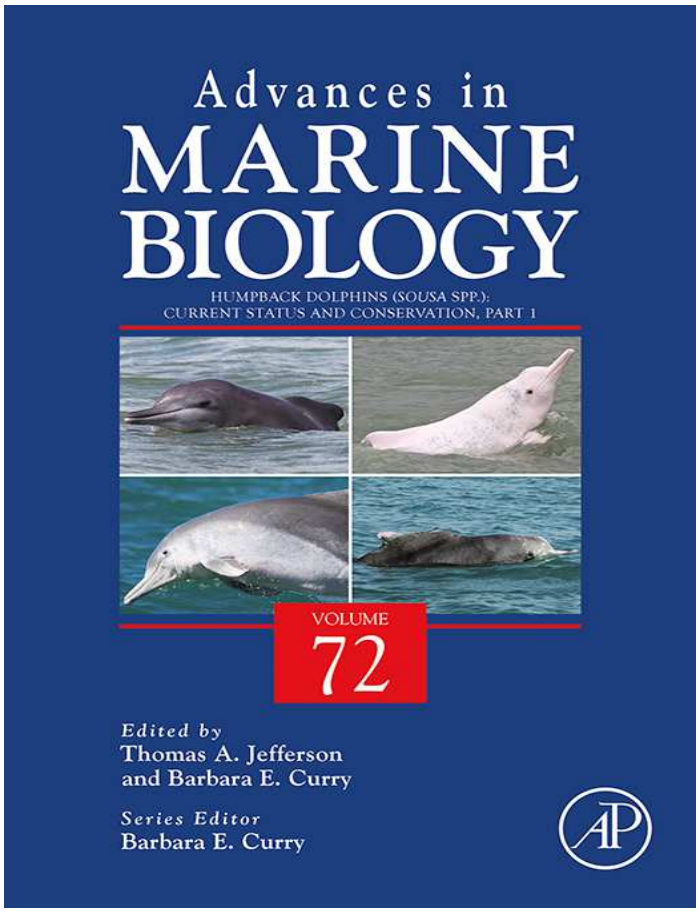

From Salvatore Cerchio, Norbert Andrianarivelo and Boris Andrianantenaina, Ecology and Conservation Status of Indian Ocean Humpback Dolphins (*Sousa plumbea*) in Madagascar. In: Thomas A. Jefferson and Barbara E. Curry, editors, *Advances in Marine Biology, Vol. 72*, Oxford: Academic Press, 2015, pp. 163-199.
ISBN: 978-0-12-803258-9

CHAPTER SEVEN

Ecology and Conservation Status of Indian Ocean Humpback Dolphins (*Sousa plumbea*) in Madagascar

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Contents

Abstract

The Indian Ocean humpback dolphin (*Sousa plumbea*) has been studied in several range states in the Southwest Indian Ocean, however little information exists on populations in Madagascar. Here, we review available literature and describe a study on *S. plumbea* conducted between 2004 and 2013 on the west coast of Madagascar, involving boat-based field surveys in the southwest and northwest regions, and interview surveys with local fishers from villages along most of the west coast. Field surveys in the southwest region of Anakao/St. Augustine Bay revealed low encounter rates and mean group size, and markedly declining trends in both from 1999 to 2013. Conversely, in the northwest region around Nosy Be and Nosy Iranja, encounter rates were higher, as were mean group sizes, suggesting an apparently more abundant and less impacted population. Interview surveys revealed by-catch of coastal dolphins along the entire west coast, including *S. plumbea*, as well as other species. Directed hunting, including drive hunts

Advances in Marine Biology, Volume 72
ISSN 0065-2881
http://dx.doi.org/10.1016/bs.amb.2015.09.004

of groups of dolphins, was reported primarily in the southern regions, in the range of the Vezo Malagasy ethnicity; however, there was evidence of hunting starting in one area in the northwest, where hunting dolphins is normally considered taboo for the predominant Sakalava ethnicity. Thus, the conservation status of *S. plumbea* in Madagascar appears to be spatially heterogeneous, with some areas where the local population is apparently more impacted than others. Conservation measures are recommended to mitigate further decline in the southwest of Madagascar, while protecting habitat and ensuring resilience in the northwest.

1. INTRODUCTION

The Indian Ocean humpback dolphin (*Sousa plumbea* G. Cuvier, 1829) has recently been re-established as a distinct species, separated from *Sousa chinensis* after a protracted series of studies and reviews debating the phylogeny and taxonomy of the genus (Cockcroft et al., 1997; Frère et al., 2008; Jefferson and Karczmarski, 2001; Jefferson and Rosenbaum, 2014; Jefferson and Van Waerebeek, 2004; Mendez et al., 2013; Rice, 1998). The most recent and comprehensive assessments (Jefferson and Rosenbaum, 2014; Mendez et al., 2013) support a range extent for *S. plumbea* encompassing the coastal waters of the western Indian Ocean from approximately E20° to E95° longitude, or from western South Africa to Myanmar. In this chapter, we briefly review currently available information on the species in Madagascar, and then report general results of (i) extensive field survey work from 2004 to 2013 in locations on the southwest and northwest coasts of Madagascar, and (ii) socio-ecological interview surveys from 2010 to 2013 with local fishers in villages spread along the entire west coast of Madagascar.

1.1 Current Knowledge on *S. plumbea* in Madagascar

Within the Southwest Indian Ocean (SWIO), populations of *S. plumbea* have been documented and studied to varying extents in South Africa (Algoa Bay: Karczmarski, 1999; Karczmarski et al., 1998, 1999a,b; Richards Bay/KwaZulu Natal: Atkins and Atkins, 2002; Atkins et al., 2004; Keith et al., 2002, 2013), Mozambique (Maputo Bay: Guissamulo, 2007; Guissamulo and Cockcroft, 2004; Peddemors and Thompson, 1994), Tanzania (Zanzibar: Amir et al., 2002, 2005b; Stensland et al., 2006) and Madagascar (Andrianarivelo, 2001; Cerchio et al., 2009a; Razafindrakoto et al., 2004). Significant population structure in the mtDNA control region

has recently been reported along the East Africa coast, with little/no evidence for genetic structure between South Africa and Mozambique samples, but strong genetic differentiation between South Africa/Mozambique and Tanzania, and between Tanzania and Oman samples (Mendez et al., 2011). Two Madagascar samples included in the analysis were generally associated with the Tanzania samples in a haplotype network, suggesting a closer population connection with Tanzania than with South Africa/Mozambique; however, the sample size was too small to include in statistical analyses.

Information on *S. plumbea* in Madagascar is highly limited and currently consists of a single published review of existing records (Razafindrakoto et al., 2004), and several unpublished reports and documents many of which focused on broader topics (Andrianarivelo, 2001; Cerchio et al., 2009a; Cockcroft and Young, 1998; Cockcroft, 1993; Collins et al., 2009; Laran et al., 2012; Razafindrakoto et al., 2008; Robineau and Rose, 1984; Van Canneyt et al., 2010). There is documentation of *S. plumbea* in several locations along the west coast of Madagascar: in the far northwest off Nosy Be and Nosy Mitsio (Cerchio et al., 2009a; Cockcroft and Young, 1998; Robineau and Rose, 1984); on the lower northwest coast in the Loza Lagoon system, approximately 150 km north of Mahajunga, during the response to a mass stranding of melon-headed whales (*Peponocephala electra*) (Collins et al., 2009), and off Mahajanga (Cockcroft and Young, 1998; Razafindrakoto et al., 2004); during aerial surveys along extensive stretches of coast around Madagascar, in the northwest between Mahajanga and Nosy Be, in the mid-west south of Maintirano and in the southwest north of Morombe and near Andavadoake (Laran et al., 2012; Van Canneyt et al., 2010); and most extensively in the southwest off Anakao (Andrianarivelo, 2001; Cerchio et al., 2009a; Razafindrakoto et al., 2004). There are no documented observations of *S. plumbea* along the northeast coast of Madagascar, despite extensive cetacean surveys in near-shore waters of Antongil Bay from 1996 to 2006 (Cerchio et al., 2009b; Ersts and Rosenbaum, 2003), regular whale-watching tours around Ile Saint Marie from 1999 to 2008 (Vely et al., 2009), shorter expeditions along the Masoala Peninsula's east coast (M. Vely, Megaptera NGO, personal communication, 23 March 2015) and west coast (S. Cerchio, personal observation, July 2005), and aerial surveys from the Masoala peninsula to Tamatave (Laran et al., 2012). On the southeast coast, Razafindrakoto et al. (2004) reported the absence of sightings from Fort Dauphin. However, there are some anecdotal reports from Fort Dauphin, and for the deep-south coast near Cap St.

Marie in July/August of 2000 (M. Nicoll, personal communication, 24 March 2015). There are no reports known to us along the large stretch of east coast from Fort Dauphin to Ile St. Marie, or north of the Masoala Peninsula, but there is also a complete lack of survey effort in these regions. Therefore, the range is suspected to be restricted largely to the west coast, and likely around the south coast to Fort Dauphin.

By-catch and hunting, along with consumption and sale of dolphin meat has been reported from most sources assessing fisheries interactions in Madagascar (Cockcroft and Young, 1998; Razafindrakoto et al., 2004, 2008; Robineau and Rose, 1984). Socio-ecological interview surveys in the southwest in 1999 indicated extensive hunting of coastal dolphins by Anakao fishermen of Vezo ethnicity (Andrianarivelo, 2001). Dolphin species most often taken were the spinner dolphin, *Stenella longirostris*, the Indo-Pacific bottlenose dolphin, *Tursiops aduncus* and *S. plumbea*. Vezo fishers hunted coastal dolphins for local consumption and sale of meat, and the most serious drive hunts are associated with the period between August and December, when fishermen aggregate to fish for bonefish, *Albula vulpes*, and Indian anchovy, *Stolephorus indicus*. Fishers thus have the opportunity to cooperate for corralling and hunting dolphins in a drive hunt. Andrianarivelo (2001) estimated that over 6000 individual dolphins, predominantly *Stenella* spp. and *Tursiops* spp., but also *S. plumbea*, were taken between 1985 and 1999 from a single village, Anakao, with a substantial increase in catches evident during 1995–1999 accounting for 57% of all catches (Cerchio et al., 2009a). The trend suggested an increase in intensity of hunting and in the impact on populations; this was likely associated with a change in hunting technique (from harpoons to nets) in the mid to late 1980s, and depletion of other food resources (e.g. decrease in fish populations), and subsequent increased adoption of cetacean hunting and consumption throughout the 1990s.

