SEABIRD AND CETACEAN OCCURRENCE IN THE BAY OF BENGAL ASSOCIATED WITH MARINE PRODUCTIVITY AND COMMERCIAL FISHING EFFORT

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ABSTRACT

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At-sea observations of seabirds and cetaceans provide essential baseline information about their biogeography and behaviour, facilitating marine spatial planning and management. Much of the world's oceans have been surveyed, yet some regions remain particularly data-poor for seabirds and cetaceans, including the Bay of Bengal. We performed 39 d of vessel-based observations within the Bay of Bengal from 2012 to 2014, surveying an overall linear distance of 4722.3 km. We observed 2697 seabirds of 17 species and 1441 cetaceans of at least eight species. Among the seabirds, Sooty Terns *Onychoprion fuscatus* (n = 2282, 85% of all birds) and Wedge-tailed Shearwaters *Ardenna pacifica* (n = 327, 12%) predominated, whereas cetacean numbers were dominated by Spinner Dolphins *Stenella longirostris* (n = 772, 54% of all cetaceans) and Indo-Pacific Bottlenose Dolphins *Tursiops aduncus* (n = 533, 37%). Other seabirds and cetaceans accounted for only 4% and 7%, respectively, of all sightings. The abundance and diversity of both groups was low compared to other tropical areas. We propose that low seabird and cetacean abundance results from low productivity due to stratification in the Bay of Bengal, as well as long-lasting disturbance, overexploitation of marine resources, possible impacts of longline fisheries, and the near absence of seabird breeding sites.

Key words: at-sea survey, biogeography, cetaceans, conservation, Bay of Bengal, seabirds,upper trophic level predators, overfishing

INTRODUCTION

Seabirds form only ~3% of all bird species, but their collective biomass far outweighs that of land birds (Brooke 2004, Birdlife International 2010). Cetaceans contribute an even smaller proportion of mammal diversity (~2%), but their large biomass and generally high trophic position make them ecologically important (Katona & Whitehead 1988, Pauly *et al*. 1998, Schipper *et al*. 2008). Therefore, mapping seabird and cetacean species' distributions and relative abundance across the oceans provides insight into marine food web dynamics and marine community structure; further, mapping facilitates effective marine conservation strategies. Many studies on seabirds (Burger & Gochfeld 2004, Piatt *et al*. 2007, Mallory *et al*. 2010) and cetaceans (Reddy *et al*. 2001, Wells *et al*. 2004, Ainley *et al*. 2009) have demonstrated their importance as ecosystem sentinels.

Most seabird and cetacean studies have focused on temperate and high-latitude zones (Phillips *et al*. 2006, Karnovsky *et al*. 2010); much less effort has been carried out in subtropical and tropical areas, with most attention directed to the tropical Pacific Ocean (e.g., Bailey 1966, Bailey 1968, Ashmole 1971, Ainley 1977, Pocklington 1979, Abrams & Griffiths 1981, Au & Pitman 1986, Pitman & Ballance 1992, Ballance *et al*. 1997, Spear *et al.* 2001, Vilchis *et al.* 2006). These studies revealed, in general, that seabird species diversity is higher in warmer subtropical and tropical seas when compared to the colder temperate and high-latitude seas; while densities were higher in the latter (Newton 2003, Ballance 2007).

In the tropical and subtropical regions of the Indian Ocean, only a few large-scale surveys have been conducted (e.g., Pocklington 1979, Hyrenbach *et al*. 2007, Thiebot & Weimerskirch 2013), and most studies have focused on its western sector (e.g., Bailey 1968, Ballance *et al*. 2002, Jaquemet *et al*. 2005, 2014). Little attention has been given to the Indian Ocean's eastern sector (Dunlop *et al*. 1988), and the Bay of Bengal (BOB) has received even less attention. There is, to the best of our knowledge, no previous systematic study of seabirds and cetaceans in the northeastern Indian Ocean, especially for the Bay of Bengal Large Marine Ecosystem (BOBLME). The BOB is the largest bay in the world (2.2 million km^2) and is believed to be globally significant for seabirds (Mondreti *et al*. 2013, Le Corre *et al*. 2012, Jaeger *et al*. 2017) and cetaceans (Alling *et al*. 1986, Kumaran 2002, Afsal *et al.* 2008, Smith *et al*. 2008, Malakar *et al*. 2015).

