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Spinner dolphins *Stenella longirostris* off south-west Mauritius: abundance and residency

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Spinner dolphins *Stenella longirostris longirostris* off the south-west coast of Mauritius are subject to ongoing anthropogenic disturbance in the form of daily dolphin tourism, which has intensified since 1998. Abundance of this species was estimated using photo-identification data and mark-recapture analysis. Between April 2008 and June 2010, identification photographs were collected from dolphins occurring along a 30 km length of the coast of south-west Mauritius. A total of 250 groups were encountered over 229 survey days. Mark-recapture analyses were performed on a photographic dataset of more than 8 000 good- and excellent-quality images and 83 animals were identified as distinctively marked individuals. The majority (85.5%) were seen more than once and resightings indicated a resident population. The compiled version of SOCPROG 2.4 was used to investigate the lagged identification rate. The fitted model supported a mostly resident population with additional animals moving in and out of the study area. The estimated abundance of the total population in the study area ranged between 138 and 399 individuals. Our results can be used for monitoring the population for fluctuations and for encouraging both the enforcement of laws regarding dolphin watching and the development of further means of management needed to ensure the long-term presence of this population.

Keywords: conservation, dolphin watching, mark-recapture, photo-identification, resident population

Introduction

Spinner dolphins are distributed throughout the world's tropical and subtropical oceans (Perrin 1998). Of the four recognised forms, the Hawaiian form *Stenella longirostris longirostris*, referred to hereafter as the spinner dolphin, is the most abundant and widespread (Norris et al. 1994). Spinner dolphins are occasionally found in the open ocean, but are more often associated with island chains or atolls (Norris et al. 1994; Perrin 1998). At a local level, this species exhibits a daily movement pattern that is determined by the movement of their prey (Norris et al. 1994; Benoit-Bird and Au 2003). Some populations show considerable fidelity to particular sites whereas others will move substantial distances between bays or islands (Norris et al. 1994; Karczmarski et al. 2005; Oremus 2008). These differences may be due to isolation and/or availability of suitable resting sites (Lammers 2004; Karczmarski et al. 2005; Andrews et al. 2010).

Stenella longirostris longirostris occurs around archipelagos such as Hawaii (Norris et al. 1994) and French Polynesia (Poole 1995) and atolls in the Red Sea, Egypt (Notabartolo-di-Sciara et al. 2009), as well as off the coast of Brazil (Silva et al. 2005). All these populations exhibit a daily behaviour pattern in which the animals rely on sheltered bays or lagoon areas for daytime resting and socialising, before moving offshore to feeding grounds (Norris and Dohl 1980; Würsig et al. 1994; Lammers 2004; Silva et al. 2005; Oremus 2008; Notabartolo-di-Sciara et al. 2009). Resting areas have several common features, including clear and shallow water with a sandy substratum and protection from deeper water environments. Such areas may be in the form of atolls in the case of some of the Hawaiian Islands and the Red Sea (Karczmarski et al. 2005; Notabartolo-di-Sciara et al. 2009) or bays such as on Moorea, French Polynesia (Poole 1995), and on the main islands of Hawaii (Norris and Dohl 1980; Norris et al. 1994). The availability of these areas, their size and distance from neighbouring islands seem to be influencing factors in the social structure (Oremus 2008; Andrews et al. 2010), site fidelity and size of the local population (Gowans et al. 2008).

In Mauritius, groups similarly enter bays during the early morning to socialise and rest, before leaving several hours later in the early afternoon (IW unpublished data). The predictable movement pattern displayed by this species makes it ideal for the development of dolphin-watching activities, but these subject them to disturbance during a time when they would normally be resting and socialising. Since 1998, the whale- and dolphin-watching industry in Mauritius has grown by an average of 56% annually (O'Connor et al. 2009). Studies on many different small cetacean species have shown that disturbance from this kind of industry can have both short- and long-term negative effects on dolphins (e.g. Samuels and Bejder 2004; Danil et al. 2005; Bejder et al. 2006; Delfour 2007; Courbis and Timmel 2009; Steckenreuter et al. 2011, 2012a) and investigations are ongoing in this field of study.

Few detailed studies on spinner dolphins have emanated from research in the Indian Ocean although they are considered to be the most abundant semi-pelagic species in this region (Ballance and Pitman 1998; de Boer et al. 2002; Kiszka et al. 2009). Spinner dolphins have been recorded from Comoros (Kiszka et al. 2010a), Mayotte (Kiszka et al. 2010b), La Réunion Island (Dulau-Drouot et al. 2008), Seychelles (Hermans and Pistorius 2008), Maldives (Anderson 2005) and off the coast of East Africa (de Boer et al. 2002). Most of these studies report on cetacean diversity and/or occurrence but very little research has been conducted on abundance. Off south-west Mauritius, given the increase in dolphin-watching and swimming-with-dolphins activities it is important to gather baseline information about the population and its movements in order to monitor the impact of these and other anthropogenic activities on these animals. Abundance estimates, site fidelity, distributional ranges and other demographic factors can be monitored using photo-identification (Connor et al. 2000; Hammond 2001; Sargeant et al. 2007). Once baselines have been established for these factors, they can be used as indicators for the management of populations that may be at risk from environmental and/or human activity pressures (Wilson et al. 1997; Chilvers and Corkeron 2003).