Based on the interview surveys, Andrianarivelo (2001) estimated a minimum of 61 mortalities of *S. plumbea* between 1985 and 1999 in Anakao, 26 reported as directed hunting, and 35 as 'strandings', which the author interpreted as likely related to drive hunts. As with the overall mortality numbers, the majority occurred between 1995 and 1999, including 58% of reported hunts and 49% of 'strandings'. Interestingly, there were no reports of *S. plumbea* by-catch and few by-catch reports of other species. During 2005 a renewed interview effort, including other surrounding villages, revealed a reported 56 by-catch events between 2000 and 2005, accounting for 79 taken individuals, 12 of which were *S. plumbea* (Razafindrakoto et al., 2008). All *S. plumbea* by-catches occurred in a

large-mesh gillnet called 'Jarifa' used primarily to catch sharks. Considering that only a fraction of fishers in this region were interviewed in these studies, the numbers reported for hunting and by-catch likely underestimate the total mortality. There is no reliable abundance estimate or trend for the population, but given the relatively small population sizes reported throughout the SWIO region, the reported mortality rate due to fisheries interactions in the Anakao region is almost certainly unsustainable.

The remainder of this chapter reports on research conducted between 2004 and 2013, investigating the diversity, distribution and status of cetacean populations on the west coast of Madagascar, which focused on coastal dolphin species *S. plumbea* and *T. aduncus*. Small boat-based field surveys were conducted in two regions, the southwest around Anakao and the northwest around Nosy Be, and socio-ecological interviews were conducted in villages spread widely along the majority of the west coast.

2. DOLPHIN SURVEYS ON THE WEST COAST OF MADAGASCAR

Between 2004 and 2013, coastal dolphins including *S. plumbea* and other cetacean populations were assessed in two major regions of Madagascar (Figure 1). On the southwest coast during 2004–2009 the site was the Anakao/Saint Augustine Bay region, where previous socio-ecological interview work indicated extensive dolphin hunting as well as incidental by-catch in artisanal fisheries (Andrianarivelo, 2001; Razafindrakoto et al., 2004, 2008).

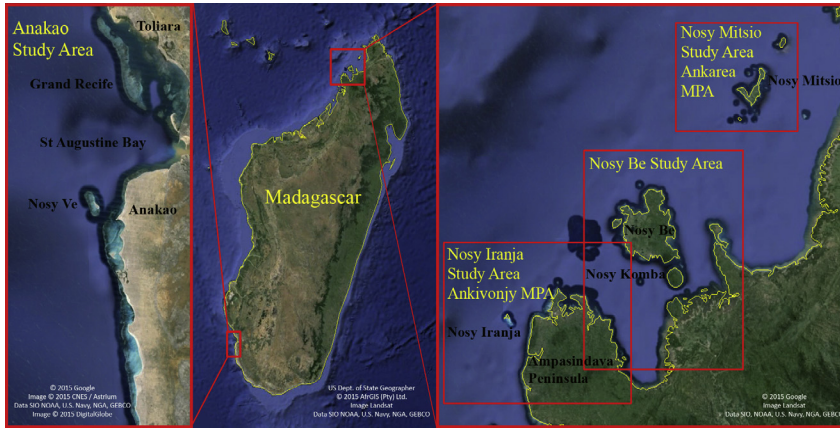

Figure 1 Dolphin survey study sites on Madagascar from 2004 to 2013, showing details of the southwest (Anakao) and northwest (Nosy Be, Nosy Mitsio and Nosy Iranja) study areas.

On the northwest coast during 2007–2013 the site included Nosy Be, Nosy Mitsio and Nosy Iranja/Ampasindava Peninsula, regions where there were anecdotal reports of high encounter rates of *S. plumbea* around Nosy Be (J. Kiszka, University of La Rochelle, personal communication, early 2007), and conservation concerns related to two recently created marine protected areas (MPAs), the Ankarea MPA covering 173,690 ha, and the Ankivonjy MPA covering 196,659 ha.

2.1 General Methodology

Boat surveys were conducted from an eight metre outboard boat with two to four observers. Previous work in Madagascar (Andrianarivelo, 2001; Razafindrakoto et al., 2004) and elsewhere in the SWIO (Atkins et al., 2004; Karczmarski et al., 2000; Keith et al., 2013; Stensland et al., 2006) has indicated that *S. plumbea* is almost exclusively distributed in shallow water (<25 m depth), often very close to coasts and fringing reefs. Initial effort in 2004 and 2005 in the southwest, employed standardized line-transect surveys with parallel transect lines that were orthogonal to the bathymetric gradient. However, weather-related time constraints and sparse distribution yielded low effort in shallow water and low encounter rates for coastal dolphins, and consequently these transects were highly inefficient. Therefore, near-shore transects parallel to the coast and fringing reefs were employed to effectively cover shallow-water coastal habitat and maximize encounters with coastal dolphins. For deep water surveys past the shelf break in the northwest, saw-tooth and parallel transects were conducted orthogonal to the bathymetric gradient in order to ensure equal-coverage of different depth regimes. Daily boat tracks and precise records of effort were logged so as to calculate standardized sighting per unit effort (SPUE) measures. Three types of search effort were logged: (1) coastal waters (generally shallower than 20 m), (2) open shelf waters (generally, but not always, greater than 20 m and less than 100 m), and (3) deep offshore waters (generally greater than 100 m; exclusively off Nosy Iranja). When groups of dolphins were encountered, every possible effort was made to obtain individual identification photographs of right and left sides of dorsal fins from each individual. To infer depth of sightings, bathymetric data were downloaded from the 2014 GEBCO dataset (www.gebco.net), and sighting depths in the northwest were improved from georeferenced digital scans of marine navigational charts. Due to gross inaccuracy of available data for the southwest, depth inference was not attempted there.

2.2 Effort Summary

Effort is reported in terms of the actual daily boat tracks (Figures 2–4), kilometres of track line, total boat-hours, and hours searching in three categories of habitat (Table 1). In any given year/region, a concerted attempt was made to spread effort throughout the region within the safe working range of our boat, focusing on different areas on consecutive days. In the Anakao region, surveys were conducted in six years between 2004 and 2013, primarily in the austral winter/spring months of July to October (Tables 1 and 2), and encompassed all coastal waters north and south of Anakao (Figure 2). The year 2004 was a pilot season by a different team, before effort recording protocol was established and without the collection of GPS track data, so 2004 is not represented in track data or SPUE calculations. In the Nosy Be region, surveys were conducted each year from 2007 to 2012, with all effort prior to 2012 in the austral winter/spring months of July to October, the 2012 effort primarily in December (see Tables 1 and 2), and encompassed all coastal waters around Nosy Be, adjacent small islands, and the Madagascar mainland (Figure 3). The year 2007 was a short pilot season of 1 week, and the 2010 season was also a single-week short visit. During July and November 2011, surveys were conducted in the Nosy Mitsio island group (Ankarea MPA), and were focused in all coastal waters around the main island and all surrounding small islands, as well as offshore around near-by shallow banks. In the Ankivonjy MPA, surveys were conducted during 2012 and 2013 in coastal waters around Nosy Iranja and along the coast of the Ampasindava peninsula, on the shallow shelf between Nosy Iranja and the coast, and offshore past the shelf break (see Table 1; Figure 3).

2.3 Sightings and Encounter Rates

Species diversity ranged among the sites from 15 cetacean species sighted off Anakao and 14 species sighted off Nosy Iranja, to six species in the Nosy Be region and three species off Nosy Mitsio (S. Cerchio, unpublished data). In each site, Indian Ocean humpback dolphins and Indo-Pacific bottlenose dolphins were sighted with varying frequency. Although here we focus on *S. plumbea*, we also note the presence of *Tursiops* spp., since they broadly co-occur in the same habitat and were regularly sighted in mixed species groups. In the north study sites, *T. aduncus* and probably the common bottlenose dolphin, *T. truncatus* were observed, both at times in association with *S. plumbea*. *Tursiops truncatus* was clearly more robust, moderately larger in length, and had an apparent lack of spots on the belly.

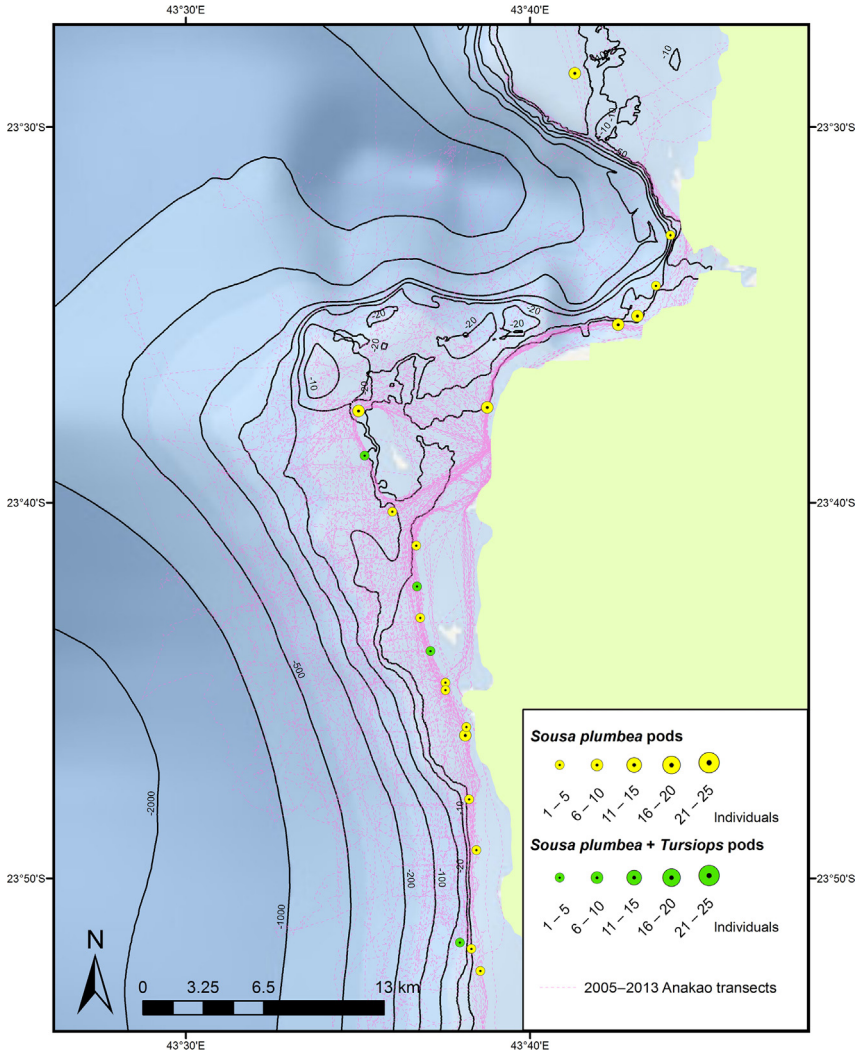

Figure 2 Effort and coastal dolphin sightings in the Anakao study area, all years 2004–2013. Bathymetric data were downloaded from the 2014 GEBCO dataset (www.gebco.net) in the form of a 1 arc second raster format and contour lines were extruded from the underlying raster using the Contour tool. However, inaccuracy of the data along the coastline led us to amend the GEBCO dataset with soundings taken in the field defining fringing reefs before re-interpolating a more accurate bathymetric raster using the Topo to Raster tool in ArcGIS v.10.2.

