

Capture-mark-recapture modelling suggests an Endangered status for the Mayotte Island (eastern Africa) population of Indo-Pacific bottlenose dolphins

Claire Pusineri^{1,*}, Christophe Barbraud², Jeremy Kiszka^{3,4}, Sarah Caceres¹,
Justine Mougnot¹, Gabriel Daudin¹, Vincent Ridoux³

¹Office National de la Chasse et de la Faune Sauvage, 12 allée de la Forêt/Parc de la Providence, 97400 Saint-Denis, France

²Centre d'Etudes Biologiques de Chizé, CNRS UPR 1934, 79360 Villiers en Bois, France

³Université de La Rochelle, Laboratoire LIENSs, UMR 7266, CNRS-Université de La Rochelle, 2 rue Olympe de Gouge, 17000 La Rochelle, France

⁴Marine Sciences Program, Department of Biological Sciences, Florida International University, 3000 NE 151 St., North Miami, Florida 33181, USA

ABSTRACT: We evaluated whether the Indo-Pacific bottlenose dolphins around the fast-developing island of Mayotte are threatened. We used opportunistic photo-identification data and capture-mark-recapture models to estimate key demographic parameters and then assessed the conservation status of the species using the IUCN Red List regional criteria. The population home range was estimated with the minimum convex polygon method as 978 km², the annual abundance was estimated from closed population models as 82 ± 19 SE individuals and the annual survival rate was estimated using a Cormack-Jolly-Seber model as 0.937 ± 0.059 SE. From the data available, we believe migrations of individuals between Mayotte and its neighbouring islands are likely but would not exceed a few individuals per year. Based on IUCN guidelines for classification at local scales, we classified Indo-Pacific bottlenose dolphins around Mayotte as Endangered. We strongly recommend the establishment of a long-term population-monitoring program and the implementation of management measures.

KEY WORDS: Close population models · Cormack-Jolly-Seber · Abundance · Birth rate · Survival rate · Population growth rate · IUCN classification · Photo-identification

Resale or republication not permitted without written consent of the publisher

INTRODUCTION

The bottlenose dolphin *Tursiops* sp. is one of the most common and widely distributed cetaceans worldwide, and is probably the best known. It is currently represented by 3 recognized separate species: the common bottlenose dolphin *T. truncatus*, the Indo-Pacific bottlenose dolphin *T. aduncus*, and the newly described Burrunan dolphin, *T. australis*, restricted to a small geographic region of southern and south-eastern Australia (Charlton-Robb et al. 2011). However, the taxonomic structure of this species complex

is still debated. Indeed, recent genetic studies suggest that coastal bottlenose dolphins in the western Indian Ocean, ranging from Oman to South Africa, constitute another species within the genus *Tursiops* (Natoli et al. 2004, Särnblad 2011). In the present study, we are interested in a population of this putative species and use its current name: the Indo-Pacific bottlenose dolphin *T. aduncus*.

The waters of Mayotte, Comoros archipelago, are home to a great diversity of odontocetes, with at least 20 species identified to date, including the Indo-Pacific bottlenose dolphin (Kiszka et al. 2010).

Studies conducted around Mayotte in recent years have greatly improved our knowledge of the habitat characteristics of this species. Kiszka et al. (2011) showed that the Indo-Pacific bottlenose dolphin has an inshore and shallow water distribution: mean (\pm SE) sighting depth was 48 ± 70 m, mean (\pm SE) distance from the coast was 2002 ± 2170 m. The 4 islands of the volcanic Comoros archipelago are separated by 40 to 190 km and are surrounded by deep oceanic waters (>2000 m depth), making the coastal Indo-Pacific bottlenose dolphin unlikely to undertake regular transoceanic movements between the islands. A similar pattern was documented by Baird et al. (2009) for *Tursiops truncatus* around the volcanic Hawai'i islands. Photo-identification data in Mayotte highlighted numerous within-year and between-year resightings, suggesting a high level of residency in the coastal waters of the islands (Kiszka et al. 2012). Finally, the genetic variation and differentiation among *T. aduncus* from Zanzibar, South Africa, Oman and Mayotte, and within individuals around Mayotte, suggests that Indo-Pacific bottlenose dolphins form a single panmictic population with low genetic diversity and limited gene flow with other east African populations (Särnblad 2011, Kiszka et al. 2012). All these results suggest that, like most other Indo-Pacific bottlenose dolphin populations, the species in Mayotte is coastal and relatively isolated (Reeves & Brownell 2009).

Such habitat characteristics potentially make this population vulnerable to human activities. Mayotte has benefited from rapid economic development and fast human population growth, especially over the last decade. This has resulted in an exponential increase in anthropogenic pressure and degradation of the marine environment. For example, studies conducted on organic pollutant levels in coastal waters showed concentrations exceeding European environmental standards (Turquet et al. 2010). The emergence of skin diseases has been observed in recent years in bottlenose dolphins around Mayotte that may be related to degradation of the coastal environment (Kiszka et al. 2009). Loricourt (2005) and Chabanet (2002) observed deterioration of seagrass beds and coral reefs concurrently with urbanization. Finally, reef fish stocks seem to be depleted within the lagoon and neighbouring waters (Herfaut 2006). These findings suggest that coastal dolphins around Mayotte may be under threat.

The conservation status of delphinid species has been widely assessed using photo-identification (e.g. Krebs 2004, Kerr et al. 2005, Mansur et al. 2012,

Nicholson et al. 2012). Indeed, photo-identification data may be used to estimate parameters such as home range, birth rate or the degree of isolation of a population (e.g. Würsig & Jefferson 1990). Besides, a wide range of capture-mark-recapture (CMR) models are now available to estimate population parameters such as abundance, survival rate or population growth rate (Cooch & White 2009), even from opportunistic photographic data (Verborgh et al. 2009, Poncelet et al. 2010). These estimated parameters can then be used to assess the status of species under most IUCN criteria (IUCN Standards and Petitions Subcommittee 2010).

The IUCN Red List categories and criteria are easy to understand and are now widely used and recognized by scientists and managers, as well as the general public. Since the publication of the 'Guidelines for application of IUCN Red List criteria at regional levels' (IUCN 2003), the categories can be applied at local scales, which is often the most relevant level for management purposes.