Some 50 species of seabirds have been recorded from the Indian subcontinent; except for some terns, most are non-breeding migrants (Birdlife International 2014). Of the 11 tern species recorded from the region, nine breed on the Indian subcontinent and most are coastal species that forage from inland estuaries to the edge of the continental shelf (Mondreti *et al*. 2013). In contrast, Sooty Terns *Onychoprion fuscatus,* a super-abundant pan-tropical species, breed on some of the islands of the Lakshadweep Archipelago (Arabian Sea) and in this region are thought to occur only in pelagic waters of the BOB and Arabian Sea. The BOB is potentially an important foraging site for oceanic species such as Sooty Terns (Jaeger *et al.* 2017), shearwaters (Le Corre *et al*. 2012), and petrels (Legrand *et al*. 2016). Past observations of cetaceans in the BOB, off the coast of Bangladesh, showed that at least four cetacean families (Platanistidae, Delphinidae, Phocinidae, and Balaenopteridae) were present (Smith *et al.* 2008).

Seabirds and cetaceans are impacted by the consequences of climate change, but effects of pelagic longline fishing are also important for seabirds (Delord *et al*. 2010, Rollinson *et al.* 2017, Bugoni *et al*. 2008, Petersen *et al*. 2009) and cetaceans (Werner *et al*. 2015, Macías-López *et al.* 2012), notably through incidental mortality (bycatch). In some cases, longlining has been driving seabird populations to near extinction (Croxall *et al.* 2012), even though mitigation measures have brought major improvements in some areas (Rollinson *et al.* 2017). Therefore, it is helpful to estimate the extent of spatial overlap between seabirds, other upper trophic level predators, and commercial longlining fishing to examine whether further marine spatial planning may be needed (Cuthbert *et al*. 2005, Petersen *et al.* 2008, Copello & Quintana 2009, Thiebot *et al.* 2016).

TABLE 1
Total survey effort indicating the number of days at sea, distance covered, and hours of observation

Year	Transect[a]	Month	Days of observation at sea	Sampling effort (hours)	Distance covered (km)
2012	MPB	April	3	26	333.6
	PBM	May	3	32	370.6
	KPB	May	4	26	270.2
	PBK	May	3	26	273.4
	MD	May, June	14	106	2161.6
2013	MPB2	March	3	23	279.6
	PBK2	March, April	3	27	326.1
2014	MPB3	January	3	31	370.1
	PBK3	January	3	26	337.1
Total			39	323	4722.3

[a] MPB = Chennai-Port Blair, PBM = Port Blair-Chennai, KPB = Kolkata-Port Blair, PBK = Port Blair-Kolkata, MD = Marion Dufresne.

