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# Cetacean Distribution and Diversity in Lakshadweep Waters, India, Using a Platform of Opportunity: October 2015 to April 2016

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## Abstract

Prior stranding records suggest that at least 12 cetacean species occur within the Lakshadweep archipelago off the southwest coast of India. These islands consist of coral atolls and form the northern part of the undersea Chagos-Laccadive ridge. Distinct oceanographic features, seasonal monsoon cycles, and high productivity make this region a potentially rich cetacean habitat. In this article, we report findings from the first systematic visual cetacean surveys, which were conducted from high-speed passenger ferries that sail between nine Lakshadweep islands. The surveys were carried out between October 2015 and April 2016 during both the northeast monsoon (October to December) and inter-monsoon (January to April) seasons. We used a line-transect survey framework to record sightings as well as group size estimates. We documented 139 sightings over 3,880 km of which 78 sightings were during systematic survey effort. Eight odontocete species were confirmed from these sightings: *Stenella longirostris*, *S. attenuata*, *S. coeruleoalba*, *Tursiops* spp., *Globicephala macrorhynchus*, *Pseudorca crassidens*, *Grampus griseus*, and *Feresa attenuata*. One *Balaenoptera* sp. was also encountered during this survey. *S. longirostris* was sighted the most often ($n = 22$) followed by *Tursiops* spp. ($n = 18$) and *G. macrorhynchus* ($n = 13$). We documented significantly higher sightings in the northeast monsoon season compared to the inter-monsoon season. Along ferry routes, cetacean species differed significantly from each other with respect to their associations with seafloor slope gradients and distances to nearest landmass. We encountered mixed species assemblages of *G. macrorhynchus* with *Tursiops* sp. and *S. attenuata* with *Tursiops* sp. Given the confirmed high cetacean diversity and occurrence in this region, there is a need for in-depth, long-term studies on biogeography, ecology, and population status of cetaceans here.

**Key Words:** cetacean, dolphin, whale, island, season, slope, Lakshadweep, India, platform of opportunity, distribution

## Introduction

In the northern Indian Ocean, seasonal southwest and northeast monsoons play an important role in shaping biological productivity through intense winds resulting in upwelling processes and/or advection of fresher water from the Bay of Bengal into an otherwise hypoxic Arabian Sea (Pernetta, 1993; Prasannakumar et al., 2004). In the open ocean habitat, island archipelagos characterized by steep underwater slopes provide the setting for distinct flow features and eddy formation that aggregate nutrients and plankton (Genin, 2004). Tropical upwelling regions and complex topographies are associated with high fisheries productivity and can be important in sustaining oceanic marine mammal and other higher trophic-level populations (Madhupratap et al., 2001; Ballance et al., 2006). The Lakshadweep islands in the Arabian Sea is one such area, located on the northern tip of Chagos-Laccadive ridge. This island chain consists of coral atolls, submerged reefs, lagoons, and steep slopes amidst deep open ocean waters, providing a mosaic of habitat types for tuna, sharks, corals, seabirds, and cetaceans (Pernetta, 1993).

Distinct mysticete (baleen whale) populations such as the Arabian Sea humpback whales (*Megaptera novaeangliae*) and highly diverse odontocete (toothed whales) populations occur in the northern Indian Ocean (Mikhalev, 1997; Branch et al., 2007; Pompa et al., 2011; Anderson et al., 2012b; Pomilla et al., 2014). Lakshadweep waters are contained within the larger Indian Ocean Whale Sanctuary established by the International Whaling Commission (2019) to protect critical breeding populations of large whales. Studies report the occurrence of 23 cetacean species from nearby Maldivian waters, 21 species from the western tropical Indian Ocean, and 27 species from Sri Lanka and the southeastern Arabian Sea (Ballance & Pitman, 1998; Afsal et al., 2008; Anderson et al., 2012a; Ilangakoon, 2012a). Lakshadweep waters present a data gap in this mosaic of regional marine mammal habitats, and little knowledge exists from this area. Ocean-scale surveys of the Arabian Sea that include Lakshadweep waters or nearby areas, along with other anecdotal reports and stranding and bycatch reports, indicate that at least 12 species of cetaceans occur in these waters (Burton, 1941; Alling, 1986; James & Panicker, 1990; Afsal et al., 2008; Kumarran, 2012; Sajikumar et al., 2014; also visit the Marine Mammals of India database, 2019). These reports and the known habitat requirements of tropical cetacean species suggest a potentially high cetacean diversity in the Lakshadweep region (Ballance & Pitman, 1998; Kiszka et al., 2007; Redfern et al., 2017).

The aim of our study was to examine occurrence and species composition of cetacean communities in Lakshadweep waters using a non-scientific platform of opportunity. More specifically, the objectives of the study were to (1) estimate species diversity and distribution of cetaceans with encounter rates; and (2) to examine the relation of cetacean sightings with season, seafloor depth, seafloor slope gradient, and distance to nearest landmass.

## Methods

The Lakshadweep archipelago, situated between 220 to 440 km off the southwest Indian mainland, is comprised of 36 islands of which ten are inhabited (Figure 1; Kokkranikal et al., 2003). The islands consist of shallow lagoons surrounded by coral atolls leading to open ocean habitats of depths more than 1.5 km (Varkey et al., 1979; Pernetta, 1993). The region has an active tuna fishery, where over 80% of the total fish catch (> 15,000 tonnes per year) is comprised of pole- and line-caught tuna (*Thunnus albacare, Euthynnus affinus,* and *Katsuwonus pelamis*; Vinay et al., 2017).

