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Random Forest population modelling of striped and common-bottlenose dolphins in the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea)

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A B S T R A C T

This study provides the first estimates of density and abundance of the striped dolphin *Stenella coeruleoalba* and common bottlenose dolphin *Tursiops truncatus* in the Gulf of Taranto (Northern Ionian Sea, Central Mediterranean Sea) and identifies the predictive variables mainly influencing their occurrence and concentration in the study area. Conventional Distance Sampling (CDS) and the Delta approach on Random Forest (DaRF) methods have been applied to sightings data collected between 2009 and 2016 during standardized vessel-based surveys, providing similar outcomes. The mean value of density over the entire study area was 0.72 ± 0.26 specimens/km^2 for the striped dolphin and 0.47 ± 0.09 specimens/km^2 for the common bottlenose dolphin. The abundance estimated by DaRF in the Gulf of Taranto was 10080 ± 3584 specimens of *S. coeruleoalba* and 6580 ± 1270 specimens of *T. truncatus*, respectively. Eight predictive variables were selected, considering both the local physiographic features and human activities existing in the investigated area. The explanatory variables depth, distance from the coast, distance from industrial areas and distance from areas exploited by fishery seem to play a key role in influencing the spatial distribution of both species, whereas the geomorphological variables proved to be the most significant factors shaping the concentration of both dolphins. The establishment of a Specially Protected Area of Mediterranean Importance (SPAMI) according the SPA/BD Protocol in the Gulf of Taranto is indicated as an effective management tool for the conservation of both dolphin populations in the Central-eastern Mediterranean Sea.

1. Introduction

Striped dolphin (*Stenella coeruleoalba* Meyen, 1833) and common bottlenose dolphin (*Tursiops truncatus* Montagu, 1821) are habitual species throughout the Mediterranean Sea. Nonetheless, the knowledge about their distribution and abundance is rather incomplete and it is mainly restricted to the western basins with large areas of the central-eastern regions still scarcely or completely un-surveyed (Notarbartolo di Sciara and Birkun, 2010).

A significant lack in knowledge is evident in the Adriatic-Ionian macro-region within the Mediterranean Sea (EUSAIR, 2014; http://www.adriatic-ionian.eu), where several studies have reported the abundance estimates of both dolphin species, mostly referring to the North-Eastern Adriatic Sea (Bearzi et al., 1997; Ribarič, 2016) and Eastern Ionian Sea (Bearzi et al., 2008; 2011; Gonzalvo et al., 2016; Santostasi et al., 2016). Indeed, a regular presence of both striped dolphin and common bottlenose dolphin has been reported in the Northern Ionian Sea (Carlucci et al., 2016; Dimatteo et al., 2011), but the abundance estimate in the area was only reported for *S. coeruleoalba* deriving from an aerial survey carried out all around the Italian seas during the spring of 2010 (Panigada et al., 2017).

Both species proved to be potentially threatened (Azzellino et al., 2014; Fossi et al., 2012) by the elevated levels of anthropogenic impact occurring in the Mediterranean waters (Coll et al., 2012; Halpern et al., 2008; Lotze et al., 2011; Micheli et al., 2016)

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and the IUCN Red List of Threatened Species assessed their conservation status as vulnerable with evidence of an unknown and a declining trend in their respective populations (Aguilar and Gaspari, 2012; Bearzi et al., 2012). In fact, both dolphins are very sensitive to habitat fragmentation and loss (Simmonds and Nunny, 2002), alterations in distribution and availability of resources (Gambaiani et al., 2009; Learmonth et al., 2006; MacLeod, 2009), noise from military sonar or seismic surveys (Dolman et al., 2010; Fossi and Lauriano, 2008; Hildebrand, 2005) as well as chemical pollution including marine litter (Aguilar and Borrell, 2005; Cózar et al., 2015; Fossi et al., 2003; Panti et al., 2011; Patterson et al., 2004; Triantafillou, 2008). Unpredictable mortality significantly affecting population dynamics of both dolphin species was also due to incidental captures in pelagic purse-seines, drifting long-lines, gill nets and drift-nets (Bearzi, 2002; Di Natale and Notarbartolo di Sciara, 1994; Tudela et al., 2005) as well as to outbreaks of morbillivirus infections particularly impacting *S. coeruleoalba* (Cotté et al., 2010; Di Guardo and Mazzariol, 2013; Domingo et al., 1990; Fernández et al., 2008; Forcada et al., 1994; Garibaldi et al., 2008; Raga et al., 2008; Van Bressem et al., 1993).

The abundance of the striped dolphin and common bottlenose dolphin, their habitat distribution, extent and condition could represent fundamental indicator classes within the EU Marine Strategy Directive Framework (MSFD, 2008) providing a common metric for evaluating the impacts of different human activities on the ecosystem functioning in both off-shore and coastal waters. Coherently with Directive 2008/56/EC, the criteria and methodological standards to assess Good Environmental Status (GES) in EU marine waters establish threshold values for each species through regional or sub-regional cooperation, taking account of natural variation in population size and mortality rates. Thus, their conservation status is a key parameter in the assessment of the marine ecosystem health condition and it is assumed as favourable only when data about population dynamics indicate that they are not adversely affected by anthropogenic pressures and their long-term viability is ensured (EU Commission Decision n. 848/2017).

The Gulf of Taranto is characterized by a marked anthropogenic presence due to heavy industries, fishing activities, intense commercial shipping and navy exercise areas (Cardellicchio et al., 2000; Marsili and Focardi, 1997; Russo et al., 2017). Therefore, both *S. coeruleoalba* and *T. truncatus* could be exposed to elevated levels of anthropogenic threats such as strikes from merchant traffic, disturbance from high intensity military sonar and fishing activities as well as exposure to chemical pollution from the nearby harbour of Taranto. These conditions represent serious harm to the long-term survival of both dolphin species, reducing their habitat suitability as a response to human-induced environmental changes.

This study aims to provide abundance estimation for *S. coeruleoalba* and *T. truncatus* using sightings data collected for both species during a standardized vessel-based survey carried out from 2009 to 2016 in the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea). Analysis was carried out to assess the driving forces influencing both dolphin populations and, in turn, suggesting indications and practices for their conservation and management. With this aim, Conventional Distance Sampling (CDS) and the Delta approach on Random Forest (DaRF) regressions were tested. The latter method was applied as an innovative modelling approach, testing predictive variables including the main physiographic and anthropogenic features influencing the spatial distribution of both species in the area (Carlucci et al., 2016). Both regression methods were performed simultaneously to evaluate the soundness of Random Forest as a novel approach that, if reliable, can open the possibility of expanding the prediction estimates of abundance on a wider scale over larger un-surveyed areas.

Prediction and explanation are among the main objectives of statistical analysis. Nonetheless, most of these methods generate distributions and predictions that may prove useful but fail in the characterization of the relationship between the response and the predictors. Conversely, traditional statistical models such as linear regression can explain data relationships, but they are often poor predictors. Random Forest can help to fill this gap as it is able to provide both types of information (De'ath, 2007).

Finally, the results are discussed in the perspective of establishing a Specially Protected Area of Mediterranean Importance (SPAMI) according the SPA/BD Protocol in the Gulf of Taranto as an effective management tool for the conservation of both dolphin populations in the Central-eastern Mediterranean Sea.

2. Materials and methods

2.1. Study area

The Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea) extends from Santa Maria di Leuca to Punta Alice covering an area of approximately 14000 km^2 (Fig. 1). The basin is characterized by complex morphology with a narrow continental shelf and steep slope cut by several channels in the western sector and terraces in the eastern one, both descending toward the NW-SE submarine canyon system in the "Taranto Valley" (Capezzuto et al., 2010; Harris and Whiteway, 2011; Pescatore and Senatore, 1986; Rossi and Gabbianelli, 1978). This singular morphology involves a complex distribution of water masses with a mixing of surface and dense bottom waters and the occurrence of high seasonal variability in upwelling currents (Bakun and Agostini, 2001; Carlucci et al., 2014; Matarrese et al., 2011; Milligan and Cattaneo, 2007; Sellschopp and Álvarez, 2003).

