Marine Environmental Research xxx (2014) 1–8

Contents lists available at ScienceDirect

Marine Environmental Research

journal homepage: www.elsevier.com/locate/marenvrev

Abundance and distribution of *Tursiops truncatus* in the Western Mediterranean Sea: An assessment towards the Marine Strategy Framework Directive requirements

Giancarlo Lauriano [a,*], Nino Pierantonio [b], Greg Donovan [c], Simone Panigada [b,a]

[a] *Institute for Environmental Protection and Research (ISPRA), Via V. Brancati 60, 00144 Roma, Italy*
[b] *Tethys Research Institute, Viale G.B. Gadio 2, 20121 Milano, Italy*
[c] *The International Whaling Commission, The Red House, 135 Station Road, Impington, Cambridge, Cambridgeshire CB24 9NP, UK*

Keywords:
Marine mammals
Common bottlenose dolphin
Aerial survey
Distance sampling
Abundance
Mediterranean Sea
Marine Strategy Framework Directive

ABSTRACT

The Mediterranean Sea common bottlenose dolphin population has been assessed as *Vulnerable* according to the IUCN Red List Criteria. The species is also included in several International Agreements, European Union Regulations and Directives. Amongst them, a strict protection and identification of special conservation areas are requested by the EU Habitats Directive. Despite direct takes, by-catch, chemical and acoustic pollution, and prey depletion, general habitat degradation and fragmentation have been indicated as detrimental for the species, the degree to which these threats pose population risk is still largely unknown. At present it is thus not possible to depict the actual status of the population and to assess prospective trends. To address this gap in the current knowledge, line transect distance sampling aerial surveys were conducted in a wide portion of the Western Mediterranean Sea between the summer of 2010 and winter 2011. A total of 165 parallel transects equally spaced at 15 km were designed providing homogeneous coverage probability. Overall, 21,090 km were flown on effort and 16 bottlenose dolphin sightings were recorded and used for the analysis. The surface abundance and density estimates resulted in 1676 animals (CV = 38.25; 95% CI = 804–3492) with a density of 0.005 (CV = 38.25%). These results represent the first ever estimates for the common bottlenose dolphin over a wide portion of the Western Mediterranean Sea Subregion, with the potential to be useful baseline data to inform conservation. Specifically, they could be used as indicators under the Marine Strategy Framework Directive requirements, in conjunction with other study methods.

1. Introduction

The European Union (EU) Marine Strategy Framework Directive (MSFD – Directive 2008/56/EC) states the need to establish a framework for community actions in the field of marine environmental policy to achieve the 'Good Environmental Status' (GES) by 2020 across Europe's marine regions. In this context, the EU member States shall establish coordinated monitoring programmes aimed at "*a description of the population dynamics, natural and actual range and status of species of marine mammals …*". Moreover, the systematic monitoring of density and abundance of large vertebrates is among the priorities listed in the Pelagos Sanctuary for Mediterranean Marine Mammals (hereafter Pelagos Sanctuary) Management Plan, the Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS) and in the Specially Protected Areas (SPA) and Biodiversity Protocol under the Barcelona Convention.

The Mediterranean Sea common bottlenose dolphin subpopulation (*Tursiops truncatus*) (hereafter bottlenose dolphin) is listed in the Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS), in the Appendix II (Strictly Protected Fauna Species) of the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), and under the Annexes II and IV of the EU Habitats Directive (Council Directive 92/43/EEC).

Systematic research effort on cetaceans in the Region dates back to the late 1980s (Notarbartolo di Sciara and Bearzi, 2005), with the bottlenose dolphin being one of the most studied and well known species (Bearzi et al., 2008). Bottlenose dolphins have been reliably reported along the coast of the entire Mediterranean Basin (Bearzi

---

* Corresponding author. Tel.: +39 06 50074762.
E-mail address: giancarlo.lauriano@isprambiente.it (G. Lauriano).

http://dx.doi.org/10.1016/j.marenvres.2014.04.001
0141-1136/

Please cite this article in press as: Lauriano, G., et al., Abundance and distribution of *Tursiops truncatus* in the Western Mediterranean Sea: An assessment towards the Marine Strategy Framework Directive requirements, Marine Environmental Research (2014), http://dx.doi.org/10.1016/j.marenvres.2014.04.001

et al., 2008) and occur regularly around many of the region's offshore islands and archipelagos. They can also be encountered along continental shelf and shallow plateau waters (Notarbartolo Di Sciara et al., 1993; Bearzi et al., 2004; Ben Naceur et al., 2004; Gómez de Segura et al., 2006; Gannier, 2005; Gnone et al., 2006; Azzellino et al., 2008; Bearzi et al., 2008). Despite the widespread distribution of the species in the Basin, most of the research in the western Mediterranean Sea has been carried out on easily accessible populations (Bearzi et al., 2012), where the logistics of the studies (i.e. limited resources) allowed to easily perform the research activities, mainly focussing on photo-identification techniques (Table 1).

In general, a small scale approach does not allow for the description of the distribution and abundance of species with a wide distribution. Accordingly, at present it is difficult to clearly depict the current conservation status of the bottlenose dolphin and to reasonably compare past and present occurrence in terms of distribution and abundance throughout the Basin. Furthermore, the lack of these baseline information weakens the possibility to measure the degree to which threats such as by-catch (Silvani et al., 1992; Bearzi et al., 2004), chemical and acoustic pollution (Corsolini et al., 1995; Aguilar et al., 2002; Fossi and Marsili, 2003), prey depletion and a general habitat degradation and fragmentation (Bearzi et al., 1999, 2005, 2006) pose population risk (Reeves and Notarbartolo di Sciara, 2006).

As a matter of fact, to date it has been possible to only infer an overall abundance reduction of the population of at least 30% during the last 60 years, suggesting a size in the low 10,000s of individuals with a patchy distribution throughout the whole Basin (Bearzi et al., 2008, 2012), in contrast to a past coastal continuous one (Bearzi et al., 2012). The concern about the conservation status of the bottlenose dolphin was first raised in 2006 when the Mediterranean Sea sub-population of bottlenose dolphins was assessed as *Vulnerable* according to the International Union for the Conservation of Nature (IUCN) Red List criteria (Reeves and Notarbartolo di Sciara, 2006) during an IUCN/ACCOBAMS Red List Workshop (2006).

In light of the above considerations, this paper presents abundance estimates for bottlenose dolphins for a portion of the Western Mediterranean Sea Subregion (WMS). The potential for these data to represent crucial baseline information for the conservation of the species and to support the initial assessment requested by the MSFD is discussed.

2. Materials and methods

2.1. Study area

The study area (Fig. 1) covers a large sector of the WMS accounting for a total of 844,450 km^2. Specifically, the bodies of water monitored during the study period are: in Sub-area A – the Central Tyrrhenian Sea, the Ligurian Sea and portions of the Seas of Corsica and Sardinia and in Sub-area B the Southern Tyrrhenian Sea.