With the existing level of dolphin-watching activity and the potential for further growth, a management plan is required urgently to ensure the sustainability of this population. This study was designed to obtain the first abundance estimate, and to determine residency patterns, of the spinner dolphin population using the south-west coast of Mauritius, and hence to establish a baseline for long-term monitoring and conservation planning.

Methods

Study area

Situated in the south-western Indian Ocean approximately 900 km east of Madagascar, Mauritius (20°17′ S, 57°33′ E) is a volcanic island with extensive barrier reef and a narrow continental shelf. The study area encompassed about 30 km of coastline along the protected south-west coast of the island between Point Moyenne (20°14′33″ S, 57°22′49″ E) in the north and Le Morne (20°29′30″ S, 57°20′22″ E) in the south (Figure 1). Extending offshore to a depth of 100 m, the study area covered approximately 75 km^2 and included sandy-bottomed and sheltered bays, reef-fringed open coast and a peninsula (Le Morne) on the south-western corner of the island, which, although also reef-fringed, experiences rougher conditions due to exposure to southerly and easterly winds.

Boat-based surveys were conducted year-round between April 2008 and June 2010, 2–3 times a week when conditions were favourable (Beaufort sea state ≤3). Given that the dolphins were inshore – and dolphin watching occurred – predominantly between 06:00 and 14:00, all surveys were conducted during this period. Objectives for each survey were either to monitor dolphin behaviour or to examine cetacean diversity and distribution. However, the same area was covered for both survey types and photo-identification was always performed, with effort focused on obtaining photographs of every individual in the group. Detailed descriptions of surveys and data collection are available in Webster et al. (2014).

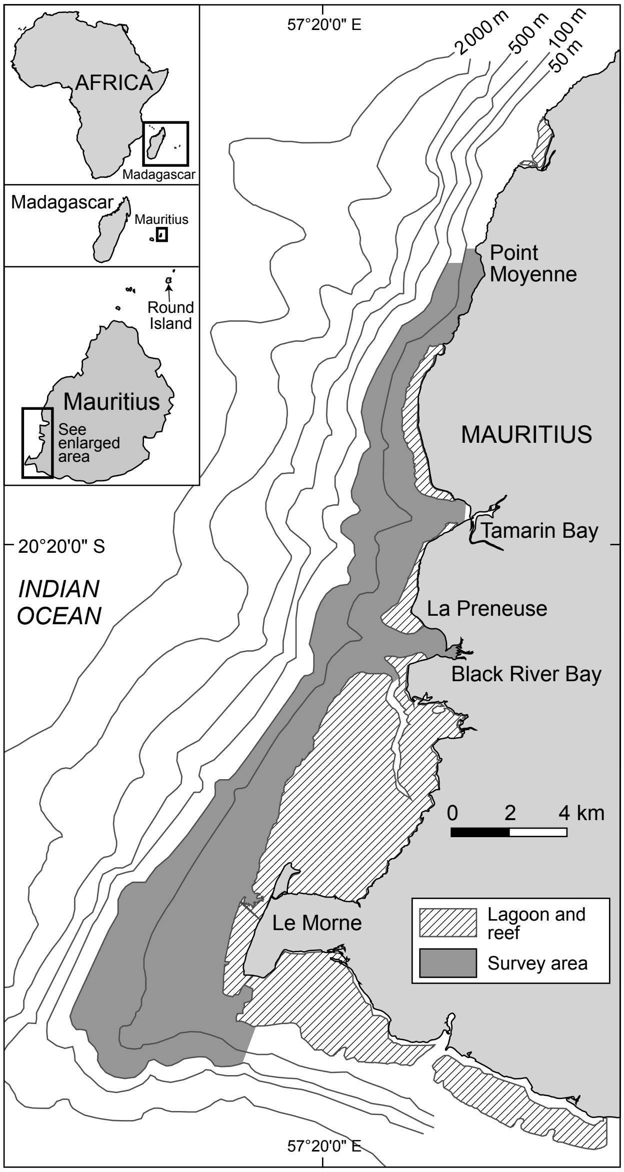

Figure 1: The study area, extending to the 100 m isobath, on the south-west coast of Mauritius. The extent of the lagoon and reef complex is indicated

Photo selection and photo-identification

Depending on photographic quality (angle of the dorsal fin to the photographer, clarity, contrast and size of the fin in the image), images were classified as poor, good or excellent. Only photographs of good or excellent quality were examined further. Distinctiveness varies between dorsal fins of individuals and capture–recapture analyses relate to the distinctively marked population (Wilson et al. 1999; Read et al. 2003). Hence, individuals were given a distinctiveness score (1–3) and an identification catalogue was developed (Würsig and Jefferson 1990). Distinctiveness scores were allocated according to Urian et al. (1999), with scores of 1 and 3 representing very distinct and indistinct individuals, respectively. New images were compared to those already in the catalogue to identify resightings or new animals. Dolphins with a distinctiveness score of 1 or 2 were included in the mark-recapture analysis and are referred to further as 'distinctively marked individuals' (DMIs).