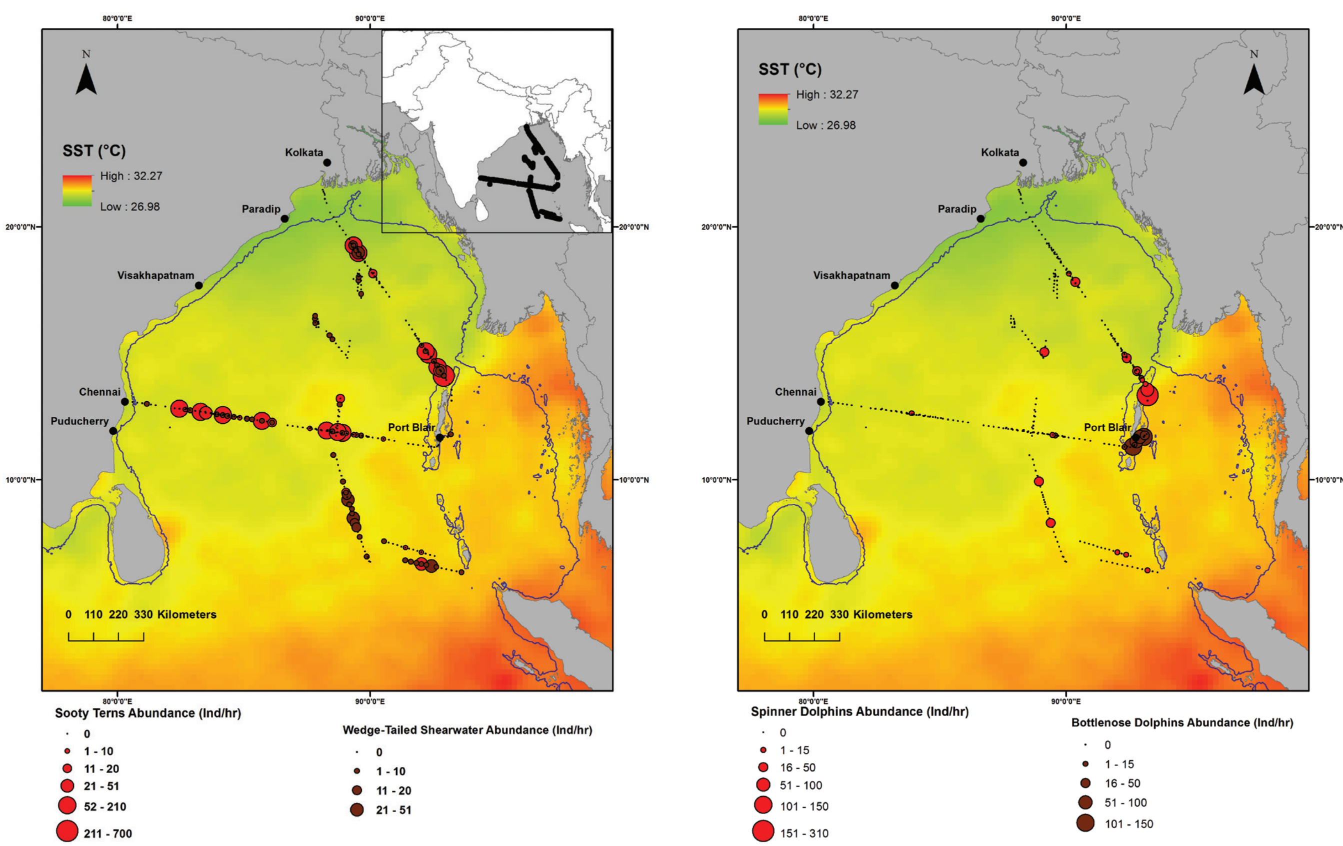

Fig. 1. The abundance of A) Sooty Terns and Wedge-tailed Shearwaters; and B) Spinner Dolphins and Indo-Pacific Bottlenose Dolphins relative to sea surface temperature (SST). The solid line indicates the 200-m bathymetric contour. Inset shows the extent of the study area with respect to the Indian subcontinent.

Broadly, our main research objective was to provide important baseline information on seabird and cetacean sightings for the data-poor BOB (Narvekar & Prasanna Kumar 2006). The specific objectives of our study were to: (i) provide information about the at-sea distributions and abundances of seabirds and cetaceans within the BOB; (ii) understand broad links between these occurrences and abiotic (sea surface temperature, bathymetry) as well as biotic (chlorophyll a) parameters; and (iii) illustrate potential overlaps between seabird and cetacean occurrences and pelagic longlining activities.

MATERIALS AND METHODS

Study area

The BOB (Fig. 1) is designated as one of 64 global Large Marine Ecosystems (LMEs; Sherman & Hempel 2009, Heileman *et al*. 2009, Hossain 2004). It spans an area equivalent to 6% of the Indian Ocean, although the International Hydrographic Organization (IHO) publication, *Limits of Oceans and Seas*, excludes the BOB and Arabian Sea from the Indian Ocean (International Hydrographic Organization 1953). The BOB forms a semi-closed tropical basin that receives freshwater output from the Ganges, Brahmaputra, and Godavari rivers. Nutrient-rich runoff from these rivers is the primary reason for the high primary production of the region's coastal waters (Sarma *et al*. 2016). By comparison, the central parts of the BOB are less productive due to the absence of upwelling and mixing (Dwivedi 1993). The continental shelf along the east coast of India is < 45 km wide, except for the northern portion, where the continental shelf is > 200 km wide (Varkey *et al*. 1996). The BOB is considered to have lower biological production than the neighbouring Arabian Sea (Prasanna Kumar *et al.* 2002), but, nonetheless, is a class I highly productive ecosystem (> 300 g·cm^{-2}·y^{-1}; Sherman & Hempel 2009). Annual primary productivity in the BOB is at least twice that of the Benguela upwelling ecosystem and the North Sea (Sherman & Hempel 2009, Mondreti *et al*. 2013), from which one might presume that the BOBLME possesses numerous seabird and cetacean species.

At-sea surveys

We surveyed seabirds and cetaceans, either from the flying bridge or the bow, onboard passenger and research vessels during nine cruises in April–May 2012, February–March 2013, and January 2014, along two major shipping routes: Chennai to Port Blair (CPB) and Kolkata to Port Blair (KPB) (Table 1, Fig. 1). RM performed most observations during 3–5 d cruises on board passenger vessels of the shipping corporation of India: M/V *Nancowry* (157 m), M/V *Akbar* (149.5 m) and M/V *Harshavardhana* (132.5 m). PGR performed additional observations during a 23-d research cruise of R/V *Marion Dufresne* (120 m). Due to very low bird and cetacean densities, we used Method II described by Tasker *et al*. (1984) to perform continuous surveys of seabirds and cetaceans (Ballance & Pitman 1998).

