Baseline data on abundance, site fidelity and association patterns of common bottlenose dolphins (*Tursiops truncatus*) off the northeastern Tunisian coast (Mediterranean Sea)

R. Benmessaoud[1,2], M. Chérif[1,2] and N. Bejaoui[1]

Contact e-mail: benmessaoud_rimel@yahoo.fr

ABSTRACT

The common bottlenose dolphin has been studied intensively in numerous locations around the world but very little is known about this species along the South Mediterranean Basin. In this study, the temporal distribution of dolphins, group dynamics, site fidelity and association patterns of common bottlenose dolphins along the northeastern coastal waters of Tunisia was assessed through mark-recapture photo-identification techniques. Prior to this study, no research has focused on bottlenose dolphins within these waters, despite the potential for human impacts on this species. A total of 718h of boat-based observations, spanning 284 days, were spent at sea between August 2008 and July 2010. During this period, 253h were spent in direct observation of 317 groups of common bottlenose dolphins. Bottlenose dolphins were observed in all seasons, although seasonality was evident, with more encounters during the summer. Photo-identification studies show that 43 individuals used the northeastern coast of Tunisia on a regular basis, while others were present less often. Based on a social structure analysis it was possible to discriminate different communities related with the spatial distribution of the sightings (Zembra island, Hammamet, Kelibia and Galite island).

KEYWORDS: BOTTLENOSE DOLPHIN, SURVEY-VESSEL; ABUNDANCE ESTIMATE; PHOTO-ID; SCHOOL SIZE; SITE FIDELITY; MEDITERRANNEAN SEA; NORTHERN HEMISPHERE; STATISTICS

INTRODUCTION

Tursiops truncatus (Montagu 1821), hereafter referred to as the bottlenose dolphin, has been studied intensively in numerous locations around the world and today is one of the most comprehensively studied cetaceans, primarily due to its coastal proximity, interaction with human activities and adaptability in captivity (Reeves *et al.*, 2002). Ranging from tropical to temperate waters, common bottlenose dolphins show extreme diversity in abundance, distribution, and habitat use (Reynolds *et al.*, 2000). Some bottlenose dolphin communities (e.g. in the Azores (Portugal); Silva *et al.,* 2005) clearly fit a resident pattern, while others (e.g. in the northwestern Sardinian coastal waters (Italy); Díaz López *et al.,* 2013) fit a wide-ranging pattern. Mediterranean bottlenose dolphins occur regularly in a number of coastal areas but empirical data on seasonal abundance, site fidelity and residence patterns of these communities are lacking (Bearzi *et al.*, 2008).

Bottlenose dolphins are affected by man's use of coastal waters, particularly by fisheries activities, aquaculture and habitat modification (Fertl and Leatherwood, 1997; Díaz López *et al.,* 2005; Díaz López, 2006a; Díaz López and Shiray, 2007; Bearzi *et al.,* 2008; Díaz López, 2012). In the Mediterranean, numerous studies have documented bottlenose dolphins interacting with small-scale fisheries: Greece (Casale *et al.*, 1999); Spain (Gazo *et al.*, 2001; Brotons & Grau, 2005; Broton *et al.*, 2008; Gonzalvo *et al.*, 2008); Morocco (Zahri *et al*., 2004); Tunisia (Ben Naceur, 2000); Cyprus (Reeves *et al.*, 2001); Italy (Cannas *et al.*, 1994; Quero *et al.*, 2000; Tringali *et al.*, 2004; Lauriano *et al.*, 2004; Díaz López, 2006b; Díaz López, 2012); Corsica (Rocklin *et al.*, 2009).

The Mediterranean bottlenose dolphin 'subpopulation' is 'Vulnerable' according to the International Union for Conservation of Nature (IUCN) Red List criteria[3]. Thus, it is widely believed that numbers of Mediterranean common bottlenose dolphins have declined in recent decades as a consequence of human activities and habitat degradation (Bearzi *et al.,* 2009) and there is a demand for the development and implementation of conservation management and monitoring programmes (Buscaino *et al.,* 2009; Fortuna *et al.,* 2010; Gaspari *et al.,* 2013; Gonzalvo *et al.,* 2013; Rako *et al.,* 2013).

Although the Tunisian State has develop a national strategy and an Action Plan on Biological Diversity (1998) and is a signatory to most of the international and regional conventions on the protection of the marine environment and its biodiversity: CITES (1974); UNESCO Word Heritage (1974); RAMSAR (1979); the Convention to Combat Desertification (1979); the Bonn Convention (1986); the Convention on Biological Diversity (1993); the Berne Convention (1995); Barcelona Convention (1977/1995); and ACCOBAMS (1996) there have been few studies on the species. Studies that have been undertaken have been mainly focused on strandings (Ben Mustapha, 1986; Bradai, 1991; Kartas and Bradai, 1971, 1991; Karaa, 2005) and on interactions with fisheries (Ben Naceur and Mhenni, 1995; Ben Naceur, 2000; M'kacher, 2004; Benmessaoud, 2008). The lack of information about the presence and distribution of this species makes our ability to assess the impact of human activities on Mediterranean common bottlenose dolphins difficult.

[3]*http://www.iucnredlist.org/details/16369383/0.*

[1]*Institut National Agronomique de Tunisie – 43, Avenue Charles Nicolle – 1082 Tunis – Mahrajène – Tunisie.*
[2]*Institut National des Sciences et Technologie de la Mer (INSTM) annexe la Goulette-Tunis – 2060 – Tunisie.*

Data presented here represent the first dedicated effort to assess site fidelity, group dynamics and social structure of bottlenose dolphins along the northeastern coastal waters of Tunisia assessed through mark-recapture photographic-identification techniques. Prior to this study, no research has focused on bottlenose dolphins within these waters, despite the potential for human impacts on this species.

MATERIALS AND METHODS

Study area

The study area was located along the northeastern coast of Tunisia (Fig. 1). The area extended 12 n. miles offshore covering an approximate sea surface area of 510km². This coastal strip is the boundary between the western and eastern Mediterranean basins. The study took place at the intersection point between the Sicilian-Tunisian channel to the north and the south of the Gulf of Hammamet. This zone is characterised by a small shelf and a very rugged and steep slope (Azouz, 1973). The hydrological phenomena are complex and seasonal where two thermal regimes can be considered (Winter–Spring and Summer–Autumn periods) (Gaamour *et al.,* 2004).

Data collection

Boat-based surveys were conducted *ad libitum* between August 2008 and July 2010 on board a fishing vessel, based at the port of Kelibia (36°50'N, 11°04'E). Although the geographic distribution of effort could vary according to weather conditions, an attempt was made to provide an even coverage of the area (up to 250m depth) with at least three surveys per month.

Surveys were considered satisfactory when the visibility was not reduced by rain or fog, and sea conditions were 3 or below on the Douglas sea state scale (Díaz López, 2006a). Surveys were conducted during daylight at a speed lower than 7 knots with at least two experienced observers scanning the sea surface in search of dolphins from two positions with an eye height of 2m and 5m, respectively. To maintain consistent observation effort two teams of two observers each, organised in consecutive two hours shifts, were scanning the sea surface by naked eye.

In order to analyse the seasonality of bottlenose dolphins in the study area, four seasons were defined: winter (January to march); spring (April to June); summer (July to September); and autumn (October to December).