Here, we evaluated whether the Indo-Pacific bottlenose dolphins around the fast-developing island of Mayotte are threatened. For that purpose, we used opportunistic photo-identification data and CMR models to estimate key demographic parameters: home range size, abundance, survival probability. We then assessed the conservation status of the species using the IUCN Red List regional criteria.

MATERIALS AND METHODS

Study area

Mayotte (12° 50' S, 45° 10' E, Fig. 1) is located in the north-eastern Mozambique Channel and is part of the Comoros archipelago. The islands are surrounded by a 197 km long barrier reef. The lagoon and surrounding reef complexes are 1500 km², with an average depth of 20 m and a maximum depth of 80 m. There are some 20 islets in the lagoon, ranging in size from 1 to 242 ha and surrounded by fringing reefs. There are approximately 6.7 km² of mangrove forests around the main island (Grande Terre), and seagrass beds stretch over 7.6 km² (Loricourt 2005). The insular slope on the exterior of the barrier reef is very steep (Audru et al. 2006). Three marine protected areas are found in the lagoon and the whole lagoon is part of the newly created Marine Natural Park, which extends across the whole exclusive economic zone (EEZ) and is in the initial phase of establishing its management plan.

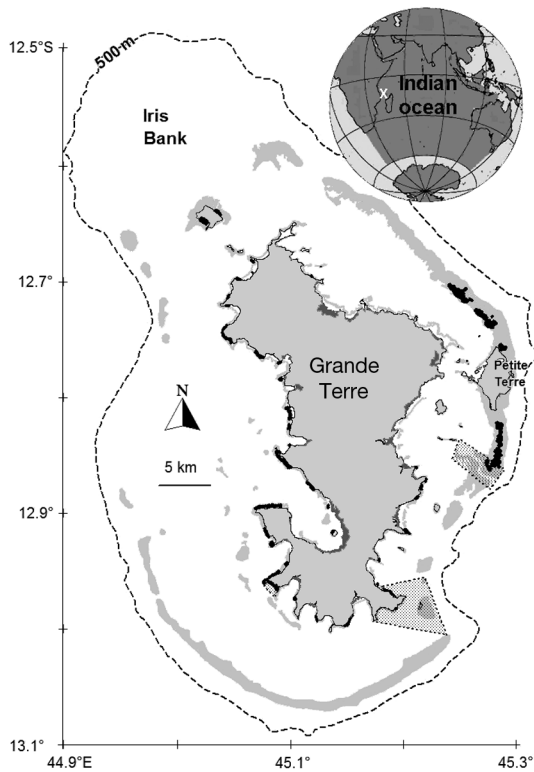


Fig. 1. Mayotte. Coral reefs are shown in light grey, seagrass beds in black and mangroves in dark grey. Dotted polygons are marine protected areas

Data collection

From July 2004 to May 2009, surveys were undertaken from small boats around the island of Mayotte. Surveys were conducted during daylight hours between 07:00 and 18:00 h in sea conditions not exceeding Beaufort 3. The survey effort was spread across the whole lagoon and immediately outside of the barrier reef (see Fig. 2). Constant GPS logging data were collected every 5 s from departure to return to the harbour. When dolphins were encountered, standard sighting data were recorded: group size, geographic position, group classification on the basis of relative size of individuals (adults, immature, calves) and group behaviour (Shane 1990). Groups were approached and photographs were taken using cameras with a 300 mm lens. Attempts were made to photograph the dorsal fins of all animals in encountered groups.

Photographic identification catalogue

Each identified individual was given an identification number and its image was placed in a catalogue.

We compared each distinctive dolphin to every other individual before adding it to the catalogue, and every match was checked by a second researcher. Individuals were assigned an identification value (M0 to M3) based on the marks, scars, and distinctiveness of their fins (Chilvers & Corkeron 2003). M0 was assigned to individuals that had no distinguishing features, such as calves, and M3 to individuals highly distinguishable because of large scars, marks or amputations visible from both sides. Photographs were given a quality grade (Q0 to Q2) depending on focus, size and orientation of dorsal fin (Verborgh et al. 2009, Poncelet et al. 2010). Q0 was given to poor quality photographs unsuitable for identification, Q2 represented top quality photographs from which even poorly marked individuals (M1) could be identified with certainty.

Home range

The home range of the population was determined using the minimum convex polygon method (Mohr 1947), also called the extent of occurrence in the IUCN guidelines (IUCN 2001). This refers to the area contained within the shortest continuous boundary which can be drawn to encompass all the known sightings of a taxon. In the present study, we subtracted the land surface area from the result to obtain the true extent of occurrence.

Abundance estimate

We used closed population models from the CAPTURE program (Otis et al. 1978) to determine dolphin abundance for each year of the data series (2004 to 2009) and computed a final abundance estimate from the mean of annual estimates. The sampling occasions were defined *a posteriori* as month: we had a maximum of 12 sampling occasions in a year, and an individual was recorded as captured for a sampling occasion when it was photo-identified during at least one session conducted in the corresponding month.

Closed population mark-recapture analyses assume the following: (1) marks are not lost during the study, (2) marks are correctly recognized on recapture, (3) births and deaths do not occur during the study, (4) immigration and/or emigration do not occur during the study, (5) animals do not respond to being captured in a way that affects their subsequent probability of recapture (also called trap-dependence),

(6) within a sampling occasion, all animals of the population have equal probability of being captured and (7) capture probabilities are equal for all sampling occasions.