2.2. Sightings data

Sightings data of both *S. coeruleoalba* and *T. truncatus* were collected from April 2009 to December 2016 during standardized vessel-based surveys carried out with a rib boat until 2012 and successively, with a 12-m-long catamaran. Surveys were performed on a daily base and only in favourable weather conditions (Douglas scale ≤ 3 and Beaufort scale ≤ 4) with a sampling effort set to approximately 5 h/day along 35 nautical miles (nm) and a survey speed of about 7.5 knots (Table 1). In agreement with Buckland et al. (2001), a line transect sampling was adopted to investigate a survey area of about 640 km^2 (Fig. 2). The random equally spaced zigzag transects with an angle of 45° to the x-axis were generated each day using the Distance 6.0 software (Thomas et al., 2010). Off-effort time was generally due to the navigation from the harbours of Taranto or Policoro to the starting point of each random transect line. A grid with 38 points spaced 3 km apart was generated to estimate the proportion of stratum area and the mean coverage probability for each transect (Table 2).

The observer team on board consisted of at least three people. One observer searched for targets around 180° and counting the dolphin individuals during each sighting. The others supported the activities of the former observer, investigating a sector from the track-line to 90° on both starboard and port side, ensuring the assumption required by Distance sampling that all dolphins at a distance x on the line are detected (detection function $g(0) = 1$) (Buckland et al., 2001; Thomas et al., 2002). The observer team rotated roles every 90 min. Observations were made with both the naked eye and 7×50 binoculars. Once a target had been sighted, the GPS position and the angle at the first contact were measured using an on-board compass. The perpendicular distance was then calculated trigonometrically, using the known track distance covered during the sighting. In addition, the date, sea weather

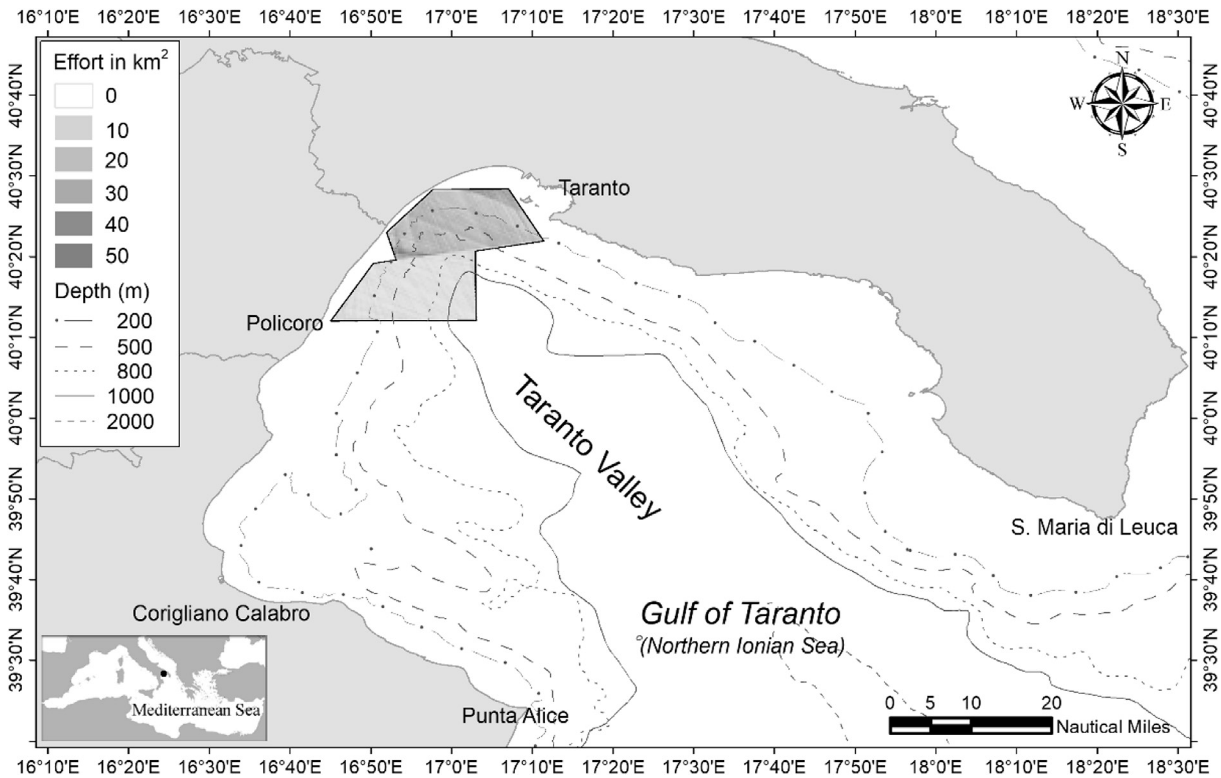

Fig. 1. Map of the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea) with indication of sampling effort in terms of investigated km^2 applied in the survey area from 2009 to 2016. The amount of sampling effort for each cell is represented by a grey scale.

conditions, geographic coordinates, depth (m), time of first contact and group size (number of specimens) were recorded during sightings. A cross-check of the collected information was processed to validate the entry data.

To prevent any interference in dolphin activity due to interaction with the vessel the sampling was interrupted when specimens were observed at less than approximately 50 m (Baş et al., 2015; Carlson, 2008). In addition, observers had to maintain a safe distance of not less than 5 m from dolphins, lowering speed or interrupting navigation to prevent collisions and possible injuries.

2.3. Data analysis

2.3.1. Conventional Distance Sampling

Sighting data of both dolphin species collected in the Gulf of Taranto from 2009 to 2016 were analysed using Conventional Distance Sampling (CDS) to provide an abundance estimation of the species in the survey area. Right truncation was set at the largest observed distance. The fitting of the detection function model was based on the Akaike Information Criteria (AIC) (Akaike, 1979). AIC gives an estimate of both the inaccuracy and the complexity (or the penalty) due to the increased unreliability (or compensation) for the bias due to inaccuracy, which depends upon the number of parameters used to fit the data. Thus, in case of competing models the minimum value of AIC has to be found (Posada and Buckley, 2004). The estimation of the encounter rate was assessed using the default option in CDS when a random design survey was applied (Fewster et al., 2009). The expected value of group size was assessed by a size-biased regression method. Finally, the estimation of the encounter rate, the expected value of group size, the abundance and density of *S. coeruleoalba* and *T. truncatus* throughout the study period was calculated using the post-stratification option by species field, reporting the coefficient of variation (CV).

2.3.2. Delta approach on Random Forest

Although the Delta approach has been long used in ecological studies (e.g. Aitchison and Brown, 1957; Krebs, 1999; Pennington, 1983; Seber, 1982), to date it is virtually absent from any scientific application concerning cetaceans and this may represent the first application in the field. However, as promoted by recent studies (Fletcher et al., 2005; Serafy et al., 2007) the application of the Delta approach for the estimation of abundance could be considered a promising tool for datasets including a large occurrence of zeros and positive skewness. In this way it can reflect the patchiness in the distribution of the species and habitat which generally occurs in the case of cetaceans, providing more robust and reliable estimates (Gaston, 1994; Lo et al., 1992; Ortiz et al., 2000, 2001; Serafy et al., 2007). The Delta approach entails separately calculating the species occurrence over transects surveyed (hereafter termed “occurrence”) and concentration (i.e., density where present, exclusive of zeros), generating two data sets from the original: the former indicating the species presence/absence predicted probability (occurrence − O) and the latter reporting the estimated density where present (concentration − C). The product of occurrence (O) and concentration values (C) yields an index of relative density, hereafter termed “Delta-density” (D) (Fletcher et al., 2005):

$$D = O * C$$

Both the occurrence (O) and the concentration (C) can be assessed by the application of Random Forest,a methodology based on regression trees able to model a response variable from several predictive variables by subdividing a dataset into subgroups (Breiman, 2001). This can be represented as a binary tree, a hierarchical structure formed by nodes and edges, the latter representing some sort of information flow between adjacent nodes. Subgroups originate from recursive partitions based on decision

Table 1
Effort in terms of number of daily surveys (Nds), hours (h) and nautical miles (nm) with indication of mean and standard deviation, applied during the study period.