2.2. Surveys design

The survey was designed following the line transect distance sampling methodology according to Buckland et al. (2001). The study area was further divided into 10 *strata*, in agreement to the need to orient the transects perpendicular to the coast line according to bathymetric features and the available knowledge of cetacean presence and distribution. Transects were designed using the software Distance 5.0 (http://www.ruwpa.st-and.ac.uk/distance/; Thomas et al., 2010) to provide equal coverage probability. A total of 165 parallel transects, equally spaced at 15 km, were designed totalling 15,870 km. We used a two engine high-wing aircraft (*Partenavia* P-68) equipped with bubble windows to allow direct observation of the track-line. Flight altitude and ground speed were kept constant at 750 feet (229 m) and 100 knots (185 km/h), respectively. For each sighting two observers and one data logger collected continuous GPS position (latitude and longitude), group size and composition, and the declination angle to the animal/group of animals when abeam or estimated as such. Additional relevant information such as sea state, glare, cloud coverage and subjective sighting conditions were recorded at the beginning of each transect and/or whenever changes occurred. Effort flown in sea state three or less on the Beaufort scale was defined as positive conditions. The declination angles together with the plane altitude allowed the estimation of the perpendicular distance of the sightings to the track line.

Table 1
Summary of abundance estimates for bottlenose dolphin in the western Mediterranean Sea.

Area	km^2	Sampled area	Years	N	CV	95% CI	Estimation method	Reference
Alboran sea (Spain)	11,821	In – and off-shore	2000–3	584	0.28	278–744	Distance sampling and GAMs	Cañadas and Hammond, 2006
West coast of Liguria and North Tuscany	na	Inshore	2005	260	na	Na	Mark-recapture	Nuti et al., 2006
East Coast of Liguria	na	Inshore	2006	170	na	Na	Mark-recapture	Manfredini et al., 2007
Gulf of Lion, Hyeres Archipelago, Gulf of Genoa and Corsica	na	Na	na	424–515	na	Na	Direct counting	Ripoll et al., 2001
Corsica Island	na	Na	na	130–173	na	Na	Direct counting	Dhermain et al., 2003
East coast of Corsica	na	Inshore	na	25–36	na	na	Direct counting	Bompar et al., 1994
West coast of Corsica	na	Inshore		102–118	na	na	Direct counting	Bompar et al., 1994
Almeria (Spain)	4232	In- and off-shore	2001–3	279	0.28	146–461	Distance sampling and GAMs	Cañadas and Hammond, 2006
Asinara island (Italy)	480	Inshore	2001	22	0.26	22–27	Mark-recapture	Lauriano et al., 2003
Spanish waters between the Gulf of Vallencia and the Gulf of Vera	32,270	In – and off-shore	2001–3	1333	0.31	739–2407	Conventional Distance Sampling	Gómez de Segura et al., 2006
Balearic Islands (Spain)	16,659	Inshore	2002	1030	0.35	415–1849	Conventional Distance Sampling	Forcada et al., 2004
Balearic Islands and Catalan Sea (Spain)	86,000	In – and off-shore	2002	7654	0.47	1608–15,766	Conventional Distance Sampling	Forcada et al., 2004
Valencia (Spain)	32,270	In – and off-shore	2001–3	1333	0.31	739–2407	Conventional Distance Sampling	Gómez de Segura et al., 2006
Pelagos Sanctuary (Italy–France – Monaco)	87,500	In-shore	2005–6	884–1023	na	729–1234	Mark recapture	Gnone et al., 2011

Please cite this article in press as: Lauriano, G., et al., Abundance and distribution of *Tursiops truncatus* in the Western Mediterranean Sea: An assessment towards the Marine Strategy Framework Directive requirements, Marine Environmental Research (2014), http://dx.doi.org/10.1016/j.marenvres.2014.04.001

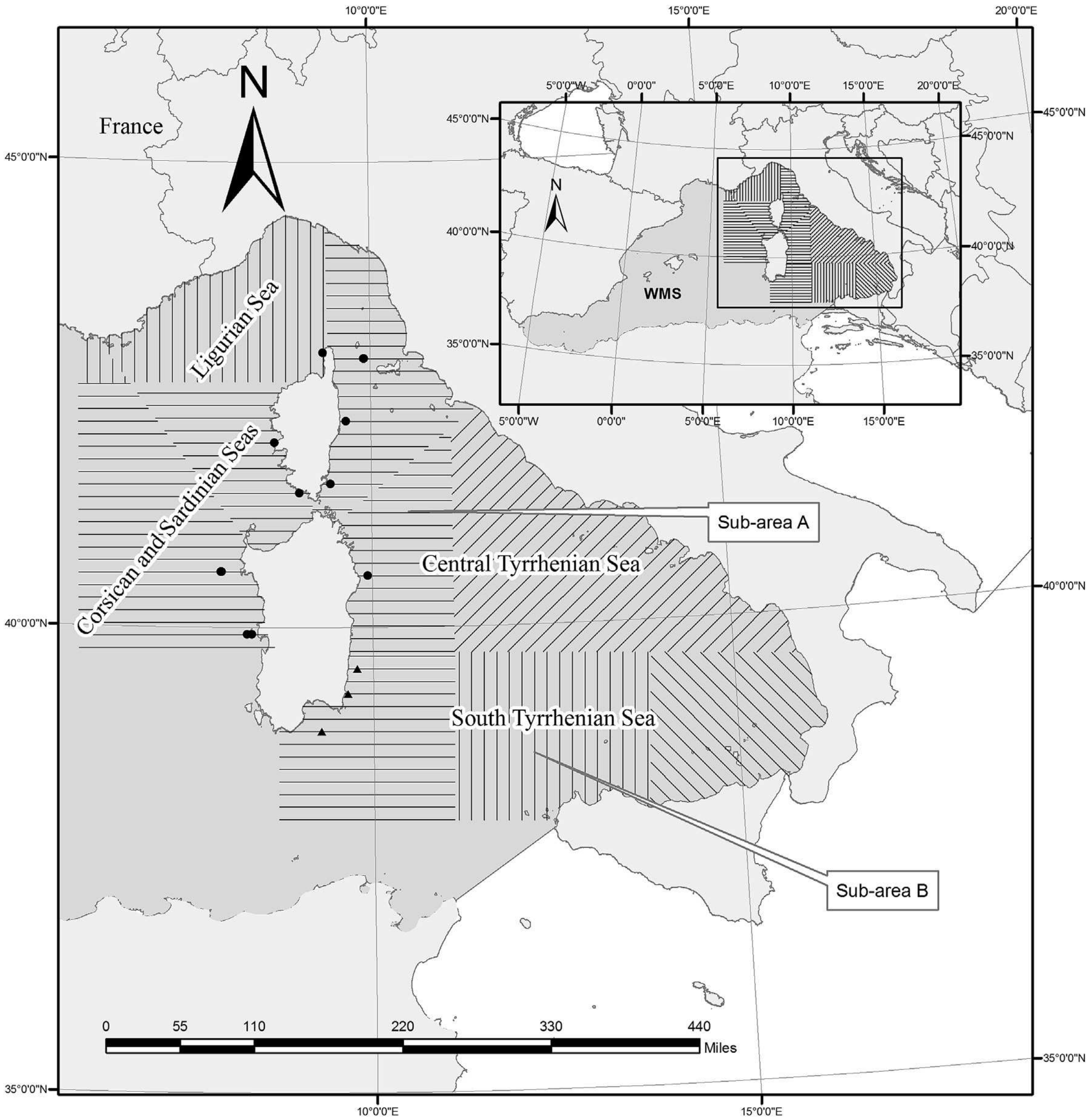

Fig. 1. The overall study area with the line transect, the *T. truncatus* sightings (circle = Sub-area A; triangles = Sub-area B) and the extension of the Western Mediterranean Sea Subregion (WMS) (darker grey).