Upon sighting a group of bottlenose dolphins, searching effort ceased, and the vessel slowly manoeuvred to approach the group in order to minimise disturbance. Position (within approximately 10m of the animals), time, depth, composition and the group size were recorded. A 'dolphin group' was defined as one or more bottlenose dolphins observed in the visual area, usually involved in the same activity, following Díaz López (2006a); and an interaction with a dolphin group was termed an 'encounter'. Searching effort stopped at sighting, and restarted when the encounter was finished. The encounter continued until the group was lost, or weather became adverse.

Group dynamics

Group size was estimated based on the initial count of individuals observed to surface at one time (Merriman *et al.,* 2009). The group size and age categories were assessed visually *in situ*, and the data were later verified with photographs taken during each sighting. Group composition was determined by counting the minimum number of adults, calves and newborns present. Age class definitions followed those adapted by Mann *et al.* (2000) and Díaz López (2006b).

The Kruskal-Wallis test was performed on data to test the equality of medians of several group size samples. If the test shows significant inequality of the medians, a Tukey's *post-hoc* contrast was performed (Zar, 1998).

Photo-identification

During each encounter effort was made to photograph all members of the group, using a digital SLR camera (*Canon*

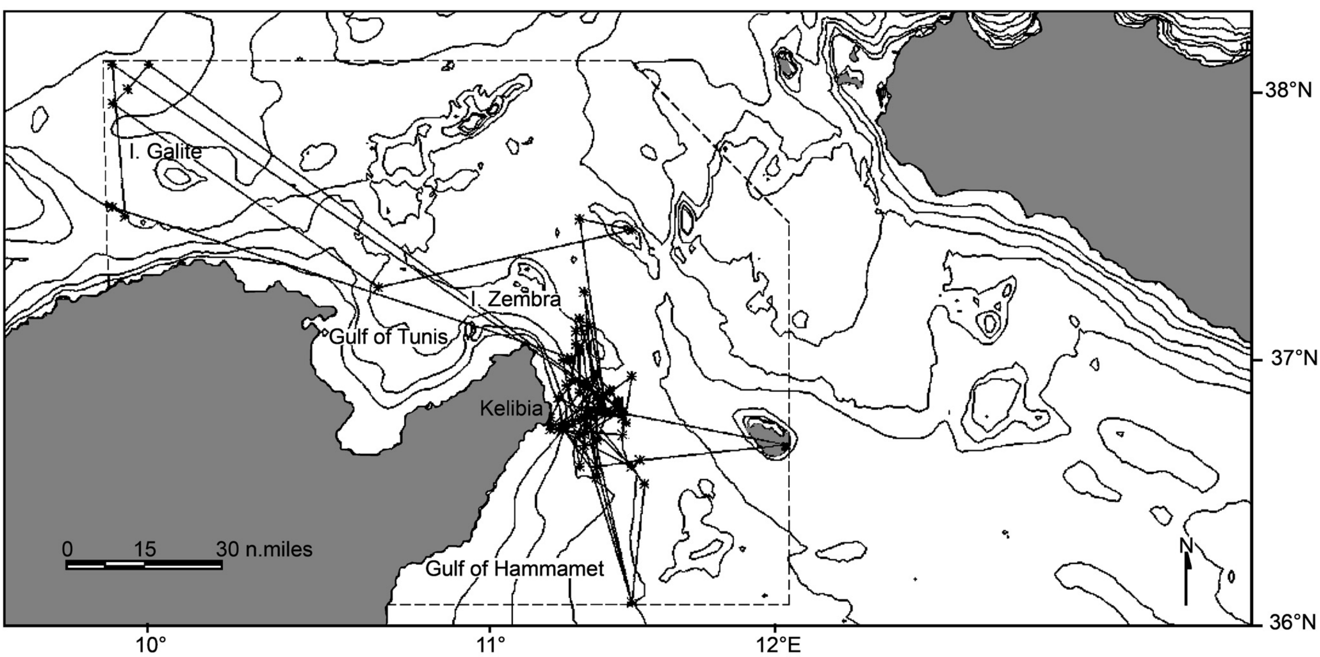

Fig. 1. Study area of the northeast Tunisian survey.

EOS450) equipped with 75–300mm (f: 4–5.6D) zoom lens, in order to determine individual identification based on natural marks on the dorsal fin and surrounding area (Würsig and Jefferson, 1990). To have a representative sampling and to minimise the problem of capture probabilities heterogeneity, attempts were made to photograph the dorsal fins of the majority of dolphins present in a group. At least four pictures were taken for each individual estimated to be in the group (Würsig and Jefferson, 1990).

Only good quality photographs (in focus, with the dorsal fin perpendicular to the plane of the photograph and with the dorsal fin large enough to identify small notches) were used for subsequent analyses (Díaz López and Shirai, 2008). Bad quality photographs or not marked individuals were excluded from the analysis to minimise bias.

Best photographs taken of every dolphin in each encounter were selected and matched with an annual catalogue of identified individuals. If a match was not found, the individual was given a unique identification code (number and letter) and added to the catalogue. Identifications and details relating to group membership, such as sighting location, time, and environmental and anthropogenic conditions were recorded on a database from which individual sighting histories could be reconstructed (Díaz López, 2012).

Abundance

The two year study period was divided by seasons, resulting in eight sampling periods. Population size was estimated based on all good quality photographs of reliably marked dolphins applying the POPAN model of SOCPROG 2.4 (Whitehead, 2008). 'Closed' (Schnabel), 'mortality', 'mortality + trend', 're-immigration' and 're-emmigration' models were run (Gowans *et al.,* 2000; Whitehead, 1990). The Akaike Information Criterion (AIC; Akaike, 1974) was used to determine the model that best fitted the population for each estimate. Model selection was based on the lowest AIC.

Site fidelity

To investigate the presence of identified individuals in the study area over time, two temporal sighting rates were calculated; yearly and seasonal. A seasonal occurrence rate was defined as the number of seasons a recognisable dolphin was identified as a proportion of the eight seasons in which at least one bottlenose dolphin was identified. A yearly occurrence rate was defined as the number of calendar years a dolphin was identified as a proportion of the two surveyed years.

Following the methods of Parra *et al.* (2006) and Díaz López (2012) individual dolphins were divided subsequently into three arbitrary categories based on their temporal occurrence rates:

(1) 'Resident' category: those bottlenose dolphins seen on the northeastern coast of Tunisia the most often, with both occurrence rates higher (or equal) than 0.5;

(2) 'Frequent' category: those bottlenose dolphins with seasonal occurrence rates lower than 0.5 and higher (or equal) than 0.25; and

(3) 'Sporadic' category: those bottlenose dolphins seen on the study area seldom, with occurrence rates lower than 0.25.

Social patterns

Animals photographed in the same group were considered associated. Of those data, only individuals sighted more than three times were considered for the analyses to reduce inaccuracies and biases associated with small sample sizes, and to compare the results with existing studies (Slooten *et al.,* 1993; Quintana-Rizzo and Wells, 2001; Rogers *et al,.* 2004; Gero *et al.,* 2005; Díaz López and Shirai, 2008). Unidentified animals and calves were excluded from the analyses (Díaz López and Shirai, 2008). Calves were excluded because of their unique dependent relationship with their mothers.