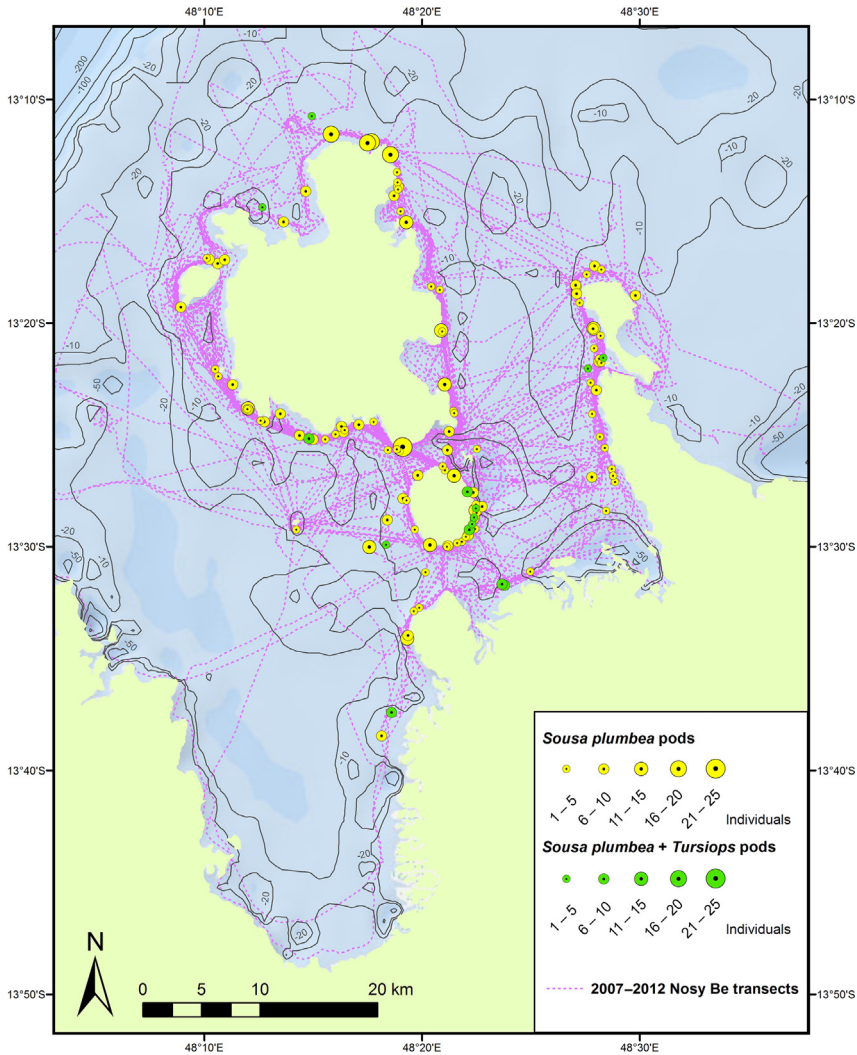

Figure 3 Effort and coastal dolphin sightings in the Nosy Be study area, all years 2007–2012. Bathymetric data were downloaded from the 2014 GEBCO dataset (www.gebco.net) in the form of a 1 arc second raster format and contour lines were extruded from the underlying raster using the Contour tool.

2.3.1 Anakao Region

Groups of *S. plumbea* were encountered on 23 occasions during the 6 study years off Anakao, and were moderately more common than *T. aduncus* (Table 3). Group size of *S. plumbea* was generally small, ranging from

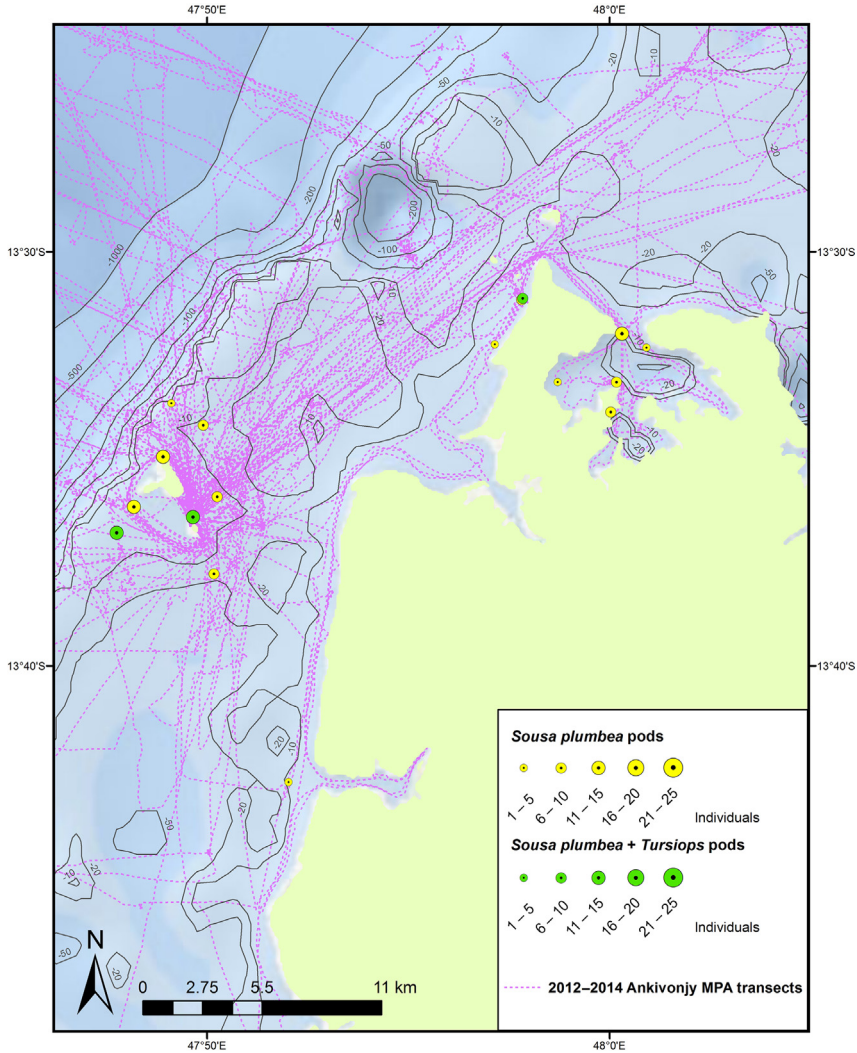

Figure 4 Effort and coastal dolphin sightings in the Nosy Iranja/Ankivonjy MPA study area. Bathymetric data were downloaded from the 2014 GEBCO dataset (www.gebco.net) in the form of a 1 arc second raster format, and bathymetric contour lines were extruded from the underlying raster using the Contour tool.

one to nine individuals, with a mean of 3.6 (SD 2.7); mean group size for *T. aduncus* was somewhat larger at 6.1 (SD 3.5) individuals (Table 4). Mixed species groups of *S. plumbea* and *T. aduncus* were encountered on five occasions.

Table 1 Distribution of Dolphin Survey Effort By Year Off Anakao, Nosy Be, Nosy Mitsio, and Nosy Iranja

Southwest	Anakao						
Effort Type	**2004**	**2005**	**2006**	**2007**	**2009**	**2013**	**Total**
Boat days	23	25	35	19	19	11	132
Total km		1442	2243	1399	1300	1084	7467
Total hours		105	187	142	133	95	663
Search effort hours							
Coastal		20	34	13	16	35	117
Open shelf+ deep offshore		27	44	33	24	13	141
Total		47	78	46	40	48	258

Northwest	Nosy Be							Nosy Mitsio	Nosy Iranja		Grand Total
Effort Type	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**Total**	**2011**	**2012**	**2013**	
Boat days	6	21	17	5	24	15	88	17	17	24	146
Total km	517	1772	1502	340	2092	1384	7607	1336	1561	1954	12,458
Total hours	50	160	135	31	185	118	679	113	132	181	1105
Search effort hours											
Coastal	18	67	47	13	65	40	251	41	19	20	331
Open shelf	11	17	18	2	23	32	103	35	4	41	183
Deep offshore									40	31	70
Total	29	84	65	15	88	72	354	76	63	92	584

Effort is expressed as total working boat days, kilometres of track line, and hours on water. Time spent actively searching for cetaceans is expressed in three broad habitat categories: along the coast or fringing reefs (Coastal), on the open water shelf (Open shelf), or in deep water past the shelf break (Deep offshore); in Anakao no distinction was made between the latter two categories due to the lack of a distinct shelf break on available digital charts.

Distribution of *S. plumbea* was exclusively along the coasts and fringing reefs of the study area (see Figure 2), typically within 100–200 m of the break zone. During 2004, a concerted effort of standardized track lines (not depicted in Figure 2, due to lack of GPS track data) was made to search

Table 2 Distribution of Dolphin Survey Effort by Month off Anakao and Nosy Be

	Anakao							Nosy Be						
Month	**2004**	**2005**	**2006**	**2007**	**2009**	**2013**	**Total**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**Total**
June				22.5			22.5							
July				119.6	12.8		132.4					74.8		74.8
August			9.5		120.5	95.4	225.4			16.6		109.9		126.5
September			120.3				120.3	6.6	160.1	118.6				285.3
October		80.1	57.5				137.7	43.2			31.3			74.6
November		25.2					25.2						12.5	12.5
December													105.8	105.8

Effort is expressed in total hours on water.

Table 3 Encounters with Groups of Coastal Dolphins Off Anakao, Nosy Be, Nosy Mitsio, and Nosy Iranja

Southwest	Anakao						
Species	**2004**	**2005**	**2006**	**2007**	**2009**	**2013**	**Total**
Sousa plumbea	6	5	4	4	3	1	23
Tursiops aduncus	4	3	2	2	1	1	13

Northwest	Nosy Be						Nosy Mitsio	Nosy Iranja		
Species	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2011**	**2012**	**2013**	**Total**
Sousa plumbea	9	35	18	5	40	19	2	10	6	144
Tursiops aduncus	2	8	4	1	11	1	0	3	6	36
Tursiops sp.	0	4	4	1	2	3	5	0	1	20

Values represent the number of groups encountered while surveying; mixed species groups (see Table 5) are counted twice, once for each species.