Effort	2009				2010				2011				2012			
	Nds	h	nm	mean ± s.d.	Nds	h	nm	mean ± s.d.	Nds	h	nm	mean ± s.d.	Nds	h	nm	mean ± s.d.
January	–	–	–	–	–	–	–	–	1	5	39.7	39.7	1	5	39.6	39.6
February	–	–	–	–	–	–	–	–	1	5	30.6	30.6	–	–	–	–
March	–	–	–	–	–	–	–	–	–	–	–	–	3	15	92.0	30.7 ± 0.1
April	1	5	30.5	30.5	1	5	30.7	30.7	2	10	67.7	33.8 ± 4.7	1	5	32.8	32.8
May	–	–	–	–	–	–	–	–	3	15	101.1	33.7 ± 2.9	–	–	–	–
June	–	–	–	–	5	25	168.4	33.7 ± 3.4	11	55	389.0	35.4 ± 3.4	14	70	469.7	33.5 ± 3.3
July	8	40	274.8	34.3 ± 3.8	13	65	457.1	35.2 ± 3.4	16	80	525.4	32.8 ± 1.9	15	75	491.0	32.7 ± 2.6
August	4	20	127.3	31.8 ± 1.0	5	25	177.6	65.8 ± 5.2	20	100	655.4	32.8 ± 2.3	16	80	527.7	33.0 ± 1.8
September	–	–	–	–	–	–	–	–	3	15	98.7	32.9 ± 2.3	–	–	–	–
October	–	–	–	–	–	–	–	–	1	5	35.2	35.2	–	–	–	–
November	–	–	–	–	–	–	–	–	3	15	98.4	32.8 ± 0.3	–	–	–	–
December	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

rules that allow each part to be divided successively into smaller data portions. A random selection of predictive variables is chosen for the growth of each tree (3 predictors at each node) and each tree is based on a different random data subset, created by bootstrapping (Efron, 1979). Finally, the optimal "splitting" in comparison with real data is identified and selected as a predictor. The data portion used as a training subset is known as the "in-bag" data, whereas the rest is called the "out-of-bag" data. The latter are not used to build the tree, but provide estimates of generalization error, which always converges as the forest size increases. The number of trees has to be sufficiently high (800 in this case) since the mean square error is calculated from prediction with the test dataset averaged over all trees (out-of-bag error).

Thus, data were arranged on a regular grid of 109720 square cells (422 horizontal and 260 vertical cells) of about 450 × 450 m covering the entire Gulf of Taranto. Therefore, for the estimation of O and C, two dependent variables were generated: a binary (0-1) variable identifying the cells with/without at least one occurrence and a variable reporting the concentration of individuals in the case of presence. A set of 8 predictive variables was selected including the main physiographic and anthropogenic features influencing the distribution of both species in the study area (Carlucci et al., 2016) (Table 3). The considered variables are: depth; slope; distance from coast; distance from the canyon system in the "Taranto Valley"; distance from navy exercise areas; distance from merchant shipping routes; distance from areas exploited by fishery; and distance from industrial areas.

The rank importance of each predictive variable is accounted for as the changes in mean square error estimated by leaving a variable out of the model. After the most relevant variables had been identified, the following step consisted of exploring the dependence between a response variable and each explanatory variable. Thus, partial dependence plots were obtained and used to characterize graphically relationships between individual predictive variables and the predicted probabilities of presence obtained from RF (Hastie et al., 2001).

3. Results

A total effort of 610 daily surveys was applied accounting for approximately 3050 h of observations and 39540 km (Table 1). This investigation produced 580 and 64 sightings of *S. coeruleoalba* and *T. truncatus*, respectively (Table 4). The striped dolphin was observed in 90.1% of the total sightings with a frequency of occurrence, calculated as the number of sightings per daily survey, that ranged from 0.74 (2014) to 1.17 (2016) with sightings occurring in a depth range between 8 and 1000 m. The common bottlenose dolphin was observed in 9.9% of total sightings showing a frequency of occurrence from 0.07 (2013) to 0.15 (2011) with sightings occurring in a depth range between 2 and 586 m.

3.1. Conventional Distance Sampling (CDS)

The longest perpendicular distance of observation measured during sightings was 0.6 nautical miles (nm). The best models fitting the detection functions were a half normal function with no adjustment terms for *S. coeruleoalba* (AIC = -723.53) and a uniform key model with one cosine adjustment for *T. truncatus* (AIC = -103.27) (Table 5 and Fig. 3). For the striped dolphin, the overall encounter rate estimated by CDS was 0.017 sightings/km (CV = 1.59%) and the expected group size value was approximately 42 specimens (CV = 3.35%). The overall abundance in the survey area was 682 striped dolphins (CV = 5.44%; 95% CI = 613-758 specimens), with a density of 1.07 specimens/km^2 (CV = 5.44%; 95% CI = 0.96–1.19 specimens/km^2).

For the common bottlenose dolphin, the overall encounter rate estimated by CDS was 0.012 sightings/km (CV = 6.34%) and the expected group size value was approximately 11 specimens (CV = 9.59%). The overall abundance in the survey area was 111 common bottlenose dolphins (CV = 23.84%; 95% CI = 70-177 specimens), with a density of 0.17 specimens/km^2 (CV = 23.84%; 95% CI = 0.11–0.28 specimens/km^2).

3.2. Delta approach on Random Forest

The ranking of the most important explanatory variables driving the distribution of occurrence and concentration of *S. coeruleoalba* and *T. truncatus* was obtained (Fig. 4). For the striped dolphin both occurrence and concentration are mainly driven by depth and distance from the coast. Occurrence is also significantly affected by the distance from industrial areas and from areas exploited by fishery. Concentration is also significantly affected by the distance from canyons and slopes. In the case of the common bottlenose dolphin the most important variables for occurrence and concentration were depth, distance from areas exploited by fishery and from the coast. In addition, the distance from industrial areas is only important for the prediction of occurrence whereas the distance from canyons is relevant for concentration.

The range of optimal values expected to increase the probability of occurrence and concentration of both species for each predictive variable was analysed through the univariate partial dependence plots. For the striped dolphin, RF showed the higher probability of

2013				2014										2015	2016
Nds	h	nm	mean ± s.d.	Nds	h	nm	mean ± s.d.	Nds	h	nm	mean ± s.d.	Nds	h	nm	mean ± s.d.
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–		–	–	–	–	11	55	389.0	35.4 ± 3.4	15	75	524.4	35.0 ± 2.5
–	–	–	–	14	70	473.8	33.8 ± 3.1	21	105	659.5	33.0 ± 2.2	23	115	760.3	33.1 ± 2.0
14	70	450.3	32.2 ± 1.9	17	85	588.1	34.6 ± 3.4	18	90	606.0	33.7 ± 2.9	22	110	768.1	34.9 ± 3.4
15	75	516.8	34.5 ± 2.7	27	135	940.3	34.8 ± 2.9	30	150	1022.3	34.1 ± 2.6	28	140	991.0	34.2 ± 2.2
23	115	772.7	33.5 ± 3.2	31	155	1063.1	34.3 ± 3.1	30	150	999.5	33.3 ± 2.6	24	120	821.7	34.2 ± 2.8
12	60	403.1	33.6 ± 2.0	11	55	361.9	32.9 ± 3.7	15	75	485.7	32.4 ± 2.3	17	85	466.1	33.3 ± 2.6
4	20	138.1	34.5 ± 2.5	6	30	212.7	35.4 ± 3.0	3	15	108.2	36.1 ± 2.8	9	45	297.6	33.1 ± 2.3
3	15	98.5	32.8 ± 0.2	4	20	145.4	36.9 ± 3.3	5	25	170.9	34.2 ± 3.7	6	30	209.2	34.9 ± 2.3
2	10	66.6	33.3 ± 0.3	1	5	32.9	32.9	–	–	–	–	1	5	32.9	32.9

occurrence in waters deeper than 200 m at more than 7 km from the coast and industrial areas (Fig. 5). In addition, *S. coeruleoalba* seems to avoid the areas exploited by fishery, increasing occurrence with distance reaching its maximum presence probability values at distances greater than 20 km.

Occurrence of the common bottlenose dolphin resulted higher within 200 m, at distances lower than 7 and 5 km from the coast and the areas exploited by fishery, respectively (Fig. 6). In addition, *T. truncatus* seems to avoid the industrial areas showing a sudden increase in occurrence at distances greater than 40 km.

The striped dolphin concentration was positively affected by depth mostly in the range between 200 and 400 m at distances from the coast greater than 12 km (Fig. 7). In addition, the higher concentrations of *S. coeruleoalba* were estimated at distances from the canyon system greater than 6 km with a slope greater than 0.10.

The higher concentrations of *T. truncatus* occurred at depths between 50 and 100 m at distances from the coast and canyon system greater than 5 and 8 km, respectively (Fig. 8). In addition, higher concentrations of common bottlenose dolphin were also found in areas overlapping those exploited by fishery.