The half-weight index (HWI) was used as a measure of association as it accounts best for observer biases inherent in photo-identification techniques (Caims and Schwager, 1987; Bräger *et al*., 1994; Díaz López and Shirai, 2008). This is the most appropriate index as it introduces a bias to correct for missed identifications of one member of a dyad (Caims and Schwager, 1987).

$$\mathrm{HWI} = 2N / (Na + Nb)$$

Where N is the number of encounter that included both dolphins a and b, Na is the number of sightings that included dolphin a but not dolphin b, and Nb is the number of sightings that included dolphin b but not dolphin a. This index results in values ranging from zero to one, with zero representing two animals never seen together, and one representing two animals never seen apart. The resulting indices were grouped into five association categories: low (<0.20), moderate–low (0.21–0.40), moderate (0.41–0.60), moderate–high (0.61–0.80), and high >0.80 (Wells *et al.,* 1987; Quintana-Rizzo and Wells, 2001).

A hierarchical cluster analysis of associations data was created, which displays the results as a dendrogram. The individuals are arranged on one axis and their degree of association on the other, in order to examine relationships between all dolphins photo-indentified. The cluster was made using complete average linkage (cophenetic correlation coefficient = 0.90).

A permutation test, as in Bejder *et al.* (1998), was used (with modifications as in Whitehead *et al.,* 2005), to test for non-random associations for all data against the null hypotheses that dolphins associate randomly with one another. If some individuals preferentially associate with other individuals (indicating non-random associations), then the Standard Deviation (SD) of the real association indices will be significantly higher than the SD calculated in the random data (Whitehead, 1999; Christal and Whitehead, 2001). Associations were permuted within daily sampling intervals to remove possible demographic effects (i.e. mortality, recruitment or migration to or from the study area; Whitehead, 1999). The calculations of the HWI, clusters analysis and permutation tests were carried out using the compiled version of SOCPROG 2.4 (Whitehead, 2008).

Table 1

Field effort for period study (2008–10).

Seasons	Winter	Spring	Summer	Autumn	Total
Days at sea	66	76	88	54	284
Days with sightings	23	13	28	17	81
Sightings per seasons	35	22	72	35	164
No. of individuals photo-id'd	39	31	42	19	

RESULTS

Survey effort and sighting rate

In all, 284 days and 718h were spent at sea in satisfactory conditions (Table 1). On average, about 6.5 hours (1.38h per day) were spent conducting observations. During 81 days, 253h were spent in direct observation of 317 groups of common bottlenose dolphins (mean sighting duration = 12.57 ± 0.30min, SD = 5.36min).

Group dynamics

Group dynamics were examined for 317 independent groups. Group size ranged from 1 to 19 individuals (mean = 5.17 ± 0.16; SD = 2.89; median = 5) (Fig. 2). Group composition revealed 69.77% (n = 221.17) of the individuals encountered in groups were deemed adults, 30.23% (n = 95.83) immature dolphins (calves and/or newborns). Moreover, 12.8% (n = 40.57) were solitary animals, 57.95% (n = 183.70) were groups with immature dolphins (calves and/or newborns) and 30.05% (n = 96.68) groups with only adults. The results revealed no differences in the group size during the two years of research (Kruskal-Wallis test, KW-H (1,317) = 1.77; $p > 0.05$). In contrast, group size showed seasonal fluctuations (Kruskal-Wallis test, KW-H (12,317) = 19.38; $p < 0.05$), with bigger groups during the summer season. Group sizes between groups with immature dolphins and groups formed only by adults were significantly different (5.90 ± 2.88 groups containing immatures vs. 3.46 ± 2.03 groups containing adults only; Kruskal-Wallis test, $p < 0.05$).

Photo-identification and site fidelity

Only 43 individuals were mark-recaptured using photo-identification techniques from 317 independent dolphin groups encountered during the study period. Eleven of those dolphins (25.58%) were positively identified as females based on strong association and synchronised surfacing with a calf or observation of genital and mammary slits.

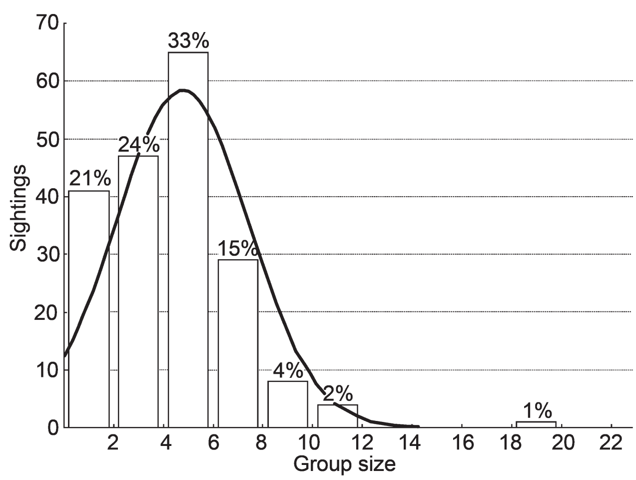

Fig. 2. Histogram of the group size frequency of distribution.

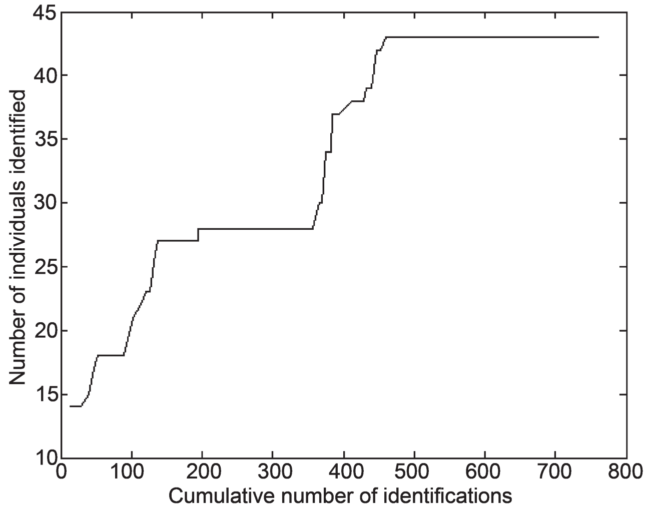

Fig. 3. Discovery curve showing number of mark-recaptured bottlenose dolphins (n = 43) identified between 2008 and 2010.

The cumulative number of identified individuals generally became less steep with time. A flattening of the curve could be interpreted as the catalogue progressively reaching its maximum number of individuals and that probably all individuals present in the study area have been identified (Fig. 3). The average number of photographic recaptures per individual was 31.42 (SD = 11.36).

It is of note that 17 common bottlenose dolphins, accounting for 39.53% of all identified individuals, were identified more than 20 times throughout the study period. However, nine common bottlenose dolphins (20.93%) were identified only once throughout the study period. This shows that some individuals used the northeastern coast of Tunisia on a regular basis, whilst others were present less often (Table 2). Relative to the total number of seasons surveyed, most common bottlenose dolphins identified were sighted occasionally (0.65 ± 0.3 resightings per season) with a peak presence in summer and a minimum in spring (χ^2, $p < 0.05$). Dolphins photo-identified in study area were divided subsequently into three arbitrary categories based on their temporal occurrence rates:

(1) 'Resident' category: this category contained 22 identified adult bottlenose dolphins, accounting for 51.1% for all 43 identified individuals;

(2) 'Frequent' category: this category contained 7 identified bottlenose dolphins, accounting for 16.3% for all 43 identified individuals; and

(3) 'Sporadic' category: this category contained 14 bottlenose dolphins, accounting for 32.6% for all 43 identified individuals.