2.3. Data analysis

Data analysis was performed using the software Distance 6.0. The overall small data set did not allow to include additional explanatory covariates along with the perpendicular distance for the estimation of the detection function, and hence the effective strip width (*esw*). Accordingly, only Conventional Distance Sampling (CDS) (Buckland et al., 2001) with half normal function and cosine series expansion was used for the analysis, with truncation set at the longest sightings distance. The model was selected based on the minimum Akaike Information Criteria (AIC) (Akaike, 1979; Buckland et al., 2001).

Within CDS method, a detection function is fitted to the distribution of perpendicular distances which is then used to estimate the *esw*. The density is then estimated as:

$$D = \frac{n\,E(s)}{2L\,esw\,g(0)} \tag{1}$$

where n is the number of sightings, L is the total search effort in positive conditions, $E(s)$ is the mean school size and $g(0)$ is the detection probability on the track-line. Animal abundance is finally estimated as:

$$\widehat{N} = A\frac{n}{2L\widehat{\mu}}\widehat{E}[s] \tag{2}$$

where A is the area, $\widehat{\mu}$ is the *esw* and $\widehat{E}[s]$ represents an estimate of mean group size.

School size can affect the probability of detection; large schools are more easily detected than smaller ones, especially with increasing perpendicular distance. The mean group size of the sightings was 3.5 individuals (SD = 2.73); accordingly the mean of the cluster size was the selected option on the data analysis software.

Encounter rate and abundance variance were assessed using the estimator S2 (Fewster et al., 2009) in Distance; thus, transects were

Please cite this article in press as: Lauriano, G., et al., Abundance and distribution of *Tursiops truncatus* in the Western Mediterranean Sea: An assessment towards the Marine Strategy Framework Directive requirements, Marine Environmental Research (2014), http://dx.doi.org/10.1016/j.marenvres.2014.04.001

grouped in adjacent pairs to reduce biases in the estimate of the encounter rate variance for systematic designs (Fewster et al., 2009).

Since the observers, survey platform and research protocols did not change among the surveys, and considering the consistency of data collection, all sightings were pooled to obtain a common detection function applied to the whole data-set, without further stratification for the sub-areas. This accounted for the small sample size and obtained more robust estimates. Furthermore, when performing abundance estimates, perception and availability biases need to be taken into consideration. These biases may occur when accessible animals are missed by the observer and/or animals are not visible at the surface when observations take place (Buckland et al., 2001), and can negatively affect the abundance estimates.

The availability bias depends on bottlenose dolphin surfacing behaviour and on the amount of time that the region of sea visible from the survey platform is in the observer's view. In light of the above considerations, correction factors were applied according to the general equation as described by Forcada et al. (2004):

$$\widehat{a}(S,x) = \frac{E(sf)}{E(sf)+E(d)} + \frac{\widehat{w}(x) - \widehat{w}(x)^2 E(d)^{-1} 0.5}{E(s)+E(d)} \tag{3}$$

where *E(sf)* and *E(d)* are the average length of a surfacing and of a dive, respectively estimated at 231.8 and 68.7 s. The quantity of time the area is in the observer's view at a perpendicular distance *x* is expressed by the parameter *w(x)*; this term was calculated considering the airplane speed over ground (ms^{-1}) and the truncation (m) fitted to the longest perpendicular distance. Finally, in light of the expertise of the observers and the consistency across surveys, the perception bias, estimated by Forcada et al. (2004) as irrelevant (between 0.95 and 0.99), was considered to be 1 and therefore not taken into consideration for density and abundance estimate calculations.

3. Results

The sub-area A was surveyed on 14 days between the 17 June and the 4 July 2010, while, due to poor weather conditions, the Southern Tyrrhenian Sea (sub-area B) was surveyed on 18 days between 21 and 23 October 2010 and in 2011 between the 13 and 23 of January. Table 2 summarises the details for the two time windows and areas. A total of 16 bottlenose dolphin sightings were recorded, 13 in the sub-area A and 3 in the sub-area B, respectively. The total group size ranged between 1 and 8 animals (mean = 3.5; SD = 2.73).

3.1. Abundance and density estimates

All the recorded sightings were considered for abundance and density analysis. A width of 488.95 m, corresponding to the maximum estimated perpendicular distance, resulted from the truncation; the pooled detection function is shown in Fig. 2.

The goodness-of-fit of this model was investigated through a quantile–quantile plot (qq-plots; Fig. 3) and diagnostic tests. The first points of the graphs in the qq-plot depart appreciably from the 1-1 line indicating an excess of observation at zero distance. Nevertheless the line through the point does not go far from the 1-1 line and fit appears quite good, with most points close to the line. A Kolmogorov–Smirnov goodness-of-fit test, based on the largest discrepancy between observed and predicted values, did not indicate a lack of fit ($p = 0.7821$). The Cramer-von Mises tests, based on the overall differences between the observed and predicted values, showed no evidence for lack of fit (Cramer-von Mises test with uniform weighting $0.500 < p \leq 0.600$; Cramer-von Mises test with cosine weighting $0.500 < p \leq 0.600$).

The resulted overall uncorrected abundance estimate is 1676 animals at the surface (CV = 38.25; 95% CI = 804–3492) with a density of 0.005 (CV = 38.25%) and an encounter rate of 0.000758 groups/km (CV = 27.5%). The probability *p* of recording a bottlenose dolphin in the surveyed area (probability of detection) resulted in 0.54544 (%CV = 18.04; 95% CI = 0.37248–0.79869). The estimates for the sub-areas A and B are summarised in Table 2.

The parameter *w(x)* in equation (3) was calculated to be 9.5163 considering the truncation distance of 488.95 m and aircraft speed of 51 m^{-1}. The resulting availability bias was 0.8, corresponding to 20% of the animals missed during the survey, similar to the value obtained by Forcada et al. (2004) ($\hat{a} = 0.7784$; CV = 0.04:95% CI = 0.721–0.825). Given the similarities in the values, we have used the CV from Forcada et al. (2004) to obtain the CV of the corrected abundance estimate as it follows (Heide -Jorgensen et al., 2012):

$$CV(N_c) = \sqrt{CV(N_c)^2 + CV(\widehat{a})^2} \tag{4}$$

The final estimate (N_c), corrected for the availability bias, for the whole study area is therefore 2095 individuals and the CV resulted from eq. 4, is 38.25%.

Encounter rate, detection probability and cluster size accounted respectively for 51.7%, 22.2% and 26% of the overall variance. These high values were expected given the low number of encounters and the differences in dolphin encounter rates across the study area.

4. Discussion

This study provides the first ever information on the occurrence, distribution and abundance of bottlenose dolphins for a large previously unexplored sector of the western and central Mediterranean Sea. In light of this, these results could support the MSFD requirements, providing robust data on the abundance and the distribution of the species. Furthermore, they represent preliminary information for the planning of future monitoring efforts aimed to evaluate potential population trends and to cover wider areas.