As regards assumption (1), changes in dorsal fin marks occur relatively infrequently over short periods of time, such as the sampling intervals used here (Wilson et al. 1999). It is therefore considered that mark loss is negligible. Concerning assumption (2), progressive addition of new dorsal fin nicks and notches over time can make photographs of the same dorsal fin difficult to match. However, the experience of the persons performing the visual comparisons and the use of a combination of dorsal fin features can solve the problem in most cases (Bearzi et al. 2008). This same assumption may also be violated by the use of poor quality photographs; in the present study, however, only good quality photographs (Q2) were considered in the analyses. Therefore, violation of the mark recognition assumption was considered unlikely. As for demographic closure, assumption (3), calves (which are unmarked) were not included in the data sets used in the models. Furthermore, bottlenose dolphins are large mammals with high adult survival rates; hence the violation of this assumption was unlikely. The geographic closure of the population, assumption (4), was assessed with the accumulated discovery curve of identified individuals and the sighting frequencies. We also tested population closure for each year with the Otis et al. (1978) close test. We examined assumption (5) with TEST 2CT in the U-CARE program, also called the trap-dependence test, which enables detection of individuals responding positively or negatively to capture (Choquet et al. 2009). As for assumption (6), individual heterogeneity in capture probability was highly probable because individuals differ in their mark recognition and therefore in their detectability, and also because there was geographical heterogeneity in survey effort between the east and the west of the lagoon. In addition, variation in capture probability between individuals is likely to occur in relation to sex, age, reproductive status or individual 'personality'. Capture probability might also vary between sampling occasions, assumption (7), because sightings are dependent on sea conditions that differ between the rainy and dry seasons.

The CAPTURE program offers a set of alternative models that allow these assumptions to be relaxed: model M(h) allows heterogeneity in capture probability between individuals (assumption 6), and model M(th) allows heterogeneity in capture probability

between both animals and capture occasions (assumption 7). We used the CAPTURE model selection procedure to help us select the model that best suited our data. In this procedure, the data set is examined with a series of statistical tests looking for variation in capture probability. Then a discriminant function analysis is used to weight and linearly combine the significance levels of the tests in such a manner that the models are forced to be as statistically distinct as possible. The models are then classified so that the model that best fits the data is given the highest probability. This model selection algorithm is described in detail by Otis et al. (1978).

As we relied on natural markings to identify individuals, our estimates pertained to the population of marked animals only. Hence, total population size was estimated as:

$$N = \frac{\hat{N}}{\theta} \quad (1)$$

where N is the estimated total population size, \hat{N} the mark-recapture estimate of the number of animals with long-lasting marks, and θ the estimated proportion of animals with long-lasting marks in the population. We calculated θ from the annual mean ratio of distinctive (M1 + M2 + M3) to total (M0 + M1 + M2 + M3) animals in all photos that exceeded photo quality thresholds (>Q0, Read et al. 2003).

Standard errors for total population size were derived from the variance of \hat{N} (Wilson et al. 1999):

$$\text{Variance } N = N^2 \times \left(\frac{\text{var } \hat{N}}{\hat{N}^2} + \frac{1-\theta}{n \times \theta} \right) \quad (2)$$

where n is the total number of captures and recaptures from which \hat{N} was estimated.

Survival probability

We used the Cormack-Jolly-Seber model (CJS, Lebreton et al. 1992) in the MARK program (White & Burnham 1999) to estimate the apparent survival probability of marked (M1 + M2 + M3) individuals over the whole study period (2004 to 2009). Sampling occasions were here defined as years; we had 6 sampling occasions (2004 to 2009 included) and an individual was said to be captured for a sampling occasion when it was photo-identified during at least one session conducted in the corresponding year. The CJS model was run on a data set of 64 individuals, of which 45 were recaptured during at least 2 capture occasions. We tested and compared models with and without variability in survival and capture probabilities between years.

The underlying assumptions for this model are: (a) marks are not lost during the study, (b) marks are correctly recognized on recapture, (c) all samples are instantaneous and all individuals are released immediately after capture, (d) all marked individuals in the population that are alive on a given sampling occasion have the same probability of surviving to the next sampling occasion, and (e) within a sampling occasion all animals in the population have equal probability of being captured (Williams et al. 2002).

Assumptions (a) and (b) are the same as assumptions (1) and (2), and as stated before, their violation is unlikely. We considered violation of assumption (c) unlikely as sampling occasions selected for analysis were relatively short in duration (1 yr), in comparison with the dolphin lifespan (decades). Assumption (d) was examined with TEST 3SR in the U-CARE program (Choquet et al. 2009). This test is also called the test for transients, as it allows detection of migratory individuals leaving the sampling area shortly after marking. Assumption (e) was assessed with TEST 2CT and also by comparing the CJS model with a model where capture probability was modelled with individual random effects (Gimenez & Choquet 2010). Model selection was performed using the Akaike Information Criterion adjusted for small sample size (AIC_c , Burnham & Anderson 2002).

The goodness of fit (GOF) of our initial model was assessed using the U-CARE program, which allows testing the fit of the CJS model when survival and capture probabilities are time dependent. Since the GOF test was significant (see 'Results'), indicating a lack of fit, we used a variance inflation factor as recommended by Lebreton et al. (1992), calculated as χ^2/df .

RESULTS

Data were collected during 226 boat-based survey days, resulting in 18 618 km effectively surveyed to find and sample dolphins. Spatial coverage of searching effort was more important in the eastern lagoon, but covered all available habitats both inside and outside the lagoon (Fig. 2). A total of 115 sightings and 90 photo-identification sessions were performed with Indo-Pacific bottlenose dolphins, resulting in 7228 photographs taken. Among these, 14% were classified as poor quality (Q0), 68% as medium quality (Q1) and 18% as high quality (Q2) photos. A total of 71 individuals were identified, of which 44% were classified as highly distinguishable (M3), 25% as M2 and 31% as M1.

The extent of occurrence of the population around Mayotte was 948 km² (Fig. 2). Of the 71 photo-identified Indo-Pacific bottlenose dolphins, 82% were sighted during 2 or more photo-identification sessions (maximum of 23 sessions for 1 ind. Fig. 3), and 77% were sighted in 2 or more years (maximum of 6 yr for 7 ind., Fig. 3).

The identification discovery curve did not quite reach a plateau but tended to slow down (Fig. 4), indicating that most of the identifiable individuals had been identified by the end of the study period.