The proportion of marked animals in the population (θ) was determined by dividing the number of dorsal fins that could be identified reliably by the total number of photographed fins for which the image quality was good or excellent. This calculation was performed for a random selection of 40 photo-identification surveys distributed over the total study period.

Population estimate

A population was defined as the number of individuals frequenting the study area (Begon et al. 1996). Encounter histories, consisting of values of 1 or 0 according to whether or not an individual was captured within a sampling period, were compiled for each identifiable individual remaining after photo-grading and considered to be distinctively marked. There were 13 bimonthly primary periods and 26 monthly secondary periods. These durations were used as they allowed time to cover the entire study area and for animals to immigrate/emigrate and/or die between sampling periods. The spinner dolphin population size was then estimated from models available in the program MARK (White and Burnham 1999). Pollock's robust design was used to estimate abundance (Pollock 1982) where primary and secondary levels of sampling are used. The population is assumed to be closed to additions and deletions across all secondary sampling periods within primary periods. Data within each secondary period are used to calculate abundance for each primary period. Initial analysis involved testing the fully time-dependent model for goodness-of-fit (GOF) using the program RELEASE GOF to validate model assumptions. If lack of fit was indicated from the GOF Test 2+Test 3, adjustments were made accordingly via the variance inflation factor ($\hat{c}$) for to allow for overdispersion in the data (Lebreton et al. 1992).

Encounter histories of DMIs were run through a number of models to obtain estimates of the marked individuals in the population ($\hat{N}$). A set of 14 models accounting for variation in probability of first capture (p) and recapture (c), temporary emigration (γ'', γ') and apparent survival (φ) were fitted to the data. Temporary emigration could be one of three patterns: (i) no movement ($\gamma'' = \gamma' = 0$), no emigration occurs; (ii) random ($\gamma'' = \gamma'$), probability of an individual being present in the study area is independent of whether or not it was present in the study area in the previous period; and (iii) Markovian (γ'', γ'), probability of an individual being present in the study area is conditional on whether it was present or not in the previous sampling occasion (Kendall and Nichols 1995; Kendall et al. 1997; Williams et al. 2002).

Capture probability was allowed to vary with time for each sampling occasion and was never constant because environmental conditions and sampling area were not constant. For all models, recapture probability was set to equal probability of first capture ($p = c$), as recaptures should not be affected when using photo-identification methods (Parra et al. 2006).

Model selection was based on the quasi Akaike information criterion (QAIC), whereby the model with the lowest QAIC was the best fit to the data. The difference between the best model and subsequent models is represented by delta QAIC (ΔQAIC). Models within two QAIC units of the best-fit model should not be dismissed (Burnham and Anderson 2002). The estimate of $\hat{N}$ from this model represents the marked population. These estimates were adjusted to account for the unmarked animals in the population by dividing $\hat{N}$ by the proportion of DMIs (θ) to estimate total population (N_{Total}).

The variance for the estimated total population size was obtained using the formula described in Williams et al. (1993). Log-normal 95% confidence intervals were calculated using the method described in Burnham et al. (1987). See Webster et al. (2014) for detail.

Resighting frequencies and residency

To determine the proportion of animals seen more than once the distribution of resightings was calculated for each individual. Only resightings of individuals that occurred a minimum of 24 hours apart were used in residency analysis. Additionally, the number of months an individual was seen, as a proportion of the total number of months in which at least one survey was conducted, was calculated (Parra et al. 2006).

Residency was also investigated using the sighting histories of all identified animals by calculating the lagged identification rate (LIR) in the movement model of the compiled version of SOCPROG 2.4 (Whitehead 2009).

Results

During 229 days of both behaviour and diversity surveys, 250 groups of spinner dolphins were recorded (Table 1). Groups were encountered every month between April 2008 and June 2010, with a mean size of 52.4 animals (SE 1.9, range 1–225). On average, 10% of each group consisted of calves and these were present throughout the year, but they were not included in the mark-recapture analysis. Behaviour surveys were conducted on 125 days and accounted for 57.6% of all groups encountered ($n = 144$) (Figure 2). Only photo-identifications from these behaviour surveys were used for abundance analyses.