Table 2

Bottlenose dolphin estimates in the two portions (A and B) of the study area and the overall estimate; L = total length of transect lines; K = number of transects; n = number of observed clusters; $\widehat{N}$ = abundance estimate; D = estimate of density (animals per km^{-2}); CV = coefficient of variation CI = confidence interval; $\widehat{N}$ corrected = $\widehat{N}/0.8$ of animals.

Study area	*L*	*k*	*n*	$\widehat{\mathbf{N}}$ (%cv)	D (%cv)	95% CI ($\widehat{\mathbf{N}}$)	95% CI (D)	$\widehat{\mathbf{N}}$ corrected
West Sardinia, the Pelagos Sanctuary and the central Tyrrhenian Sea – **Area A**	15160.54	126	13	1216 (43.33)	0.00514 (43.33)	532–2782	0.0022–0.0117	
South Tyrrhenian Sea – **Area B**	5930	39	3	435 (82.84)	0.0043 (82.84)	91–2082	0.0009–0.0207	
A + B	**21,090.58**	**165**	**16**	**1676 (38.25)**	**0.0058 (38.25)**	**804–3492**	**0.0023–0.0103**	**2095**

Please cite this article in press as: Lauriano, G., et al., Abundance and distribution of *Tursiops truncatus* in the Western Mediterranean Sea: An assessment towards the Marine Strategy Framework Directive requirements, Marine Environmental Research (2014), http://dx.doi.org/10.1016/j.marenvres.2014.04.001

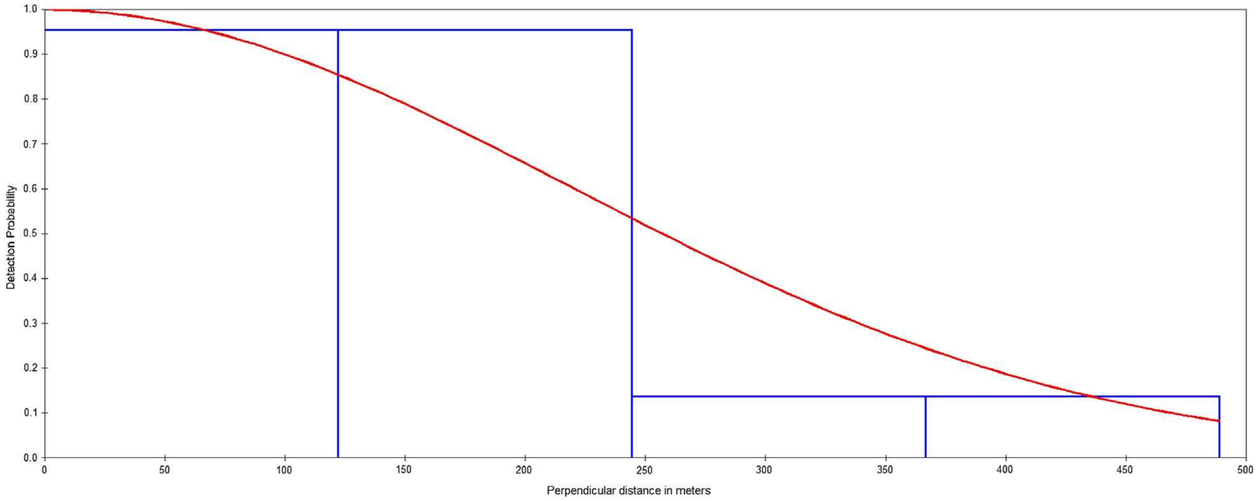

Fig. 2. The detection function with the right truncation at the largest observed distance.

The surveys were conducted in different periods across the study area; this could represent a limiting factor towards pooled abundance estimates due to potential movements of individuals across adjacent areas, with additional variance compared to a synoptic survey (Skaug et al., 2004). Nevertheless, even though the available information on movements of bottlenose dolphins in the Mediterranean Sea are scant, they depict the species as resident with home ranges extending between 100 and 150 km^2 (Maze and Würsig, 1999; Wells and Scott, 1999; Bearzi et al., 2011a,b) and with high and long-term site fidelity [Island of Losinj, Croatia (Bearzi et al., 1997, 1999); the Asinara Island, Italy (Lauriano et al., 2003), and the Amvrakikos Gulf, Greece (Bearzi et al., 2008)]. More recently, Gnone et al. (2011) reported a site fidelity and mid-range movements, most likely limited to about 50 km in the waters of the Pelagos Sanctuary. Moreover, differences in habitat characteristics are believed to restrict the movements of bottlenose dolphins in the basin (Natoli et al., 2005).

Indeed its opportunistic feeding behaviour and flexible social organization (Bearzi et al., 2008) allow the ability to colonize small coastal system in which the distribution of prey strictly effects Bottlenose dolphin presence (Barros and Odell, 1990; Barros et al., 2000) with groups also taking advantage from the local fishing activities such as trawlers (Fertl and Leatherwood, 1997) and other small scale artisanal fishery (Lauriano et al., 2004, 2009) or fish farm and aquaculture facilities (Bearzi et al., 2008).

To this respect the uneven distribution of the sightings can be regarded in light of the prey availability and the consistent fishery activities. For example, in the northern Tyrrhenian Sea and in the Pelagos Sanctuary area, the European hake (*Merluccius merluccius*), one of the main preys of the bottlenose dolphins (Blanco et al., 2001; Silva and Sequeira, 1997) represents up to the 90% of the weight of the total catch landings (Mannini and Relini, 2008). Moreover, *M. merluccius* shows here the highest juvenile concentration among the whole western Mediterranean Basin (Mannini and Relini, 2008), and the 200 m bandwidth is hosting an *M. barbatus* nursery area (Mannini and Relini, 2008).

Furthermore, Sardinia Island, Liguria and Tuscany are among the regions with the highest bottlenose dolphin interaction rates with the fishery (Lauriano et al., 2009), where depredation is reported on a seasonal basis, mostly in autumn during striped red mullets fishing in trammel nets (Lauriano et al., 2004), and all year round during gillnet fishing operations (Diaz Lopez, 2006).