Regarding abundance estimates, no recapture was performed in 2009 and the closed population hypothesis was rejected in 2005 and 2006 (Otis et al. 1978 close tests: $z = -5.91$, $df = 11$, $p < 0.001$ and $z = -2.10$, $df = 3$, $p = 0.02$, for 2005 and 2006 respectively, Table 1). As a consequence, abundance was estimated only from the 2004, 2007 and 2008 data sets. The trap-dependence test did not show evidence for a behavioural response to capture for any

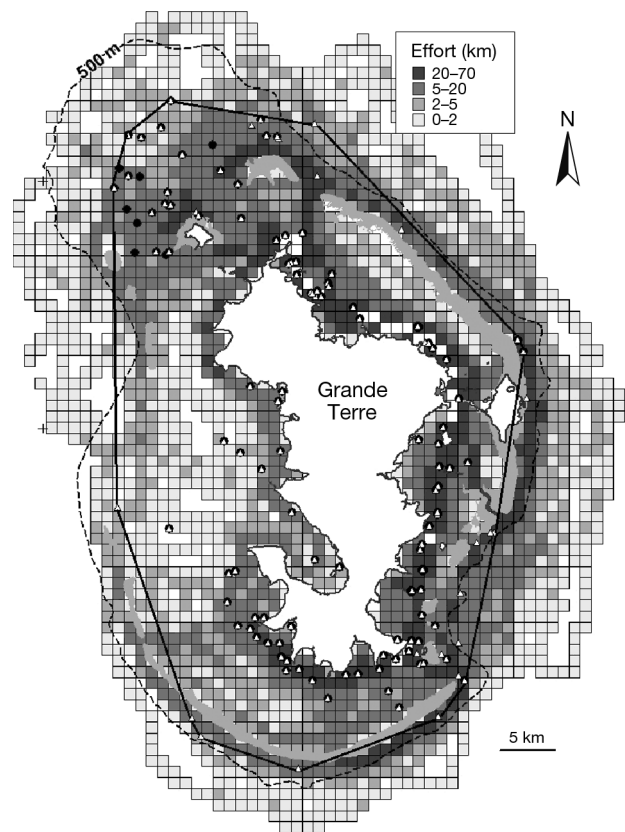


Fig. 2. Effort deployed and data collected from July 2004 to May 2009. (●) Sightings ($n = 115$); (Δ) photo-identification sessions ($n = 90$) for bottlenose dolphins *Tursiops aduncus*. The dashed line indicates 500 m depth and the solid line is the home range (minimum convex polygon)

of the 3 selected years ($p > 0.05$, Table 1). The CAPTURE model selection procedure favoured the model with heterogeneity in capture probability between individuals and between capture occasions for 2004 and 2007, and the model with heterogeneity in capture probability between individuals only

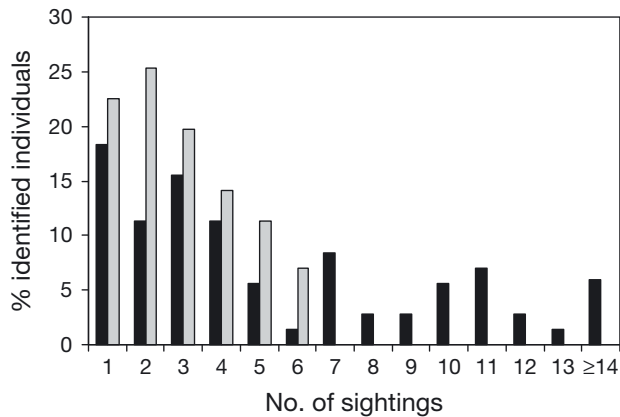


Fig. 3. Frequency distribution of identified bottlenose dolphin *Tursiops aduncus* individuals (% of total no. of identified individuals; $n = 71$) as a function of sighting numbers expressed as years (grey) or photo-identification sessions (black)

for 2008 (i.e. models M(th) and M(h), Table 2). The estimated total population abundance, computed from the estimated number of marked individuals (Table 2) corrected for the proportion of marked individuals (Table 1) was 82 ± 19 SE ind. (95% CI: 24 to 169).

For the survival rate estimate, the GOF test of the CJS model indicated overdispersion of the data ($\chi^2 = 31.37$, $df = 12$, $p = 0.002$). However, we did not detect transience (TEST 3SR: $\chi^2 = 6.83$, $df = 4$, $p = 0.145$; statistic for transience: $z = 1.85$, $p = 0.065$), or trap-dependence (TEST 2CT: $\chi^2 = 8.71$, $df = 3$, $p = 0.033$; statistic for trap-dependence: $z = 1.12$, $p = 0.264$). We thus used a variance inflation factor ($\lambda = 2.616$), which was considered acceptable (i.e. < 3). Model selection indicated that capture and survival probabilities were constant, whether or not individual heterogeneity in capture probability was taken into account (Table 3). In addition, there was no strong evidence for individual effects on capture probability between years. The model-averaged annual survival was 0.937 ± 0.059 SE (95% CI: 0.678 to 0.990) and the model-averaged annual capture probability was 0.499 ± 0.095 SE (95% CI: 0.320 to 0.678).

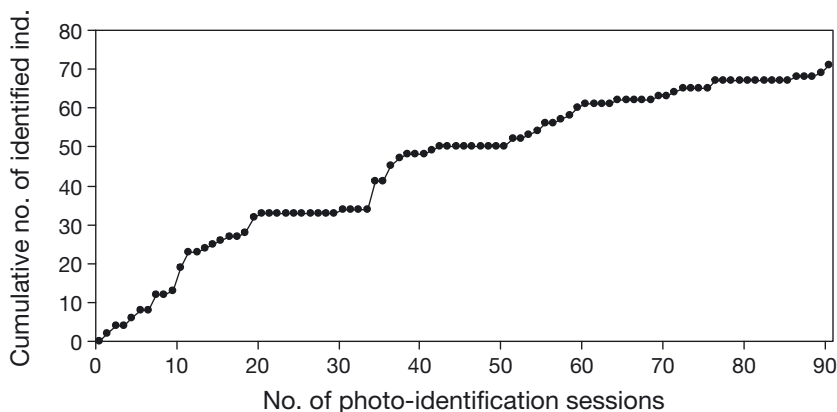


Fig. 4. Identification discovery curve showing the accumulation in the number of identified bottlenose dolphin *Tursiops aduncus* individuals with increasing number of photo-identification sessions