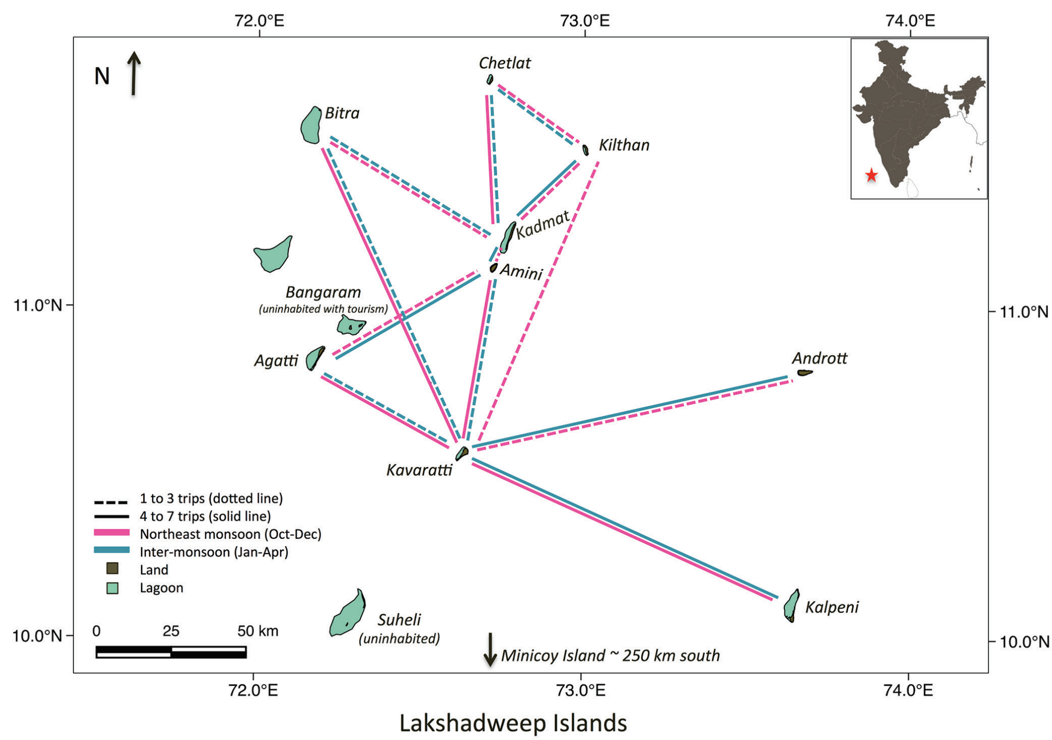


**Figure 1.** Study area map showing schematic ferry routes surveyed from October 2015 to April 2016

Visual vessel-based surveys (Schwarz et al., 2010) were undertaken from government-run passenger ferries that sailed between nine Lakshadweep islands (Figure 1). The surveys were in passing mode where the vessel did not stop at or approach cetacean sightings. Two sizes of high-speed vessels were used: 35 and 32 m in length with viewing platforms of 5.8 and 3.5 m height above sea level, and an average speed of 18.4 and 15.2 kts, respectively.

We used a line-transect survey methodology framework (Buckland et al., 2001, 2005) for 46 survey days between October 2015 and April 2016. Three trained observers surveyed from abeam port to abeam starboard using 7 × 50 handheld binoculars; they recorded cetacean sightings, along with group size, instantaneous group behavior, and identification notes with photographs when possible. Species identifications were assigned only when characteristic identification features were seen (as described in Jefferson et al., 2015). We categorized unidentified sightings into unidentified cetacean, unidentified small dolphin (below 2.5 m), unidentified large dolphin (approx. 2.5 to 5 m), unidentified small whale (5 to 10 m), unidentified large whale (above 10 m), or unidentified blackfish (black color, 5 to 10 m, and negligible beak structure) based on estimated body size and shape. We recorded minimum, best, and maximum estimates for group size based on actual counts for smaller groups. For larger groups, we counted a section of the group and extrapolated to the area occupied by the larger group. We report only the best estimate in this article. The location of the ferry was recorded when a sighting was made within 2 km of the trackline using a Garmin 78s handheld marine GPS. If cetacean groups were encountered when survey effort was suspended, we collected information for these groups and classified these sightings as off-effort. Rough weather, observer fatigue, and returning along an already surveyed track were the reasons to go off survey effort.

*Analyses*

On-survey sightings were used to calculate encounter rates and test for association with season. These sightings were categorized according to the northeast monsoon (late October to December) or inter-monsoon (late January to April) seasons. All sightings (observed both on- and off-survey effort) were pooled in the analysis to test whether there were differences among species with respect to their associations with seafloor depth, seafloor slope gradient, and distance to nearest landmass along the ferry routes. We extracted seafloor depth from existing datasets on global multi-resolution topography synthesis datasets (GMRT) from the software *GeoMapApp*, Version 3.6.6 (Ryan et al., 2009; visit www.geomapapp.org) for every cetacean sighting. Slope gradients and distance to nearest landmass were calculated using the spatial analyst toolbox in *ArcGIS*, Version 10.5 (Environmental Systems Research Institute [ESRI], 2011). To examine habitat use and seasonality, we used non-parametric tests as sample sizes were low. All statistical tests were conducted using *R* (R Core Team, 2019). Data used for analyses in this study can be accessed through Panicker et al. (2019).