In light of the above considerations, we assumed that very limited or no relevant movements occurred between the two

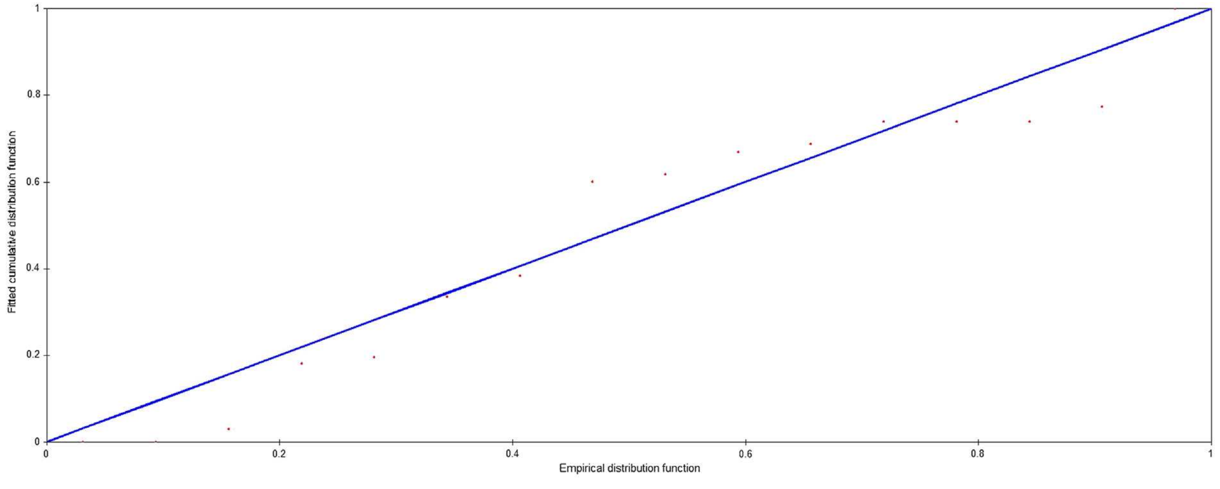

Fig. 3. The quantile–quantile plot.

Please cite this article in press as: Lauriano, G., et al., Abundance and distribution of *Tursiops truncatus* in the Western Mediterranean Sea: An assessment towards the Marine Strategy Framework Directive requirements, Marine Environmental Research (2014), http://dx.doi.org/10.1016/j.marenvres.2014.04.001

adjacent sub-areas A and B, resulting in negligible or absent effects on the obtained pooled abundance estimates.

The absence of sightings and/or low animal densities in a given portion of the species' range is not necessarily a sign of low importance for the species itself (Hooker et al., 2011), potentially migration corridors could exist in which animals spend enough time but not sufficiently long to be detected during an aerial survey. In this context, Gnone et al. (2011) reported bottlenose dolphin movements from the Côte d'Azur (France coast) and west Corsica as well as from the Tuscany archipelago northwards to east Liguria with linear distance movements up to 100–130 km.

Movements within and across pelagic waters may occur as documented for some sectors of the Mediterranean Sea (e.g. Dhermain et al., 1999; Gnone et al., 2006). Nonetheless, no bottlenose dolphins were observed in the pelagic waters of the study area, confirming similar results obtained by Forcada et al. (1995) and Lauriano et al. (2010) for the Pelagos Sanctuary.

4.1. Conservation implications

The prevailing coastal occurrence of bottlenose dolphins observed across the surveyed area hampers the conservation in light of the existence of many anthropogenic activities which may represents potential negative effects on the specie. The coastal area throughout the Mediterranean Region is characterised by heavy habitat degradation caused by the synergistic effects of prey depletion, overfishing, acoustic noise, commercial shipping and high volumes of vessel traffic, artisanal fishery activities, coastal development and chemical contaminants.

Considering the difficulty in isolating the main factors that pose a serious threat to the species' conservation, and in light of the fact that these same threats might have a stronger effect when combined, a useful tool to address the anthropogenic impacts on the coastal bottlenose dolphin is certainly the development of Marine Protected Areas (MPAs). In the whole study area 18 MPAs are already in place; nevertheless, these are mainly designed to protect small coastal areas and their extension is limited to a few square kilometres. As a consequence, none or very little conservation outcome could be achieved in relation to far ranging species such as cetaceans and/or sea turtles that require measures at scales relevant to their spatial ambits and life-history (Hooker et al., 2011).

Finally, the strategic planning of networks of MPAs would allow countries to meet key conservation obligations such as those set by the Convention on Biological Diversity (CBD), the EU Habitats Directive, and the Marine Strategy Framework Directive among the others, as recently expressed by Portman et al. (2013).

4.2. Future needs

From a practical point of view, to obtain robust baseline information on species occurrence, distribution and abundance, and to overcome some of the limitations reported here, future aerial survey effort should take into account the following issues:

- *Availability bias* – an accurate correction factor resulting from data obtained from the study area. In our case the correction factor used to adjust the abundance estimate was derived from data gathered in Galicia (Spain). Since differences in the surface pattern as well as dive intervals of the dolphins can occur across different areas, these same differences should be taken into account.
- *Perception bias* – This bias can be considered to be negligible as previously discussed; nevertheless, it can be addressed by means of double platform surveys (Buckland, 2001), that should be thus always considered in the designing and planning of future monitoring activities.
- *Survey design* – The output of our study confirmed a coastal and patchy distribution of bottlenose dolphins throughout the study area. This uneven occurrence of animals and the low number of the encounters suggest that an adjustment of the survey to a more powerful design, together with a revision of the main flight parameters, necessary to better focus on bottlenose dolphin, should also be considered. An example of such adjustment comes from the small cetaceans in the European Atlantic and North Sea projects (SCANS I and II), aimed to assess the abundance of small cetaceans, with the harbour porpoise (*Phocoena phocoena*) being the main target, the flight altitude was set at 600 feet (182.88 m) and the speed at 90 knots (166.68 km h^{-1}) (Hammond et al., 2002, 2013). A recent study on Black Sea harbour porpoise (*Phocoena phocoena relicta)*, common dolphin (*Delphinus delphis ponticus)* and bottlenose dolphin (*T. truncatus ponticus)* adopted the same flight altitude (Panigada pers. com.). Several others study on harbour porpoises (Scheidat et al., 2008, 2012; Haelters et al., 2011; Dahlheim et al., 2000; Geelhoed et al., 2013) and on bottlenose dolphins (Durden, 2011) selected a flight altitude ranging between 500 and 600 feet and a speed between 90 and 100 knots. Finally, a species specific survey, performed in the well known bottlenose dolphins habitat (i.e. over the continental platform) with a reduction of the distance between the transects (i.e. 10 instead of 15 km), hence resulting in a higher coverage and a better resolution of the area, might be profitable, increasing the detectability of individuals (due to their patchiness distribution) and leading to more robust and reliable abundance estimates.

Systematic monitoring programmes are a legal requirement under the EU Habitats Directive; aerial surveys have proved to be an effective and more efficient method to obtain abundance estimates than traditional sea level platforms (Panigada et al., 2011) and have been conducted to obtain data on several marine species such as sea turtles (Witt et al., 2009; Lauriano et al., 2011) and jellyfish (Houghton et al., 2006; Hays et al., 2003) in addition to cetaceans. In this context, the method represents a useful tool to gather data on a large scale and to fulfil the requirements under the MSFD to conduct, following the 2012 initial assessment, a coordinated monitoring programme which is consistent across different marine regions to easily allow for comparisons.

Nevertheless, to accomplish the conservation obligations, there is a need to overcome the difficulties and limitations arising from patchy, discontinuous and fragmented distribution of the species as well as to rise above the lack of information on some biological/ecological factors influencing the occurrence of the species.