Table 4 Group Size of Coastal Dolphins Encountered Off Anakao, Nosy Be, Nosy Mitsio, and Nosy Iranja

Southwest	Anakao						
Species	**2004**	**2005**	**2006**	**2007**	**2009**	**2013**	**Overall**
Sousa plumbea	5.5	4.4	2.8	1.5	3.0	1.0	3.6
Tursiops aduncus	10.0	4.3	2.5	4.5	4.0	8.0	6.1

Northwest	Nosy Be							Nosy Mitsio	Nosy Iranja		
Species	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**Overall**	**2011**	**2012**	**2013**	**Overall**
Sousa plumbea	4.9	4.7	5.7	5.0	6.7	7.3	5.9	1.0	6.5	8.2	7.1
Tursiops aduncus	2.5	5.8	6.8	7.0	4.6	4.0	5.2		7.0	8.2	7.8

Values represent means of 'best' estimates of group size across all encountered pods of each species, and include single individuals as a group size = 1. During sightings, group size is recorded as minimum, best and maximum estimates, all of which being equivalent when size is confidently determined.

the shallow lagoons within the fringing reef stretching from Anakao to the south, and within the Grand Récif de Toliara, north of St. Augustine Bay (see Figure 1), with no sightings of *S. plumbea*. Only a single incidental lagoon sighting was made inside the Grand Récif during a transit to Toliara

in 2005 (see Figure 2). Besides the lack of sightings within lagoons, there were no obvious indications of habitat avoidance or preference, or spatial clustering of encounters, with sightings spread fairly evenly south of Anakao and along the coast of St. Augustine Bay.

Encounter rates for *S. plumbea* and *T. aduncus* were calculated as SPUE for both groups and individuals, using the effort spent searching in coastal waters (no sightings occurred during other search effort categories) for each year individually and across all years (Table 5). Encounter rate for *S. plumbea* was generally low with an overall mean of 0.42 individuals sighted per hour of search time (ind/h). The lowest encounter rate was observed in 2013 (0.03 ind/h), when the team returned to Anakao four years after the main study period and encountered only one individual, despite 34.7 h of coastal search effort representing the most in any single year. Groups of *T. aduncus* were less frequently encountered (0.08 gp/h overall), but had a similar individual encounter rate (0.33 ind/h) due to the larger mean group size as compared to *S. plumbea*.

Table 5 Group Encounter Rates (Top Rows) and Individual Encounter Rates (Bottom Rows) for Coastal Dolphin Species By Year

Southwest	Anakao						
Species	**2004**	**2005**	**2006**	**2007**	**2009**	**2013**	**Overall**
Sousa plumbea	n.a.	0.25	0.12	0.31	0.19	0.03	0.14
	n.a.	1.11	0.32	0.46	0.57	0.03	0.42
Tursiops aduncus	n.a.	0.15	0.06	0.15	0.06	0.03	0.08
	n.a.	0.66	0.15	0.70	0.25	0.23	0.33

Northwest	Nosy Be							Nosy Mitsio	Nosy Iranja		
Species	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**Overall**	**2011**	**2012**	**2013**	**Overall**
Sousa plumbea	0.49	0.52	0.38	0.38	0.61	0.48	0.50	0.05	0.52	0.30	0.41
	2.40	2.44	2.18	1.90	4.10	3.46	2.95	0.05	3.38	2.43	2.89
Tursiops aduncus	0.11	0.12	0.08	0.08	0.17	0.03	0.11		0.13	0.10	0.11
	0.27	0.69	0.57	0.53	0.78	0.10	0.56		1.09	2.43	1.78

To calculate encounter rates for *S. plumbea* and *T. aduncus*, the total number of groups or individuals encountered was divided by the total effort searching to derive number of groups or individuals sighted per hour search effort.

2.3.2 Nosy Be Region

Sousa plumbea was the most commonly sighted cetacean around Nosy Be by nearly fivefold, with 126 encounters of groups over the six years, as compared to 27 groups of *T. aduncus* (Table 3). There were many re-sightings of individuals across encounters (mark–recapture using photographic identification will be useful for future estimates of population abundance for *S. plumbea*). Average group size for *S. plumbea* was 5.9 (SD 4.2) individuals across the entire six years (Table 4), with a maximum group size of 22 individuals encountered in 2011, and a total of 22 groups with greater than 10 individuals across all years. Average group size for *T. aduncus* was similar (see Table 4), however, with lower maximum size of 10 individuals, observed on two occasions. Groups of *S. plumbea* were sighted in association with both forms of *Tursiops* spp., but much more commonly with *T. aduncus* (11 of 14 encounters of mixed species groups). During these encounters, individuals of the two species were clearly associating, typically forming subgroups of one or two members of each species, as opposed to subgroups of entirely the same species segregated from each other. In some instances, it appeared that multiple *Tursiops* were pursuing or chasing a single *S. plumbea*, but on at least one occasion the reverse was occurring.

Distribution of *S. plumbea* around the Nosy Be region was heterogeneous, with several areas appearing to be favoured by dolphins (see Figure 3). The pattern of geographic distribution was consistent across the four main sampling years. There were several cases noted of individuals being re-sighted across encounters and years within the same general area, suggesting there might be site fidelity within the high sighting probability areas and restricted individual ranges. Heterogeneous distribution and site fidelity can be tested by spatially modelling encounter probability and assessing photographic recapture within areas of high sighting probability. The mean depth of sightings was 8.2 m (SD 5.15 m), with a maximum depth of 25 m and 95% of sightings $<$20 m.

Sousa plumbea in the northwest had the highest encounter rates for coastal dolphin species across the entire study, and around Nosy Be ranged from a low in 2009 at 1.90 ind/h, to a high in 2011 at 4.10 ind/h (Table 5). Considering variation across the six survey months (July to December), the months of July and August had the highest encounter rates (Table 6). However, year and month are conflated, since all July effort and the majority of August effort occurred in 2011 (see Table 2), so it is difficult to distinguish between seasonal and yearly effects without further sampling. Moreover, it is yet to be determined if this variation in SPUE is real or a product of variation

Table 6 Individual Encounter Rates for Dolphins by Month for Nosy Be

Species	July	Aug	Sept	Oct	Nov	Dec
Sousa plumbea	4.64	3.72	2.19	2.41	n.a.	2.98
Tursiops aduncus	1.01	0.52	0.65	0.42	n.a.	0.36

Encounter rates are calculated as in Table 5, with all encounters and effort being summed across all years for each month. November was excluded due to having too little coastal search effort (3.4 h).

in spatial coverage from year to year, coupled with a heterogeneous distribution pattern. The spatial assessment of effort and sighting probability will be used to assess this. The SPUE for *S. plumbea* was four- to sevenfold greater than for *T. aduncus*, the next most frequently encountered species, for all years and months (see Tables 5 and 6).

2.3.3 Nosy Mitsio Region

Numbers of sightings of coastal dolphins were low in both July and November expeditions, with only one sighting of *S. plumbea* during each month, and three and two sightings, respectively, of *Tursiops* sp. (Table 3). The identity of *Tursiops* species sighted is not certain, but was likely to have been *T. truncatus*, as opposed to *T. aduncus* based on the size, behaviour and apparent lack of belly spots. The encounter rate for *S. plumbea* (0.05 ind/h) was dramatically less than that documented in the Nosy Be region (Table 5).

2.3.4 Nosy Iranja Region

Along the shallow coastal waters of Nosy Iranja, and the extensive coastline of Ampasindava, we sighted 16 groups of *S. plumbea*, nine groups of *T. aduncus* (associated in a mixed species group on two occasions) and 1 group of undetermined *Tursiops* sp. (Table 3; Figure 4). Based upon observations of photographic recaptures, it appeared that at least two different social groups of *S. plumbea* were encountered on multiple occasions, one repeatedly seen around the shallow waters of Nosy Iranja and another around the north of the Ampasindava peninsula (Figure 4). Both were found with relatively large group sizes, at times in excess of 10 individuals, and mean group size was somewhat larger than documented around Nosy Be (Table 4). As in the Nosy Be region, *S. plumbea* was sighted only in the shallow, near-shore waters; however, *T. aduncus* was sighted frequently on the shallow shelf in open water inshore of Nosy Iranja, particularly in 2013. For this reason, encounter rates for *S. plumbea* were calculated as in Nosy Be using only coastal search effort, but for *T. aduncus* using coastal and shelf

search effort combined. The encounter rate for *S. plumbea* in the Nosy Iranja region was similar to that documented in the Nosy Be region, both of which were dramatically higher than that documented on Nosy Mitsio (Table 5). The encounter rate for *T. aduncus* was also very similar for Nosy Iranja and Nosy Be, and consistently lower than documented for *S. plumbea* in both regions (Table 5). The mean depth of sightings for *S. plumbea* was 10.5 m (SD 7.09 m) with a maximum depth of 23 m and 82% of sightings <20 m.

3. ASSESSING BY-CATCH AND HUNTING THROUGH INTERVIEW SURVEYS

A programme of rapid assessment socio-ecological interview surveys has been conducted since 1999 to assess local communities' perceptions of and interactions with coastal marine mammals along the west coast of Madagascar. These interviews provided an initial understanding of artisanal fisheries interactions, focusing on coastal dolphin hunting and by-catch; early efforts led to discoveries of, and conservation work on, unsustainable hunting in the southwest of Madagascar, in the Anakao region (Andrianarivelo, 2001; Razafindrakoto et al., 2008). Following the 1999 interviews, a targeted interview campaign was conducted in villages along a ca. 1400 km stretch of the west coast of Madagascar from Toliara to Nosy Be, between 2008 and 2013. This included distinct efforts: in the Nosy Be region in 2008–2009; in the extended northwest region (the Ankarea and Ankivonjy MPAs, and Baie d'Ambaro on the Madagascar mainland to the east of Nosy Be) during 2011–2013; and during a long-range sailing vessel expedition in 2010, conducting interviews in villages on the route between Toliara and Mahajanga. The general objectives were to assess fisheries interactions in terms of the geographic scope and magnitude of directed hunting and by-catch. Additionally, we collected local knowledge on cetacean species encountered by fishers, complementing results from boat-based surveys.

Since hunting of marine mammals is illegal in Madagascar, the collection of data regarding hunting and by-catch of marine mammals is very sensitive (Andrianarivelo, 2001; Razafindrakoto et al., 2008). Therefore, interview protocols were aimed at creating a relaxed atmosphere and gaining the confidence of interviewees, and involved an informal, standardized set of questions that were delivered by an exclusively Malagasy team through casual conversation. Reports on marine mammals were categorized into one of four different event types: hunting, by-catch, stranding, or live sighting.