Photo-identification and proportion of animals identifiable

In all, 8 480 good and excellent images were extracted from more than 23 000 clear dorsal fin images. From these images, 121 animals were identified and catalogued. Of these, 83 were DMIs, which were used for population analysis. The cumulative number of identified individuals increased during the first year of the study then reached a plateau (Figure 3). By the end of the first year (March 2009), 86.7% of spinner dolphin DMIs had been identified and the

Table 1: Summary of survey effort off the south-west coast of Mauritius between April 2008 and June 2010 during the diversity and behaviour surveys. The numbers of spinner dolphin groups seen during the different surveys are given

Survey period	No. of months	Total survey days	Total spinner dolphin groups	Behaviour survey days only	Spinner dolphin groups on behaviour survey days
April 2008–March 2009	12	90	95	59	64
April 2009–March 2010	12	115	131	61	72
April 2010–June 2010	3	24	24	5	8
Total	27	229	250	125	144

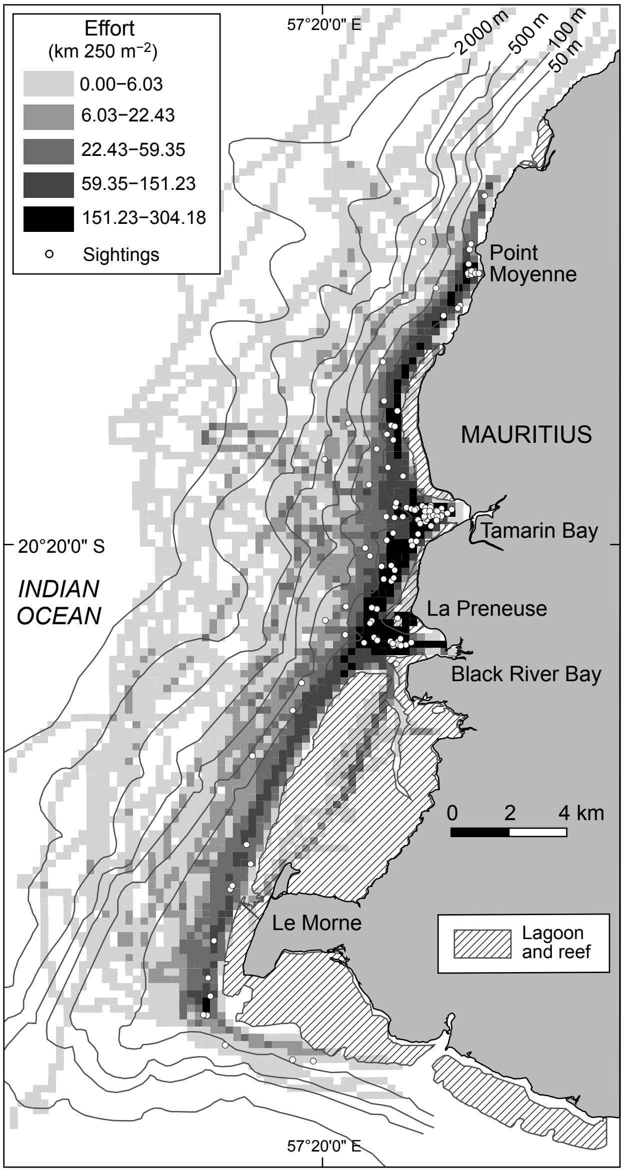

Figure 2: Distribution of effort and sightings of spinner dolphins during behaviour surveys conducted between April 2008 and June 2010

discovery rate of new individuals had averaged 6.50 (SE 2.18) animals per month. The average monthly discovery rate then decreased to 0.42 (SE 0.19) for the following 12 months, or 0.73 (SE 0.28) if the three months of the third (partial) year were included.

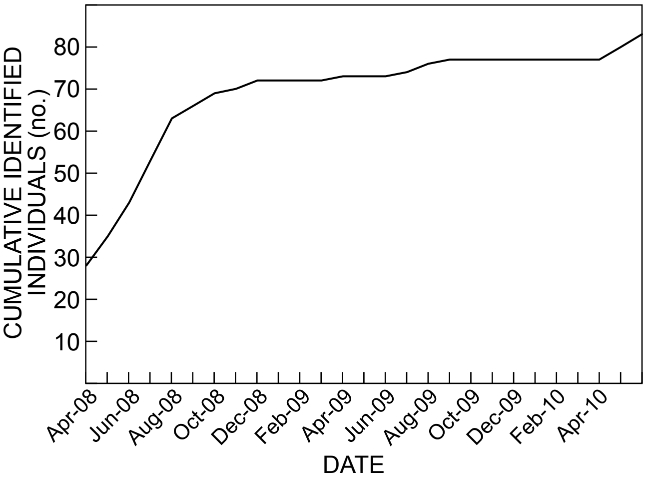

Figure 3: Rate of discovery of newly identified spinner dolphins for the period April 2008–June 2010

Analysis of all good and excellent quality fins from a random selection of 40 surveys indicated that the mean proportion of animals that were distinctively marked and could be identified over time was 0.22 (0.21 and 0.22 for Years 1 and 2, respectively).

Resighting patterns and residency

Identified dolphins were resighted between one and 45 times during the study period. Of the 83 distinctively marked spinner dolphins, 85.5% were sighted more than once, 62.7% five or more times and 39.8% 10 or more times. The mean resighting frequency per individual was 10.9 (SE 1.2).