A way to move forward on these issues is to integrate data from multiple sources and study methodologies. For instance, line transect aerial surveys can be conducted in conjunction with photo-identification programs from local studies which are an effective method for describing distribution and core habitats (Thompson et al., 2009) to obtain abundance estimates via mark-recapture models (Wilson et al., 1999; Bearzi et al., 2008) and to study movements (Bearzi et al., 2011). A relevant example of integration of multiple data sources arises from Cheney et al. (2013) who assessed the distribution and abundance of bottlenose dolphin in Scottish waters. In the Mediterranean Sea the only example of this approach is from the effort of Gnone et al. (2011) in the Pelagos Sanctuary. Moreover, an additional source of information arises from stranding data which can be considered as indicators of the present and past marine mammals occurrence (Pyenson, 2011), and therefore should be included in monitoring and conservation strategies (Peltier et al., 2013).

Please cite this article in press as: Lauriano, G., et al., Abundance and distribution of *Tursiops truncatus* in the Western Mediterranean Sea: An assessment towards the Marine Strategy Framework Directive requirements, Marine Environmental Research (2014), http://dx.doi.org/10.1016/j.marenvres.2014.04.001

Nonetheless, the above consideration on the legal obligations and considering the current conservation status of the Mediterranean Sea bottlenose dolphin sub-population and the inferred decreasing trend suggested in the Basin during the last decades (Bearzi et al., 2008, 2012), regular monitoring activities should be a priority. In this context, decision makers and Governments must intervene by implementing the existing conservation tools provided by national and international regulations.

Acknowledgements

The authors wish to thank Michele Albertario, the pilot of the Partenavia P68 from Mach 014, Pine Eisfeld-Pierantonio for reviewing the English, Caterina M. Fortuna for some advice and corrections and two anonymous reviewers for their valuable comments on this manuscript. The surveys were carried out thanks to funds provided by the Italian Ministry of the Environment, Land and Sea (MATTM).

References

Aguilar, A., Borrell, A., Reijnders, P.J., 2002. Geographical and temporal variation in levels of organochlorine contaminants in marine mammals. Mar. Environ. Res. 53, 425–452.

Akaike, H., 1979. A Bayesian extension of the minimum AIC procedure of autoregressive model fitting. Biometrika 66, 237.

Azzellino, A., Gaspari, S., Airoldi, S., Nani, B., 2008. Habitat use and preferences of cetaceans along the continental slope and the adjacent pelagic waters in the western Ligurian Sea. Deep Sea Res. Part Oceanogr. Res. Pap. 55, 296–323.

Barros, N.B., Odell, D.K., 1990. Food Habits of Bottlenose Dolphins in the Southeastern United States. In: Leatherwood, S., Reeves, R.R. (Eds.), The Bottlenose Dolphin. Academic Press, San Diego, pp. 309–328.

Barros, N.B., Parsons, E.C.M., Jefferson, T.A., 2000. Prey of offshore bottlenose dolphins from the south China Sea. Aquat. Mamm. 26, 2–6.

Bearzi, G., Notarbartolo Di Sciara, G., Politi, E., 1997. Social Ecology of bottlenose dolphins in the Kvarnerić (northern Adriatic sea). Mar. Mammal. Sci. 13, 650–668.

Bearzi, G., Politi, E., Notarbartolo di Sciara, G., 1999. Diurnal behavior of free-ranging bottlenose dolphins in the Kvarnerić (northern Adriatic sea). Mar. Mammal. Sci. 15, 1065–1097.

Bearzi, G., Holcer, D., Notarbartolo di Sciara, G., 2004. The role of historical dolphin takes and habitat degradation in shaping the present status of northern Adriatic cetaceans. Aq. Conserv.: Mar. Freshw. Ecosyst. 14, 363–379.

Bearzi, G., Politi, E., Agazzi, S., Bruno, S., Costa, M., Bonizzoni, S., 2005. Occurrence and present status of coastal dolphins (*Delphinus delphis* and *Tursiops truncatus*) in the eastern Ionian Sea. Aq. Conserv.: Mar. Freshw. Ecosyst. 15, 243–257.

Bearzi, G., Politi, E., Agazzi, S., Azzellino, A., 2006. Prey depletion caused by overfishing and the decline of marine megafauna in eastern Ionian Sea coastal waters (central Mediterranean). Biol. Conserv. 127, 373–382.

Bearzi, G., Fortuna, C.M., Reeves, R.R., 2008. Ecology and conservation of common bottlenose dolphins *Tursiops truncatus* in the Mediterranean Sea. Mammal. Rev. 39 (2), 92–123.

Bearzi, G., Bonizzoni, S., Agazzi, S., Gonzalvo, J., Currey, R.J.C., 2011a. Striped dolphins and short -beaked common dolphins in the Gulf of Corinth, Greece: abundance estimates from dorsal fin photographs. Mar. Mammal. Sci. 27, E165–E184.

Bearzi, G., Bonizzoni, S., Gonzalvo, J., 2011b. Mid-distance movements of common bottlenose dolphins in the coastal waters of Greece. J. Ethol. 29, 369–374.

Bearzi, G., Fortuna, C., Reeves, R., 2012. *Tursiops truncatus* (Mediterranean sub-population). In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. www.iucnredlist.org.

Ben Naceur, L., Gannier, A., Bradai, M.N., Drouot, V., Bourreau, S., Laran, S., Khalfallah, N., Mrabet, R., Bdioui, M., 2004. Recensement du grand dauphin *Tursiops truncatus* dans les eaux tunisiennes. Bull. del l'Inst. Natl. Sci. Technol. Mer Salammbô 31, 75–81.

Blanco, C., Salomón, O., Raga, J. a, 2001. Diet of the bottlenose dolphin (*Tursiops truncatus*) in the western Mediterranean Sea. J. Mar. Biol. Assoc. U. K. 81, 1053–1058.

Bompar, J.M., Baril, D., Dhermain, F., Ripoll, T., 1994. Estimation of the Corsican population of bottlenose dolphins *Tursiops truncatus*: is there a real conflict with fishermen? Eur. Res. Cetacean 8, 92–94.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L., 2001. Introduction to Distance Sampling. Oxford University Press, London.

Cañadas, A., Hammond, P.S., 2006. Model -based abundance estimates for bottlenose dolphins (*Tursiops truncatus*) off southern Spain: implications for management. J. Cetacean Res. Manag. 8, 13–27.

Cheney, B., Thompson, P.M., Ingram, S.N., Hammond, P.S., Stevick, P.T., Durban, J.W., Culloch, R.M., Elwen, S.H., Mandleberg, L., Janik, V.M., Quick, N.J., ISLAS-Villanueva, V., Robinson, K.P., Costa, M., Eisfeld, S.M., Walters, A., Phillips, C., Weir, C.R., Evans, P.G.H., Anderwald, P., Reid, R.J., Reid, J.B., Wilson, B., 2013. Integrating multiple data sources to assess the distribution and abundance of bottlenose dolphins *Tursiops truncatus* in Scottish waters. Mammal. Rev. 43, 71–88.

Corsolini, S., Focardi, S., Kannan, K., Tanabe, S., Borrell, A., Tatsukawa, R., 1995. Congener profile and toxicity assessment of polychlorinated biphenyls in dolphins, sharks and tuna collected from Italian coastal waters. Mar. Environ. Res. 40, 33–53.

Dahlheim, M., York, A., Towell, R., Waite, J., Breiwick, J., 2000. Harbor Porpoise (*Phocoena phocoena*) Abundance in Alaska: Bristol Bay to Southeast Alaska, 1991–1993. Publications, Agencies and Staff of the U.S. Department of Commerce.