## Results

*Survey Effort, Number of Sightings, and Encounter Rate*

We surveyed 3,880.33 km between October 2015 and April 2016 on routes between the following islands: Kavaratti, Agatti, Kilthan, Chetlat, Bitra, Andrott, Kalpeni, Amini, and Kadmat (Figure 1; Table 1). The duration of total survey effort was 128 h and 45 min (per day observation: 1.65 ± 0.1 h with range of 0.2 to 3.2 h). All routes were covered during both seasons except for the Kavaratti-Kilthan route, which was traversed only once during the northeast monsoon season. For seven routes, the effort between the northeast monsoon and inter-monsoon seasons was comparable. For another four routes, slightly more effort occurred in the inter-monsoon season. Beaufort Sea State conditions for 80.6% of the total distance of on-survey effort were between 0 to 3 (excellent to good sighting conditions), while 15.5% were at Beaufort 4 (marginal), and 4% were at Beaufort 5+ (poor). Surveys were carried out between 0700 and 1730 h. We conducted a total of 78 transits between the islands (Figure 1; Table 1).

The total number of cetacean sightings was 139 (74 identified to species), with 78 on-effort and 61 off-effort (Figure 2; Table 2). Of the 78 sightings on-effort, 31 were identified to species. The overall encounter rate of cetaceans was 2.01 sightings per 100 km for the survey effort in the study area. The overall encounter rate of cetaceans based on survey hours was 0.61 sighting per hour.

The highest encounter rate was for the Kavaratti-Kilthan route (10.87 sightings/100 km; Figure 1; Table 1); however, this route was traversed only once as compared to other survey routes for which five to nine trips were carried out. The routes between Agatti and Amini-Kadmat complex and between Amini and Kadmat also showed high encounter rates: 3.35 and 3.87 sightings per 100 km, respectively. The lowest rate of cetacean encounters was between Chetlat and Amini-Kadmat complex (0.68 sighting/100 km; Figure 1; Table 1).

We identified eight odontocete species and one mysticete genus during the study period (see Table 2 for list of species and Figure 2 for

**Table 1.** Route data on sightings, total distance surveyed, encounter rates, and surveyed depths

| Route name | Number of times | Total distance (km) | Number of sightings | Encounter rate (No. of sightings per 100 km) | Average depth (m) | Depth range (m) |
|---|---|---|---|---|---|---|
| Agatti-Amini/Kadmat complex | 7 | 387.83 | 13 | 3.35 | 962.71 | 2-1,626 |
| Kavaratti-Agatti | 7 | 330.76 | 10 | 3.02 | 1,276.71 | 95-1,865 |
| Bitra-Amini/Kadmat complex | 5 | 279.56 | 4 | 1.43 | 1,478.15 | 11-1,939 |
| Kavaratti-Amini/Kadmat complex | 7 | 326.28 | 6 | 1.84 | 839.53 | 10-1,663 |
| Chetlat-Amini/Kadmat complex | 7 | 292.78 | 2 | 0.68 | 1,244.07 | 81-2,005 |
| Kilthan-Amini/Kadmat complex | 6 | 212.14 | 3 | 1.41 | 1,057.07 | 6-1,918 |
| Kavaratti-Andrott | 8 | 557.69 | 6 | 1.08 | 1,516.92 | 4-2,109 |
| Bitra-Kavaratti | 7 | 472.53 | 10 | 2.12 | 1,050.06 | 2-1,818 |
| Kilthan-Chetlat | 5 | 174.74 | 2 | 1.14 | 1,383.59 | 112-1,979 |
| Kavaratti-Kalpeni | 9 | 705.97 | 14 | 1.98 | 1,765.18 | 215-2,297 |
| Amini-Kadmat | 9 | 103.26 | 4 | 3.87 | 250.76 | 19-691 |
| Kavaratti-Kilthan | 1 | 36.79 | 4 | 10.87 | 1,568.97 | 281-1,915 |

**Note:** Amini and Kadmat have been combined to the Amini-Kadmat complex as these islands are very close to each other. Surveys were also conducted between Amini and Kadmat.

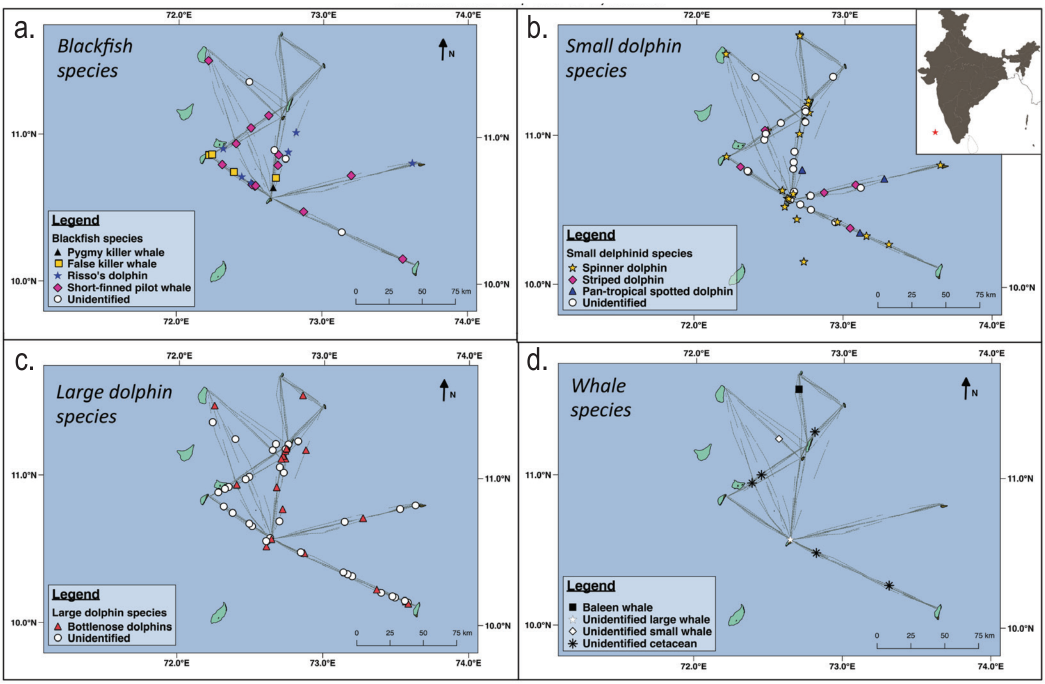


**Figure 2.** Cetacean sightings in the Lakshadweep waters categorized by species and classes: (a) blackfish, (b) small dolphin species, (c) large dolphin species, and (d) whales and unidentified cetacean species. Faint lines on the map show surveyed tracks.