For hunting and by-catch events, the type of fishing gear was recorded along with if, and how, the marine mammal meat was used (i.e. consumed, sold). The number of individuals hunted or by-caught in each event was recorded, along with the timing of the event by the year of occurrence. More detailed description of interview methods can be found in Cerchio et al. (2014).

3.1 Results

Surveyed villages in close proximity were grouped into separate 'locations' (Figure 5; Table 7), and among the 15 locations surveyed, a total of 78 villages were visited and 1066 fishers interviewed during 339 interview sessions (see Table 7). Estimated population size, summed for each location among only the villages surveyed varied widely, from 14,170 in Nosy Be to 60 in the Barren Islands; thus, the estimated percentage of fishers interviewed varied similarly from a low of 1% to high of 40% (see Table 7). Estimated age of interviewees ranged from 15 to 80 (children under 15 were not considered in the interviews), with a modal age of 31–40 years representing 31% of all interviewees (Figure 6). Interviewees were predominantly men (89%), and all but one woman interviewed was within a focus group, reflecting the role bias toward men being the fishers in this traditional society (although women routinely participate in collecting invertebrates from exposed reefs at low tide).

Although focusing on *S. plumbea* for this chapter, we report here interview results for *Tursiops* spp. as well, given the similarity and overlap of habitat of *S. plumbea* and *T. aduncus*, and the likelihood that the two species are subjected to similar pressures and threats from artisanal fisheries. In only two cases fishers reported large offshore common bottlenose dolphins, *Tursiops truncatus*, and we assume all reports of *Tursiops* to represent coastal animals, predominantly *T. aduncus*. However, due to the observations of *T. turncatus* in the coastal waters of Nosy Be, here we refer to *Tursiops* spp.

There were a total of 194 reports of *S. plumbea* and 471 reports of *Tursiops* spp. across all locations, years, and categories of report (Table 8). The most frequently reported category was live sighting; however, there were substantial reports of hunting and by-catch, being predominantly attributed to affect *Tursiops* spp. (see Table 8). *Sousa plumbea* was reported geographically widespread from the northwest to southwest (Figure 7), with the highest incidence of reports in the northwest locations of Nosy Be, Baie d'Ambaro and Nosy Faly, having 92%, 92% and 82% of interview sessions, respectively, reporting the species. Among the northwest locations, Nosy Mitsio and

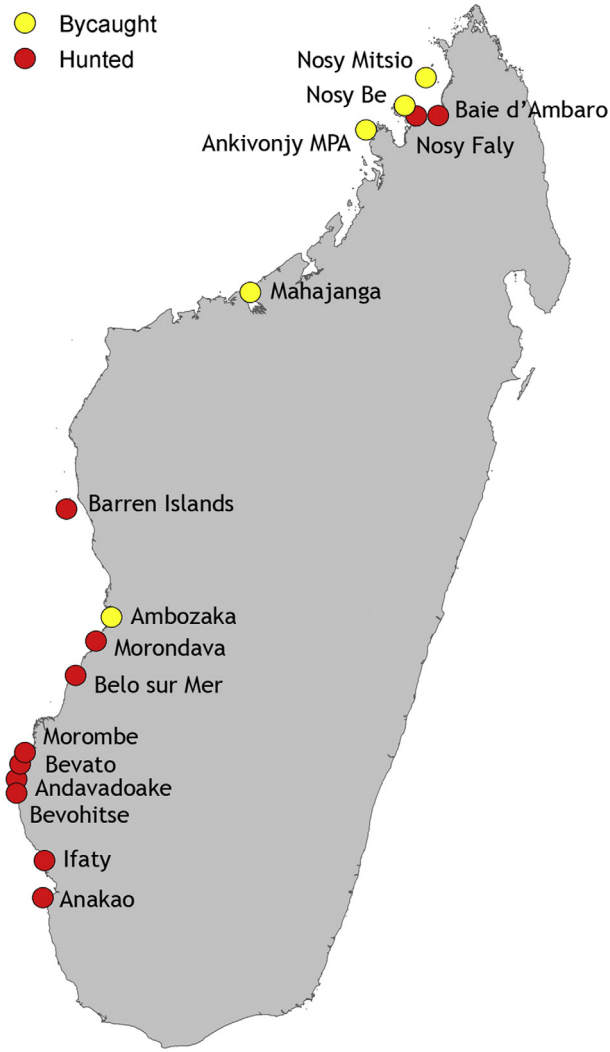

Figure 5 Position of locations where interviews were conducted along the west coast of Madagascar. Anakao, in the southwest, was surveyed previously in 1999 (Andrianarivelo, 2001) and 2004 (Razafindrakoto et al., 2008), and all sites north of Anakao were surveyed from 2010 to 2013 as part of the reported study. Marker colour indicates whether coastal dolphins (either *Sousa plumbea* or *Tursiops aduncus*) were reported by fishers as either hunted or by-caught, but not hunted. In all locations, at least one species was reported as either hunted or by-caught. See Figure 7 and Table 9 for specific reports for each species.

Table 7 Description of All West Coast Locations Were Sampled and Interviews Were Conducted Since 2008

	Location Stats.				Interview Stats.				
Location	Villages	Est. Pop.	Est. # Fishers	%Pop. Fishers	Tot. # Interv.	Single Interv.	Focus Groups	Tot. Individ.	%Fisher Interv.
Nosy Mitsio	18	547	142	26%	41	31	10	58	40%
Nosy Be/Komba	8	14,170	686	5%	24	14	10	143	20%
Baie d'Ambaro	11	6727	1883	28%	60	27	33	218	12%
Nosy Faly/GT*	5	2979	1115	37%	22	6	16	173	16%
Ankivonjy MPA	9	2983	270	9%	56	35	21	97	36%
Mahajanga	4	2300	1390	60%	13	4	9	27	2%
Barren Islands	3	60	60	100%	5	0	5	20	33%
Ambozaka	1	2040	1800	88%	4	1	3	13	1%
Morondava	2	8980	1700	19%	4	0	4	12	1%
Belo sur Mer	3	5187	3440	66%	30	17	13	107	3%
Morombe	2	9144	2220	24%	7	2	5	21	1%
Bevato	1	437	300	69%	9	3	6	37	12%
Andavadoake	4	892	691	77%	28	14	14	57	8%
Bevohitse	3	475	251	53%	24	14	10	57	23%
Ifaty	4	11,540	3730	32%	12	7	5	29	1%
Total	78				339	175	164	1069	

Villages indicate the number of separate villages that were visited at each location; the estimated population (Est. Pop.), and estimated number and percentage of fishers (Est. # Fishers and %Pop. Fishers) are the summations for all indicated villages (as estimated by an elder or mayor in each village). Interviews are defined as each separate session (Tot. # Interv.) irrespective of number of individuals; Single Interv. indicate number of single person sessions, and Focus Groups indicate the number of sessions with focus groups of two or more people; Tot. Individ. is the summation of all people present in all sessions, and %Fisher Interv. is the percentage of the estimated number of fishers represented by Tot. Individ.

*GT="Grande Terre", referring to nearby main land of Madagascar.

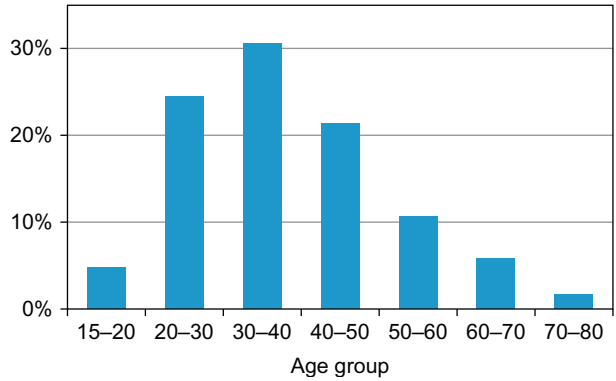

Figure 6 Age breakdown of all interviewed fishers from all locations combined.

Table 8 Summation of All Reports of Coastal Dolphins in All Interviews for All Locations, Irrespective of Time Period Being Reported (Ranging from 1950 to 2010)

Species	Live	Hunt	By-catch	Stranded	Total
Sousa plumbea	173	3	16	2	194
Tursiops spp.	251	93	103	24	471
Total	424	96	119	26	665

Values represent numbers of events reported, not summation of individual dolphins reported, nor number of interview sessions in which events were reported, such that a single interview session may have resulted in multiple reports of events, and a single event may involve multiple dolphin individuals. Reports are grouped by whether dolphins were sighted live, hunted, by-caught or stranded.

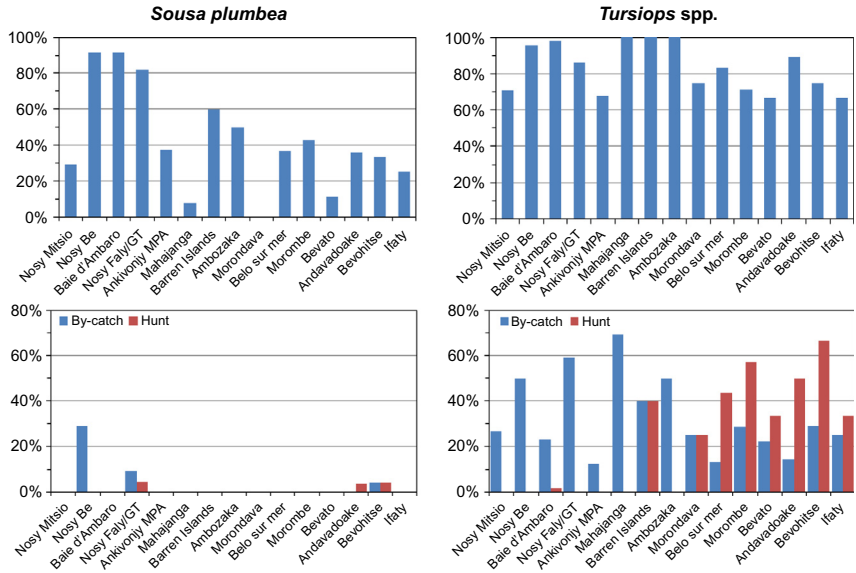

Figure 7 Percentage of interview sessions in which *Sousa plumbea* and *Tursiops* spp. were reported, irrespective of type of sighting (top row), and percentage in which hunting and by-catch were reported (bottom row). Locations are arranged left to right from north to south.