Abundance

Table 3 show the abundance estimate for bottlenose dolphins seen in study area. Based on the lowest AIC value (AIC = 214.01), the 'mortality model' seems to be the most adequate model which describes our population. This model describes those associations in which this model assumes a population of constant size, where mortality is balanced by

Table 2

Summary of occurrence pattern of photo-IDed bottlenose dolphins during the research period. The grey coloured cell indicates presence of animals.

Indiv./ months	Winter 2008–09			Spring 2008–09			Summer 2008–09			Autumn 2008–09			Total sightings 2008–09	Winter 2009–10			Spring 2009–10			Summer 2009–10			Autumn 2009–10			Total sightings 2009–10
	J	F	M	A	M	J	J	A	S	O	N	D		J	F	M	A	M	J	J	A	S	O	N	D	
RK1													37													28
RK2													14													6
RK3													41													27
RK4													15													9
RK5													36													26
RK6													28													17
RK7													22													22
RK8													31													17
RK9													24													19
RK10													21													9
RK11													38													31
RK12													8													21
RK13													35													24
RK14													15													17
RK15													12													17
RK16													14													11
RK17													21													21
RK18													11													7
RK19													1													14
RK20													0													21
RK21													0													17
RK22													0													20
RH1													6													12
RH2													3													6
RH3													4													10
RH4													3													12
RH5													3													12
RH6													4													13
RH7													0													9
RZ1													2													8
RZ2													1													6
RZ3													4													6
RZ4													1													7
RZ5													0													9
RZ6													0													0
RZ7													0													0
RG1													1													3
RG2													0													3
RG3													1													3
RG4													0													0
RG5													0													0
RG6													0													0
RG7													0													0

birth. The estimate of population size is 42 individuals (95% CI = 42.0–43.1) with an annual estimated mortality rate of 0.0053.

Association pattern

The association index for 34 dolphins seen three or more times was examined. The half weight index (HWI) has been selected. Calculated HWIs ranged from 0 to 1. Mean HWIs were found to range from 0.00 to 0.92. All individuals were associated on average 0.28 ± 0.009 times.

The majority of dolphins have low-level associations. For the 820 identifications, the most frequently occurring levels were low level (45%, n = 316). However, some identified individuals seemed to form relatively stable groups over the study period with a few dyads that have high and moderate high level associations. For the 820 identifications, only 3% (n = 22) have a moderate high-level association and 6% (n = 43) have high-level associations (Fig. 4).

The agglomeration plot of hierarchical clustering showed a linear increase in the number of clusters with a slight increase in the rate of agglomeration (Fig. 4). Based on the structure of the dendrogram three different communities related to the spatial distribution of the sightings can be discriminated. The first group of dolphins is present in the north of the study area (Zembra Island). The second in the north-west of the study area (Galite Island) and the third in Kelibia waters (central portion of study area).

Significantly higher associations were identified as the standard deviations of observed association indexes were significant larger than for the randomly permuted data ($p < 0.05$). Association datasets were randomly permuted 10,000 times with 1,000 trials per permutation. The results of the 'permute all groups' test showed that the coefficient of variation of real association was 0.83 which is higher than the coefficient of variation of random association

Table 3

Abundance estimates of marked bottlenose dolphins.

Notations: *N* = estimated population size; CI = 95% confidence interval; N/A = not available; *m* = estimated mortality rate; *t* = estimated trend rate; *e* = estimated emigration rate; *re* = estimated re-immigration rate; *Nc* = number of animals captured; s.p. = number of sampling periods; AIC = Akaike Information Criterion; LogL: log likehood.

	Estimates						Model selection			
Models	*N*	CI	*m* (CI)	*t* (CI)	*e* (CI)	*re* (CI)	*Nc*	s.p.	LogL	AIC
Mortality	42.00	42.0–43.1	0.00538 (0,003–0,0244)	N/A	N/A	N/A	43	8	–105.00	214.01
Re-immigration	41.00	N/A	N/A	N/A	0.005	0.004	43	8	–104.54	215.08
Mortality trend	41.85	41.9–43.4	0.00535 (0.0000–0.0349)	0.00174 (–0.0089–0.1510)	N/A	N/A	43	8	–104.70	215.41
Closed (Schnabel)	42.49	42.0–44.0	N/A	N/A	N/A	N/A	43	8	–106.86	215.73
Re-immigration + mortality	41.32	N/A	0.00548	N/A	1.05e–009	0.020	43	8	–104.54	217.08