Due to low seabird and cetacean numbers observed during all the cruises, we recorded them out to the limit of detection (~500 m). All observations were made continuously during steaming from

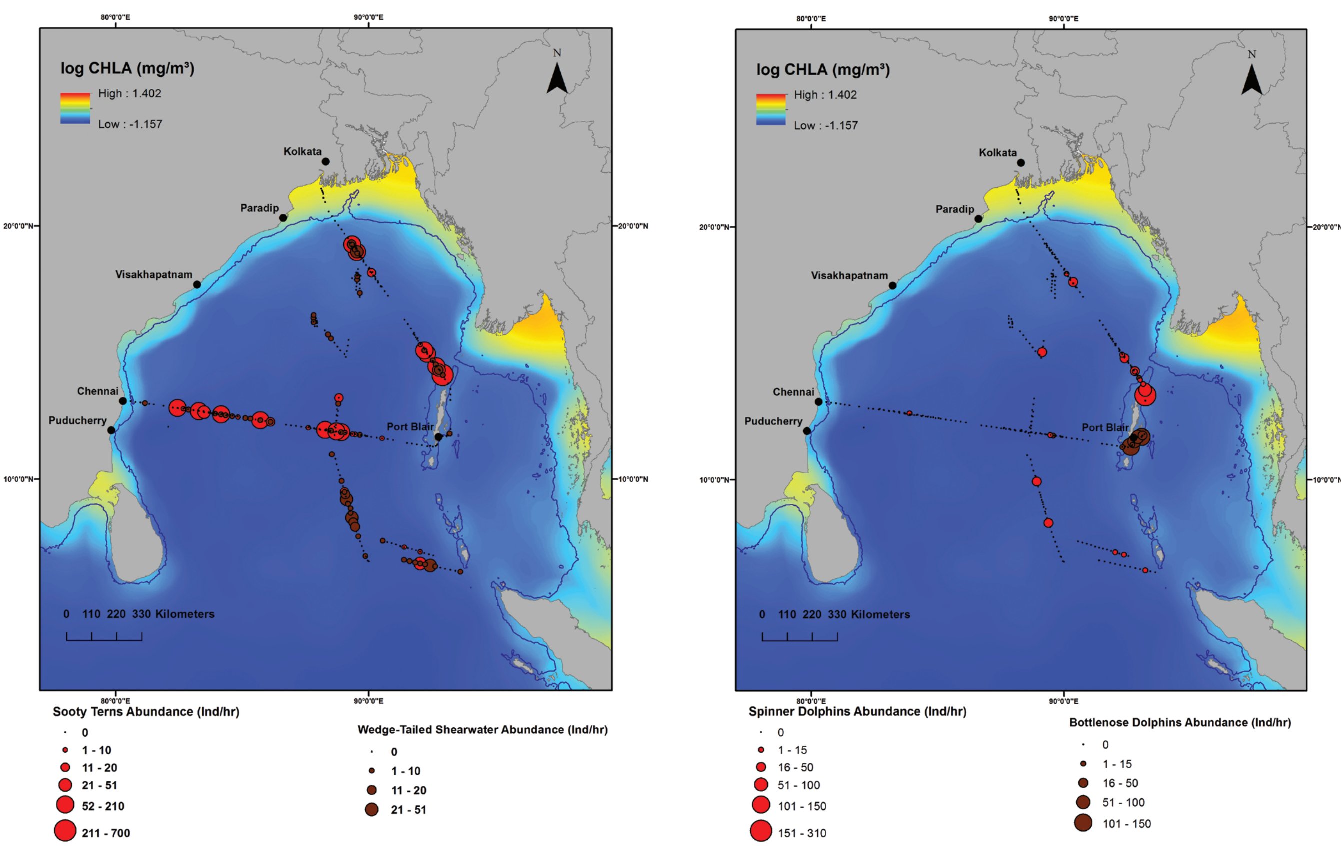

Fig. 2. The abundance of A) Sooty Terns and Wedge-tailed Shearwaters; and B) Spinner Dolphins and Indo-Pacific Bottlenose Dolphins in relation to chlorophyll *a* (ChlA) levels. The solid line indicates the 200-m bathymetric contour.