Ankivonjy MPA had a lower incidence of reports, represented in only 29% and 38% of interview sessions, respectively. These findings are generally congruent with the encounter rates of *S. plumbea* found in the northwest field research surveys, with the exception of the Ankivonjy MPA. There were no reports of *S. plumbea* from Morondova, and all southwest locations had a generally lower incidence with reports ranging from 11% in Bevato to 43% in Morombe. *Tursiops* spp. were more commonly reported than *S. plumbea* and more uniformly reported across locations from north to south (Figure 7).

Both hunting and by-catch were reported extensively, with relatively few for reports *S. plumbea* as compared to *Tursiops* spp. (Tables 8 and 9; Figure 7). Hunting reports were predominantly made in southwest locations from the Barren Islands to Ifaty, and overwhelmingly involved *Tursiops* spp. There were only two reports of *S. plumbea* hunted in the southwest: one report from Andavakoake of six individuals taken in 2008 (technique/gear not reported), and one report from Bevohitse of 10 individuals taken in 2010 (by drive hunt). Although hunting was rarely reported in the northwest, a single event for *S. plumbea* was reported from the Nosy Faly/Grande Terre (the main land of Madagascar, hereafter referred to as Nosy Faly/GT) village of Ampasimbary, of two individuals taken in 2009 using nets. Notably, by-catch of *S. plumbea* was reported in 30% of interviews from Nosy Be, involving 13 different events for 31 individuals killed, of which eight events were reported to have occurred off Nosy Faly. In addition, two by-catch events of *S. plumbea* reported from Nosy Faly/GT (using an unspecified net type) were from the same village as the reported hunt. Finally, a single by-catch event (of *Tursiops truncatus*) was observed during our 2009 research surveys, also off the same village near Nosy Faly involving gillnets (described below).

Reports of hunting for *Tursiops* spp. were made in all eight locations in the southwest represented in 25–67% of interviews, with the highest incidence in Bevohitse (see Figure 7). A total of 1414 individual dolphins were killed in 92 reported events, with 56% of individual mortalities reported since the year 2000 (Table 9). By-catch of *Tursiops* spp. was reported in all locations, and reported in 13–69% of interviews, with the highest incidence in Mahajanga (which notably had no reports of hunting). A total of 366 individuals were reported killed in by-catch events, with 90% reported since 2000 (see Table 9). A single case of by-catch was directly documented during the boat surveys in the Nosy Faly/GT area during 2009 involving a relatively large group of *T. truncatus* inshore, and is worth noting here. A group of 10–15 dolphins were encountered already associated with a small group of traditional fishers that had set gillnets, on which

Table 9 Summation of *S. plumbea* and *Tursiops* spp. Individual Mortality Reports for all Interviews

	All Reports				Reports Since 2000			
	Sousa plumbea		*Tursiops* spp.		*Sousa plumbea*		*Tursiops* spp.	
Location	**Hunt**	**By-catch**	**Hunt**	**By-catch**	**Hunt**	**By-catch**	**Hunt**	**By-catch**
Nosy Mitsio	0	0	0	29	0	0	0	23
Nosy Be	0	31	0	12	0	24	0	3
Baie d'Ambaro	0	0	5	116	0	0	0	112
Nosy Faly/GT*	2	3	0	126	2	3	0	118
Ankivonjy MPA	0	0	0	21	0	0	0	15
Mahajanga	0	0	0	24	0	0	0	24
Barren Islands	0	0	7	2	0	0	7	2
Ambozaka	0	0	0	6	0	0	0	6
Morondava	0	0	25	2	0	0	25	2
Belo sur mer	0	0	272	6	0	0	112	6
Morombe	0	0	89	3	0	0	53	3
Bevato	0	0	24	2	0	0	24	2
Andavadoake	6	0	279	7	6	0	71	6
Bevohitse	10	1	655	8	10	1	455	7
Ifaty	0	0	58	2	0	0	50	2
Total	18	35	1414	366	18	28	796	330

Results are presented irrespective of time period being reported (ranging from 1950 to 2010), and for only reports after the year 2000. Values represent actual numbers of individual dolphins reported and are grouped by whether they were hunted or by-caught.
*GT="Grande Terre", referring to nearby main land of Madagascar.

the dolphins were apparently depredating. An immature dolphin became entangled, and the fishers hauled it into their canoe and allowed us to briefly examine it and take pictures. The fishers claimed that the animal had died in the water (drowned), and that this was a rare event and they do not normally catch dolphins. However, it appeared that they had the severed tail of a second dolphin in the canoe, and were acting very wary and uneasy at our approach and questions. The fishers said that it is not taboo (*Fady* in Malagasy) to eat dolphin, contrary to reports from the majority of Sakalava villages in the northwest, and that they would take the by-catch with them

back to their village to sell and/or consume. The impression of our Malagasy team discussing this event with the fishers, was that the fishers may have been deliberately setting gillnets with the hope of entangling dolphins in this specific area (where we had repeatedly seen fishers setting nets, and encountered *Tursiops* spp. and *S. plumbea* on many occasions; near the Nosy Faly/GT village of Ampasimbary).

A total of 74 reports of hunting and 88 reports of by-catch were accompanied by information on the technique and gear used during the event (Figure 8). The majority of directed hunting events were done by drive hunts, accounting for 83% of *S. plumbea* and 90% of *Tursiops* spp. hunt mortalities. The reported *S. plumbea* drive hunt was a single recent event in 2010 in the southwest village of Bevohitse, with a take of 10 individuals. Drive hunts for *Tursiops* spp. were more frequently reported, accounting for 977 reported mortalities, and restricted to the southwest locations of Bevohitse (29 reports), Andavadoake (13 reports), Belo sur Mer (six reports) and Bevato and Morombe (one report each). Drive hunts were reported as far back as the 1970s, however they occurred predominantly in

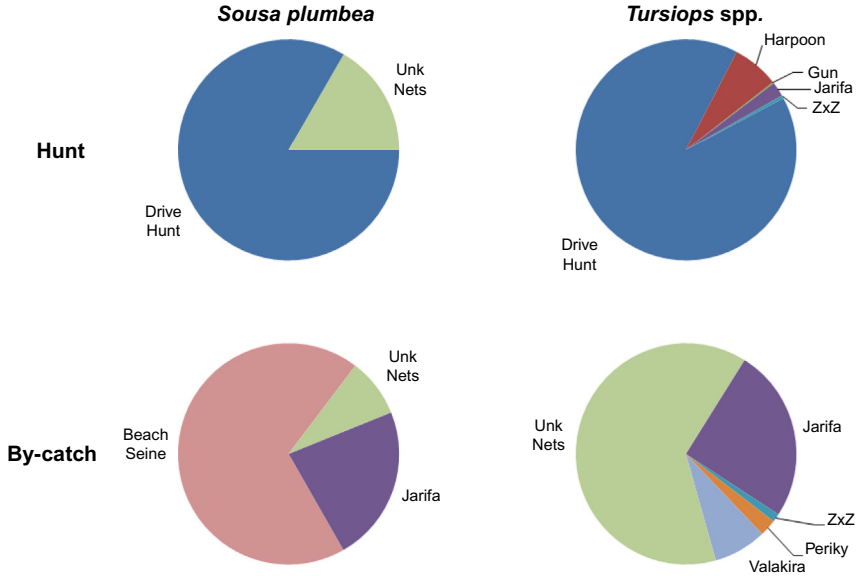

Figure 8 Fishing gear/technique to be reported used during hunting and by-catch, of *Sousa plumbea* and *Tusiops* spp. representing percentages of individuals caught. 'Jarifa' and 'ZxZ' are large-mesh gillnet (12–25 and 8–10 cm, respectively), both used primarily for large pelagic fish and shark; 'Periky' is a small-mesh gillnet (20–35 mm) used to catch sardines; and 'Valakira' is a barrage fence style trap, 150–300 m long and V-shaped, used to catch shrimp.

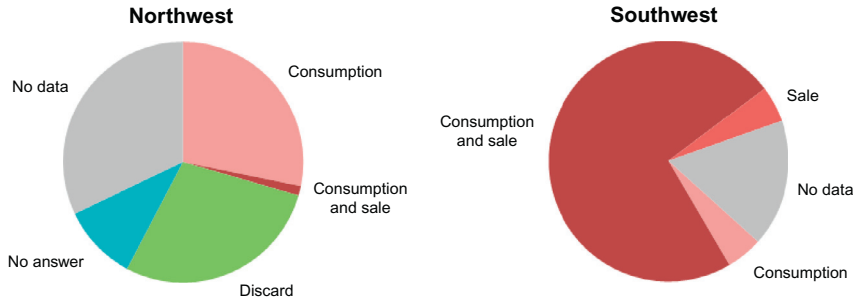

Figure 9 Reported use of by-catch for 16 *Sousa plumbea* and 103 *Tursiops* spp. events combined, separated by Northwest (all locations north of Mahajanga; 78 events) and Southwest (Ifaty north to and including Mahajanga; 41 events).

the 2000s (39 reports for 508 mortalities). A fewer number of reports, from 19 interviews for 74 mortalities, indicated the use of harpoon, dating back to the 1950s. By-catch of *S. plumbea* was reported primarily in beach seine nets (all reported occurred off Nosy Faly, for 24 individuals), with the remainder made with 'Jarifa', a very large-mesh (12–25 cm) gillnet, used primarily for large pelagic fishes and sharks (Gough et al., 2009). The majority of *Tursiops* spp. by-catch was reported to have occurred in an unspecified net type, and was accounted in 25 reports for 155 mortalities. The net type was likely a large-mesh gillnet similar to the widely used Jarifa, which was reported in 38 interviews for 62 mortalities. In all cases where information was collected on the use of dolphin meat from hunts (83 of 93 reports), interviewees reported both direct consumption and local sale in their home village or near-by villages. Use of by-catch on the other hand, showed more variation and varied markedly between the northwest and southwest locations (including Mahajanga with all more southerly locations; Figure 9). 'Direct consumption and local sale' accounted for 73% of by-catch reports from the southwest, whereas only 1% from the northwest; 'local consumption with no sale' accounted for only 5% of reports in the southwest, but 28% in the northwest. By-catch was reported as 'discarded without consumption or sale' in 28% of northwest events, but never in the southwest. There was no indication of use of by-catch or hunted animals as fishing bait.

4. GENERAL DISCUSSION

The field surveys and interview surveys reported here provide the most extensive data collected to date on *S. plumbea* in Madagascar. The

survey effort and interviews, combined with previous reports, suggests a range extent in Madagascar that covers primarily the western coasts (Figure 10). Moreover, the spread of field effort between two distinct regions, coupled with interview surveys that revealed patterns of artisanal hunting and by-catch, suggests important implications for the status and conservation of the species in Madagascar. Generally, the northwest region appears to have larger, potentially healthier populations of *S. plumbea* than the southwest region, and interviews indicated that this difference is at least correlated with the level of hunting and artisanal fisheries interactions with coastal dolphins that are reported by local fishers.