The occurrence and concentration regressions were both considered in DaRF to predict mean values of density and abundance of *S. coeruleoalba* and *T. truncatus* in the survey area. Thus, the density and abundance for the striped dolphin were 1.08 ± 0.38 specimens/km^{2}and 690 ± 241 specimens, respectively. For the common bottlenose dolphin, the density was 0.19 ± 0.09 specimens/km^2 and the abundance 121 ± 56 specimens. The projected mean values of density over the entire study area were 0.72 ± 0.26 and 0.47 ± 0.09 specimens/km^2 for the striped dolphins and common bottlenose dolphin, respectively (Fig. 9). The highest values of density occurred between 200 and 800 m in depth surrounding the canyon system in the "Taranto Valley" for *S. coeruleoalba*. Differently, the common bottlenose dolphin showed its higher values of density in the shallower water within 100 m in depth close to Policoro and Corigliano Calabro.

The dolphin populations projected by DaRF in the Gulf of Taranto were 10080 ± 3584 specimens of *S. coeruleoalba* and 6580 ± 1270 specimens of *T. truncatus,* respectively (Fig. 9).

4. Discussion and conclusions

The results shown in this study represent the first estimates of density and abundance provided for *S. coeruleoalba* and *T. truncatus* in the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea) derived from sightings data collected for both species during a standardized vessel-based survey carried out from 2009 to 2016. DaRF was used to test a simple framework to model the spatial abundance distribution of both species not only in the survey area but also in the entire surrounding Gulf of Taranto, opening the possibility of expanding the prediction estimates from smaller investigated areas to larger un-surveyed areas. Due to the considerable number of zero-abundance value in the datasets, the adequacy of this conditional model for positively skewed data was proved to be applicable in this study, as already tested in other ecological contexts (Aitchison and Brown, 1957; Fletcher et al., 2005; Grüss et al., 2014; Krebs, 1999; Lo et al., 1992; Ortiz et al., 2000, 2001; Pennington, 1983; Seber, 1982; Serafy et al., 2007; Stefánsson, 1996; Welsh et al., 1996). However, although the idea of a two-step model is not new, the Delta approach on Random Forest has never been applied to the evaluation of cetacean abundance and this study represents the first application in the field. Therefore, taking into consideration the novelty of the Delta approach, a verification of the modelling performance has been performed, comparing the RF results obtained for *S. coeruleoalba* and *T. truncatus* with the relative CDS outcomes, which in turn have been consistently applied for the abundance estimation of cetacean species (e.g. Forcada and Hammond, 1998; Gannier, 2005). This comparison indicates that the application of CDS and DaRF regressions provides very similar outcomes in the Gulf of Taranto. In fact, the relative density and abundance values estimated for both striped dolphin and common bottlenose dolphin overlapped, confirming this innovative approach as a promising modelling tool.

In addition, this study identified the predictive variables mainly influencing occurrence and concentration of both dolphin species in the study area. Depth, distance from the coast, distance from industrial areas and distance from areas exploited by fishery seem to play a key role in influencing the spatial distribution of both species. However, whereas the occurrence of *T. truncatus* showed a sudden increase within 5 km of fishing areas, that of *S. coeruleoalba* sharply decreased within 10 km, suggesting an inverse influence on the two species for this activity. These findings confirm previous knowledge. *T. truncatus* which is well-known to be particularly attracted by fishing vessels, due to its ability to prey on discard or entrapped fish (Brotons et al., 2008; Chilvers and Corkeron, 2001; Corkeron et al., 1990; Diaz Lopez, 2006; Fertl and Leatherwood, 1997; Lauriano et al., 2004; Pace et al., 2003; Pulcini et al., 2002; Wells and Scott, 2009), while *S. coeruleoalba* seems to show a wider distribution, mainly in areas with lower fishing pressure (Azzellino et al., 2017; Campana et al., 2015).

The geomorphological variables proved to be the most

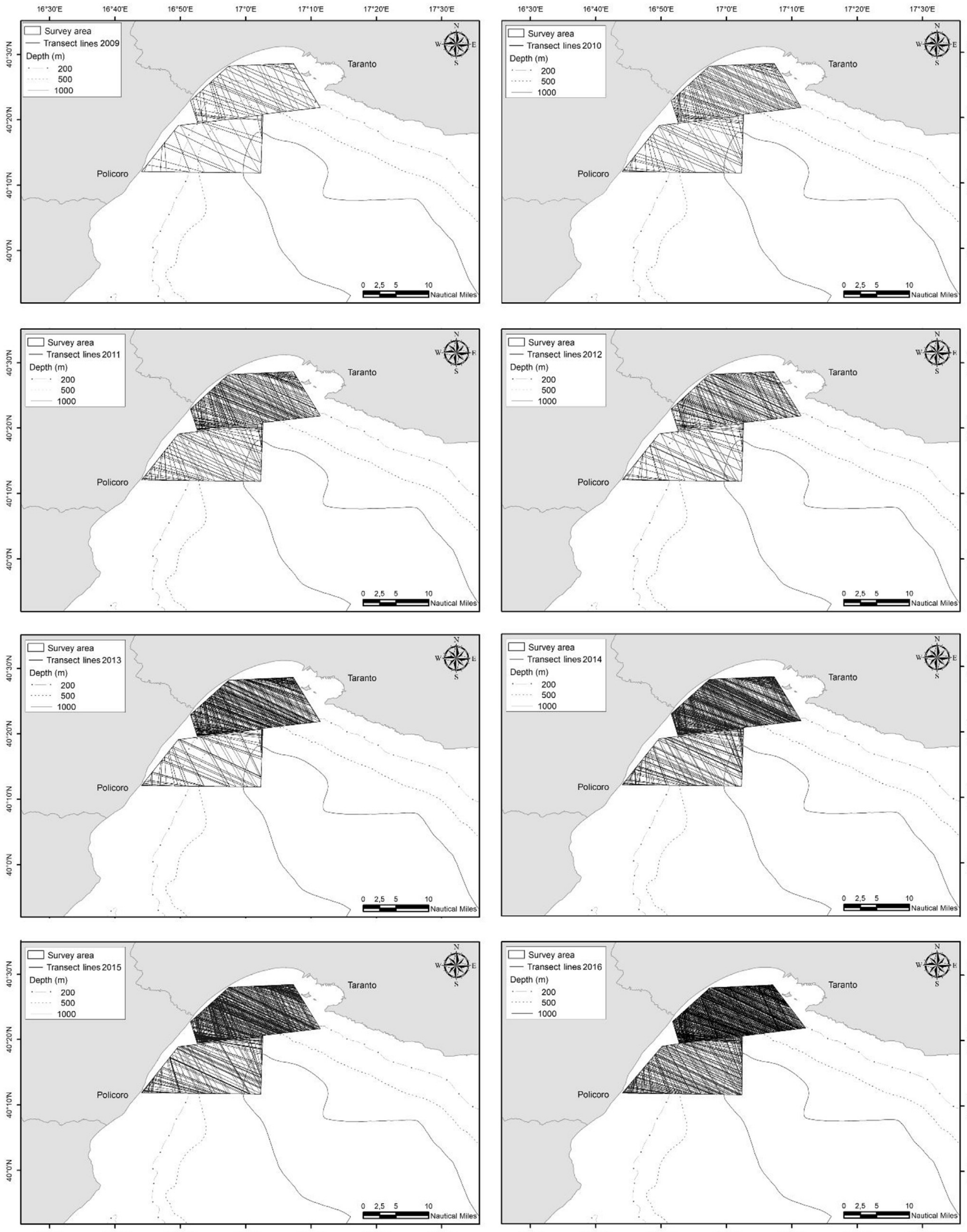

Fig. 2. Sampling transect lines carried out from 2009 to 2016 in the survey area.

Table 2
Sampling period, proportion of stratum sampled (mean and CV) and coverage probability (minimum, maximum, mean and CV) for the random transect line generated by CDS to investigate the survey area from 2009 to 2016.

