian models. Positive relationships between dolphin and artisanal fishing boats in this area have been already demonstrated both in terms of foraging strategy specialization (Pennino et al. 2013) and fishery interactions (Pennino et al. 2015).

In addition, other variables appeared to have a relevant influence on dolphin relative abundance in the Archipelago de La Maddalena. There is for example a seasonal effect on dolphin relative abundance in the area. Our results are consistent with those obtained by Brotons et al. (2008) in the Balearic Islands, Campana et al. (2015) in the Western Mediterranean Sea and Pennino et al. (2015) in the same study area. Estimated dolphin relative abundance is highest in winter and lowest in spring and summer. There are several possible reasons for this observed seasonal variation, which may operate alone or in tandem. Firstly, natural seasonal movement by dolphins could be related to prey availability or other habitat characteristics (*e.g.* salinity, temperature, etc). Secondly, the increased nautical traffic in summer that distinguishes this area could prompt displacement of these animals to areas where there are fewer recreational boats, to avoid noise and the risk of collisions.

There was also spatial variation superimposed on the temporal patterns, with dolphin relative abundance being highest in the western zone. This pattern in the relative abundance was not directly related to the vessel traffic but could involve other variables, as mentioned before for the seasonal effect. It will be necessary to explore the ecological and biological response of the species to the habitat features in this area to clarify this hypothesis. However, the type of seabed and the depth of the location monitored were not relevant in the Bayesian models and thus appear not to influence the relative abundance of the species.

Our results also confirmed a relationship between moon phase and sightings, as already reported for the short-beaked common dolphin (*Delphinus delphis*, Linnaeus, 1758) and Atlantic spotted dolphin (*Stenella frontalis,* Cuvier, 1829) in the Azores. Indeed, the lunar cycle is likely to be important in determining the behaviour of the many delphinid species that forage on vertically migrating prey (Hernandez-Milian et al. 2008; Benoit-Bird et al. 2009).

The presence of calves was positively correlated with relative abundance of adult dolphins. A higher occurrence of calves in large groups has been reported for several bottlenose dolphin populations (Wells, 1991; Bearzi et al. 1997) and has been related to potential advantages including enhanced calf assistance and protection, reduced maternal investment, and the benefit of learning for its young members (Johnson & Norris, 1986).

Concerning the behavioural analysis, results showed that dolphins reduced the variety of behaviour exhibited in the presence of boats, but also decreased mean dive intervals (MDI) when the number of vessels increased. Other studies have also reported dolphins reacting to disturbances by reducing the mean dive and moving faster, in areas such as the Pacific and Atlantic Oceans (Nowacek et al. 2001; Lusseau, 2003; Lemon et al. 2006), north-east Scotland (Sini et al. 2005), but also in the Mediterranean sea (Underhill, 2006; Papale et al. 2011).

Behaviours such as foraging and socializing, which usually imply longer MDI, were not recorded where more than three boats are present. Nevertheless, our results showed that this pattern is dependent on the typology of the vessel. Indeed, higher MDI values were recorded in presence of fishing boats, probably correlated with feeding behaviour.

Depth of the seabed also influenced the mean dive intervals (MDI). Dolphins tend to have shorter MDI in shallower water with respect to deeper waters. A likely explanation is that prey distribution of dolphins is strongly affected by depth and consequently the predator distribution is also related to depth (Massutí & Reñones, 2005). Also this pattern indirectly confirms the interaction between dolphin feeding strategy and the local artisanal fisheries. Indeed, it is well known that recruitment for most of the fish species in the Archipelago de La Maddalena, takes place in shallow water near the coast (depth< 60 m.), where the trammel nets are set (Pennino et al. 2015). Consequently dolphins will undertake longer dives in deeper waters to catch their prey.

Conclusion

In this study, we found evidence consisting in changes in relative abundance and behaviour of bottlenose dolphins in the presence of vessel traffic, potentially harmful due to increased stress and energy costs and reduced feeding rate (although feeding rates appear to be higher in the vicinity of fishing vessels). Given that the bottlenose dolphin is protected under EU Habitat Directive, with a requirement to avoid activities harmful to dolphins these effects imply a need to develop and enforce regulations for vessel traffic, especially for recreational boats in areas in which a resident bottlenose dolphin population is present (Pennino et al. 2013) such as the National Park of the Archipelago de La Maddalena that is also part of the Pelagos Sanctuary. The management of vessel traffic clearly does not address all the other issues to which dolphins are subjected in this area, such as prey limitation, fishery interactions and pollution. However, vessel traffic is a demonstrated threat that lends itself to immediate mitigation. The number of recreational boats in the habitats where dolphin relative abundance are higher should be monitored regularly and public awareness raising programs should be implemented during seasonal peaks in tourist presence.

Future research could attempt further elucidation of age, sex and individual differences in response to vessel traffic. Strong behavioural responses of animals to disturbance do not always indicate population-level effects (Bejder et al. 2006; Lusseau et al. 2009, 2014; New et al. 2013; Pirotta et al. 2015b). Indeed, inter-individual variability in site fidelity and availability of alternative suitable habitats make it difficult to infer population level consequences. Thus, it will be important to develop the link between short-term effects and population dynamics, which requires long-term study and individual recognition of individuals, e.g. based on photo-identification.

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