sunrise to sunset, counting birds on one side of the vessel in a 90° quadrant (usually the side with best visibility, i.e., least sun glare). All cetaceans seen were counted, irrespective of the side of the vessel on which they were first detected. Observations were not made during unfavourable weather conditions (visibility < 3 km and rainy days) and stopped when the coasts were visible at a distance of 10–15 km. We used 10× binoculars from an approximate eye height of 25 m (ship's bridge) or 8 m (bow), when the ship was cruising at 12–26 km·h^{-1} (6.5–14 knots). Because the counts were not quantified according to the area searched, and given the possible confounding effects of ship avoidance or attraction, we focused on the relative number of individuals sighted instead of absolute abundance. Counts were made following international Seabirds at Sea (SAS) standards (Camphuysen *et al*. 2004, Camphuysen & Garthe 2004, Tasker *et al*. 1984, Johansen *et al*. 2015), incorporating sightings of cetaceans. The geographic position of the ship at the beginning of each transect was recorded from a hand-held Geographic Positioning System (GPS; Garmin eTrex10) and was later checked with the ship's GPS navigation system for accuracy. During each transect, the time and exact coordinates of each seabird or mammal observation was recorded. Subsequently, for analysis, transects were divided into one-hour bins, with sightings allocated accordingly into the appropriate bins. There were no ship-following seabirds except for coastal species, observations of which were restricted to the continental shelf (< 100 km from shore).

Oceanographic variables

We retrieved oceanographic variables, including bathymetry (ETOPO1, spatial resolution 0.01667 degrees), sea surface temperature (SST; NOAA POES AVHRR, GAC, 0.1 °C), and chlorophyll *a* concentration (ChlA; Aqua MODIS, NPP, 0.05 degrees) from the Bloomwatch website (https://coastwatch.pfeg.noaa.gov/coastwatch/CWBrowser.jsp). We selected these variables based on their ecological and functional relevance for seabirds and cetaceans (Garthe *et al*. 2009). Remotely sensed SST and ChlA data are proxies of surface water mass distributions and primary productivity, respectively. Similarly, water depth or bathymetry can also influence seabird occurrence (Schneider 1997) and cetacean distributions (Yen *et al*. 2004). Frequent cloud cover prevented the use of daily or weekly satellite-derived datasets, so we used monthly environmental datasets. For some variables, remote sensing data were not available for the survey month in the year of the survey, so we used the data from previous years. Given the irregular spatial resolution of the oceanographic variables, we aggregated all data of the survey bins into 0.2° × 0.2° grid cells and recalculated the abundance of seabirds and cetaceans for these grid cells.

Fisheries data

Longline fishing catch and effort data were retrieved and compiled from publicly available sources: the Indian Ocean Tuna Commission (http://www.iotc.org) and the Regional Fisheries Management Organizations for the period 1952–2013. All sectors in the BOB were mapped into 5° × 5° grid cells. Wherever the spatial resolution of fishing data was not uniform, the larger cells (10° × 10° and 20° × 20°) were parsed and the smaller cells (1° × 1°) were aggregated into 5° × 5° standard grid cells. The data were integrated and analysed in ArcGIS 10.1 (ESRI, Inc. Redlands, CA, USA) to produce maps of fishing effort (number of hooks per 5° × 5° cell), following the methodology described in Lewison *et al*. (2004). Fishing effort is expressed as the mean number of longline fishing hooks per year deployed in a standard 5° × 5° cell.

Data processing

We overlaid bins of seabird and cetacean abundances over SST and ChlA raster layers (kriged) to examine the spatial distributions. All spatial analyses were performed using ESRI ArcGIS, version 10.1 (ESRI 2012). Because each of the environmental variables were not normally distributed, wherever necessary, we applied data transformation and performed our analysis using the mean. There were some temporal mismatches between sightings and environmental data that could confound identification of patterns in the data. Therefore, we did not attempt to model the possible factors explaining species distributions. Due to varying cruise speeds, we expressed abundance as the number of individuals sighted per hour. We then extracted the oceanographic variables (SST, ChlA, bathymetric characteristics) for each grid cell using ArcGIS 10.1 software. At-sea bird abundance data were converted to the same resolution (5° × 5°) as that of fishing effort maps. We calculated a single value mean for each of these 5° × 5° cells. Each point, which represents numbers of seabirds and cetaceans seen per hour of observation, was overlaid on the longline fishing effort raster. Additionally, we calculated mean encounter rates per 100 linear km for each species for all of the survey months.

RESULTS

In accordance with our research objectives, we collected seabird and cetacean observations in some areas of the BOB, thereby providing important baseline information for this data-poor region. Sightings were scarce, and low animal occurrences precluded detailed analyses of links with patterns of primary productivity, SST, bathymetry, and fisheries. Despite these limitations, we were able to draw interesting general conclusions from our data.