Two DMIs were sighted in 21 of 27 months, 12 were sighted in only one month and 55.4% of DMIs were sighted in five or more months of the study ($\bar{x} = 7.4$ months; SE 0.7) (Figure 4).

Lagged identification rate

The LIR was calculated from 157 surveys and all 83 DMI spinner dolphins were included in the analysis. The model of best fit for the data (with the lowest QAIC) included emigration, re-immigration and mortality (Table 2), and the shape of the curve implies that animals were spending several days in the study area before leaving and then

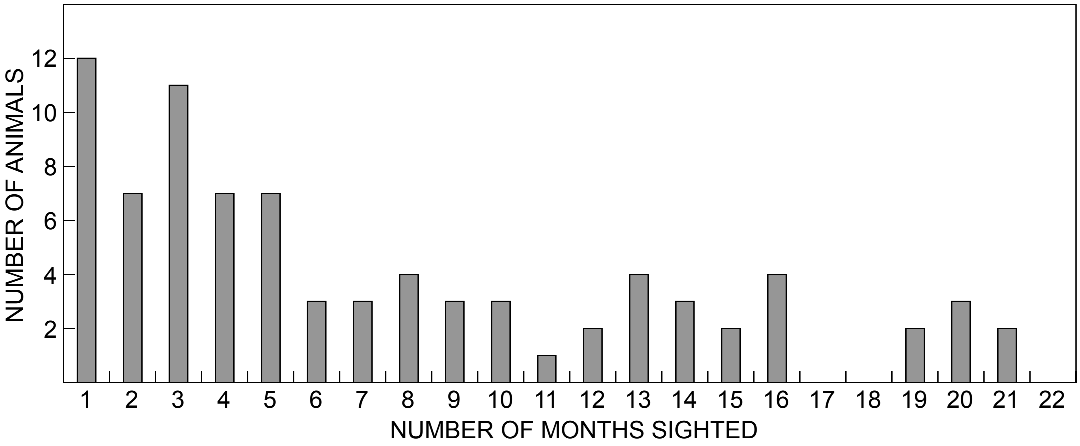

Figure 4: Sighting frequencies of distinctively marked individuals expressed in terms of the number of months in which each individual was sighted

Table 2: Comparison of the possible models of lagged identification rate for movement into and out of the study area by spinner dolphins, based on the quasi Akaike information criterion (QAIC); td = time delay in days. ΔQAIC indicates the difference between the QAIC of a given model and the minimum QAIC obtained, and a value of <2 indicates there is substantial support for the model (indicated in bold)

Model	Explanation	QAIC	ΔQAIC	Model evaluation
$(\exp(-\alpha4 \times \text{td})/\alpha1) \times ((1/\alpha3) + (1/\alpha2) \times \exp(-(1/\alpha3 + 1/2) \times \text{td}))/(1/\alpha3 + 1/\alpha2)$	Emigration/ re-immigration/mortality	112 250.2457		Best
$\alpha3 \times \exp((-\alpha1 \times \text{td}) + \alpha4 \times \exp(-\alpha2 \times \text{td})$	Emigration/ re-immigration/mortality	112 251.2276	**0.9819**	Substantial support
$(1/\alpha1) \times \exp(-\text{td}/\alpha2)$	Emigration/mortality	112 251.8197	**1.5740**	Substantial support
$\alpha2 \times \exp(-\alpha1 \times \text{td})$	Emigration/mortality	112 251.8197	**1.5740**	Substantial support
$\alpha2 + \alpha3 \times \exp(-\alpha1 \times \text{td})$	Emigration/ re-immigration	112 279.1662	28.9205	No support
$(1/\alpha1) \times ((1/\alpha3) + (1/\alpha2) \times \exp(-(1/\alpha3 + 1/\alpha2) \times \text{td}))/(1/\alpha3 + 1/\alpha2)$	Emigration/ re-immigration	112 280.1338	29.8881	No support
$\alpha1$	Closed	112 285.8024	35.5567	No support
$1/\alpha1$	Closed	112 285.8024	35.5567	No support

returning (Figure 5). The fitted model levels off above zero, suggesting that a number of animals were frequently using the study area as residents (23.33 individuals), and additional animals were moving into and out of it (Figure 5). Residence time within the study area and subsequent time outside the area before returning were estimated at 3.05 days (95% CI 0.50–31.67) and 2.46 days (95% CI 1.14–8.37), respectively. There was a second drop after more than 100 days, indicating a decrease in the number of animals within the study area. The estimate for mortality was negligible at <0.5%.

Three further models with some support are shown in bold in Table 2. All of these indicated that emigration occurred in the population under study and, of the three, the model with the best fit also included re-immigration.