distribution of sightings). Depth ranges for cetacean sightings ranged from 5 to 2,259 m with a mean of 1,179 ± 57.34 m (Table 2). The most commonly sighted species was the spinner dolphin (*Stenella longirostris*) with 22 sightings, followed by bottlenose dolphins (*Tursiops* spp.) with 18 sightings and short-finned pilot whales (*Globicephala macrorhynchus*) with 13 sightings.

**Table 2.** Species recorded during the study period, including number of sightings, group size, and depth at sighting location

| Species | Number of sightings on- & off-effort | Group size | | Depth (m) | |
|---|---|---|---|---|---|
| | | Mean ± SE | Range | Mean ± SE | Range |
| Spinner dolphin (*Stenella longirostris*) | 22 | 96.10 ± 35.7 | 5-600 | 827.91 ± 144.12 | 5-1,870 |
| Striped dolphin (*Stenella coeruleoalba*) | 5 | 40 ± 10.5 | 20-70 | 1,733.20 ± 143.51 | 1,276-2,076 |
| Pantropical spotted dolphin (*Stenella attenuata*) | 3 | 76.67 ± 37.1 | 30-150 | 1,662 ± 132.03 | 1,481-1,919 |
| Bottlenose dolphin (common & Indo-Pacific) (*Tursiops* spp.) | 18 | 4.75 ± 0.7 | 1-10 | 1,007.50 ± 186.11 | 10-2,107 |
| Risso's dolphin (*Grampus griseus*) | 7 | 15.57 ± 5.4 | 2-40 | 1,308.71 ± 195.69 | 198-1,664 |
| False killer whale (*Pseudorca crassidens*) | 4 | 8.0 ± 4.0 | 3-20 | 869.50 ± 401.67 | 101-1,618 |
| Short-finned pilot whale (*Globicephala macrorhynchus*) | 13 | 17.46 ± 3.6 | 2-40 | 1,351.23 ± 137.38 | 540-2,259 |
| Pygmy killer whale (*Feresa attenuata*) | 1 | 10 | NA | 1,558 | 1,558 |
| Baleen whale (*Balaenoptera* spp.) | 1 | 2 | NA | 955 | 955 |
| Unidentified cetacean | 5 | -- | -- | -- | -- |
| Unidentified small dolphin | 20 | -- | -- | -- | -- |
| Unidentified large dolphin | 34 | -- | -- | -- | -- |
| Unidentified large whale | 1 | -- | -- | -- | -- |
| Unidentified small whale | 1 | -- | -- | -- | -- |
| Unidentified blackfish | 4 | -- | -- | -- | -- |

*Species Diversity and Select Species Accounts*

*Spinner Dolphin*—Twenty-two sightings of spinner dolphins were recorded. Individuals had a tripartite design, slight falcate to triangular dorsal fins, long beaks with dark beak tips, and an eye to flipper stripe, which are characteristic of this species (Figure 3a; Jefferson et al., 2015). Large groups of 500 or above were documented on the Kavaratti-Kalpeni route on 2 December 2015 and the Kavaratti-Andrott route on 11 February 2016. Group sizes for all the sightings are provided in Table 2. Sightings occurred both in the northeast monsoon ($n$ = 8) and inter-monsoon ($n$ = 14) seasons and varied over a wide range of depths (Table 2).

*Striped Dolphin*—Five groups of striped dolphins (*Stenella coeruleoalba*) were documented (group sizes are given in Table 2). Individuals were identified by the light gray spinal blaze protruding into the cape and the dark stripe that runs between the eye and the anal region (Figure 3b). In all the sightings, the dolphins were highly acrobatic, and roto-tailing (rotating the tail during a high leap; Jefferson et al., 2015) was observed during one instance. All sightings were in the northeast monsoon season except for one in the inter-monsoon season.

*Risso's Dolphin*—Seven groups of Risso's dolphins (*Grampus griseus*) were sighted. Five sightings were in the northeast monsoon season and two in the inter-monsoon season. Individuals were not as heavily scarred or lightly colored as described in Jefferson et al. (2015); however, blunt square heads were observed along with other identification features, including the vertical crease on the melon (Figure 3c). More scarring was observed near the head of individuals than the body (Figure 3c). Group size and seafloor depth ranges are provided in Table 2.