TABLE 2
Monthly survey effort of seabirds and cetaceans, including the numbers sighted and encounter rate of each species

Month	Effort (hrs)	No. of individuals sighted[a]				Mean encounter rate (sightings/100 km)			
		SOTE	WTSH	BNDO	SPDO	SOTE	WTSH	BNDO	SPDO
January	65	1	3	156	12	0.08	0.15	0.30	0.08
March	35	775	10	163	461	0.57	0.57	0.28	1.00
April	41	652	6	102	50	1.34	0.60	0.24	0.12
May	120	768	113	112	114	0.66	0.87	0.08	0.29
June	62	86	195	0	45	0.80	1.93	0.00	0.16

[a] SOTE = Sooty Tern, WTSH = Wedge-tailed Shearwater, BNDO = Indo-Pacific Bottlenose Dolphin, SPDO = Spinner Dolphin.

Total numbers and species sightings

During at-sea transects, we covered a total distance of 4722.3 km, at an average speed of 20 km·h^{-1}, for a total number of 39 d and with a linear survey effort of 323 observation hours (Table 1). We observed 2697 seabirds of 17 species and 1441 cetaceans of at least eight species (Table 2).

Sooty Terns *Onychoprion fuscatus* (*n* = 2282 individuals) and Wedge-tailed Shearwaters *Ardenna pacifica* (*n* = 327 individuals) accounted for 97% of all birds observed, while 91% of all individual cetaceans observed were Indo-Pacific Bottlenose Dolphins *Tursiops aduncus* (*n* = 533 individuals) and Spinner Dolphins *Stenella longirostris* (*n* = 772 individuals). Although we sighted cetaceans along all transects, they were most abundant close to the Andaman and Nicobar islands (Figs. 1B, 2B). Overall, throughout the study area, cetaceans were sighted sporadically, usually in low numbers.

Seasonality in seabird and cetacean sightings

Our at-sea observations revealed noticeable monthly (seasonal) differences in both seabird and cetacean numbers (Table 2). The only exception was the Indo-Pacific Bottlenose Dolphins, which were encountered frequently throughout all months of the study. Peak Sooty Tern numbers were observed during spring (March–May), whereas maximum numbers of Wedge-tailed Shearwaters were seen during the commencement of the southwest monsoon (June; Table 2). Maximum encounter rates for Sooty Terns (average 1.34 sightings·km^{-1}) occurred during spring (April), whereas maximum encounter rates for Wedge-tailed Shearwaters (average 1.93 sightings·km^{-1}) occurred in June. Maximum encounter rates for Spinner Dolphins (average 1.0 sighting·km^{-1}) occurred during March, whereas bottlenose dolphins (average 0.3 sightings·km^{-1}) were sighted most frequently in winter (January).

Physical and biological habitat

SST and ChlA values varied little across the BOB (Figs. 1, 2). However, SST increased significantly from North to South—the northern waters were cooler than the south (Figs. 1A, B). High ChlA values occurred at the head of the Bay and along the east coast. Overall, we observed low SST and high ChlA values at the head of the bay; high SST and low ChlA values occurred in the central and southern areas of the bay (Figs. 1A, 2A). By comparison, water depth (bathymetry, BATH) increased gradually from north to south (Fig. 3A). The floor of the central BOB is flat, with depths ranging from 2000–3000m; depths of up to 4700m occur towards the mouth of the BOB.

We observed seabirds throughout the study area, independent of changes in SST, ChlA, or bathymetric characteristics (Figs. 1A, 2A, 3A). However, the highest numbers of Sooty Terns were observed

TABLE 3
Seabird and cetacean species observed during the present study in Bay of Bengal

Group	Species name	Number of individuals
Seabirds	Sooty Tern (*Onychoprion fuscatus*)	2282
	Wedge-tailed Shearwater (*Ardenna pacifica*)	327
	Greater Crested Tern (*Thalasseus bergii*)	29
	Lesser Crested Tern (*Thalasseus bengalensis*)	15
	Sandwich Tern (*Thalasseus sandvicensis*)	11
	Caspian Tern (*Hydroprogne caspia*)	10
	Flesh-footed Shearwater (*Puffinus carneipes*)	5
	Streaked Shearwater (*Calonectris leucomelas*)	5
	Jouanin's Petrel (*Bulweria fallax*)	3
	Barau's Petrel (*Pterodroma baraui*)	2
	Black-naped Tern (*Sterna sumatrana*)	2
	Wilson's Storm Petrel (*Oceanites oceanicus*)	1
	Masked Booby (*Sula dactylatra*)	1
	Red-tailed Tropicbird (*Phaethon rubricauda*)	1
	South Polar Skua (*Catharacta maccormicki*)	1
	Pomarine Skua (*Stercorarius pomarinus*)	1
	Roseate Tern (*Sterna dougallii*)	1
Cetaceans	Spinner Dolphin (*Stenella longirostris*)	772
	Indo-Pacific Bottlenose Dolphin (*Tursiops aduncus*)	533
	Striped Dolphin (*Stenella coeruleoalba*)	77
	Pantropical Spotted Dolphin (*Stenella attenuata*)	50
	Dwarf Sperm Whale (*Kogia sima*)	5
	Pygmy Sperm Whale (*Kogia breviceps*)	3
	Short-finned Pilot Whale (*Globicephala macrorhynchus*)	1