Sampling period	Proportion of stratum sampled		Coverage probability			
	Mean	CV	Minimum	Maximum	Mean	CV
April-August 2009	0.51	0.07	0.15	0.83	0.54	0.01
April-August 2010	0.53	0.09	0.18	0.83	0.55	0.01
January-November 2011	0.52	0.08	0.11	0.95	0.53	0.01
January-August 2012	0.51	0.08	0.15	0.92	0.54	0.01
June-December 2013	0.51	0.08	0.14	0.88	0.54	0.01
May-December 2014	0.52	0.10	0.15	0.87	0.54	0.02
April-November 2015	0.51	0.08	0.10	0.99	0.55	0.02
April-December 2016	0.51	0.08	0.16	0.99	0.54	0.01

significant factors shaping the concentration of dolphins, in agreement with other estimations carried out on habitat preference for *S. coeruleoalba* and *T. truncatus* in the Mediterranean Sea (Azzellino et al., 2012; Marini et al., 2015; Panigada et al., 2008). In fact, the concentration of both striped dolphin and common bottlenose dolphin proved to be positively influenced by depth, distance from the coast and distance from the canyon system in the Taranto Valley. In addition, the concentration of *S. coeruleoalba* was positively influenced by the steep slope. Differently, that of the common bottlenose dolphin was affected by the distance from fishery.

It is worth noticing that the distribution of social species such as dolphins is not only controlled by environmental and physiographic features. Therefore, predictor variables such as population memory, social interactions and demography could eventually be added to the Delta approach when the data are available (Loots et al., 2010), together with the prey density and abundance (Blasi and Boitani, 2012; Davis et al., 2002).

The density values estimated for *S. coeruleoalba* in the present study are the highest among those reported for both the Adriatic-Ionian macro-region (Bearzi et al., 2011; Panigada et al., 2017; Santostasi et al., 2016) and the Western Mediterranean region (Cottè et al., 2010; Gómez de Segura et al., 2006, 2007; Lauriano et al., 2010; Panigada et al., 2009, 2011) (Table 6). In addition, the abundance value estimated in the Gulf of Taranto (Northern Ionian Sea) was higher than those provided for the Gulf of Corinth (Bearzi et al., 2011; Santostasi et al., 2016), but lower than corresponding values reported for the Ionian Sea (Panigada et al., 2017) and the Western Mediterranean region (Cotté et al., 2010; Gómez de Segura et al., 2006, 2007; Lauriano et al., 2010; Panigada et al., 2009, 2011). Concerning *T. truncatus,* both density and abundance values estimated in the Gulf of Taranto were higher than values

Table 3
List of the predictive variables selected for modelling the spatial distributions and density of *S. coeruleoalba* and *T. truncatus* in the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea).

Variable	Calculation method	Acronym
Depth	Depth values are derived from EMODnet Bathymetry dataset provided by the European Marine Observation and Data Network (http://www.emodnet.eu/bathymetry)	Depth
Slope	Maximum rate of depth variation between adjacent cells	Slope
Distance from coast	Minimum distance of the cell centre from the coastline	Coast
Distance from canyon	Minimum distance of the cell centre from the main axes of the “Taranto Valley” canyons system	Canyon
Distance from the navy exercise areas	Minimum distance of the cell centre from the areas of navy exercises	Navy
Distance from the merchant shipping routes	Minimum distance of the cell centre from the main merchant routes recorded in/out the Taranto harbour	Commercial
Distance from the industrial areas	Minimum distance of the cell centre from the areas identified as addressed to heavy industrial activities	Industry
Distance from the areas exploited by fishery	Minimum distance of the cell centre from the areas with recorded fishing effort in the 30 days before each sighting	Fishery

Table 4
Sampling period, number of daily surveys, range time, investigated depth range (m), effort (hours and kilometres), number of sightings, frequency of occurrence (number of sightings per daily survey) and range depth for the sightings of *S. coeruleoalba* and *T. truncatus* occurred in the Gulf of Taranto from 2009 to 2016.

Sampling period	Daily surveys (n.)	Range time	Investigated depth range (m)	Effort		Number of sightings		Frequency of occurrence		Depth range (m)	
				hours	kilometres	*S. coeruleoalba*	*T. truncatus*	*S. coeruleoalba*	*T. truncatus*	*S. coeruleoalba*	*T. truncatus*
April-August 2009	13	07:00-18:30	93–500	65	843	11	1	0.85	0.08	200–500	93
April-August 2010	24	07:00-18:30	180–636	120	1556	27	3	1.13	0.13	200–636	180–419
January-November 2011	61	07:00-18:30	15–665	305	3954	54	9	0.89	0.15	15–665	36–586
January-August 2012	50	07:00-18:30	20–694	250	3241	41	6	0.82	0.12	35–694	20–500
June-December 2013	73	07:00-18:30	20–882	365	4732	64	5	0.88	0.07	117–882	20–421
May-December 2014	111	07:00-18:30	2–1000	555	7195	82	11	0.74	0.10	144–1000	2–401
April-November 2015	133	07:00-18:30	25–950	665	8621	131	12	0.98	0.09	110–950	25–500
April-December 2016	145	07:00-18:30	8–1000	725	9399	170	17	1.17	0.12	8–1000	11–277
Total	610	07:00-18:30	2–1000	3050	39540	580	64	0.95	0.10	8–1000	2–586

Table 5
Detection functions tested in CDS to estimate density and abundance of *S. coeruleoalba* and *T. truncatus* with their respective AIC values.

	Detection function model	AIC value
Stenella coeruleoalba	Half-normal key	−723.6324
	Half-normal key + Cosine adjustments of orders: 1, 2	−723.0238
	Uniform key	−593.5794
	Uniform key + Cosine adjustments of order: 1	−721.7272
	Uniform key + Cosine adjustments of orders: 1, 2	−723.6309
	Uniform key + Cosine adjustments of orders: 1, 2, 3	−721.8636
Tursiops truncatus	Half-normal key	−101.8270
	Half-normal key + Cosine adjustments of orders:1, 2	−100.4387
	Uniform key	−64.3640
	Uniform key + Cosine adjustments of order: 1	−103.6749
	Uniform key + Cosine adjustments of orders: 1,2	−102.6788