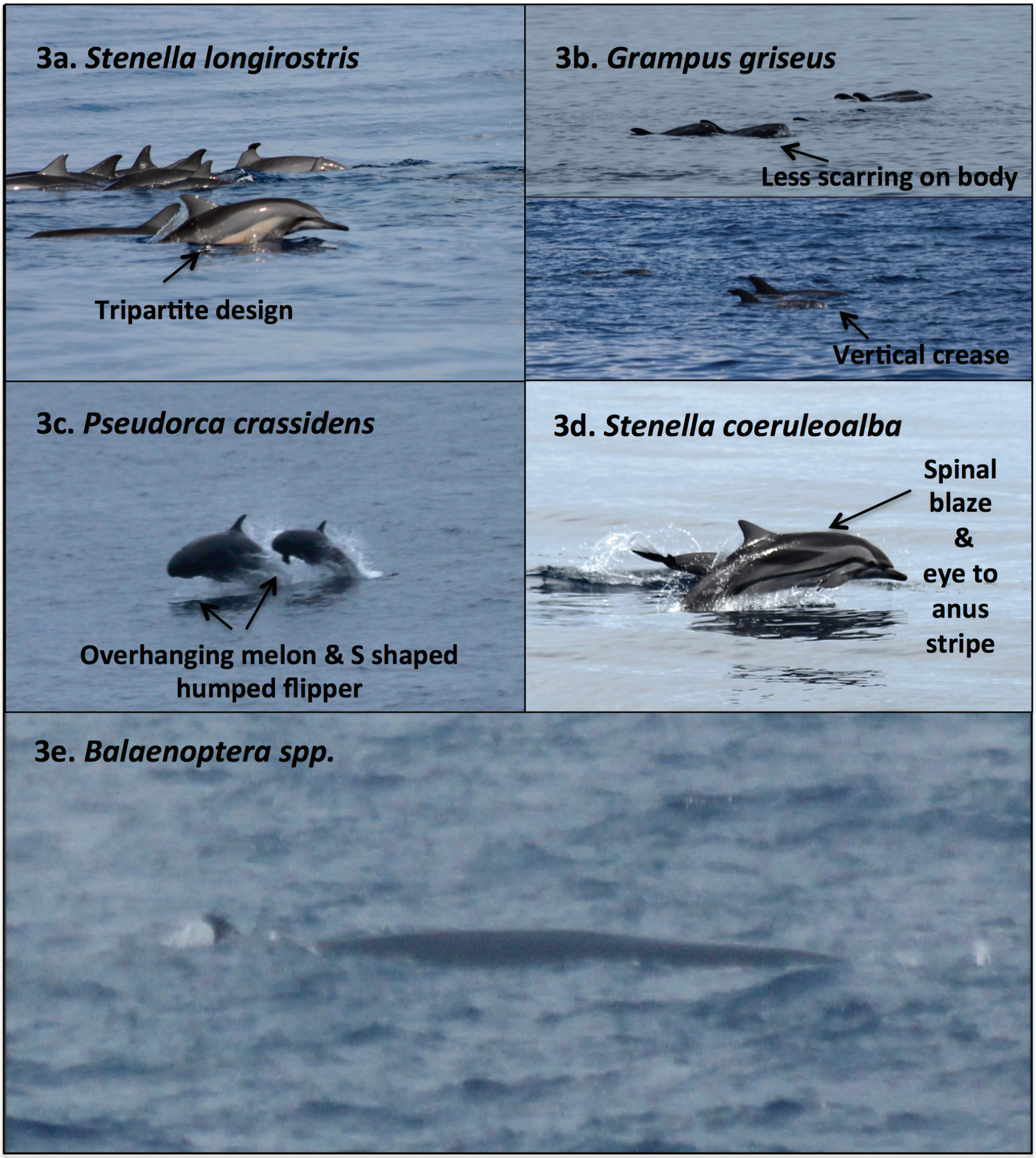


**Figure 3.** (a) Spinner dolphin off Kavaratti, (b) Risso's dolphin near Bangaram Islands, (c) false killer whale on Kavaratti-Agatti route, (d) striped dolphin on Kavaratti-Agatti route, and (e) baleen whale on Chetlat-Amini route

*False Killer Whale*—Four groups of false killer whales (*Pseudorca crassidens*) were sighted. Three sightings were in the northeast monsoon season and one in the inter-monsoon season. Group sizes and seafloor depth ranges are provided in Table 2. A sighting in December was on the Kavaratti-Agatti route, where increased aerial display such as breaching, porpoising, and what appeared to be ferry wake surfing was observed. This sighting lasted for 17 min, and it was not apparent whether the same individuals were transiting with the ferry. Juveniles were also present within this group (see Figure 3c).

*Baleen Whales*—One group of two individuals of *Balaenoptera* sp. were sighted on 7 November 2015 on the ferry route between Chetlat and Amini Islands. This sighting could not be confirmed to species (Figure 3e). The dorsal fin was falcate and placed further along the back. The blow of the animal was tall and columnar with an estimated large body size comparable to a pygmy blue (*B. musculus brevicauda*) or fin (*B. physalus*) whale (estimated by the proportional distance between the blowhole and the dorsal fin). The skin was dark with no mottling. The whales surfaced three to four times in succession, and the last observed dive was a tail out dive.

*Mixed Species Groups*—Two mixed species groups were observed. A group of seven bottlenose dolphins and four short-finned pilot whales were spotted along the Kavaratti-Bitra route on 6 December 2015. A group of ~150 pantropical spotted dolphins (*Stenella attenuata*) were observed with at least one bottlenose dolphin (*Tursiops truncatus*) along the Kavaratti-Andrott route on 12 March 2016.

*Unidentified Sightings*—An unidentified large whale was sighted on the Kavaratti-Kalpeni route, and its blow was visible from a distance and could have been from any of the large whale species. One sighting of an unidentified small whale was recorded between Bitra and Amini Islands. The individual was light brown in color, had a falcate fin placed further along the back, and surfaced twice. The estimated size range was 5 to 7 m. The number of unidentified sightings in each category has been provided in Table 2.