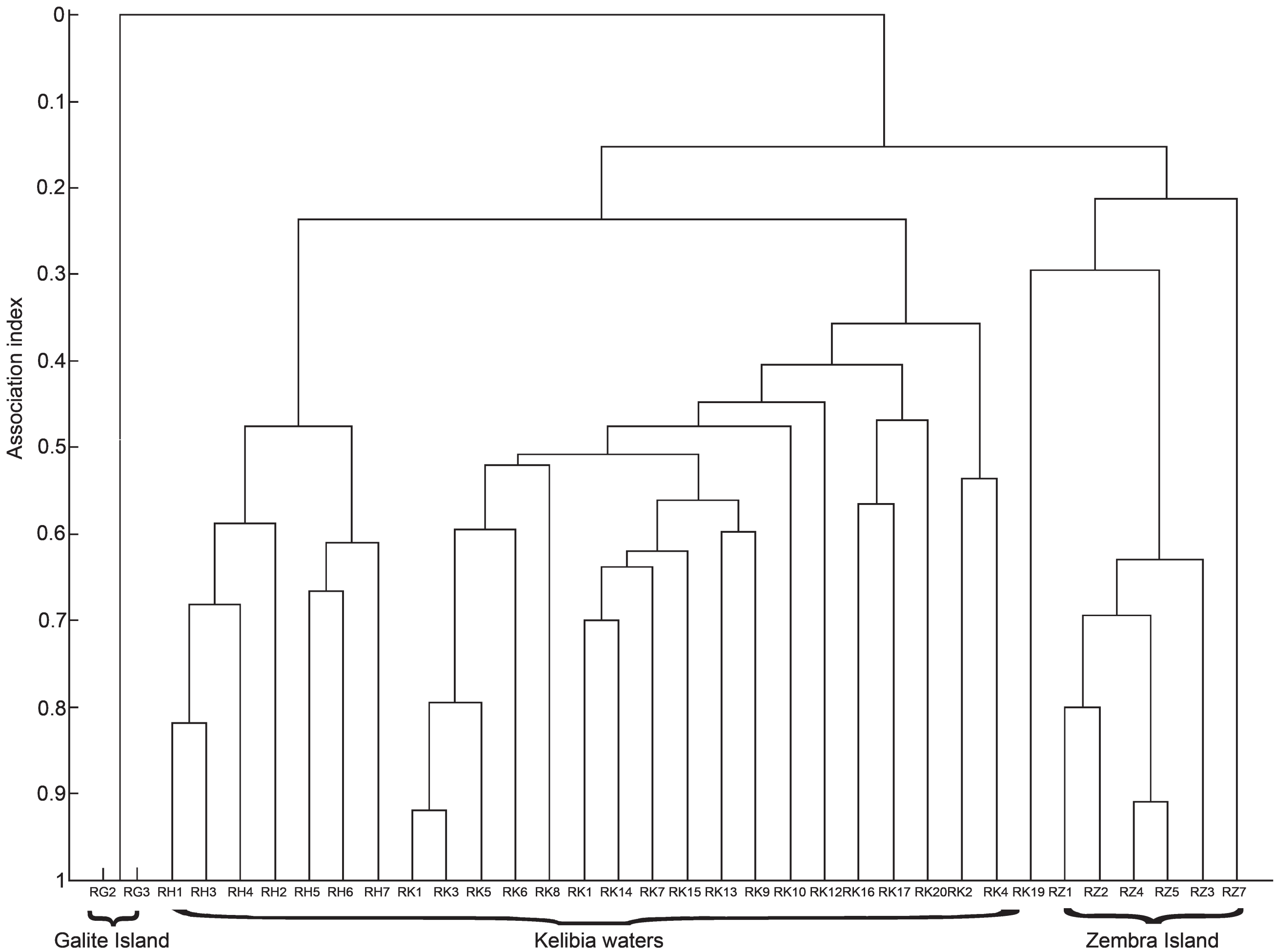

Fig. 4. Dendrogram showing the average-linkage cluster analysis of associations between well-marked individual bottlenose dolphins seen ≥ 3 times in the Kelibia waters, from 2008–10.

(CV = 0.57). Therefore dolphins seen in the same study area in the same sampling period are not likely to group together at random, but show preferred/avoided companionships.

Overall associations between dolphins can be seen in a sociogram (Fig. 5) where points representing the individuals are arranged around the circle and the thickness of lines between the points indicates the strength of their relationship. They are clearly not random, based on the relative absence and asymmetry of linkages through the axes of the sociogram.

DISCUSSION

This study reveals important information on the occurrence of bottlenose dolphins in northeastern Tunisian waters. Bottlenose dolphins are found year round in this area, which is likely to represent an important part of their habitat rather than simply a corridor between other key areas.

The fact that bottlenose dolphins were the most frequently encountered cetacean species during the surveys was consistent with previous studies conducted in Tunisian waters (Benmessaoud, 2009; Benmessaoud *et al.,* 2013; Ben Naceur, 2004; Karaa *et al.,* 2011; Zanardelli, 2002).

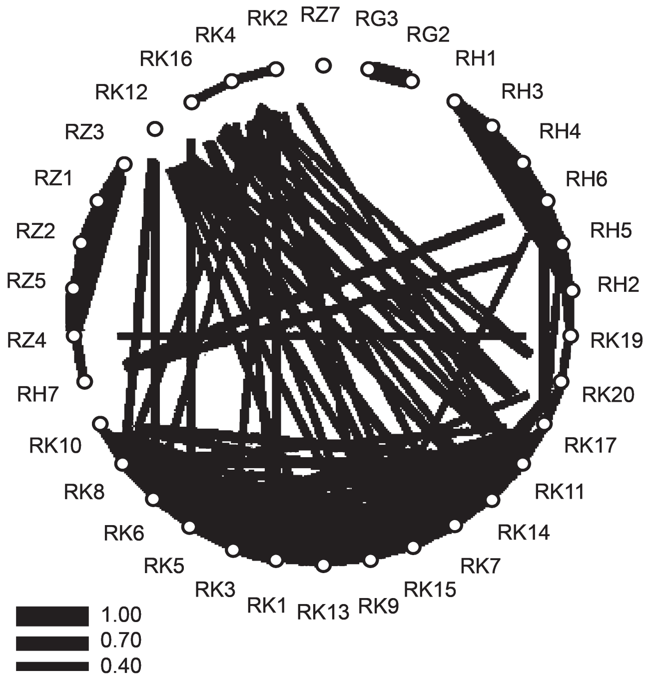

Fig. 5. Sociogram showing associations between all individuals.

Several individuals (n = 29) were resighted on repeated occasions, both within two years, suggesting strong site-fidelity for a significant part of the population. Similar observations were reported in other Mediterranean populations by Pearson (2002), Fortuna (2006), Díaz López and Shirai (2008) and Díaz López (2012). There appear to be both residents and non-residents (both sporadic and occasional visitors) present in community. However, Bearzi *et al.* (2010) documented that bottlenose dolphins in Greek coastal waters that appear to be resident within a given area can temporarily leave 'home' and range over large portions of sea. Likewise, it is clear that the survey area did not encompass the whole range of this regional population. The initial increase in the discovery rate of new individuals during 2008 (Fig. 2) is an attribute of the beginning of the study. However, the alternating increases and plateaus in the discovery curve later in the study could suggest a regular influx of new individuals to the study area and/or unrecognisable animals due to acquired new marks as our study progressed. Nevertheless, other communities of bottlenose dolphins are known to occur in adjacent habitats, and a high number of 'occasional' and 'sporadic' individuals are intermittently observed within the community's core range area. Although bottlenose dolphins were never absent from the study area, site fidelity and residence patterns of identified individuals suggest that there are different degrees of residency among the dolphins using the study area.

Using social structure analysis it was possible to discriminate different communities based on the spatial distribution of the sightings (Fig. 4). Bottlenose dolphin social structure varies drastically, from fission-fusion where individuals make choices to join or leave a group (Díaz López and Shirai, 2008) to being mainly driven by constant companionship (Lusseau *et al.,* 2003). The fission-fusion structure has also been observed along the northeastern coast of Tunisia. Bottlenose dolphins identified in the study area have shown an elasticity of social interaction, where some individuals have a particular affinity for one or more companions, whereas others mutually avoid each other.

Similar group sizes observed here were reported for other areas along the Mediterranean Basin, where groups rarely contained more than ten individuals (Bearzi *et al.,* 1997; Bearzi *et al.,* 2008; Díaz López, 2006a; Díaz López and Shirai, 2007, 2008; Lauriano *et al.,* 2003). Groups with calves were larger than non-calf groups, which according to Norris and Dohl (1980) might be due to females favouring schools larger than those optimal for foraging to provide alloparental care and protection for their young.

The abundance estimate of 42 bottlenose dolphins occurring in the northeastern Tunisian waters represents an approximation of dolphins occurring within these coasts. The results reveal that this population is not closed, and it is affected by changes of density due to the influence of input (immigration and emigration) and/or output (births and deaths). The estimate of the total abundance of bottlenose dolphins in the study area varied among years (Benmessaoud pers. comm.). Based on the lowest AIC value, the 'mortality model' was also selected as the most parsimonious model of bottlenose dolphin population off the northwestern Sardinian coast (Díaz López *et al.,* 2013). The population size there was estimated as 54.8 (95% CI = 44.8–69.5). According to Bearzi *et al.* (2008), the population estimate of bottlenose dolphin inhabiting the semi-closed eutrophic Amvrakikos Gulf, Greece, was 148 individuals (95% CI = 132–180). Several models can be used to describe the size of the bottlenose dolphin population in the same area. Various factors can influence the residence of the species in the same area such as prey availability.