DISCUSSION

Degree of isolation of bottlenose dolphins

Assessing the degree of isolation of bottlenose dolphins around Mayotte was not straightforward. Indeed, as suggested in the 'Introduction' there is evidence for a high degree of isolation of Indo-Pacific bottlenose dolphins around Mayotte from patterns of distribution, geographic characteristics of the island and genetic analyses (Särn-

Table 1. Data used to estimate abundance, proportion of marked bottlenose dolphin *Tursiops aduncus* individuals (ind.) and tests from the program CAPTURE

Year	No. of capture occasions	No. of captured ind.	No. of recaptured ind.	Proportion of marked ind.	—Close test—			Trap-dependence test		
					df	z	p	df	z	p
2004	5	24	7	0.76	3	0	0.5	3	0.73	0.23
2005	5	25	4	0.82	11	-5.91	0	8	-0.61	0.73
2006	4	20	8	0.86	3	-2.1	0.02	3	0.55	0.29
2007	5	22	5	0.79	3	-0.45	0.33	2	0.00	0.5
2008	8	35	10	0.83	6	0.41	0.66	7	0.00	1
2009	8	19	0	—	—	—	—	—	—	—

Table 2. Main outputs of the CAPTURE program. The selected models are in **bold** font. M(h): heterogeneity of capture probabilities between individuals; M(th): capture probabilities vary between individuals and capture occasions

Year	Model selection		No. of marked ind. estimated from the selected model
	M(h)	M(th)	
2004	0.00	0.69	75 ± 38 SE (95 % CI: 38–213)
2007	0.00	0.83	48 ± 17 SE (95 % CI: 30–105)
2008	0.72	0.49	73 ± 14 SE (95 % CI: 54–109)

blad 2011, Kiszka et al. 2012). In the present study, photo-identification showed numerous within-year and between-year resightings, and the discovery curve tended to flatten over our sampling period (2004 to 2009). However, the number of newly identified individuals during the last years of the study (9 in 2007, 6 in 2008 and 4 in the first 3 mo of 2009) may not be explained by the birth rate alone. Indeed, the annual birth rates reported in the literature for the same species are 6 and 7% (Steiner & Bossley 2008 for Port River, Australia, and Kogi et al. 2004 for Mikura Island, Japan, respectively), while the rate of newly identified individuals in the Mayotte population equalled 10 and 7% of the mean population abundance in 2007 and 2008, respectively. Thus, unless the birth rate was higher than previously reported for this species, immigration of a few individuals probably occurred. Similarly, statistical tests indicated, on the one hand, that there was no strong evidence for the existence of transients within the population and, on the other hand, that the population could not be considered as closed in 2005 and 2006. In conclusion, from the data available, we believe migrations of individuals between Mayotte and its neighbouring islands are likely but would not exceed a few individuals per year.

Population parameters

From our results, it seems that Mayotte bottlenose dolphins constitute a small population (82 ind.) with a limited home range (948 km²), similar to most other populations of this species (Reeves & Brownell 2009).

Our estimated adult annual survival rate (0.937 ± 0.059) was in the range of values found in the literature for declining bottlenose dolphin populations: 0.94 (95% CI: 0.92 to 0.95) in Doubtful Sound, New Zealand (Currey et al. 2009b) and 0.83 ± 0.05 SE to 0.94 ± 0.04 SE in Kvarneric, Croatia (Fortuna 2007). In other areas, where populations have not been reported to be declining, survival estimates were 0.96 ±

Table 3. Modelling survival and capture probabilities of bottlenose dolphins at Mayotte, 2004 to 2009. ϕ is annual survival; p is annual capture probability; t is year; and σ_p is the variance of the individual random effect on capture probability. QDev is the adjusted deviance; np is the number of estimated parameters; QAIC_c is the adjusted corrected Akaike's information criterion (AIC_c); and Δ QAIC_c is the difference in QAIC_c from the lowest QAIC_c model

Model	QDev	np	QAIC _c	Δ QAIC _c	QAIC _c weight
ϕ, p	34.4	2	121.7	0	0.488
ϕ, p, σ_p	32.4	3	121.8	0.12	0.460
ϕ_t, p	31.0	6	126.8	5.10	0.038
ϕ_t, p_t	26.4	9	128.8	7.15	0.014

0.01 SD in Sarasota Bay, Florida (Wells & Scott 1990), 0.97 ± 0.03 SE around the Azores (Silva et al. 2009), 0.98 ± 0.02 SE in Bangladesh (Mansur et al. 2012) and 0.99 ± 0.01 SE in Bunbury, Western Australia (Smith 2012). However, because of our small population size, even a few temporary migrations or the heterogeneity of our sampling effort could result in a significant bias of the survival rate. Thus, from our results, it is not possible to determine the origin of our relatively weak survival estimate.

Regional threat assessment under IUCN Red List criteria

The first step of the IUCN classification of a population at a local scale is to evaluate the given species according to the 5 IUCN criteria (A, B, C, D, E; Table 4). Depending on the criteria-specific thresholds met by the species, it is classified as Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), or Extinct (EX) under each criterion. At the end, the highest threat category is selected. For criterion A, as there was no evidence of a past, present or future significant reduction in the population size, the population was classified as Least Concern. For criterion B, bottlenose dolphins around Mayotte seem to have a limited population home range, i.e. less than 5000 km² (948 km² in our case). In sub-criterion Ba, the term 'location' defines 'a geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present' (IUCN 2001). Several events could rapidly affect the bottlenose dolphin population around Mayotte, such as a major hurricane, coral reef bleaching event or oil spill that could drastically decrease food resources. Our population is then characterized by a single location, which satisfies sub-criterion Ba. In addition,

Table 4. *Tursiops aduncus*. IUCN criteria (IUCN 2001, 2003) and their application to the classification of the Indo-Pacific bottlenose dolphin population around Mayotte