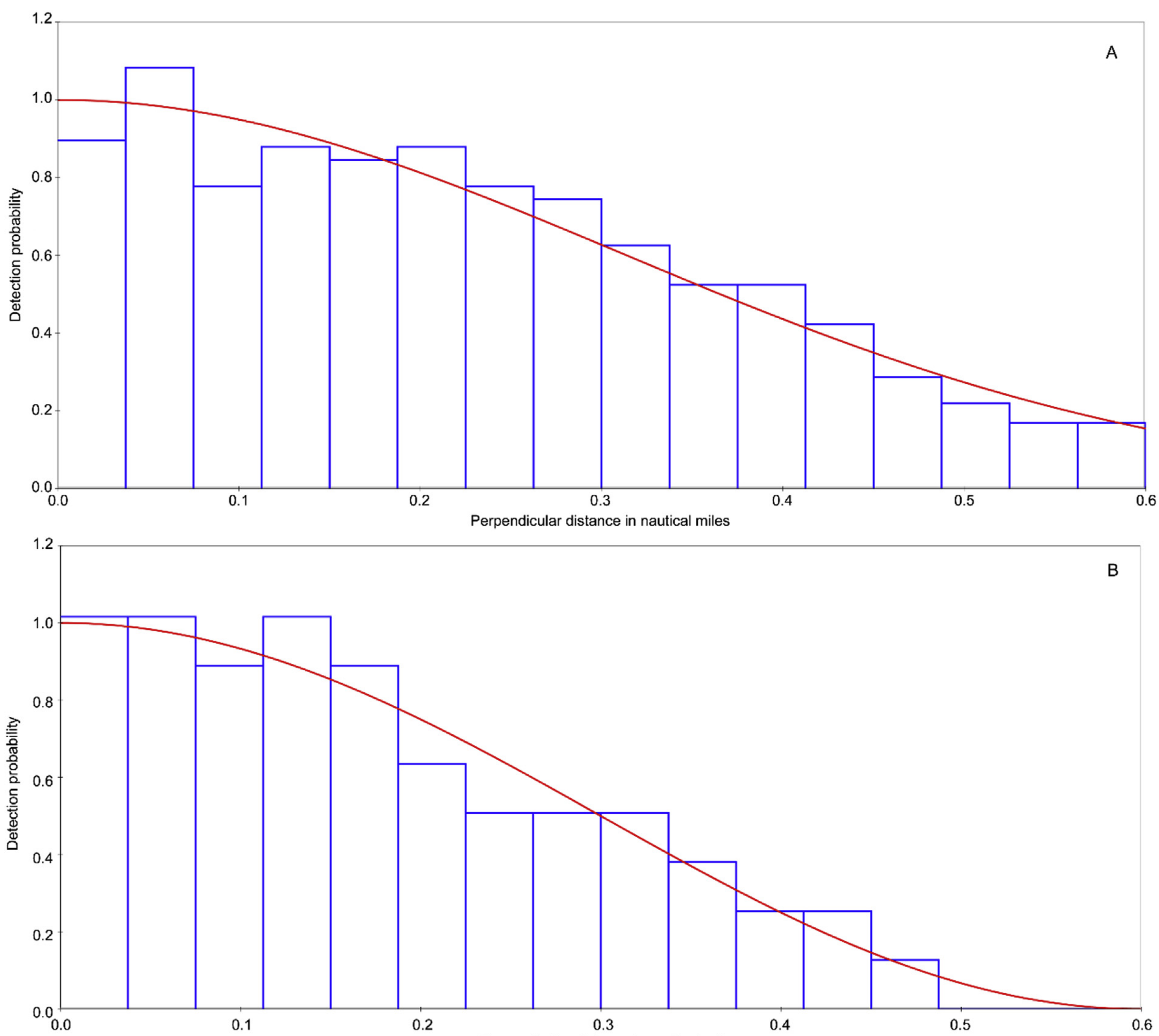

Fig. 3. The detection function, with the right truncation at the largest observed distance, modeled for *S. coeruleoalba* (A) and *T. truncatus* (B).

reported in other areas of the Adriatic-Ionian macro-region (Bearzi et al., 1997; 2008; Ribarič, 2016) and in the Western Mediterranean region (Forcada et al., 2004; Gómez de Segura et al., 2006; Gnone et al., 2011; Lauriano et al., 2014) (Table 6). However, caution in any further comparative consideration is required considering the different extensions of the study areas, platforms of observation and estimation methods applied.

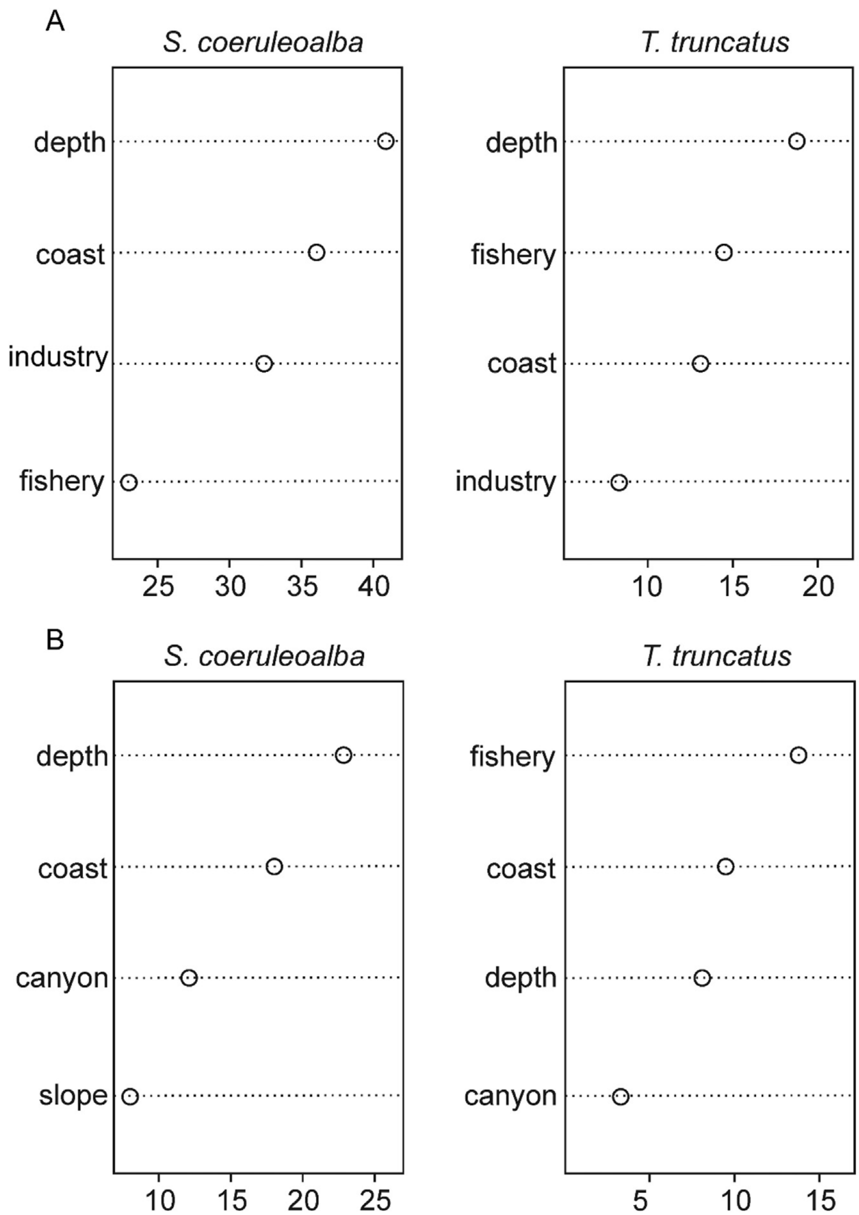

Fig. 4. Importance ranking of the predictive variables to predict occurrence (A) and concentration (B) of *S. coeruleoalba* and *T. truncatus*. Importance ranking is represented on the x-axis and it is quantified as the percentage of increase in mean square error when that explanatory variable is removed from the model.

4.1. Conclusion

The main habitats and the estimated values of density and abundance of both striped dolphin and common bottlenose dolphin derive both from the influence of environmental conditions and anthropogenic pressures presently occurring in the Gulf of Taranto (Northern Ionian Sea), representing a baseline reference for future assessment of environmental marine disturbances using cetaceans, which are considered a key group in the EU MSFD. In fact, the innovative approach used in this study to model the occurrence, concentration and, in turn, the abundance of *S. coeruleoalba* and *T. truncatus* in the Gulf of Taranto (Northern Ionian Sea, Central-eastern Mediterranean Sea) has revealed very sensitive areas requiring the implementation of conservation measures for both dolphin species. High abundance values of *S. coeruleoalba* were observed at the main head of the canyon system of the Taranto Valley between 200 and 800 m in depth, which has proved to be an area persistently and regularly used by the striped dolphins for their day-to-day survival and maintenance in a healthy condition (Carlucci et al., 2017). On the contrary, the common bottlenose dolphin occurs with its highest values of abundance in shallower waters down to 100 m off Policoro and in the surroundings of Corigliano Calabro.

The establishing of a Specially Protected Area of Mediterranean Importance (SPAMI) according the SPA/BD Protocol in the Gulf of Taranto could be effective for the conservation of both the striped and common bottlenose dolphin but also for other cetacean species such as the Risso's dolphin *Grampus griseus*, the fin whale *Balaenoptera physalus* and the sperm whale *Physeter macrocephalus* which have also been recorded to inhabit the area (Dimatteo et al., 2011; Carlucci et al., 2016).

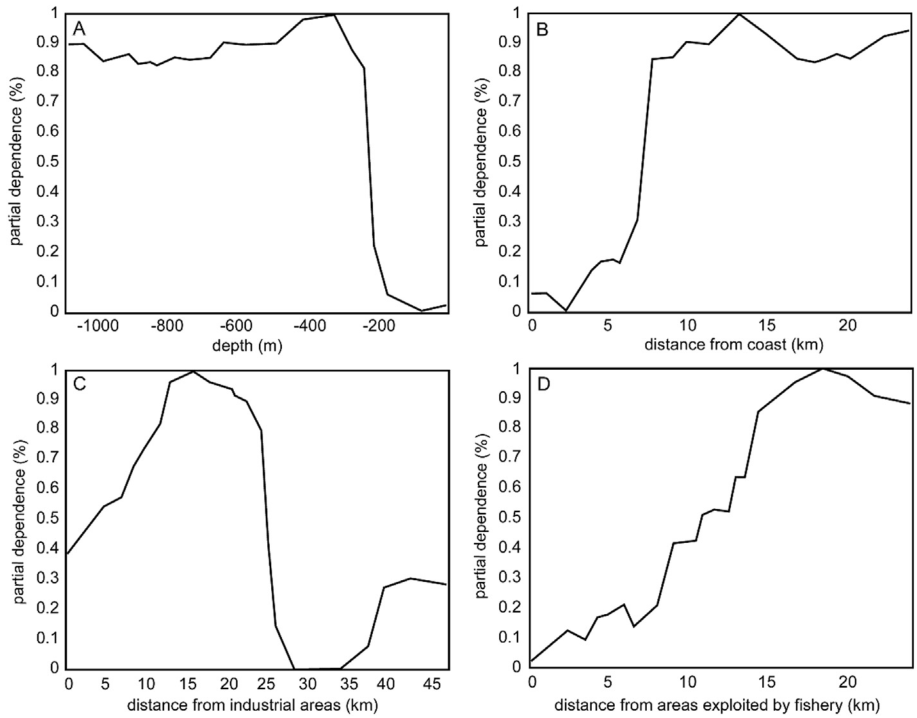

Fig. 5. Univariate partial dependence plots of the explanatory variables depth (A), distance from coast (B), distance from the industrial areas (C) and distance from areas exploited by fishery (D), estimated by the RF model for the occurrence of *S. coeruleoalba*.