The presence of different communities, with different degrees of site-fidelity, along the northeastern Tunisian coast indicates that the impacts associated with coastal fisheries on bottlenose dolphins could be different between individuals of the same regional population. Consequently, degradation and loss of coastal habitats in a study area can lead to an increase in distance among habitable patches and/or reduction in number of remnant habitats. Likewise bottlenose dolphins present in the study area inhabit an environment greatly affected by human activities including intensive fishing, maritime traffic and tourism. These pressures, particularly fisheries bycatch, may have a strong, adverse impact on population viability and need to be carefully assessed and managed at scales that are consistent with the population structure of bottlenose dolphins (Fortuna *et al.,* 2010; Gaspari *et al.,* 2013).

This study sheds light on how the members of this dolphin community are using the waters of the study area year-round. In order to have an effective conservation of bottlenose dolphin populations, a better understanding of the complexity of ecological, behavioural and social patterns is required in order to facilitate development of management plans. Population management actions should also consider how the impact of human activities differs across geographically distinct areas (Gaspari *et al.,* 2013).

The establishment of protected areas is one important aspect of a coastal zone management plan. These Marine Protected Areas are intended to protect rare, endangered or vulnerable habitats and species and to afford individuals widely differing levels of protection (Wilson *et al.,* 1997). In this context, Tunisia gives priority to environmental protection and sustainable management of natural resources. This includes measures to strengthen the regulation of fisheries, the protection of the marine environment, the prohibition of monk seal, cetacean and sea turtle capture in its territorial waters as well as their trade and captivity. With respect to Marine Protected Areas, we encourage the consideration of a new marine protected area in the Sicilian-Tunisian channel where cetacean diversity is important. We also encourage research on population genetics to assess if habitat diversity plays a significant role in shaping the genetic structure of bottlenose dolphins.

ACKNOWLEDGEMENTS

The authors especially thank Mr. Bruno Díaz López (Bottlenose Dolphin Research Institute, BDRI) for providing encouragement, guidance, advice, extensive help in the field and review. We also thank Ms. Marie Christine Grillo Compulsione and all at the ACCOBAMS Secretariat for strongly supporting this study providing encouragement and funding. The authors are grateful to the ecovolunteers for acting as observers during the survey. We are grateful to two anonymous reviewers for their constructive criticisms of earlier versions of the manuscript.

REFERENCES

Akaike, H. 1974. Maximum likelihood identification of Gaussian autoregressive moving average models. *Biometrika* 60: 225–65.

Azouz, A. 1973. Les fonds chalutables de la région nord de la Tunisie. Cadre physique et biocénoses benthiques. *Bull. Inst. Sc. Tech.* 2(4): 473–563. [In French].

Bearzi, G., Agazzi, S., Bonizzoni, S., Costa, M. and Azzellino, A. 2008. Dolphins in a bottle: abundance, residency patterns and conservation of bottlenose dolphins *Tursiops truncatus* in the semi-closed eutrophic Amvarkikos Gulf, Greece. *Aquat. Conserv.* 18: 130–46.

Bearzi, G., Bonizzoni, S. and Gonzalvo, J. 2010. Mid-distance movements of common bottlenose dolphins in the coastal waters of Greece. *J. Ethol.* 29: 369–74.

Bearzi, G., Fortuna, C.M. and Reeves, R.R. 2009. Ecology and conservation of common bottlenose dolphins *Tursiopstruncatus* in the Mediterranean Sea. *Mammal Rev.* 39: 92–123.

Bearzi, G., Notarbartolo-di-Sciara, G. and Politi, E. 1997. Social ecology of bottlenose dolphins in the Kvarneric (northern Adriatic Sea). *Mar. Mammal Sci.* 13(4): 650–68.

Bejder, L., Fletcher, D. and Brâger, D. 1998. A method for testing association patterns of social animals. *Anim. Behav.* 56: 719–25.

Ben Mustapha, S. 1986. Échouage d'un Rorqual commun: *Balaenoptera physalus* (Linné 1750) à Carthage dans le Golf de Tunis. *Bull. Inst. Sc. Tech. Mer de Salammbo* 13: 19–24. [In French].

Benmessaoud, R. 2008. Statut des Delphinidés et étude de l'interaction entre dauphins filets de pêche dans la région de Kélibia. Mémoire de mastère. *INAT* 163pp. [In French].

Benmessaoud, R. 2009. Les delphinidés dans la région du cap bon (Nord-Est Tunisie): Distribution et comportement dans les zones d'exploitation halieutique. *Première Conférence biennale sur la Conservation des cétacés dans les Pays du sud de la Méditerranée. ACCOBAAMS-Tunisie*. [In French].

Benmessaoud, R., Chérif, M. and Bejaoui, N. 2013. Interactions entre le delphinidé *Tursiops truncatus* et les filets de pêche des sardiniers le long des côtes Nord Est de la Tunisie (la région de Kélibia). *Sci. Halieut. Aquat.* 7: 233–43. [In French].

Ben Naceur, L. and Mhenni, S. 1995. Interactions mammifères marins et engins de pêche: la dispersion des dauphins par les ondes-ultrasonores. *Bull. Inst. Sc. Tech. Mer de Salammbo*: 7pp. [In French].

Ben Naceur, L. 2000. New data about dolphins in Tunisia: Interaction between dolphins and fishery craft. *Eur. Res. Cetaceans* 14:171.

Ben Naceur, L., Gannier, A., Bradaï, M.N., Brouot, V., Bourreau, S., Laran, S., Khalfallah, N., Bdioui, M. and Mrabet, R. 2004. Recensement du grand dauphin *Tursiops truncatus* dans les eaux tunisiennes. *Bull. Inst. Sc. Tech. Mer de Salammbo* 31: 75–81. [In French].

Bradai, M.N. 1991. Nouvelles mentions des delphinidés. *Revus de l'INAT* 6(2): 169–72. [In French].

Bräger, S., Würsig, B., Acevedo, A. and Henningsen, T. 1994. Association patterns of bottlenose dolphins (*Tursiops truncatus*) in Galveston Bay, Texas. *J. Mammal.* 75(2): 431–37.

Brotons, J.M. and Grau, A. 2005. Bottlenose dolphin and artisanal fisheries interactions in the Balearic Islands: a final report. Proceedings of the 19th Annual Conference of the *ECS*; Abstract Book and CD. 64pp.

Brotons, J.M., Grau, A.M. and Rendell, L. 2008. Estimating the impact of interactions between bottlenose dolphins and artisanal fisheries around the Balearic Islands. *Mar. Mammal Sci.* 24(1): 112–27.

Buscaino, G., Buffa, G., Sarà, G., Bellante, A., Tonello Junior, A.J., HardtSliva, F.A., Cremer, M.J., Bonanno, A., Cuttitta, A. and Mazzola, S. 2009. Pinger affects efficiency and damages of bottom gill nets by bottlenose dolphins. *Fish. Sci.* 75: 537–44.

Caims, J. and Schwager, S.J. 1987. Comparison of association indices. *Anim. Behav.* 35: 1,454–69.