IUCN criteria	(A) Declining population (past, present and/or projected)	(B) Limited home range plus at least 2 of the following: (a) severely fragmented or limited number of locations; (b) continuing decline or (c) extreme fluctuations of: extent of occurrence (i), area of occupancy (ii), habitat quality (iii), number of locations (iv), abundance (v).	(C) Small population size plus fragmentation, decline, or fluctuations	(D) Very small population or very restricted distribution	(E) Quantitative analysis of extinction risk
Mayotte Indo-Pacific bottlenose dolphins	No evidence of a significant reduction in population size	Limited extent of occurrence (948 km ²); Single location (a), Continuing decline in habitat quality (biii)	Small population size (82 ± 19 ind.) No evidence of fragmentation, decline or fluctuation	Very small population size (<250 mature ind.)	No quantitative analysis
IUCN classification	Least Concern	Endangered	Near Threatened	Endangered	Not applicable

there is a continuing decline in the habitat quality with signs of coastal water pollution, fish stock depletion and deterioration of seagrass beds and coral reefs (see Introduction), which satisfies sub-criterion Bb(iii). As a consequence, the species was classified as Endangered under criterion Bab(iii). For criterion C, we found that the population size is small (~80 ind.) but we found no evidence for its fragmentation, decline, or fluctuation; therefore, we classified the species as Near Threatened under this criterion. According to criterion D, the population should be classified as Endangered if the number of mature individuals is under 250, and Critically Endangered if the number is under 50. Proportions of mature individuals estimated for *Tursiops* spp. range from 0.4 to 0.7 in the literature (Fernandez & Hohn 1998, Stolen & Barlow 2003, Kogi et al. 2004, Mattson et al. 2006, Lodi & Monteiro-Neto 2012). Therefore, we considered the proportion of mature individuals in the Mayotte bottlenose dolphin population to be under 250 and classified the species as Endangered under criterion D. Criterion E was not applicable because no quantitative analysis was performed. As the highest threat category should be selected, the Mayotte bottlenose dolphin population was classified as Endangered under criteria Bab(iii)D.

The second and final step of the classification of a population at a local scale is to address the degree of isolation of the population. Indeed, immigration from outside the region will tend to decrease extinction risk within the region; hence, in such a case, the classification should be downgraded to a lower threat

category. As stated before, we believe migrations of individuals between Mayotte and its neighbouring islands are likely but would not exceed a few individuals per year. However, the role such a migration rate could play in population maintenance remains to be investigated. IUCN guidelines state the following: 'If it is unknown whether or not extra-regional populations influence the extinction risk of the regional population, the category should be kept unaltered' (IUCN 2003, p. 13). As a consequence, we classified the Mayotte Indo-Pacific bottlenose as Endangered at the local scale, recognizing that the threat category may be downgraded in the future when closer investigations of the population have been conducted.

We found 2 examples of IUCN classifications of small coastal bottlenose populations in the literature. In Réunion Island, the Indo-Pacific bottlenose dolphin population was classified as Endangered at a regional scale under the same criteria used in the Mayotte case study: home range <5000 km² with habitat degradation (Babiii) and number of mature individuals under 250 (D; IUCN & MNHN 2012). The closest land to Réunion is Mauritius, which is 250 km away, so the population was considered isolated and the threat category was not downgraded. In Fiordland, New Zealand, the coastal population of common bottlenose dolphins *Tursiops truncatus* is known from genetic studies to be isolated from other coastal New Zealand populations (Currey et al. 2009a). It consists of 205 (CV = 3.5%) ind. and is threatened by interactions with tour boats and freshwater discharge from a hydroelectric power station. This case study is

comparable to ours, but the population trajectory assessed using stochastic age-structured Leslie matrix population models showed that the population was declining and should be classified as Critically Endangered under criteria A and C. The classification of the Mayotte bottlenose population is consistent with these 2 examples.

Coastal and insular bottlenose dolphins are threatened in many other regions because their coastal distribution and their typical small populations with small ranges make them particularly vulnerable to anthropogenic threats. For example, on the south coast of Zanzibar, Tanzania, the resident population consists of 136 to 179 ind. and is threatened by by-catch and disturbance from dolphin-watching activities (Stensland et al. 2006, Christiansen et al. 2010). Around the Solomon Islands, bottlenose dolphins are threatened by live captures (Reeves & Brownell 2009). In Amakusa, western Kyushu, Japan, Indo-Pacific bottlenose dolphins appear to be threatened by dolphin-watching operations (Shirakihara et al. 2002).

Conservation

The main limitation of our work was that the sampling scheme was not originally designed for CMR analyses (Kiszka et al. 2012). This resulted in a limited amount of data as well as a significant spatial and temporal variability of sampling effort within and between years. However, despite these limitations, our opportunistic photo-identification data provided reasonably robust estimates to assess the local conservation status of the bottlenose dolphins around Mayotte under IUCN criteria. This shows that opportunistic photo-identification data can be valuable for estimating demographic parameters for management purposes at local scales.

Marine mammals around Mayotte have been identified as species of high natural heritage and tourism value, but few management measures have been implemented so far. Recent studies of dugongs *Dugong dugon* on the same site show that the species is close to extirpation (Pusineri et al. 2013). In order to prevent a similar decline of Mayotte Indo-Pacific bottlenose dolphins, we should first implement management measures to impede further degradation of dolphin habitats (e.g. build up more water-treatment plants, develop a sustainable fishery outside the lagoon, develop field patrolling and education programs to achieve better compliance with dolphin-watching legislation). Secondly, the population should be monitored, for example through an annual photo-

identification campaign with CMR-dedicated protocols. Thirdly, we need to quantify the likely migrations of individuals between the islands of the Comoros archipelago with genetics, telemetry and photo-identification. We strongly recommend the establishment of a conservation action based on the above guidelines in the coming years.

Acknowledgements. The data from July 2004 to June 2006 were collected during a dolphin research project conducted by the Office National de la Chasse et de la Faune Sauvage (ONCFS, Wildlife and Hunting Agency) and the Direction de l'Agriculture et de la Forêt (DAF, Agriculture and Forestry Office). From May 2007 to April 2009, data were collected during a joint program of the University of La Rochelle, the ONCFS, and the Conseil Général de Mayotte (CG). We thank R. Rolland, A. Jamon, I. Ousseni, J. Wickel (DAF), F. Charlier, A. Grolleau, K. Soudjoudane, A. Toilibou, M. Atoumani, P. Abbas (ONCFS) and Didier Fray (CG) for assistance in the field in Mayotte. We also thank F. Kirchner and A. Cavois from IUCN France for their advice regarding the IUCN classification criteria, as well as B. Simon-Bouhet and V. Dulau for their useful comments on the status of the species in the region.