Model selection and abundance estimates

The results of the GOF tests indicated overdispersion of data (χ^2 = 233.31, df = 84, p = 0.00), so the variance inflation factor $\hat{c}$ = 2.78, which was considered acceptable (i.e. <3), was used to make adjustments. Model selection was based on the QAIC corrected for small sample size (QAIC_c), and the model that best explained the data for bimonthly primary sampling periods had constant apparent survival and probability of temporary emigration, whereas probability of capture varied with time ($\varphi(.)\gamma''(.)\gamma'(.)p(t) = c(t)$) (Table 3). The next best models had ΔQAIC_c values >2, indicating that there was little support for these models and so they were not considered further. The model with the lowest QAIC_c value was based on Markovian movement where temporary emigration does not occur between the secondary sampling periods but does occur between primary periods (γ'' = 0.17, SE 0.05; γ' = 0.78, SE 0.11).

The proportion of DMIs in the population was estimated at 22%. Abundance calculations provide estimates of the total number of dolphins within the study area at any given time

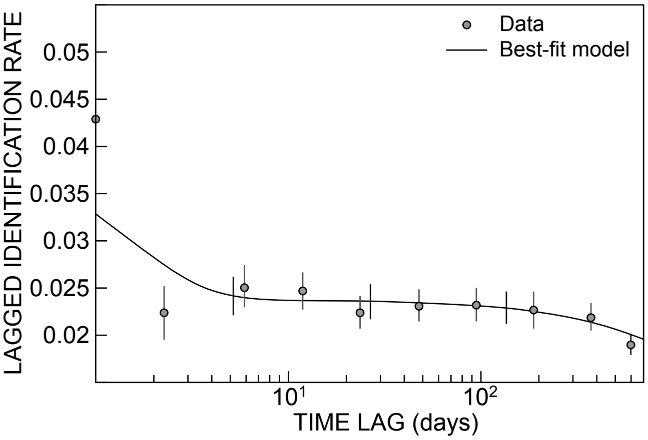

Figure 5: Lagged identification rate for all distinctively marked individual spinner dolphins. Vertical lines indicate jack-knifed error bars. The best-fit model included emigration, re-immigration and mortality, and took the form $(\exp(-\alpha4 \times \mathrm{td})/\alpha1) \times ((1/\alpha3)+(1/\alpha2) \times \exp(-(1/\alpha3+1/\alpha2) \times \mathrm{td}))/(1/\alpha3+1/\alpha2))$, where $\alpha1$ is the population in the study area (23.33 individuals; SE 9.45), $\alpha2$ is mean time in the study area (3.05 days; SE 17.96), $\alpha3$ is mean time out of the study area (2.46 days; SE 4.67) and $\alpha4$ is the mortality rate (0.0003; SE 8.93e–005)

Table 3: Robust design capture–recapture models fitted to the capture histories of 83 distinctively marked individual spinner dolphins to estimate parameters for population size ($\hat{N}$), survival (φ) emigration (γ'', γ') and capture probability (p). Capture probability was allowed to vary with time among and within primary sampling periods. Recapture probability (c) was set equal to p and therefore is not included in the model description. The quasi Akaike information criterion corrected for small sample size ($\mathrm{QAIC_c}$) was used to determine the most parsimonious model. The notation '.' indicates that a given parameter was kept constant and '*t*' indicates that a given parameter was allowed to vary with time

Model	$\mathrm{QAIC_c}$	$\Delta\mathrm{QAIC_c}$	$\mathrm{QAIC_c}$ weight
$\varphi(.)\gamma''(.)\gamma'(.)p(t)$	–85.9337	0.0000	0.96125
$\varphi(.)\gamma''(.)\gamma'(t)p(t)$	–79.4295	6.5042	0.03719
$\varphi(.)\gamma''(t)\gamma'(.)p(t)$	–72.9725	12.9612	0.00147
$\varphi(.)\gamma''=\gamma'(.)p(t)$	–66.4184	19.5153	0.00006
$\varphi(.)\gamma''(t)\gamma'(t)p(t)$	–63.1841	22.7496	0.00001
$\varphi(.)\gamma''(.)\gamma'(.)p(t)$	–62.9619	22.9718	0.00001
$\varphi(.)\gamma''=\gamma'(t)p(t)$	–58.9348	26.9989	0.00000
$\varphi(t)\gamma''(.)\gamma'(t)p(t)$	–57.3122	28.6215	0.00000
$\varphi(.)\gamma''=\gamma=0p(t)$	–54.4413	31.4924	0.00000
$\varphi(t)\gamma''(t)\gamma'(.)p(t)$	–47.5362	38.3975	0.00000
$\varphi(t)\gamma''=\gamma'(.)p(t)$	–46.4926	39.4411	0.00000
$\varphi(t)\gamma''=\gamma'(t)p(t)$	–36.5534	49.3803	0.00000
$\varphi(t)\gamma''(t)\gamma'(t)p(t)$	–36.3281	49.6056	0.00000
$\varphi(t)\gamma''=\gamma=0p(t)$	–34.8809	51.0528	0.00000

per bimonthly sampling occasion. The population estimates ($\hat{N}_{\mathrm{Total}}$) for bimonthly sampling occasions ranged between 138 (SE 77.0; 95% CI 50.0–382.9) and 398 (SE 323.0; 95% CI 98.6–1 604.9) (Table 4), with an apparent survival of 0.99 (SE 0.02).