Cannas, A., Fadda, D., Lenti, G., Massidda, P. and Pinna, D. 1994. I danni provocati dai delfini alla piccola pesca in Sardegna (Italia), dati preliminari. *Biol. Mar. Medit.* 1(1): 291–92. [In Italian].

Casale, M., Milani, C. and Kallianiotis, A. 1999. Preliminary surveys on the interactions between local populations of Delphinus delphis and Tursiops truncatus and the coastal fishery in north-eastern Aegean Sea. *Eur. Res. Cet.* 13: 100.

Christal, J.L. and Whitehead, H. 2001. Social affiliations within sperm whale (*Physeter macrocephalus*) groups. *Ethology* 107: 323–40.

Díaz López, B. 2006a. Interactions between Mediterranean bottlenose dolphins (*Tursiops truncatus*) and gillnets off Sardinia, Italy. *ICES J. Mar. Sci.* 63: 5pp.

Díaz López, B. 2006b. Bottlenose dolphin (*Tursiops truncatus*) predation on a marine fin fish farm: some underwater observations. *Aquat. Mamm.* 32: 305–10.

Díaz López, B. 2012. Bottlenose dolphins and aquaculture: interaction and site fidelity on the northeastern coast of Sardinia (Italy). *Mar. Biol.* 159: 2,161–72.

Díaz López, B., Addis, A. and Fabiano, F. 2013. Ecology of common bottlenose dolphins along the northwestern Sardinian coastal waters (Italy). *Thalassas* 29(2): 35–44.

Díaz López, B. and Shirai, J.A.B. 2007. Bottlenose dolphin (*Tursiops truncatus*) presence and incidental capture in a marine fish farm on the north-eastern coast of Sardinia (Italy). *J. Mar. Biol. Assoc. U.K.* 87: 113–17.

Díaz López, B. and Shirai, J.A.B. 2008. Marine aquaculture and bottlenose dolphins' (Tursiops truncatus) social structure. *Behav. Ecol. Sociobiol.* 62: 887–94.

Díaz López, B., Marini, L. and Polo, F. 2005. The impact of a fish farm on a bottlenose dolphin population in the Mediterranean Sea. *Thalassas* 21: 53–8.

Dohl, T.P. and Norris, K.S. 1980. The structure and function of cetacean schools. pp.211–62. *In*: Herman, L.M. (eds). *Cetacean Behavior: Mechanisms and Functions*. Robert E. Krieger Publishing Company, Malabar, Florida.

Fertl, D. and Leatherwood, S. 1997. Cetacean interactions with trawls: a preliminary review. *J. Northwest Atl. Fish. Sci.* 22: 219–48.

Fortuna, C.M., Vallini, C., Filidei, E., Ruffino, M., Consalvo, I., Di Muccio, S., Gion, C., Scacco, U., Tarulli, E., Giovanardi, O. and Mazzola, A. 2010. By-catch of cetaceans and other species of conservation concern during pair trawl fishing operations in the Adriatic Sea (Italy). *Chem. Ecol.* 26: 65–76.

Fortuna, M.C. 2006. Ecology and conservation of bottlenose dolphins (*Tursiops truncatus*) in the Northeastern Adriatic Sea. PhD thesis. University of St. Andrews. 275pp

Gaamour, A., Khemiri, S., Mili, S. and Ben Abdallah, L. 2004. L'anchois (*Engraulis encrasicolus*) des côtes Nord de la Tunisie : Reproduction et exploitation. *Bull. Inst. Sc. Tech. Mer de Salammbo* 31: 8pp. [In French].

Gaspari, S., Drassko, H., Mackelworth, P., Fortuna, C., Frantzis, A., Genov, T., Vighi, M., Natali, C., Rako, N., Banchi, E., Chelazzi, G. and Ciofi, C. 2013. Population genetic structure of common bottlenose dolphins (*Tursiops truncatus*) in the Adriatic Sea and contiguous regions: implications for international conservation. *Aquatic Conserv: Mar. Freshw. Ecosyst.*[DOI: 10.1002/aqc.2415].

Gazo, M., Fernandez-Contreras, M.M., Brotons, J.M. and Aguilar, A. 2001. Interactions between bottlenose dolphins and artisanal fisheries in the Balearic Islands: may acoustic devices be a solution to the problem? *Eur. Res. Cet.* 15:156–60.

Gonzalvo, J., Valls, M., Cardona, L. and Aguilar, L. 2008. Factors determining the interaction between common bottlenose dolphins and bottom trawlers off the Balearic Archipelago (western Mediterranean Sea). *J. Exp. Mar. Biol. Ecol.* 367: 47–52.

Gowans, S., Whitehead, H., Arch, J.K. and Hooker, S.K. 2000. Population size and residency patterns of northern bottlenose whales (*Hyperoodon ampullatus*) using the Gully, Nova Scotia. *J. Cetacean Res. Manage.* 2(3): 201–10.

Karaa, S. 2005. Contribution à l'étude des échouages des tortues marines et des cétacés dans le Sud-Est de la Tunisie. Mémoire de Master, FSS. 95pp. [In French].

Karaa, S., Bradai, M.N., Jribi, I., Attia, E.l., Hili, H. and Bouain, A. 2011. Status of cetaceans in Tunisia through analysis of stranding data from 1937 to 2009. *Mammalia* 76(1): 21–9.

Kartas, F. and Bradai, M.N. 1971. Échouage d'un dauphin à la goulette. *Bull. Inst. Sc. Tech. Mer de Salammbo* 2(2): 269–70. [In French].

Kartas, F. and Bradai, M.N. 1991. Nouvelles mentions des delphinidés. *Revus de l'INAT* 6(2): 169–72. [In French].

Lauriano, G., Fortuna, C.M., Moltedo, G. and Notarbartolo di Sciara, G. 2004. Interactions between common bottlenose dolphins (*Tursiops truncatus*) and the artisanal fisher in Asinara Island National Park (Sardinia): assessment of catch damage and economic loss. *J. Cetacean Res. Manage.* 6(2): 165–73.

Lauriano, G., Mackelworth, P. and Fortuna, C.M. 2003. Densità e abbondanza relativa del tursiope (*Tursiops truncatus*) nel parco nazionale dell'Asinara, Sardegna. *Biol. Mar. Medit.* 10: 717–20. [In French].

Lusseau, D., Schneider, K., Boisseau, O.J., Haase, P., Slooten, E. and Dawson, S.M. 2003. The bottlenose dolphin community of Doubtful Sound features a large proportion of long-lasting associations: can geographic isolation explain this unique trait. *Behav. Ecol. Sociobiol.* 4: 396–405.

M'kacher, H. 2004. Étude de l'impact des attaques du dauphin Tursiops truncatus sur la senne tournante dans la région de Mahdia et essai de dispersion des dauphins à Salakta. Projet de fin d'étude. *INAT*: 72pp. [In French].

Mann, J.C., Connor, R.C., Tyack, P.L. and Whitehead, H. (eds) 2000. *Cetacean Societies*: *Field Studies of Dolphins and Whales*. The University of Chicago Press, Chicago.

Maze-Foleky, K.S. and Wûrsig, B. 2002. Patterns of social affiliation and group composition for bottlenose dolphins (*Tursiops truncatus*) in San Luis Pass, Texas. *Gulf of Mexico Science*: 122–34.