The distinction between the conservation status of *S. plumbea* in southwest and northwest Madagascar is most apparent when directly comparing the SPUE encounter rates of individuals and mean group sizes (Figure 11). The highest encounter rate of individuals in Nosy Be, occurred in 2011, is fourfold greater than the highest rate that occurred for Anakao, in 2005 (see Figure 11; Table 5); overall the Nosy Be rate is sevenfold greater (see Table 5). This marked difference is clearly a combination of encounter rate of groups (see Table 5) and mean group size (see Table 4). The population around Anakao is characterized by smaller groups that are more sparsely distributed throughout the shallow coastal habitat (reflected in group encounter rate), relative to the Nosy Be region population.

In the southwest site of Anakao, there are alarming negative trends suggested by our data from 2004/2005 to 2013 for both encounter rate and group size of *S. plumbea* (see Figure 11). This is evident when considering only the primary field effort years of 2004 to 2009, and more dramatic when considering the 2013 data, in which only one *S. plumbea* individual was sighted, despite comparatively high effort. However the 2013 study period in Anakao was shorter in total duration than all other years, with only 11 days of boat time over a 14-day span, and this may have negatively biassed the 2013 data. Still considering reports that existed prior to our study, the evident negative trend becomes even more dramatic. Razafindrakoto et al. (2004) reported five groups encountered in 1999 for 65 individuals during 98.41 h total effort, which resulted in a crude encounter rate of 0.66 ind/h and a mean group size of 13 animals (SD 7.61, range 5–25). Comparable crude encounter rates for our data, using total hours on the water and total hours searching irrespective of depth zone, yield encounter rates of 0.12 and 0.32 ind/h, respectively, which is approximately half the rate reported for 1999. The mean group size reported for 1999 is more than twofold greater than the largest mean group size in 2004 (see Figure 11).

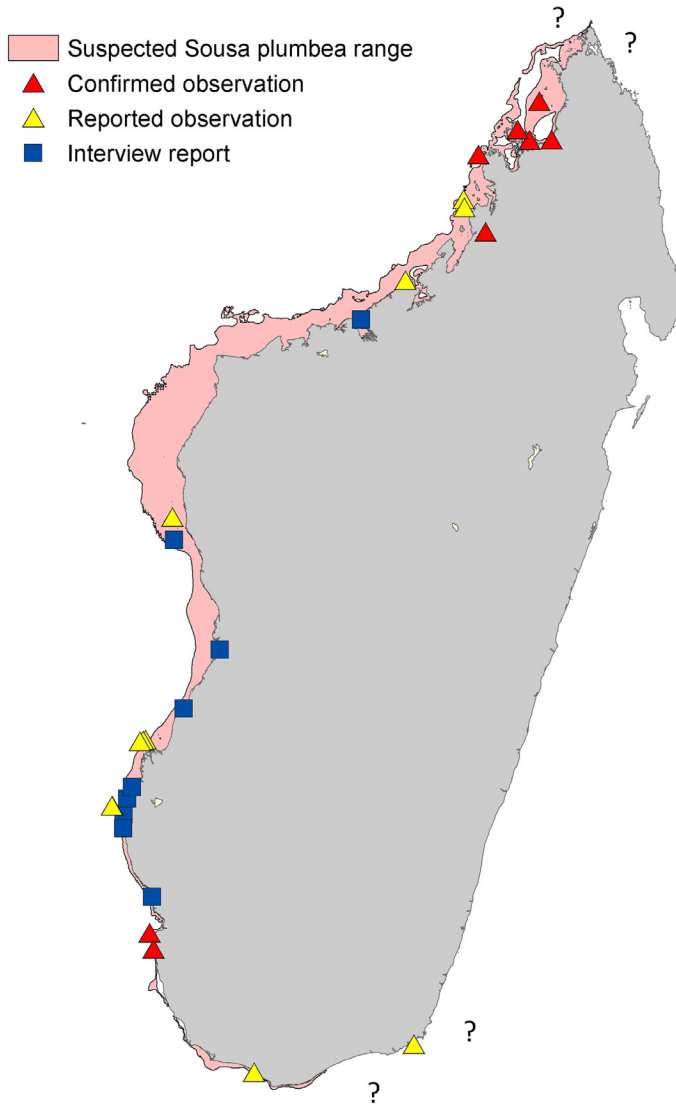

Figure 10 Suspected range of *Sousa plumbea* in Madagascar based upon existing knowledge, including known locations of sightings. The inferred distribution of the species is represented as a continuous band of coastal waters within the 30 m isobath where it is suspected to occur, with no allowance for discontinuities where the species may be absent. 'Confirmed observations' refer to locations where direct sightings or photographic evidence was collected or confirmed by the authors; 'Reported Observations' refer to visual sightings reported to the authors by trusted sources (west coast sighting positions from REMMOA survey 2010, Agence des aires marines protégées/ Observatoire PELAGIS, Laran et al., 2012; Van Canneyt et al., 2010; south coast sighting positions from M. Nicoll, World Wildlife Fund, personal communication, 24 March 2015); 'Interview reports' refer to locations reported in interviews with local fishers conducted by the authors.

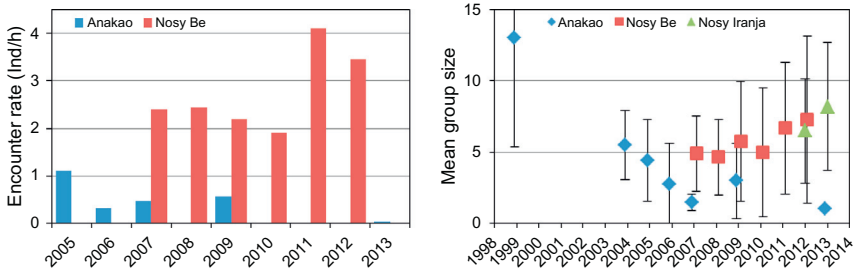

Figure 11 Comparison of individual encounter rate (left) and group size (right) for *Sousa plumbea* in the southwest (Anakao) and the northwest (Nosy Be and Nosy Iranja) across the study period. The 1999 value for mean group size in Anakao is from Razafindrakoto et al. (2004).

The largest group reported in 1999 was 25 individuals, compared to 9 individuals in 2004 representing the largest group sighting between 2004 and 2013. Although it is difficult to estimate a rate of population decline from these data, this change represents a roughly 14–18% per annum decline in mean group size between 1999 and 2013. It is conceivable that the 1999 values reported by Razafindrakoto et al. (2004) are inflated relative to 2004–2013 data reported here, since it was reported by different researchers (with the exception of N. Andrianarivelo) that was relatively inexperienced at the time. However, even if the 1999 estimates of group size were inflated twofold (which we consider an unlikely extreme bias), the trend in encounter rate and group size would still indicate a decline. Furthermore, irrespective of the comparability of the 1999 data, the trend and the observations in the final year 2013, suggest that the population of *S. plumbea* around Toliara/St. Augustine Bay/Anakao may be near extirpation. However, given the brevity of the 2013 field effort, this conclusion should be considered with some caution, and further monitoring for an extended period should be conducted to more rigorously establish the current population status in this region.

Northwest field survey results suggest that coastal dolphin species utilize shallow water areas as important habitat around the Nosy Be region, Nosy Iranja/Ampasindava Peninsula (Ankivonjy MPA) and to a lesser extent the Nosy Mitsio island group (Ankarea MPA). The encounter rate and apparent abundance of *S. plumbea* were similar between the coastal/shallow water areas of Nosy Be region and the Ankivonjy MPA, both of which were dramatically greater than that for the Nosy Mitsio island group (see Table 5) or any other region assessed by our team, including the southwest (Anakao) and other western shallow water habitat surveyed for other projects (Morombe, Belo sur Mer and Barren Islands; S. Cerchio, unpublished data).

The Nosy Be region and Ankivonjy MPA also appear to be important for *T. aduncus*. Factors influencing lower encounter rates of coastal dolphins around Mitsio are not yet understood. Group size of *S. plumbea* in the Nosy Be and Nosy Iranja regions was similar to that reported in South Africa for Algoa Bay (Karczmarski et al., 1999a, six individuals, SD 2.72). The reported South Africa individual encounter rates of 3.78 and 3.33 ind/h for Algoa Bay and St. Francis Bay, respectively (Karczmarski et al., 1999b), were also similar to that found in Nosy Be (2.95 ind/h) and Nosy Iranja (2.89 ind/h). This suggests some broad similarities between these populations. Group sizes reported by Laran et al. (2012) during aerial surveys along the west coast of Madagascar are broadly congruent with the observations reported here, both in value and declining trend from north to south: in the northwest, a mean of 5.0 individuals for three sighted groups; in the central west a single group of 4.0 individuals; and in the southwest a mean of 2.2 individuals for five sighted groups.

There were no strong trends in yearly or seasonal variation in sightings in the northwest, in part due to limitations of the dataset. There was an apparent increase in encounter rate in Nosy Be during 2011 and 2012 at approximately twofold from 2007 to 2009, and a slight increase in group size (Figure 11). However, it is difficult to determine whether this might reflect an increase in numbers due to yearly, seasonal, or spatial effort variation. Irrespective, there is no indication of decline in population numbers, as detected in Anakao, and there is potentially a suggestion of population increase in this area. Given the restricted seasonal coverage of the Nosy Be data (with no summer or autumn data), it was not possible to assess yearly seasonal variation in group size or encounter rate. However, the nominal peak in encounter rates during July/August, compared to September through December (see Table 6), was not congruent with Karczmarski et al. (1999a), who reported a low in encounter rate during May/June/July in Algoa Bay. Therefore, if there is seasonal variation in Nosy Be related to movement of individuals in and out of the area, it is likely influenced by different processes than those operating in Algoa Bay. It is not yet possible to report whether the population around Nosy Be more closely resembles the transient nature of the Algoa Bay population (Karczmarski, 1999), or the highly resident population of southern Zanzibar (Stensland et al., 2006). Analysis of photographic capture–recapture data may be useful address this question. Currently, casual observations of recaptures within and across years (S. Cerchio, unpublished data), suggests at least some level of residency, as reported for Maputo, Mozambique (Guissamulo and Cockcroft, 2004) and Richards Bay, South Africa (Keith et al., 2002).

The distribution of all sightings in both the northwest and southwest regions, concurs with the understanding that *S. plumbea* is an obligate shallow water and coastal species. There is some preliminary indication of preference for certain areas within the study range in the Nosy Be region (see Figure 3), which would be similar to results of other studies (Atkins et al., 2004; Karczmarski et al., 2000; Keith et al., 2013; Stensland et al., 2006). Karczmarski et al. (2000) reported no seasonal variation in habitat preference despite seasonal shifts in group size and influx of individuals, suggesting that these dolphins are dependent on specific habitat type within the already limited shallow water coastal zone.