Discussion

This study provides the first abundance estimates for spinner dolphins in Mauritius. Our results indicate that the sampling effort was sufficient to identify most of the individuals that inhibit the south-west coast of Mauritius and that the population is essentially closed with few animals entering or leaving the area. The low number of identified animals, high resighting rates and low proportion of animals seen only once (14.5%) suggests that the population is relatively small and that animals are resident.

The population inhabiting the study area was estimated at a maximum of 400 individuals, a value that can be used as a baseline for continued population monitoring. The variation in abundance estimates across sampling periods probably indicates how individuals varied their use of the study area, with a relatively high probability of temporary emigration occurring bimonthly (0.78; SE 0.11). However, a consequence of using data from the behaviour surveys only was that not all groups present on each day were sampled, and this may have increased the apparent level of temporary emigration.

Although many of the dolphins under study displayed some degree of marking, only 22% of them were considered sufficiently well marked to be used in photo-identification analysis. This proportion is similar to the 20% and 24%, respectively, reported by Norris et al. (1994) and Ostman (1994) for spinner dolphins in Hawaii. Results from other studies, however, range from 14% to 15% in Moorea, French Polynesia (Poole 1995), to 53% at Midway Atoll and 76% at Kure Atoll in the north-western Hawaiian Islands (Karczmarski et al. 2005). Reasons for this large variation are not documented but may be a result of many factors such as habitat and the behaviour of the dolphins in these populations. Also, the selection of what constitutes a well-marked animal might differ between studies and the skills of the photographer and improvements in camera technology can also be expected to be influential (Markowitz et al. 2003).

The population of spinner dolphins in Hawaii is possibly the most extensively studied of this species and is also the focus of dolphin-watching activity. Early estimates by Norris et al. (1994) were between 2 000 and 3 000 individuals around the main island of the archipelago, but the recent estimate by Tyne et al. (2014) is much smaller, at 631 individuals. Karczmarski et al. (2005) estimated considerably smaller populations of 260 and 120 for Midway and Kure atolls, respectively. At Moorea, estimates of 150 animals were reported (Poole 1995), similar to those at Hawaii's atolls. Groups of up to 2 000 animals have been observed in Brazil, indicating a local population of at least this size (Silva et al. 2005). The variation in population sizes could be a reflection of the different habitat types in terms of number and size of available, protected resting sites, proximity to feeding areas and isolation.

The size of the population along the south-west coast of Mauritius is comparable to those found at some Hawaiian atolls. However, the study site represents only a small

Table 4: Capture–recapture estimates of abundance for distinctively marked individual (DMI) spinner dolphins and corrected abundance estimates taking into account the proportion of unmarked individuals within the study area; *n* = number of individuals captured, $\hat{N}$ = estimated distinctively marked population size, SE = standard error, CI = confidence interval, $\hat{N}_{\text{Total}}$ = estimated total population size after correcting for the proportion of DMIs

Bimonthly occasion	*n*	Distinctively marked population			Total population		
		$\hat{N}$	SE	95% CI	$\hat{N}_{\text{Total}}$	SE	95% CI
1	35	87.5	65.4	–40.6–215.7	397.8	323.0	98.6–1 604.9
2	42	55.1	10.7	34.1–76.1	250.5	87.6	128.8–487.4
3	45	52.1	6.8	38.8–65.3	236.7	73.2	130.9–428.1
4	44	49.2	5.7	38.0–60.3	223.6	68.5	124.3–402.3
5	44	46.8	4.9	37.2–56.4	212.7	64.4	119.1–380.0
6	19	33.6	12.0	10.1–57.1	153.6	85.5	54.8–425.0
7	35	42.7	7.4	28.2–57.2	194.0	70.3	97.5–386.2
8	39	41.7	4.0	33.8–49.6	189.5	60.0	103.4–347.3
9	48	58.3	8.2	42.2–74.4	265.1	81.1	147.4–476.5
10	23	45.8	16.5	13.5–78.2	208.3	111.0	78.2–555.0
11	19	30.4	10.7	9.5–51.4	138.4	77.0	50.0–382.9
12	14	32.6	15.8	1.7–63.4	148.0	103.3	43.0–509.0
13	37	64.2	18.2	28.4–99.9	291.6	122.5	132.3–642.8