Bottlenose dolphins were not identified to *T. aduncus* or *T. truncatus* species as at-sea identification for these two species is challenging and frequently relies on internal morphology (Hale et al., 2000; Jefferson et al., 2015).

*Cetacean Species Distribution Across Season, Depth, Slope Gradients, and Distance to Nearest Landmass*

We tested against the null hypothesis that cetaceans were uniformly distributed across northeast and inter-monsoon seasons after accounting for differences in survey effort using a chi-square goodness of fit test. We found a higher number of sightings ($n$ = 51) in the northeast monsoon as compared to the inter-monsoon period ($n$ = 27, $\chi^2$ = 13.984, $df$ = 1, $p$ = 0.002; Figure 4). The expected values from the chi square goodness of fit test were calculated after accounting for distance traveled in each season (44 and 56% of total survey effort of 3,880.33 km in the northeast and inter-monsoon periods, respectively).

We examined whether the cetacean species that we recorded differed with respect to the distance to the nearest landmass, depth, and slope gradient at the points they were sighted along the ferry routes. The distance from sightings points to the nearest landmass differed among the species (Kruskal-Wallis $\chi^2$ = 16.962, $df$ = 6, $p$ = 0.009). Spinner dolphins were observed closest to land (median: 1.82 km), and striped (median: 24.72 km) and spotted (median: 43.28 km) dolphins were observed furthest from land compared to other species (Figure 5). Species also differed in slope gradient at which they were sighted (Kruskal-Wallis $\chi^2$ = 15.542, $df$ = 6, $p$ = 0.016). Spinner dolphins were encountered in relatively higher slope gradients compared to other species and were also found across a wider range from flat to steep slopes compared to the other odontocete species (0.2 to 33.68%; median: 13.54%; Figure 5). Striped and spotted dolphins were found in the lowest slope gradients with a median of 1.65 and 1.51%, respectively. There was no significant difference among species in the depth at which they were sighted along the ferry routes (Kruskal-Wallis $\chi^2$ = 10.912, $df$ = 6, $p$ = 0.091).

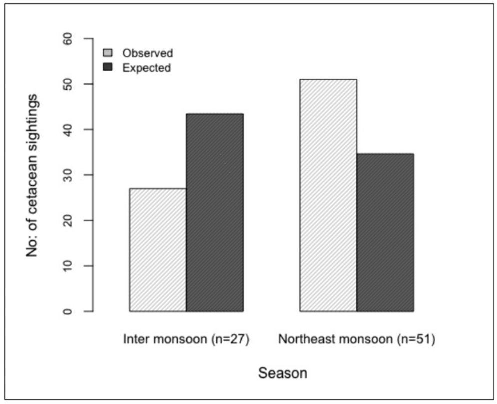


**Figure 4.** Distribution of cetaceans in inter-monsoon ($n$ = 27) and northeast monsoon ($n$ = 51) seasons. Expected values in proportion to distance traveled within each season are 43.41 and 34.59, respectively.

## Discussion

Our study used platforms of opportunity provided by ferry services between islands to conduct the first systematic surveys in an otherwise poorly studied region. Encounter rates have been estimated and differences among species in the habitat attributes with which they are associated have been examined using these platforms. A major advantage of using such platforms of opportunity is that it cuts down on costs and helps us to overcome shortages of dedicated and expensive platforms—a common problem in many tropical countries. This also has its limitations, however. We were not able to lay randomized transects or survey areas outside of the ferry routes. We also had to conduct the survey at higher vessel speeds of 18.4 and 15.2 kts per hour, respectively, than conventionally used by dedicated platforms, and we were not able to stop or deviate from routes to

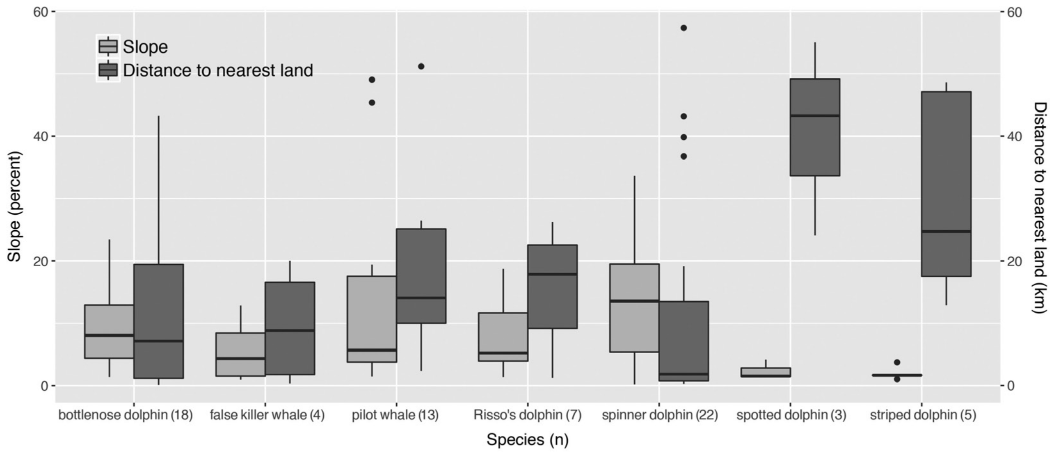


**Figure 5.** Distribution of species ($n \geq 3$) across slope gradients (left axis, light gray boxes) and distance to nearest landmass (right axis, dark gray boxes); dots are outliers of the data.

obtain better identification of cetaceans. Despite these limitations, our study demonstrates that, like other tropical oceanic island complexes such as Hawaii and the Maldives that are characterized by changing depth profiles, varying ecological niches, and high cetacean usage (Anderson et al., 2012a; Baird et al., 2013), Lakshadweep waters host a diverse tropical cetacean community.