Dhermain, F., Ripoll, T., Bompar, J.M., David, L., Di Meglio, N., 1999. First evidence of the movement of a bottlenose dolphin *Tursiops Truncatus* between Corsica and Hyeres Archipelago, southeastern France. Eur. Res. Cetaceans 13, 306–311.

Dhermain, F., Baril, D., Ripoll, T., 2003. Suivi hivernal et recensement estival des Grands Dauphins en Corse. Rapp. GECEM la DIREN Corse l'Off. l'Environ. Corse.

Diaz Lopez, B., 2006. Interactions between Mediterranean bottlenose dolphins (*Tursiops truncatus*) and gillnets off Sardinia, Italy. ICES J. Mar. Sci. 63, 946–951.

Durden, W., 2011. Abundance, distribution, and group composition of Indian River Lagoon bottlenose dolphins (*Tursiops truncatus*). Aquat. Mamm. 37, 175–186.

Fertl, D., Leatherwood, S., 1997. Cetacean interactions with Trawls: a preliminary review. J. Northwest Atl. Fish. Sci. 22, 219–248.

Fewster, R.M., Buckland, S.T., Burnham, K.P., Borchers, D.L., Jupp, P.E., Laake, J.L., Thomas, L., 2009. Estimating the encounter rate variance in distance sampling. Biometrics 65, 225–236.

Forcada, J., Notarbartolo Di Sciara, G., Fabbri, F., 1995. Abundance of fin whales and striped dolphins summering in the Corso -Ligurian Basin. Mammalia 59.

Forcada, J., Gazo, M., Aguilar, A., Gonzalvo, J., FernndezContreras, M., 2004. Bottlenose dolphin abundance in the NW Mediterranean: addressing heterogeneity in distribution. Mar. Ecol. Prog. Ser. 275, 275–287.

Fossi, M.C., Marsili, L., 2003. Effects of endocrine disruptors in aquatic mammals. Pure Appl. Chem. 75, 2235–2247.

Gannier, A., 2005. Summer distribution and relative abundance of delphinids in the Mediterranean Sea. Rev. d'Ecol. la Terre la Vie 60, 223–238.

Geelhoed, S.C.V., Scheidat, M., Bemmelen, van R.S.A., Aarts, G.M., 2013. Abundance of harbour porpoises (*Phocoena phocoena*) on the Dutch Continental Shelf, aerial surveys in July 2010–March 2011. Lutra 56, 45–57.

Gnone, G., Nuti, S., Bellingeri, M., Pannoncini, R., Bedocchi, D., 2006. Comportamento spaziale di *Tursiops truncatus* lungo la costa del Mar Ligure: risultati preliminari. Biol. Mar. Mediterr. 13, 272–273.

Gnone, G., Bellingeri, M., Dhermain, F., Dupraz, F., Nuti, S., Bedocchi, D., Moulins, A., Rosso, M., Alessi, J., McCrea, R.S., Azzellino, A., Airoldi, S., Portunato, N., Laran, S., David, L., Di Meglio, N., Bonelli, P., Montesi, G., Trucchi, R., Fossa, F., Wurtz, M., 2011. Distribution, abundance, and movements of the bottlenose dolphin (*Tursiops truncatus*) in the Pelagos Sanctuary MPA (north -west Mediterranean Sea). Aq. Conserv.: Mar. Freshw. Ecosyst. 21, 372–388.

Gómez de Segura, A., Crespo, E., Pedraza, S., Hammond, P., Raga, J., 2006. Abundance of small cetaceans in waters of the central Spanish Mediterranean. Mar. Biol. 150, 149–160.

Haelters, J., Kerckhof, F., Jacques, T.G., Degraer, S., 2011. Harbour porpoise *Phocoena phocoena* in the Belgian part of the North Sea: trends in abundance and distribution. Belg. J. Zool. 141, 75–84.

Hammond, P.S., Berggren, P., Benke, H., Borchers, D., l., Collet, A., Heide-Jørgensen, M. p., Heimlich, S., Hiby, A. r., Leopold, M. f., Øien, N., 2002. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. J. Appl. Ecol. 39, 361–376.

Hammond, P.S., Macleod, K., Berggren, P., Borchers, D.L., Burt, L., Cañadas, A., Desportes, G., Donovan, G.P., Gilles, A., Gillespie, D., Gordon, J., Hiby, L., Kuklik, I., Leaper, R., Lehnert, K., Leopold, M., Lovell, P., Øien, N., Paxton, C.G.M., Ridoux, V., Rogan, E., Samarra, F., Scheidat, M., Sequeira, M., Siebert, U., Skov, H., Swift, R., Tasker, M.L., Teilmann, J., Van Canneyt, O., Vázquez, J.A., 2013. Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biol. Conserv. 164, 107–122.

Hays, G.C., Houghton, J.D.R., Doyle, T., Davenport, J., 2003. Aircraft give a new view of jellyfish behaviour. Nature 426, 383.

Heide -Jorgensen, M.P., Laidre, K.L., Hansen, R.G., Burt, M.L., Simon, M., Borchers, D.L., Hansen, Harding, J.K., Rasmussen, M., Dietzb, R., Teilmannb, J., 2012. Rate of increase and current abundance of humpback whales in West Greenland. J. Cetacean Res. Manage. 12 (1), 1–14.

Hooker, S.K., Canadas, A., Hyrenbach, K.D., Corrigan, C., Polovina, J.J., Reeves, R.R., 2011. Making protected area networks effective for marine top predators. Endanger. Species Res. 13, 203–218.

Houghton, J., Doyle, T., Davenport, J., Hays, G.C., 2006. Developing a simple, rapid method for identifying and monitoring jellyfish aggregations from the air. Mar. Ecol. Prog. Ser. 314, 159–170.

Lauriano, G., Mackelworth, P., Fortuna, C.M., Moltedo, G., Notarbartolo Di Sciara, G., 2003. Densità e abbondanza del tursiope (*Tursiops truncatus*) nel Parco Nazionale dell'Asinara, Sardegna. Biol. Mar. Medit. 10 (2), 717–720.

Lauriano, G., Fortuna, C.M., Moltedo, G., Notarbartolo di Sciara, G., 2004. Interaction between common bottlenose dolphin (*Tursiops truncatus*) and the artisanal fishery in Asinara island National Park (Sardinia): assessment of catch damage and economic loss. J. Cetacean Res. Manag. 6, 165–173.

Please cite this article in press as: Lauriano, G., et al., Abundance and distribution of *Tursiops truncatus* in the Western Mediterranean Sea: An assessment towards the Marine Strategy Framework Directive requirements, Marine Environmental Research (2014), http://dx.doi.org/10.1016/j.marenvres.2014.04.001

Lauriano, G., Caramanna, L., Scarnò, M., Andaloro, F., 2009. An overview of dolphin depredation in Italian artisanal fisheries. J. Mar. Biol. Assoc. U. K. 89, 921–929.

Lauriano, G., Panigada, S., Canneri, R., Manca Zeichen, M., Notarbartolo di Sciara, G., 2010. Abundance estimate of striped dolphins (*Stenella coeruleoalba*) in the Pelagos Sanctuary (NW Mediterranean Sea) by means of line transect survey. J. Cetacean Res. Manage. 11 (3), 279–283.