The geographic spread of reports of *S. plumbea* from interview surveys with fishers, provides further evidence that the species ranges along the entire west coast, likely in a continuous distribution. Reports from interviews were most common in the northwest and displayed a decreasing trend from north to south (see Figure 7), broadly congruent with inferences on population status from the field surveys. There were relatively few reports of hunting and by-catch of *S. plumbea* throughout the range. However, this was offset by high levels of both hunting and by-catch reported for *Tursiops* spp. (see Table 6; Figure 7). Given the apparent takes of *Tursiops* spp., it is evident from the reports that both by-catch and/or hunting pressure on coastal dolphins are substantial along the entire west coast of Madagascar. The discrepancy between reports for *S. plumbea* versus *Tursiops* spp. could have several explanations. It may reflect a general difference in population abundance between the species, which seems most plausible for the southern part of the range where *S. plumbea* appears to be at lower abundance; however, this seems unlikely in the northwest, where field surveys indicate *S. plumbea* to be markedly more common. It could also be due to misidentification by fishers between the two species, yet, in most cases interviewees gave the impression of being well aware of the differences between the species and familiar with both (particularly among the southwest Vezo that specialize in dolphin hunting). It may also represent a difference in the behaviour of the two species, which seems plausible from field observations suggesting that *Tursiops* spp. tend toward greater curiosity and gregariousness, which may make them more vulnerable to both hunt and by-catch, whereas *S. plumbea* tend to display more wariness of humans and boats. Irrespective, the interview data evidence suggests that there is substantial pressure from fisheries interactions on coastal dolphins in general, and that *S. plumbea* are taken in both hunting and by-catch events, albeit in smaller numbers than reported for *Tursiops* spp. in Madagascar.

Regarding takes of *S. plumbea*, by-catch was reported predominantly from Nosy Be, where the species is documented as most common from both field surveys and interviews. Two-thirds of these events were reported to have occurred in the eastern channel between Nosy Be and Nosy Faly, closer to the latter island; this locale appears to be a hotspot for both by-catch and suspected hunting in the region. By-catch of *S. plumbea* in this area was reported to occur entirely in beach seine nets, unlike *Tursiops* spp. by-catch, which was never reported in this net type. This may be a function of the more shallow/coastal habitat of *S. plumbea*, or an idiosyncrasy of the specific locale. Hunting for *S. plumbea* was reported rarely, but in both the southwest and northwest primarily in locations that reported the highest incidences of dolphin hunting overall, Bevohitse in the southwest and Nosy Faly/GT in the northwest. All reported hunts and most by-catch events for *S. plumbea* were reported to have occurred in the 2000s, therefore recently relative to the sum of interview reports as a whole. Due to the non-randomized sampling for interviews and likely heterogeneity of fishing pressure, we have not attempted to extrapolate the interview reports to estimate the total number of individuals taken for entire villages or regionally. However, we emphasize that the numbers reported in interview surveys likely represent only a fraction of *S. plumbea* mortalities region-wide, given the small proportion of active fishers interviewed (see Table 7). For example, considering the southwest village of Bevohitse, the 10 *S. plumbea* hunted and one by-caught (see Table 9), would extrapolate to 48 *S. plumbea* mortalities over a decade period from this single village, considering only 23% of fishers were interviewed (see Table 7). Although this may be speculative, given the small population sizes reported for *S. plumbea* in other parts of its range and the generally slow reproductive rates of delphinids, the mortality reported in our interview surveys is almost certainly unsustainable.

Hunting of coastal dolphins was clearly more prevalent in surveyed areas from the Barren Islands south, with a sharp division between Mahajanga and the Barren Islands (see Figure 7). This is also the general boundary between the two major maritime-culture ethnic groups on the west coast, the Vezo in the south and the Sakalava in the north. The Vezo are most prevalent in the southwest regions and are semi-nomadic making migrations to the north at least as far as the Barren Islands to fish in other regions (Gough et al., 2009). All villages encountered and interviewed on the Barren Islands were in fact Vezo from Anakao or Andavadoake regions that had setup temporary fishing camps. Vezo are known to be dolphin hunters, historically using harpoons, and have developed the drive hunt tradition in the southwest, apparently in

Anakao, that has been culturally transmitted to other villages along the coast, such as Bevohitse (Andrianarivelo, 2001; Cerchio et al., 2009a). Throughout the southwest hunting communities, Vezo fishers report eating dolphin meat without hesitation, despite the common after effect of inducing gastrointestinal discomfort or diarrhoea, as reported during interviews. This is apparent in the reported use of by-catch and hunted dolphins, with the majority of southwest fishers stating that meat was consumed as well as sold locally, which indicates a local demand and market beyond simple subsistence for fishers' families. Conversely, Sakalava fishers in villages north of Mahajunga, predominantly reported that killing and eating dolphins was *Fady*, or taboo. Discarding of by-catch was reported only in the northwest, and when not discarded, fishers reported consumption alone almost exclusively, with only a single report of sale of meat. Within the northwest, the one notable exception to the predominant trend of no hunting and discarding of by-catch, was a small group of villages near Nosy Faly, to the east of Nosy Be. Interview surveys indicated a relatively high prevalence of by-catch and at least one reported hunting event in this area. This region had the only report of sale of dolphin meat and nearly 75% of reports of consumption of by-catch. Furthermore, this was the locale of the by-catch event that we observed during boat field surveys. The concentration of these events in the same specific area (despite the widespread distribution of dolphins and the regional coverage of the interview effort in the northwest), and the use of nets for apparent hunting (consequently blurring the distinction between hunting and by-catch), suggests that a few specific villages in this area are recently developing a hunting tradition. Moreover, it appears this tradition may be originating from incidental by-catch, stepping through a progression to 'non-targeted-deliberate' acquisition, and then to 'targeted' acquisition (as described in Robards and Reeves, 2011), with fishers deliberately setting their nets in an area they know to be frequented by dolphins, and targeting dolphins that exhibit the behaviour of depredating their nets.

The data we have presented here, indicate that the status of *S. plumbea* populations is heterogeneous along the west coast of Madagascar. By-catch and directed takes, as described in the interview results and documented directly during our surveys, are clearly important conservation concerns, as has been documented globally (Reeves et al., 2013; Robards and Reeves, 2011). The presence of an active hunting tradition in the southwest of Madagascar, particularly using drive hunt techniques to capture large numbers of dolphins in a single event, is unique in the SWIO, to the best of our knowledge. The impact of the hunting tradition and incidental by-catch on

dolphin populations is likely substantial, given the numbers of animals reported in interview surveys, and the marked difference in apparent abundance of *S. plumbea* between the northwest and southwest populations. Conservation efforts in the southwest region (specifically in Anakao and the Andavadoake/Bevohitse/Bevato communities) have focused on community engagement to mitigate marine mammal hunting and by-catch. Establishment of community-based ecotourism, local traditional governance structures (*Dina*; see Rakotoson and Tanner, 2006), and social outreach campaigns, have met with some success (Cerchio et al., 2009a, 2014; Razafindrakoto et al., 2008). Indicators include the creation of local conservation associations and detailed *Dina* in four separate southwest Communes (political entity of a group of villages), and increase of whale-watching tourism in Anakao from six local operators serving 143 tourists in 2010, to 25 local operators serving 1322 tourists in 2013, grossing over US$23,000.

Although hunting and by-catch are likely to be the greatest threats, other factors likely contribute to the decline of *S. plumbea* populations in the southwest, including habitat degradation and prey depletion (Brenier et al., 2011; Laroche and Ramananarivo, 1995). The Grand Recif de Toliara barrier reef complex is particularly degraded, as the result of overfishing, destructive fishing practices, pollution and sedimentation, and recovery of the system is considered by some to be unlikely (Andréfouët et al., 2013; Harris et al., 2010). Given that reefs and associated habitats may be critical for coastal dolphins (as inferred by Amir et al., 2005a; Karczmarski et al., 2000), the cumulative impacts present a bleak outlook for the conservation of these populations. Conversely, the northwest region appears to support more abundant populations of *S. plumbea*. This may be attributed directly to the cultural characteristics of the Sakalava fishers, who do not have a hunting tradition or routinely eat dolphin meat, unlike the Vezo of the southwest. However, the indication that 'deliberate' by-catch and a directed hunting tradition on dolphins are developing in one locale within the surveyed northwest region, is of notable concern. Conservation efforts should be directed to work with local communities in the northwest to stop the development and spread of hunting and mitigate existing by-catch. Together with continued field research to define priority habitat and population status, the information presented here should be used to support the development of management policy at the community and government levels, within and beyond the regional MPAs, and should inform conservation measures and policy actions throughout the region.

ACKNOWLEDGEMENTS

The authors wish to acknowledge many people and organizations that contributed to this project. The authors were employed by the Wildlife Conservation Society during the duration of the work for the study. Within WCS, we thank in particular Howard Rosenbaum and Yvette Razafindrakoto who played key roles during the early years of the project. In addition, we are grateful for the support of the WCS Madagascar Program, including: Alison Clausen, Christopher Holmes, Lisa Gaylord, Helen Crowley, Ambroise Brenier, Herilala Randriamahazo, Bemahafaly Randriamanantsoa, Francisco Ramananjatovo, Santisy Andriamiravo, Luccianie Raonison and Sylviane Raharivelo for institutional support; and Tahina Rasoloarijao, Lovasoa Andriambola and Dina Andrianaivoravelona for assistance in the field. From the WCS headquarters, we thank Josh Ginsberg, Grace Seo, Devon Litherland, Sarah Pacyna, Robert Rose and Melinda Rekdahl. Christopher Spagnoli contributed substantively for map creation. We thank the staff of IHSM in Toliara, in particular, Daniel Ramampiherika and Thierry Lavitra, and CNRO in Nosy Be for their support of and involvement in our work. For logistical support in the Nosy Be region, we thank Julien and Christian Tombozafy, Nosy Komba Aventure, the Zahir Hotel and Nosy Iranja Lodge; in the Anakao region, we thank Thierry Bournonville and the staff of Lalandaka Lodge, Michel Agou and Madam Diamondra from Le Prince Hotel and the Ministry of Fisheries PACP project. Funding for this work was provided by the International Whaling Commission Small Cetacean Conservation Fund, the U.S. Marine Mammal Commission, the Kate Sanderson Bequest to the IUCN Species Survival Commission (SSC), the Flora Family Foundation, the Eppley Foundation for Research and an anonymous donor.

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