The encounter rate of 2.01 sightings per 100 km recorded during the current study period is lower than encounter rates recorded in some prior marine mammal surveys in nearby waters. Ballance & Pitman (1998) documented 6.02 sightings per 100 km in the western tropical Indian Ocean; Ballance et al. (2001) reported an encounter rate of 13.6 sightings per 100 km off Maldives; and Ilangakoon (2012b) recorded an encounter rate of 6.11 sightings per 100 km. These studies were dedicated surveys running at lower vessel speeds. Afsal et al. (2008) reported an encounter rate of 0.1 sighting per hour that was lower than our encounter rate of 0.61 sighting per hour. This survey by Afsal et al. was opportunistic and had fewer observers than our study. Our encounter rate was comparable to the encounter rate of 1.28 sightings per 100 km recorded by Alling (1986), although survey effort, vessel type, and number of observers differed. Our surveys showed a higher encounter rate compared to opportunistic studies such as Afsal et al. (2008); however, our encounter rate was lower than that of dedicated surveys using 25x binoculars such as Ballance & Pitman (1998). Dedicated surveys in this region may improve encounter rate estimates.

Species reported in this study have been previously described in opportunistic sightings in the Lakshadweep region (Kumarran, 2012; Marine Mammals of India database, 2019). Peer-reviewed publications chronicle seven species where identification could be verified: Risso's dolphin, bottlenose dolphin, striped dolphin, spinner dolphin, short-finned pilot whales, sperm whales (*Physeter macrocephalus*), and Cuvier's beaked whale (*Ziphius cavirostris*) (Burton, 1941; Lal Mohan, 1985; Pillai et al., 1986; James & Panicker, 1990, 1994; Afsal et al., 2008; Sajikumar et al., 2014). During a marine fauna study, Nagabhushanam & Rao (1972) recorded the occurrence of common dolphins (*Delphinus delphis*), blue whales (*Balaenoptera musculus*), and killer whales (*Orcinus orca*) as part of their species inventory in the Minicoy waters of Lakshadweep, but no identification methodology, morphological descriptions, behavioral information, or exact locations were provided. This study adds false killer whales, pantropical spotted dolphins, and pygmy killer whales to this list. Burton (1941) reported the presence of common dolphins and porpoises in 1935; however, these were incorrectly identified, and pictorial evidence in the publication shows clear identification features for bottlenose and Risso's dolphins, respectively.

*Tursiops* spp. to species level was not classified in this study as detailed observations and photographs were not available for every *Tursiops* sighting in the field. It appears that both species may occur in Lakshadweep waters as we observed some sightings with robust body type and short beak characteristics and other sightings with a comparatively slender body type and longer beak. Based on our anecdotal notes, it may be a possibility that *T. aduncus* is island-associated and

*T. truncatus* occurs offshore. Anderson (2005) noted that both species may occur in the Maldives and observed a difference between the behavior of inshore and offshore bottlenose dolphins there. More investigation in our study area is required to confirm whether one or both subspecies occur in the region.

In the current study, a higher number of sightings occurred during the northeast monsoon season (November-December), suggesting that some species may be using the area seasonally. Seasonal comparisons were conducted between northeast monsoon and inter-monsoon seasons in this study; our surveys did not cover the southwest monsoon season. Seasonal cetacean usage during northeast monsoon seasons has been documented for Sri Lanka and the Maldives (Bröker & Ilangakoon, 2008; Anderson et al., 2012b; Clark et al., 2012; de Vos et al., 2014). Primary and mesozooplankton productivity in the northeast monsoon season is high in offshore regions of the Arabian Sea due to convective mixing and zooplankton community dynamics (Madhupratap et al., 1996; Barber et al., 2001). In contrast, inter-monsoon months can be less productive due to stratification (Barber et al., 2001). In Lakshadweep waters, high mesozooplankton abundance and diversity are observed in December and January (Mathew et al., 2003; Sanu et al., 2014). We hypothesize that some cetacean species may be using this area to exploit such productive conditions in the northeast monsoon season.

Cetacean species differed in seafloor slope gradients and with distance from islands in which they were sighted. Spinner dolphins occurred closest to land and across a larger slope gradient. In the Maldivian atolls, spinner dolphins are found nearshore and enter the atolls through reef channels in the mornings and move offshore to feed in the afternoons (Anderson, 2005). Striped and spotted dolphins occurred furthest from land and also inhabited a narrow slope gradient (flatter topography) in our study. This is similar to findings by Anderson (2005) in the Maldives where striped dolphins were recorded mostly outside atolls in offshore waters. Such differences are likely to reflect niches inhabited by prey species of cetaceans. Habitat analyses in our study used a presence-only approach and tested for how species differed from one another along the ferry routes; hence, the findings should be interpreted within this context. Our understanding of the habitat preferences of these species in the Lakshadweep region is currently marginal; moreover, sample sizes for some species in our study were low. Therefore, to understand habitat use and/or habitat preferences of cetacean species in Lakshadweep waters, further dedicated surveys covering available bathymetric regimes need to be undertaken.