LITERATURE CITED

- Audru JC, Guennoc P, Thinon I, Abellard O (2006) Bathymetry: la structure sous-marine de Mayotte révélée par l'imagerie multifaisceaux. *CR Geosci* 338:1240–1249
- Baird RW, Gorgone AM, McSweeney DJ, Ligon AD and others (2009) Population structure of island-associated dolphins: evidence from photo-identification of common bottlenose dolphins (*Tursiops truncatus*) in the main Hawaiian Islands. *Mar Mamm Sci* 25:251–274
- Bearzi G, Agazzi S, Bonizzoni S, Costa M, Azzellino A (2008) Dolphins in a bottle: abundance, residency patterns and conservation of bottlenose dolphins *Tursiops truncatus* in the semi-closed eutrophic Amvrakikos Gulf, Greece. *Aquat Conserv* 18:130–146
- Burnham KP, Anderson DR (2002) Model selection and multitmodel inference: a practical information-theoretic approach. Springer, New York, NY
- Chabanet P (2002) Coral reef fish communities of Mayotte (western Indian Ocean) two years after the impact of the 1998 bleaching event. *Mar Freshw Res* 53:107–113
- Charlton-Robb K, Gershwin L, Thompson R, Austin J, Owen K, Mc Kechnie S (2011) A new dolphin species, the Burrunan dolphin *Tursiops australis* sp. nov., endemic to southern Australian coastal waters. *PLoS ONE* 6:e24047
- Chilvers LB, Corkeron JP (2003) Abundance of Indo-Pacific bottlenose dolphin, *Tursiops aduncus*, off point lookout, Queensland, Australia. *Mar Mamm Sci* 19:85–95
- Choquet R, Lebreton JD, Gimenez O, Reboulet AM, Pradel R (2009) U-CARE: Utilities for performing goodness of fit tests and manipulating capture-recapture data. *Ecography* 32:1071–1074
- Christiansen F, Lusseau D, Stensland E, Berggren P (2010) Effects of tourist boats on the behaviour of Indo-Pacific bottlenose dolphins off the south coast of Zanzibar. *Endang Species Res* 11:91–99

- Cooch E, White G (2009) Program MARK, a gentle introduction, 9th edn. www.phidot.org/software/mark/docs/book/ (accessed 14 Aug 2009)
- Currey RJC, Dawson SM, Slooten E (2009a) An approach for regional threat assessment under IUCN Red List criteria that is robust to uncertainty: The Fiordland bottlenose dolphins are critically endangered. *Biol Conserv* 142: 1570–1579
- Currey RJC, Dawson SM, Slooten E, Schneider K and others (2009b) Survival rates for a declining population of bottlenose dolphins in Doubtful Sound, New Zealand: an information theoretic approach to assessing the role of human impacts. *Aquat Conserv* 19:658–670
- Fernandez S, Hohn AA (1998) Age, growth, and calving season of bottlenose dolphins, *Tursiops truncatus*, off coastal Texas. *Fish Bull* 96:357–365
- Fortuna CM (2007) Ecology and conservation of bottlenose dolphins (*Tursiops truncatus*) in the north-eastern Adriatic Sea. PhD dissertation, University of St. Andrews
- Gimenez O, Choquet R (2010) Individual heterogeneity in studies on marked animals using numerical integration: capture-recapture mixed models. *Ecology* 91:951–957
- Herfaut J (2006) Suivi statistique de la pêche artisanale mahoraise: effort de pêche, captures et CPUE en 2005. Tech Rep of Mayotte Direction of Fisheries, Mamoudzou, Mayotte
- IUCN (2001) IUCN Red List categories and criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland
- IUCN (2003) Guidelines for application of IUCN Red List criteria at regional levels: Version 3.0. IUCN Species Survival Commission. IUCN, Gland
- IUCN & MNHN (Muséum National d'Histoire Naturelle) (2012) La Liste rouge des espèces menacées en France - Premiers résultats pour la faune de La Réunion. www.uicn.fr/Liste-rouge-faune-Reunion.html
- IUCN Standards and Petitions Subcommittee (2010) Guidelines for using the IUCN Red List categories and criteria. Version 8.1. Prepared by the Standards and Petitions Subcommittee in March 2010. www.nationalredlist.org/files/2012/09/Guidelines-for-Using-the-IUCN-Red-List.pdf
- Kerr KA, Defran RH, Campbell GS (2005) Bottlenose dolphins (*Tursiops truncatus*) in the Drowned Cayes, Belize: group size, site fidelity and abundance. *Caribb J Sci* 41: 172–177
- Kiszka J, Van Bresse MF, Pusineri C (2009) Lobomycosis-like disease and other skin conditions in Indo-Pacific bottlenose dolphins *Tursiops aduncus* from the Indian Ocean. *Dis Aquat Org* 84:151–157
- Kiszka J, Breyse O, Vely M (2010) Preliminary account of cetacean diversity and humpback whale (*Megaptera novaeangliae*) group characteristics around the Union of the Comoros (Mozambique Channel). *Mammalia* 74: 51–56
- Kiszka J, Simon-Bouhet B, Martinez L, Pusineri C, Richard P, Ridoux V (2011) Ecological niche segregation within a community of sympatric dolphins around a tropical island. *Mar Ecol Prog Ser* 433:273–288
- Kiszka J, Simon-Bouhet B, Gastebois C, Pusineri C, Ridoux V (2012) Habitat partitioning and fine scale population structure among insular bottlenose dolphins (*Tursiops aduncus*) in a tropical lagoon. *J Exp Mar Biol Ecol* 416-417:176–184
- Kogi K, Hishii T, Inamura A, Iwatani T, Dudzinski KM (2004) Demographic parameters of indopacific bottlenose dolphins (*Tursiops aduncus*) around Mikura island, Japan. *Mar Mamm Sci* 20:510–526
- Kreb D (2004) Abundance of freshwater Irrawaddy dolphins in the Mahakam River in East Kalimantan, Indonesia, based on mark-recapture analysis of photo-identified individuals. *J Cetacean Res Manag* 6:269–277
- Lebreton JD, Burnham KP, Clobert J, Anderson DR (1992) Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. *Ecol Monogr* 62:67–118
- Lodi L, Monteiro-Neto C (2012) Group size and composition of *Tursiops truncatus* (Cetacea: Delphinidae) in a coastal insular habitat off southeastern Brazil. *Biotemas* 25: 157–164
- Loricourt A (2005) Etude des herbiers à phanérogames marines à Mayotte. MSc thesis, University of Pau
- Mansur RM, Strindberg S, Smith BD (2012) Mark-resight abundance and survival estimation of Indo-Pacific bottlenose dolphins, *Tursiops aduncus*, in the Swatch-of-No-Ground, Bangladesh. *Mar Mamm Sci* 28:561–578
- Mattson MC, Mullin KD, Ingram GW, Hoggard W (2006) Age structure and growth of the bottlenose dolphin (*Tursiops truncatus*) from strandings in the Mississippi Sound region of the north-central Gulf of Mexico from 1986 to 2003. *Mar Mamm Sci* 22:654–666
- Mohr CO (1947) Table of equivalent populations of North American small mammals. *Am Midl Nat* 37:223–249
- Natoli A, Peddemors VM, Hoelzel AR (2004) Population structure and speciation in the genus *Tursiops* based on microsatellite and mitochondrial DNA analyses. *J Evol Biol* 17:363–375
- Nicholson K, Bejder L, Allen SJ, Krützen M, Pollock KH (2012) Abundance, survival and temporary emigration of bottlenose dolphins (*Tursiops* sp.) off Useless Loop in the western gulf of Shark Bay, Western Australia. *Mar Freshw Res* 63:1059–1068
- Otis DL, Burnham KP, White GC, Anderson DR (1978) Statistical inference from capture data on closed animal populations. *Wildlife Monogr* 62
- Poncellet E, Barbraud C, Guinet C (2010) Population dynamics of killer whales (*Orcinus orca*) in Crozet Archipelago, southern Indian Ocean: a mark recapture study from 1977 to 2002. *Mar Mamm Sci* 11:41–48
- Pusineri C, Kiszka J, Quillard M, Caceres S (2013) The endangered status of dugongs (*Dugong dugon*) around Mayotte (Eastern Africa, Mozambique Channel) assessed through interview surveys. *Afr J Mar Sci* 35:111–116
- Read AJ, Urian KW, Wilson B, Waples DM (2003) Abundance of bottlenose dolphins in the bays, sounds, and estuaries of North Carolina. *Mar Mamm Sci* 19:59–73
- Reeves RR, Brownell RL (2009) Indo-Pacific bottlenose dolphin assessment workshop report: Solomon Islands case study of *Tursiops aduncus*. Occasional Paper of the Species Survival Commission, No. 40. IUCN, Gland
- Särnblad A (2011) Ecology and genetic population structure of Indo-Pacific bottlenose dolphins in East Africa. PhD dissertation, University of Stockholm
- Shane SH (1990) Behaviour and ecology of the bottlenose dolphin at Sanibel Island, Florida. In: Leatherwood S, Reeves RR (eds) *The bottlenose dolphin*. Academic Press, San Diego, CA, p 245–265
- Shirakihara M, Shirakihara K, Tomonaga J, Takatsuki M (2002) A resident population of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in Amakusa, western Kyushu, Japan. *Mar Mamm Sci* 18:30–41