proportion of the Mauritian coastline. Spinner dolphins have been observed at other regions around the coast of Mauritius. A number of surveys were conducted along the coast to the north of the study area and among the northern islands to determine the extent of the distribution of spinner dolphins in Mauritian waters (IW unpublished data). Analysis of photographs taken in 2009 of spinner dolphins occurring in groups of 50 individuals at Port Louis, some 10 km north of our study area (V Dulau-Drouot, GLOBICE, pers. comm.), resulted in 12 matches with individuals known from our study, indicating that our study group was using at least 40 km of the west coast. During the northern surveys, three groups of spinner dolphins were found in bays similar to those in our study area, on two of the three days sampled. Group sizes ranged between around 20 and 90 animals. Photo-identification failed to find any matches between these animals and those in our study, but at least one match was found between days, among the northern groups. Further, several sightings (but no photographs) of spinner dolphins occurred in 2009 and 2010 between the northern islands and have been reported by researchers based on Round Island Nature Reserve, approximately 22 km off the north coast (R Baxter, Mauritian Wildlife Foundation, pers. comm.; see Figure 1). Although the data from the northern parts of Mauritius are limited, the lack of matching between the groups found in our study area and those sighted in the north suggests that groups exhibit fidelity to particular areas of the coast.

The LIR results suggest movement into and out of the study area every couple of days, which is likely a result of the timing of surveys because they were generally conducted every 2–3 days but not normally over weekends, and hence the apparent lack of identifications during these times. Daily surveys might demonstrate an almost-constant presence for this population. In addition, the nature of the surveys was such that it is probable that not all groups that were present within the study area at a given time were photographed, resulting in the apparent absence of such groups when, in fact, they might have been in a different bay to where the dolphin watching was occurring. The accumulation of additional data over a longer period will improve the accuracy of the results and increase our understanding of the movement patterns of the population.

Management and conservation

The intense anthropogenic activity along the south-west coast of Mauritius has implications for the persistence of the dolphin population in this region. With their predictable, almost daily, occurrence in the bays, and large group sizes, the local population of spinner dolphins, as well as that of the Indo-Pacific bottlenose dolphin *Tursiops aduncus* (Webster et al. 2014), has become the target of tourism operations. In 2009, the MMCS recorded more than 60 operators (>120 boats) offering dolphin-watching and swim-with-dolphins activities every day of the year (IW unpublished data).

Resighting frequencies and the limited number of new individuals identified suggest that the same animals are using this area of coast and are being repeatedly subjected to the disturbance of dolphin watchers. Anthropogenic activities, particularly whale- and dolphin-watching, have been shown to interfere with and influence the behaviour of the focus animals. Boat traffic can cause dolphins to change swimming speed and direction of movement, vocalisation frequency, respiration rate and frequencies of aerial behaviours (Au and Perryman 1982; Janick and Thompson 1996; Constantine and Baker 1997; Constantine et al. 2004; Lemon et al. 2006; Delfour 2007; Steckenreuter et al. 2012a). Furthermore, there is evidence that dolphins and whales avoid areas of high boat traffic (Lusseau 2004; Bejder et al. 2006; Steckenreuter et al. 2011). Theoretically, the long-term disturbance of groups could directly affect the survivability of a population through increased risk of harassment and injury, and diminished reproductive capacity (Janick and Thompson 1996; Stensland et al. 2006; Stensland and Berggren 2007).

The global rapid growth of dolphin-watching tourism since the late 1990s (O'Connor et al. 2009) has led to increased boat traffic, noise and water pollution. When combined with extensive coastal development, the sustainability of species in such hostile environments is of concern. Control of dolphin-watching activity off south-west Mauritius needs to be implemented urgently and policed in order to reduce possible impacts to the spinner dolphin population using this area.[1] The effectiveness of such controls can be enhanced with the addition of varying protection zones (protected area networks), which have been employed successfully in cetacean conservation elsewhere (UNEP-MAP RAC/SPA 2011; Steckenreuter et al. 2012b). These methods would ensure that multiple marine species and habitats can be managed sustainability, as can marine activities that Mauritius relies upon for revenue (e.g. diving, snorkelling and fishing) (Daby 2003).

Our study has provided, for the first time, baseline information against which future comparisons can be made to monitor possible fluctuations in the local spinner dolphin population and to assess the effectiveness of management measures. As this population is exposed repeatedly to dolphin-watching activity and is relatively small, it is likely to be vulnerable to disturbance. It is recommended that mark-recapture studies of the local population are continued but it is also important to extend the area surveyed to obtain more comprehensive data on the spatial distribution of spinner dolphins off Mauritius as a whole. Opportunistic data collected from sites around the island can be used for multi-site mark-recapture analysis (Durban et al. 2005) to determine the full distributional range of identified individuals and the degree of overlap between localised populations or subpopulations. Such data will also enable the areas of importance for such populations to be determined and will provide an estimate of the overall abundance of spinner dolphins off Mauritius.

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[1] Legislation regarding dolphin watching came into effect on 1 March 2013. Skippers and operators are required to attend training sessions regarding the legislation itself, dolphin and whale species identification and behaviour recognition, and several other aspects of the industry. Almost 400 skippers attended training in February, March and November 2013. Although changes can be seen in the behaviour of boats, further awareness and training is necessary. Also, law enforcement should be intensified to ensure compliance by new entrants

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