Lauriano, G., Panigada, S., Casale, P., Pierantonio, N., Donovan, G.P., 2011. Aerial survey abundance estimates of the loggerhead sea turtle *Caretta caretta* in the Pelagos Sanctuary, northwestern Mediterranean Sea. Mar. Ecol. Prog. Ser. 437, 291–302.

Manfredini, E., Frau, F., Fossa, F., Bellingeri, M., Gnone, G., Saporiti, F., 2007. Presence and abundance of bottlenose dolphin along the east Ligurian coast in relation to the pleasure boating. In: 21st Annual Conference of the European Cetacean Society, 22–25 April 2007, San Sebastián, Spain.

Mannini, A., Relini, G., 2008. In: State of Biological Resources in the Italian Seas. Yearbook 2008 25, 26. 207 pp.

Maze, K.S., Würsig, B., 1999. Bottlenose dolphins of San Luis Pass, Texas. Occurrence patterns, site -fidelity, and habitat use. Aquat. Mamm. 25, 91–103.

Natoli, A., Birkun, A., Aguilar, A., Lopez, A., Hoelzel, A.R., 2005. Habitat structure and the dispersal of male and female bottlenose dolphins (*Tursiops truncatus*). Proc. Royal Soc. B: Biol. Sci. 272, 1217–1226.

Notarbartolo di Sciara, G., Bearzi, G., 2005. Research on Cetaceans in Italy. In: Cozzi, B. (Ed.), Marine Mammals of the Mediterranean Sea: Natural History, Biology, Anatomy, Pathology, Parasitology. Massimo Valdina Editore – the Coffee House Art Adv, Milano, pp. 1–25.

Notarbartolo Di Sciara, G.N., Venturino, M.C., Zanardelli, M., Bearzi, G., Borsani, F.J., Cavalloni, B., 1993. Cetaceans in the central Mediterranean Sea: distribution and sighting frequencies. Boll. Zool. 60, 131–138.

Nuti, S., Gnone, G., Bellingeri, M., Bedocchi, D., Pannoncini, R., Manfredini, E., 2006. Stima di abbondanza di *Tursiops truncatus* tra La Spezia, Viareggio e Marina di Pisa attraverso cattura e ricattura fotografica. In: Adria -Watch Conference “Cetaceans, Sea Turtles and Sharks of the Adriatic Sea”, 27–28 October 2006, Cattolica, Italy.

Panigada, S., Lauriano, G., Burt, L., Pierantonio, N., Donovan, G., 2011. Monitoring Winter and summer abundance of cetaceans in the pelagos sanctuary (Northwestern mediterranean sea) through aerial surveys. PLoS ONE 6, e22878.

Peltier, H., Baagøe, H.J., Camphuysen, K.C.J., Czeck, R., Dabin, W., et al., 2013. The stranding anomaly as population indicator: the case of harbour porpoise phocoena phocoena in North-Western europe. PLoS ONE 8 (4), e62180. http://dx.doi.org/10.1371/journal.pone.0062180.

Portman, M.E., Notarbartolo Di Sciara, G., Agardy, T., Katsanevakis, S., Possingham, H.P., Di -Carlo, G., 2013. He who hesitates is lost: why conservation in the Mediterranean Sea is necessary and possible now. Mar. Policy 42, 270–279.

Pyenson, N.D., 2011. The high fidelity of the cetacean stranding record: insights into measuring diversity by integrating taphonomy and macroecology. Proc. Royal Soc. B: Biol. Sci. 278, 3608–3616.

Reeves R., Notarbartolo di Sciara G., (Compilers and Editors) 2006. The Status and Distribution of Cetaceans in the Black Sea and Mediterranean Sea. IUCN Centre for Mediterranean Cooperation, Malaga, Spain.

Ripoll, T., Dhermain, F., Barril, D., Roussel, E., David, L., Beaubrun, P., 2001. First summer population estimate of bottlenose dolphins along the north -western coasts of the occidental Mediterranean basin. Eur. Res. Cetaceans 15, 393–396.

Scheidat, M., Gilles, A., Kock, K., Siebert, U., 2008. Harbour porpoise *Phocoena phocoena* abundance in the southwestern Baltic Sea. Endanger. Species Res. 5, 215–223.

Scheidat, M., Verdaat, H., Aarts, G., 2012. Using aerial surveys to estimate density and distribution of harbour porpoises in Dutch waters. J. Sea Res. 69, 1–7.

Silva, M. A., M. Sequeira. 1997. Stomach contents of marine mammals stranded on the Portuguese coast. European Research on Cetaceans 11:176–179.Proceedings of the Eleventh Annual Conference of the European Cetacean Society. Evans, P. G. H., Parsons, E. C. M., Clark, S. L. (Eds.). Stralsund, Germany, 10–12 March 1997.

Silvani, L., Raich, J., Aguilar, A., 1992. Bottlenose dolphins, *Tursiops truncatus*, interacting with fisheries in the Balearic Islands, Spain. Eur. Res. Cetaceans 6, 32–34.

Skaug, H.J., Øien, N., Schweder, T., Bøthun, G., 2004. Abundance of minke whales (*Balaenoptera acutorostrata*) in the Northeast Atlantic: variability in time and space. Can. J. Fish. Aq. Sci. 61, 870–886.

Thomas, L., Buckland, S.T., Rexstad, E.A., Laake, J.L., et al., 2010. Distance software: design and analysis of distancesampling surveys for estimating population size. J. Appl. Ecol. 47, 5–14.

Thompson, P.M., Cheney, B., Ingram, S., Stevick, P., Wilson, B., Hammond, P.S. (Eds.), 2009. Distribution, Abundance and Population Structure of Bottlenose Dolphins in Scottish Waters. Scottish Natural Heritage Commissioned Report No.354. Scottish Natural Heritage, Perth, UK.

Wells, R.S., Scott, M.D., 1999. Bottlenose dolphin *Tursiops truncatus* (Montagu, 1821). In: Ridgway, S.H., Harrison, R. (Eds.), Handbook of Marine Mammals, The Second Book of Dolphins and Porpoises, vol. 6. Academic Press, San Diego, pp. 137–182.

Wilson, B., Hammond, P.S., Thompson, P.M., 1999. Estimating size and assessing trends in a coastal bottlenose dolphin population. Ecol. Appl. 9, 288–300.

Witt, M.J., Baert, B., Broderick, A.C., Formia, A., Fretey, J., Gibudi, A., Mounguengui, G.A.M., Moussounda, C., Ngouessono, S., Parnell, R.J., Roumet, D., Sounguet, G.-P., Verhage, B., Zogo, A., Godley, B.J., 2009. Aerial surveying of the world’s largest leatherback turtle rookery: a more effective methodology for large -scale monitoring. Biol. Conserv. 142, 1719–1727.

Please cite this article in press as: Lauriano, G., et al., Abundance and distribution of *Tursiops truncatus* in the Western Mediterranean Sea: An assessment towards the Marine Strategy Framework Directive requirements, Marine Environmental Research (2014), http://dx.doi.org/10.1016/j.marenvres.2014.04.001