in the shelf break waters of Andaman and Nicobar islands. Most cetaceans were observed close to the shelf break (~200 m deep, Fig. 3B) in the coastal waters of the Andaman and Nicobar islands, which are characterised by high productivity and low surface temperatures (Figs. 1B, 2B).

Overlap with longline fisheries

While most intense longline fishing zones were situated in the centre of the bay, some effort was situated in the continental shelf areas of the Andaman and Nicobar islands (Figs. 4A, 4B). The highest numbers of both seabirds and cetaceans were observed in these intense fishing zones.

Longline fishing fleets in the BOB are operated by different countries, but most fishing effort is undertaken by Taiwan and Japan (Table 4). Taiwan's and Japan's share of the total fishing effort in BOB between 1953 and 2014 was 59.6% and 30.2%, respectively. In BOB waters, Taiwan has been operating its longline fleet since 1967, whereas Japan has been operating since 1953 (http://www.iotc.org). In comparison to Taiwan and Japan, Indian longliners constituted a mere 0.36% of the total longline fishing effort in BOB from 1953–2014.

DISCUSSION

Low occurrences of seabirds and cetaceans

Our seabird encounter rate (8.3 birds·h^{-1}) was much less than that recorded in the Mozambique Channel (89.4 birds·h^{-1}; Jaquemet *et al.* 2005, 2014). One possible explanation for the low density of seabirds in BOB is the lack of breeding colonies in the region (Feare *et al.* 2007, Le Corre *et al.* 2012, Mondreti *et al.* 2013). Only the pan-tropical Sooty Tern was fairly common in BOB. This species has impressive dispersal ability thanks to its very low flight costs, which allow it to exploit patchy prey in the vast tropical ocean (Ballance *et al.* 1997). It often occurs in large flocks associated with cetaceans and tropical tunas, which enhances foraging efficiency (Au & Pitman 1986, Jaquemet *et al*. 2005, Thiebot & Weimerskirch 2013). Indeed, recent tracking studies of Sooty Terns from the western Indian Ocean confirmed that birds breeding in remote islands off the Indian Ocean visit BOB during the non-breeding season (Jaeger *et al*. 2017). The largest breeding colonies of Sooty Terns in the Indian Ocean occur on three island groups: the Europa and Juan de Nova islands in the Mozambique Channel, and the Glorieuses Islands in Seychelles (Jaquemet *et al*. 2008). The Wedge-tailed Shearwater is another pan-tropical seabird species that breeds in the Seychelles and other remote islands of the Indian Ocean and is also known to forage in BOB (Le Corre *et al.* 2012).

The encounter rate of cetaceans (4.5 dolphin·h^{-1}) was also much lower than recorded in the western tropical Indian Ocean (77.1 dolphin·h^{-1}; Ballance & Pitman 1998). One possible reason for the low sightings of cetaceans in the BOB is low habitat quality (Qasim 1977, Gomes *et al*. 2000, Prasanna Kumar *et al*. 2002, 2010), which impacts prey abundance and availability. This low habitat quality might result from high freshwater discharge from the Ganges River (especially during the Southwest Monsoon), resulting in stratification, wherein deeper layers are not mixed with the surface layers, thus reducing primary production compared to the Arabian Sea (Qasim 1977, Gomes *et al*. 2000,