Merriman, M.G., Markowitz, T.M., Harlin-Cognato, A.D. and Stockin, A.K. 2009. Bottlenose dolphin (*Tursiops truncatus*) abundance, site fidelity, and group dynamics in the Marlborough Sounds, New Zealand. *Aquat. Mamm.* 35(4): 511–22.

Norris, K.S. and Dohl, T.P. 1980. The structure and function of cetacean schools. pp.211–61. In: Herman, L.M. (eds). *Cetacean Behaviour: Mechanisms and Functions*. John Wiley & Sons, New York. xiii+463pp.

Parra, G.J., Schick, R. and Corkeron, P.J. 2006. Spatial distribution and environmental correlates of Australian snubfin and Indo-Pacific humpback dolphins. *Ecography* 29: 1–11.

Pearson, M. 2002. The use of molecular and observational data to infer the structuring of bottlenose dolphin populations. Ph.D. thesis, University of Aberdeen, Aberdeen, Scotland. 174 pp.

Quintana-Rizzo, E. and Wells, R.S. 2001. Resighting and association patterns of bottlenose dolphins (*Tursiops truncatus*) in the Cedar Keys, Florida: insights into social organization. *Can. J. Zool.* 79: 447–56.

Quero, M.E., Chiofalo, G., Datta, S., Di Natale, A., Dremiere, P.Y. and Goodson, D. 2000. Interaction between dolphins and artisanal gillnet fishery: methods of fishery damage and sampling. *Eur. Res. Cet.* 14: 48–54.

Rako, N., Picciulin, M., Fortuna, C.M., Nimak-Wood, M., Mackelworth, P., Pleslić, G., Holcer, D., Wiemann, A., Sebastianutto, L. and Vilibić, I. 2013. Leisure boating noise as a trigger for the displacement of the bottlenose dolphins of the Cres-Lošinj archipelago (northern Adriatic Sea, Croatia). *Mar. Poll. Bull.* 68: 77–84.

Reeves, R.R., Read, A.J. and Notarbartolo di Sciara, G. 2001. Report of the Workshop on Interactions between Dolphins and Fisheries in the Mediterranean: Evaluation of Mitigation Alternatives, May 2001, Rome, Italy. Paper SC/53/SM3 presented to the IWC Scientific Committee, July 2001, London (unpublished). 44pp. [Paper available from the Office of this Journal].

Reeves, R.R. and Reijnders, P.J.H. 2002. Conservation and management. pp.388–432. *In*: Hoelzel, A.R. (eds). *Marine Mammal Biology, An Evolutionary Approach*. Blackwell Publishing, Malden, USA.

Reeves, R.R., Srewart, B.S., Clapham, P.J. and Powell, J.A. 2002. *National Audubon Society Guide to Marine Mammals of the World*. Alfred A. Knopf Inc., New York. 528pp.

Reynolds, J.E., Wells, R.S. and Eide, S.D. 2000. *The Bottlenose Dolphin: Biology and Conservation*. University Press of Florida, Gainseville, Florida, USA. 288pp.

Rocklin, D., Santoni, M.C., Culioli, J.M., Tomasini, J.A., Pelletier, D. and Mouillot, D. 2009. Changes in the catch composition of artisanal fisheries attributable to dolphin depredation in a Mediterranean marine reserve. *ICES J. Mar. Sci.* 66: 699–707.

Rogers, C.A., Brunnick, B.J., Herzing, D.L. and Baldwin, J.D. 2004. The social structure of bottlenose dolphins, (*Turisops truncatus*), in the Bahamas. *Mar. Mammal Sci.* 20(4): 688–708.

Shane, S.H. 1990. Comparison of bottlenose dolphin behavior in Texas and Florida, with a critique of methods for studying dolphin behavior. pp.541–58. *In*: Leatherwood, S. and Reeves, R.R. (eds). *The Bottlenose Dolphin*. Academic Press, San Diego, California. 653pp.

Silva, M.A., Magalhães, S., Prieto, R., Quérouil, S., Hammond, P. and Santos, R.S. *Population structure of bottlenose dolphins in the Azores determined by photo-identification*. 19th ECS conference, poster SD-14, Abstract book 120pp.

Slooten, E., Dawson, S.M. and Whitehead, H. 1993. Associations among photographically identified Hector's dolphins. *Can. J. Zool.* 71(11): 2,311–18.

Tringali, L.M., Caltavuturo, G. and Puzzolo, V. 2004. A case of opportunistic feeding: bottlenose dolphin interference with the European anchovy fishing in the Gulf of Catania (Ionian Sea). European *Cet. Soc.* 15: 105–07.

Warkentin, I.G. and Hernandez, D. 1996. The conservation implications of site fidelity: a case study involving nearctic-neotropical migrant songbirds wintering in a Costa Rican mangrove. *Biol. Conserv.* 77: 143–50.

Wells, R.S., Scott, M.D. and Irvine, A.B. 1987. The social structure of free-ranging bottlenose dolphins. pp.247–306. *In*: Genoways, H. (eds). *Current Mammalogy*. Plenum Press, New York. 519pp.

Whitehead, H. 1990. Mark-recapture estimates with emigration and re-immigration. *Biometrics* 46: 473–79.

Whitehead, H. 1999. Users's Manual 'SOCPROG' version 1.3. Dalhousie University, Halifax, Nova Scotia, Canada. [Available at: *http://is.dal.ca/~hwhitehe/social.htm*].

Whitehead, H. 2008. Programs for analyzing social structure (June 2009). Department of Biology, Dalhousie University, Halifax, Nova Scotia, B3H 4J1, Canada.

Whitehead, H., Bejder, L. and Ottensmayer, A. 2005. Testing association patterns: issues arising and extensions. *Anim. Behav.* 69: e1–e6.

Wilson, B., Thompson, P.M. and Hammond, P.S. 1997. Habitat use by bottlenose dolphins: seasonal distribution and stratified movement patterns in the Moray Firth, Scotland. *J. Appl. Ecol.* 34: 1,365–74.

Würsig, B. 1978. Occurrence and group organization of Atlantic bottlenose porpoises (*Tursiops truncatus*) in an Argentine Bay. *Biol. Bull.* 154: 348–59.

Würsig, B. and Jefferson, T.A. 1990. Methods of photo-identification for small cetaceans. *Rep. int. Whal. Commn (special issue)* 12: 43–52.

Würsig, B. and Würsig, M. 1977. The photographic determination of group size, composition, and stability of coastal porpoises (*Tursiops truncatus*). *Science* 198: 755–56.

Zahri, Y., Abid, N., Elouamari, N. and Abdellaoui, B. 2004. Étude de l'interaction entre le grand dauphin et la pêche á la senne coulissante en Méditerranée marocaine. *Rapp. Comm. Int. Mer. Medit.* Casablanca INRH. 52pp. [In French].

Zanardelli, M., Panigada, S. and Bearzi, G. In press. Short-beaked common dolphin and common bottlenose dolphin sightings along the Tunisian coasts and in the Sicily Channel. *European Research on Cetaceans*, 16. Liege, Belgium.

Zar, J.H. 1998. *Biostatistical Analyses*. Prentice Hall, New Jersey, USA. 929pp.