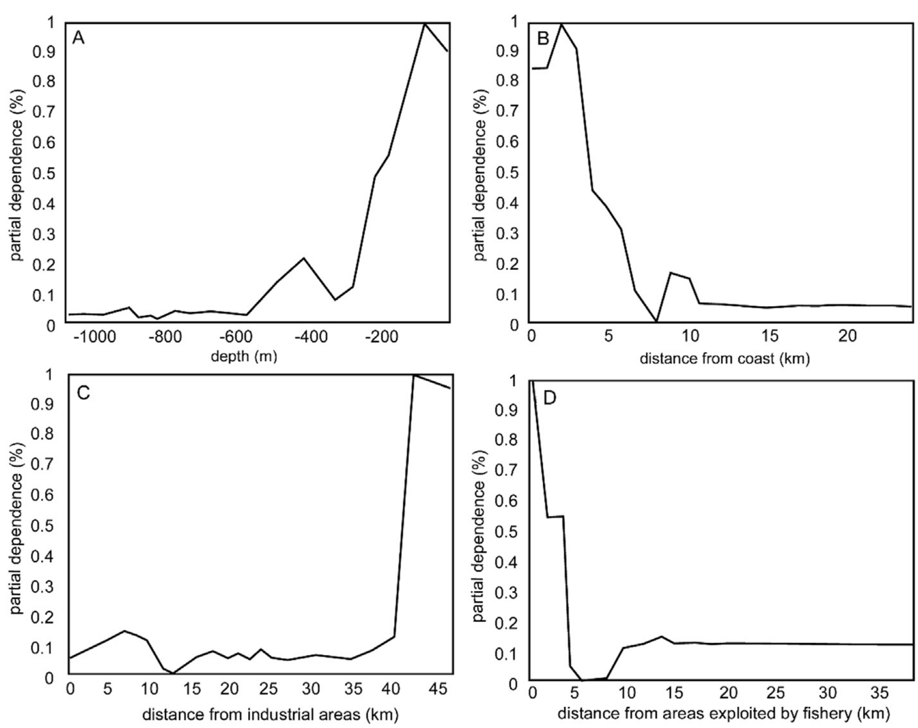

Fig. 6. Univariate partial dependence plots of the predictive variables depth (A), distance from coast (B), distance from industrial areas (C) and distance from areas exploited by fishery (D), estimated by the RF model for the occurrence of *T. truncatus*.

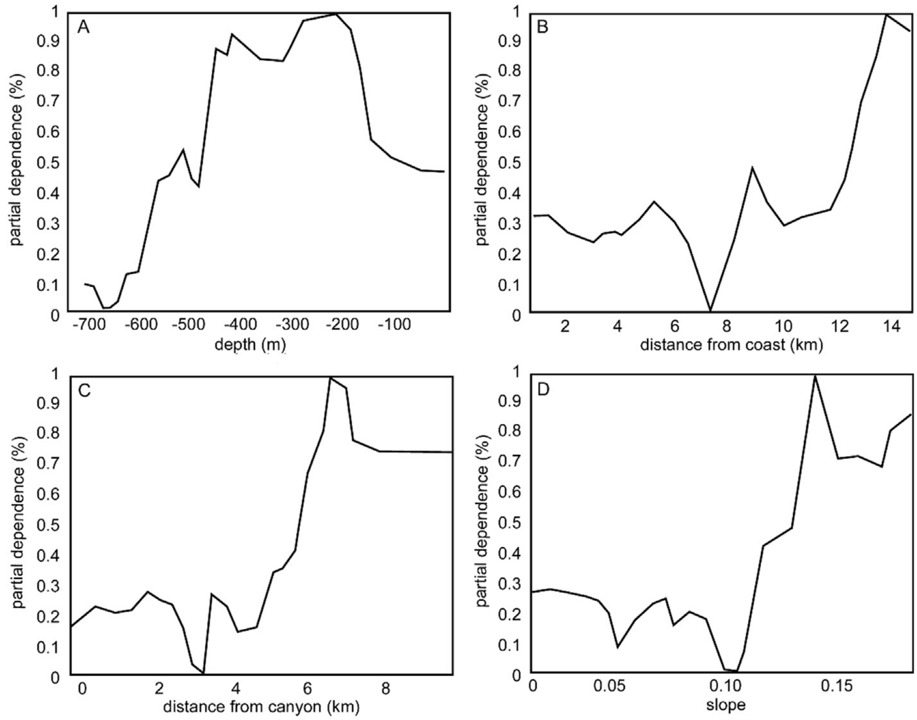

Fig. 7. Univariate partial dependence plots of the predictive variables depth (A), distance from coast (B), distance from canyon (C) and slope (D), estimated by the RF model for the concentration of *S. coeruleoalba*.

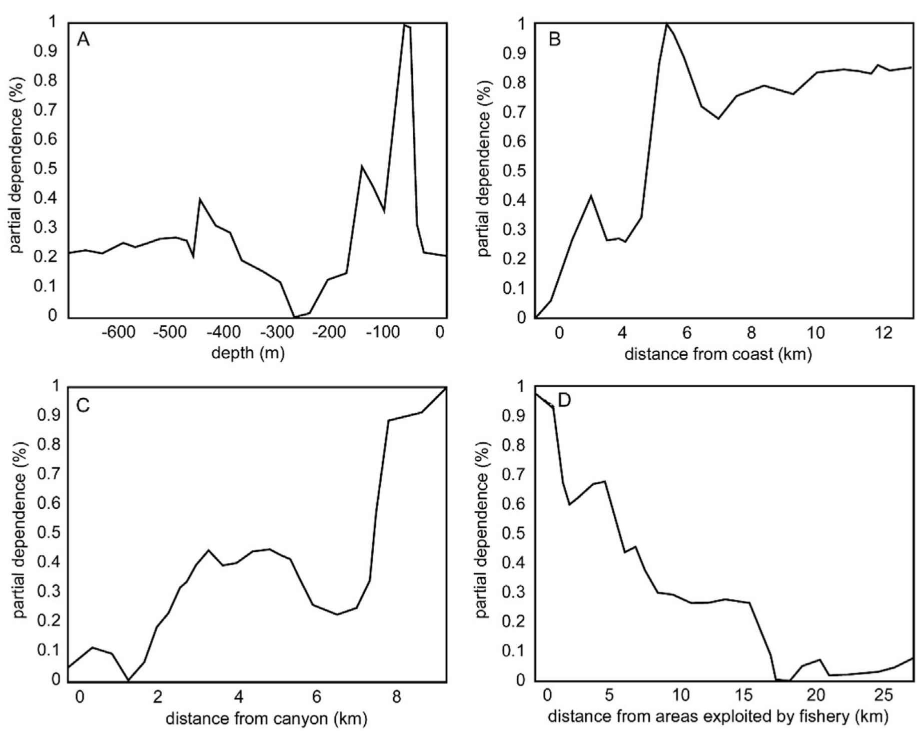

Fig. 8. Univariate partial dependence plots of the predictive variables depth (A), distance from coast (B), distance from canyon (C) and distance from areas exploited by fishery (D), estimated by the RF model for the concentration of *T. truncatus*.