- Silva MA, Magalhães S, Prieto R, Santos RS, Hammond PS (2009) Estimating survival and abundance in a bottlenose dolphin population taking into account transience and temporary emigration. *Mar Ecol Prog Ser* 392:263–276
- Smith HC (2012) Population dynamics and habitat use of bottlenose dolphins (*Tursiops aduncus*), Bunbury, Western Australia. PhD dissertation, Murdoch University, Perth
- Steiner A, Bossley M (2008) Some reproductive parameters of an estuarine population of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*). *Aquat Mamm* 34:84–92
- Stensland E, Carlén I, Särnblad A, Bignert A, Berggren P (2006) Population size, distribution, and behavior of Indo-Pacific bottlenose (*Tursiops aduncus*) and humpback (*Sousa chinensis*) dolphins off the south coast of Zanzibar. *Mar Mamm Sci* 22:667–682
- Stolen MK, Barlow J (2003) A model life table for bottlenose dolphins (*Tursiops truncatus*) from the Indian river lagoon system, Florida, USA. *Mar Mamm Sci* 19:630–649
- Turquet J, Nicet JB, Cambert H, Pareto D and others (2010) Définition des réseaux de surveillance DCE de la qualité des masses d'eau côtières de l'île de Mayotte – Tome 1: synthèse et propositions. Technical Report of the French Agency of Mining and Geology Research, Mayotte
- Verborgh P, de Stephanis R, Pérez S, Jaget Y, Barbrau C, Guinet C (2009) Survival rate, abundance and residency of long-finned pilot whales in the Strait of Gibraltar. *Mar Mamm Sci* 25:523–536
- Wells RS, Scott MD (1990) Estimating bottlenose dolphin population parameters from individual identification and capture-release techniques. *Rep Int Whal Comm Spec Issue* 12:407–415
- White GC, Burnham KP (1999) Program MARK: Survival estimation from populations of marked animals. *Bird Study* 46(Supplement):S120–S139
- Williams BK, Nichols JD, Conroy MJ (2002) Analysis and management of animal populations. Academic Press, San Diego, CA
- Wilson B, Hammond PH, Thompson PM (1999) Estimating size and assessing trends in a coastal bottlenose dolphin population. *Ecol Appl* 9:288–300
- Würsig B, Jefferson TA (1990) Methods of photo-identification for small cetaceans. *Rep Int Whal Comm Spec Issue* 12:43–52

Editorial responsibility: Ana Cañadas, Madrid, Spain

*Submitted: March 13, 2013; Accepted: October 9, 2013
Proofs received from author(s): January 12, 2014*