Mixed species groups comprised of bottlenose dolphins and short finned pilot whales, similar to what we observed, have been recorded in other regions, including the western tropical Indian Ocean, eastern tropical Pacific, southern Sri Lanka (Ballance & Pitman, 1998; Ilangakoon, 2012b), and nearby coral atolls such as the Maldives (Anderson, 2005). The second association we documented of pantropical spotted dolphins and bottlenose dolphins appears less common. In some areas, such as the Bahamas, Atlantic spotted dolphins associate with bottlenose dolphins regularly and engage in a host of activities such as foraging, play, aggression, and sexual behavior and potential hybridization (Herzing & Elliser, 2013). Pantropical spotted dolphins commonly occur with spinner dolphins in regions like the Maldives, the eastern tropical Pacific, and Hawaii (Perrin et al., 1973; Psarakos et al., 2003; Anderson, 2005). We did not observe this association, which may be due to the "passing mode" methodology used during our surveys. Quérouil et al. (2008) suggest mixed species associations in cetaceans might result in some foraging advantages for one or both species. Other reasons could include predator avoidance or social requirements such as play (Herzing & Elliser, 2003; Stensland et al., 2003; Quérouil et al., 2008). Further research into the behavioral ecology of these mixed species groups across regions would shed light on these theories.

Prior publications have reported instances of small cetacean capture in the Lakshadweep region. Burton (1941) provided a detailed account of a hunt to capture 11 Risso's dolphins on the island of Chetlat for local consumption. Manikfan (1991) documented the hunting of small cetaceans in the northern Lakshadweep islands for local consumption with harpoons and a drive fishery (also mentioned in Burton, 1941), except for in Minicoy where cetaceans are believed to drive fish into the lagoon. Lal Mohan (1985) reported that an estimated 50 dolphins were caught annually across the Lakshadweep islands, except in Minicoy. Although our research did not focus on hunting, we feel it is important to share that during the course of our study, targeted hunting was not observed or reported in Kavaratti. While fishermen's accounts indicated knowledge of such practices as isolated events, they stated this practice was largely abandoned by the younger generation after the advent of the pole and line tuna fishery in Kavaratti. Instead, several local reports from Kavaratti and Minicoy stated that dolphins act as cues for fishermen to find tuna shoals similar to in the eastern tropical Pacific Ocean (Lal Mohan, 1985; Ballance et al., 2006). The existence and extent of cetacean capture for local consumption across all the islands and the consequence of dolphins being visual aids for tuna fishers (e.g., vessels approaching groups) need to be investigated further.

The most likely candidate for the unidentified *Balaenoptera* sp. may be the fin whale based on its apparent body size. The animal seemed too large to be an Omura's (*B. omurai*) or common minke (*B. acutorostrata*) whale. Photos taken in succession of a surfacing show the long back coming up after the blow and before seeing the dorsal fin, which indicates a body size of over 20 m (Figure 3e shows the last frame of a surfacing whale with dorsal fin). There are no confirmed records of fin whales in the region, and this species is considered rare in low latitudes, with some exceptions (Wade & Gerrodette, 1993). Bryde's whale (*B. edeni*) is yet another possibility if the large size estimate is disregarded. This species has been sighted in mainland Indian coastal waters and the Maldives (Ballance et al., 2001; Sutaria et al., 2017). Sperm whale, pygmy blue whale, and humpback whale can be ruled out based on the dorsal fin shape (Figure 3e).

In the Arabian Sea, large whales are known to undertake mesoscale movements to meet energy demands (Mikhalev, 1997; Branch et al., 2007; Anderson et al., 2012b; Pomilla et al., 2014), but their ranging behavior remains unknown in many areas. There are regional reports of large whales in the Maldives, Sri Lanka, and the west coast of India (James & Panicker, 1990, 1994; Ballance & Pitman, 1998; Afsal et al., 2008; Anderson et al., 2012a; Ilangakoon, 2012a; Kumarran, 2012; Sutaria et al., 2017). Our surveys had only two observations of large whales; however, anecdotal reports by local fishermen confirm that large whale sightings occur regularly in these waters. Our methodology may have missed whale sightings or any other long-diving species due to availability bias arising from the speed of our platform and "passing mode" of survey (Barlow, 1999; Williams et al., 2006). There may also be seasonal variations (e.g., southwest monsoon season) in baleen whale presence in the region (Anderson et al., 2012b). We propose using methods such as passive acoustic monitoring and/or dedicated marine mammal visual surveys for future studies to better understand cetacean occurrence in the region.

Our surveys were conducted from ferries serving as platforms of opportunity as the primary purpose of the ferry system is to transport passengers between islands. Ferry routes were linear, making it possible for us to survey using a line-transect framework in this region, which is otherwise remote and difficult to access (Buckland et al., 2001, 2005). Although the vessel speed and direction was conducive to line-transect methodology, we had no control over route design, ferry schedule, speed of travel, or type of vessel used, making it difficult to compare effort data across the routes. Hence, we have only presented descriptive route information and refrained from making any statistical comparisons.

The Lakshadweep waters are clearly an important area for multiple cetacean species, and further surveys are required to provide a robust picture on space-use patterns, including those of rare or cryptic species. Oceanographic factors and habitat preferences of cetacean species need to be studied to identify the determinants of distribution in this region. Passive acoustic monitoring would be another relatively cost-effective method to study year-round occurrence, especially during rough weather periods such as the southwest monsoon. As the islands are not currently industrially developed, have limited tourism activities, and practice pole and line tuna fishing, cetaceans in this region may currently face relatively lower or different types of threats than neighboring areas. These are likely to change with growing demands from the high-end tourism industry and plans for large-scale tourism expansion (Kumar & Muralidharan, 2019). Hence, accounting for the high cetacean usage near the islands, the area needs to be monitored and carefully managed. The high diversity of cetaceans over many months underlines the Lakshadweep region as an important mid-ocean habitat and emphasizes the need for further studies in the region to highlight the biogeography and ecology of cetaceans here.

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