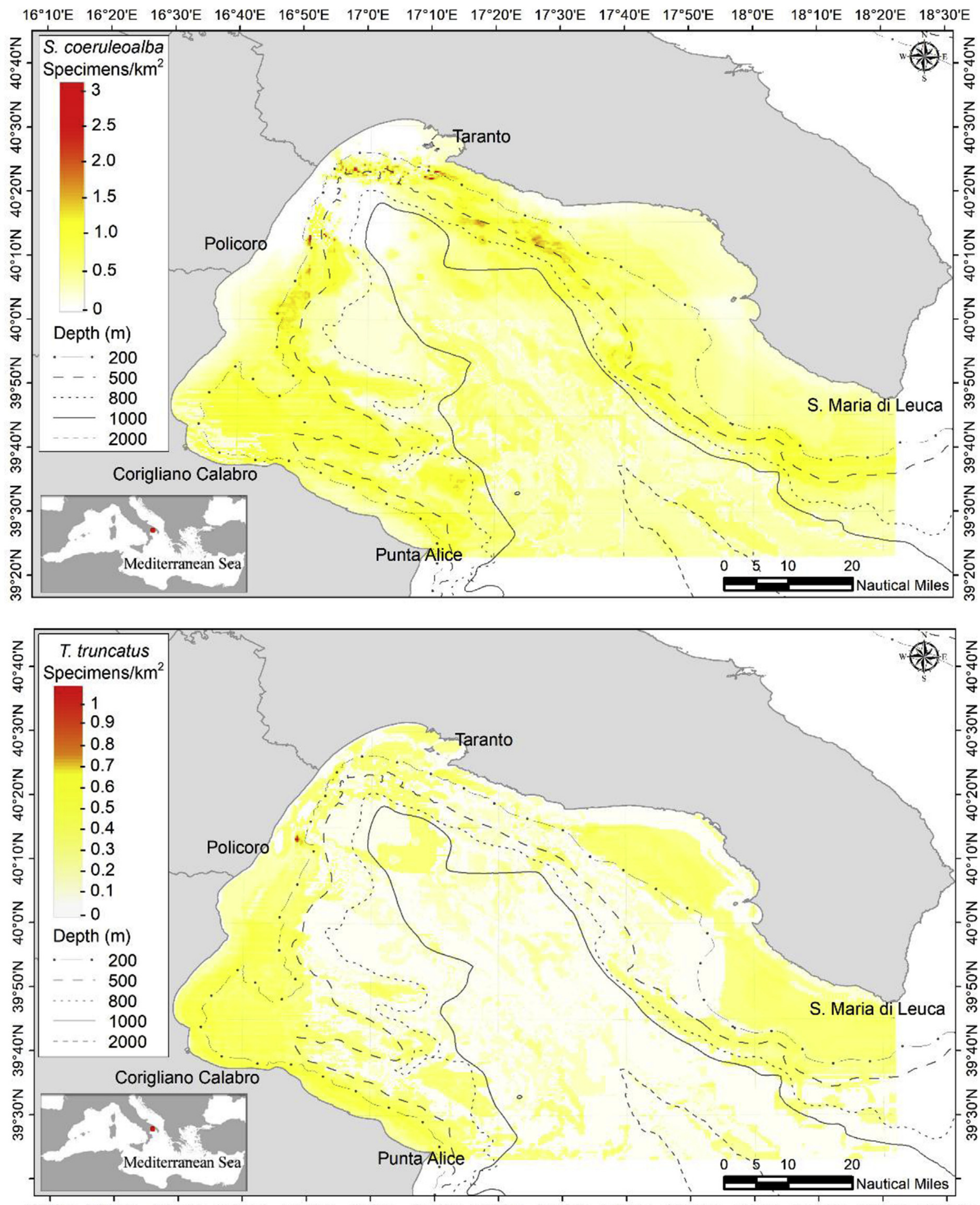

Fig. 9. Density distribution of *S. coeruleoalba* and *T. truncatus* in the Gulf of Taranto as predicted by Delta approach on Random Forest.

Table 6
Density and abundance values with coefficient of variation (%CV) estimated for *S. coeruleoalba* and *T. truncatus* in the Western Mediterranean region and Adriatic-Ionian macro-region. Indication of the investigated area, study area (km2), observation platform, years of survey, estimation method and reference were reported.

	Investigated area	Study area (km^2)	Observation platform	Years	Estimation method	Density estimated (% CV)	Abundance estimated (% CV)	Density estimated (% CV)	Abundance estimated (% CV)	References
Western Mediterranean region	Alboran Sea, Spain	11821	Boat	2000–2003	MCDS and GAMs	–	–	0.049	584	Cañadas and Hammond, 2006
	Gulf of Valencia, Spain	32270	Aerial	2001–2003	CDS	0.489 (18.80)	15778 (18.80)	0.041 (30.80)	1333 (30.8)	Gomez de Segura et al., 2006
	Gulf of Valencia, Spain	34200	Aerial	2001–2003	GAMs	0.494 (0.16)	16892 (0.16)	–	–	Gomez de Segura et al., 2007
	Balearic Sea, Spain	86414	Aerial	2002	CDS	–	–	0.089 (0.47)	7654 (0.47)	Forcada et al., 2004
	Pelagos Sanctuary	88267	Aerial	2009	CDS	0.210 (21.14)	18526 (21.14)	–	–	Panigada et al., 2009
					MCDS	0.222 (19.23)	19578 (19.23)	–	–	
	Pelagos Sanctuary	88267	Aerial	2009	CDS (Winter)	0.221 (20.90)	19462 (20.90)	–	–	Panigada et al., 2011
					CDS (Summer)	0.436 (17.20)	38 488 (17.20)	–	–	
	Pelagos Sanctuary	58000	Boat	2008	CDS	0.230 (35.55)	13232 (35.55)	–	–	Lauriano et al., 2010
	Pelagos Sanctuary	87500	Boat	2006	Mark–recapture method	–	–	–	884–1023	Gnone et al., 2011
	Gulf of Lion, France	–	Boat	2006–2007	Waiting distances and GAMs	0.380 (-)	38600 (-)	–	–	Cottè et al., 2010
	West Sardinia, Ligurian Sea, central-south Tyrrhenian Sea, Italy	844450	Aerial	2010–2011	CDS	–	–	0.006 (38.25)	1676 (38.25)	Lauriano et al., 2014
	West Sardinia, Italy	54789	Aerial	2010	CDS	0.390 (36.10)	21373 (36.10)	–	–	Panigada et al., 2017
					GAMs	0.390 (23.20)	21689 (23.20)	–	–	
	Pelagos Sanctuary	88266	Aerial	2010	CDS	0.520 (23.00)	45598 (23.00)	–	–	
					GAMs	0.510 (15.80)	44557 (15.80)	–	–	
	Central Tyrrehnian Sea, Italy	93216	Aerial	2010	CDS	0.330 (19.80)	30855 (19.80)	–	–	
					GAMs	0.310 (18.10)	28439 (18.10)	–	–	
				2013	CDS	0.270 (28.70)	24861 (28.70)	–	–	
					GAMs	0.260 (36.40)	24339 (36.40)	–	–	
	South Tyrrhenian Sea, Italy	111024	Aerial	2010	CDS	0.450 (20.30)	37729 (20.30)	–	–	
					GAMs	0.300 (24.50)	32684 (24.50)	–	–	
				2014	CDS	0.230 (21.60)	25756 (21.60)	–	–	
					GAMs	0.250 (22.30)	27833 (22.30)	–	–	
Adriatic-Ionian macro-region	Gulf of Venice, Istria	927	Boat	2012–2015	Mark–recapture method	–	–	–	47–142	Ribarič, 2016
	Kvarner Gulf, Croatia	800	Boat	1987–1994	Individual photo-identification	–	–	0.170	140	Bearzi et al., 1997
	Amvrakikos Gulf, Greece	400	Boat	2002–2005	Mark–recapture method	–	–	0.370	148	Bearzi et al., 2008
	Gulf of Corinth, Greece	2400	Boat	2009	Mark–recapture method	–	835	–	–	Bearzi et al., 2011
	Gulf of Corinth, Greece	2400	Boat	2011–2015	Individual photo-identification	–	1331	–	38	Santostati et al., 2016
	Ionian Sea, Italy	97326	Aerial	2010	CDS	0.290 (21.00)	27813 (21.00)	–	–	Panigada et al., 2017
					GAM	0.280 (29.40)	27214 (29.40)	–	–	
	Gulf of Taranto, Italy	640	Boat	2009–2016	CDS	1.070 (5.44)	682 (5.44)	0.170 (23.84)	111 (23.84)	Present study
		14000			Delta approach on Random Forest	0.720 (36.11)	10080 (35.56)	0.470 (19.15)	6580 (19.30)	Present study

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ecss.2018.02.034.

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