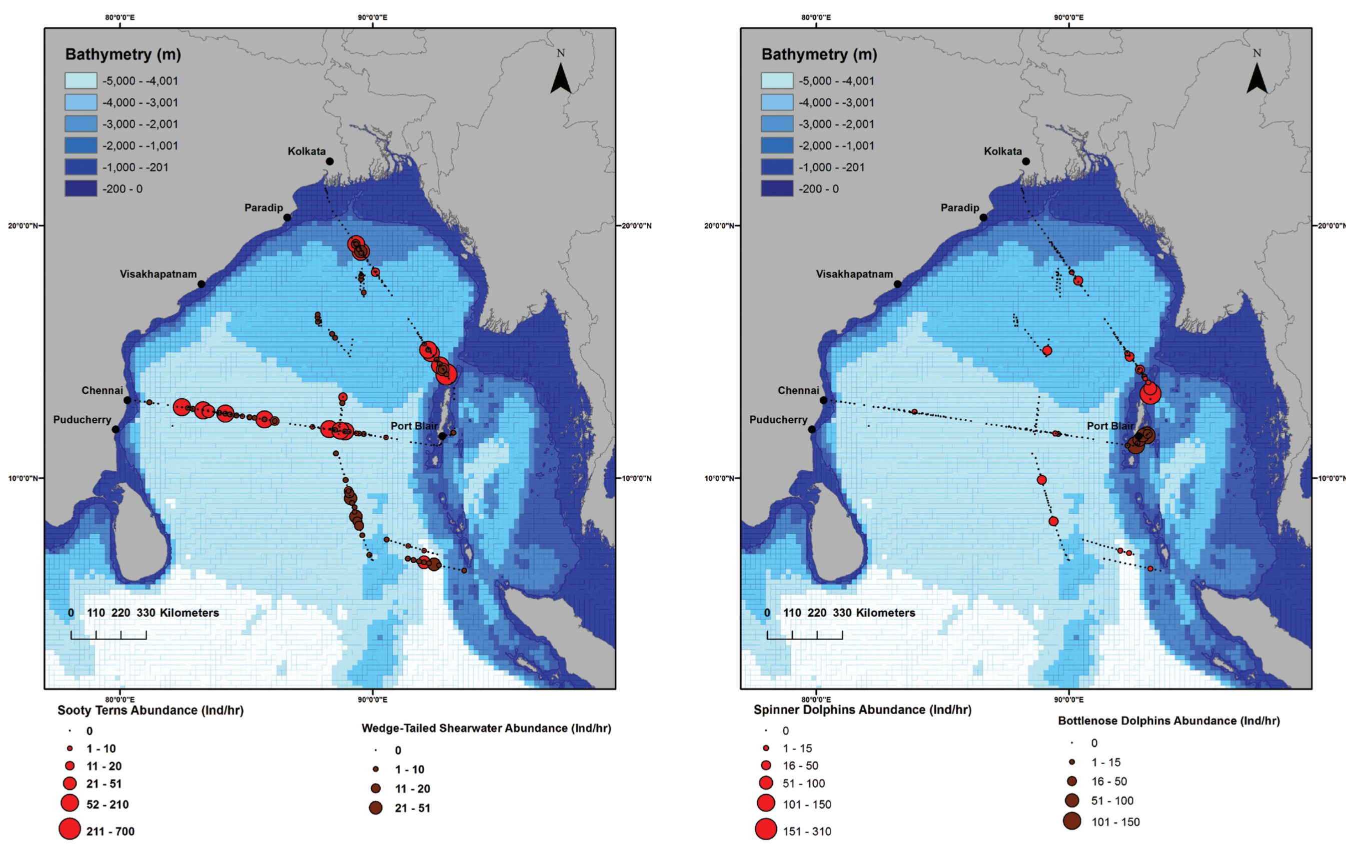

Fig. 3. The abundance of A) Sooty Terns and Wedge-tailed Shearwaters; and B) Spinner Dolphins and Indo-Pacific Bottlenose Dolphins in relation to bathymetry (BATH).

Prasanna Kumar *et al*. 2002, 2010; Olsen *et al*. 2013). In addition, the BOB, as a marine environment, is exposed to substantial levels of a wide range of pollutants (Holmgren 1994, Kaly 2004), and these stressors may also contribute to both low seabird and cetacean occurrences. Another stressor is the low concentration of dissolved oxygen due to the presence of Oxygen Minimum Zones (OMZs) in BOB (Bristow *et al*. 2017, Sarma *et al.* 2016). OMZs have acute effects on diving animals by limiting prey distribution (Nasby-Lucus *et al*. 2009).

Drivers of predator distributions

The inter-monthly variations in seabird abundances in the BOB were possibly influenced by breeding phenology, but recent studies at the Lakshadweep Islands, India, revealed breeding asynchrony of Sooty Terns (Mondreti *et al*. 2018). In Seychelles, Sooty Terns also lack a fixed breeding season (Jaquemet *et al*. 2007), and thus, seasonal changes in this species might reflect seasonal conditions within the BOB. Seasonal variation also occurred in dolphins, which are not constrained by the need to return to land to breed, and thus, environmental variables probably play a role in their seasonal occurrence in the BOB. However, it is unclear whether these drivers occur within the BOB or in adjacent waters.

Seabird and cetacean distributions probably follow changes in surface circulation patterns in the BOB, which are marked by seasonal fluctuations (Gomes *et al*. 2000, Prasanna Kumar *et al*. 2010). Surface circulation in the BOB is driven by river runoff and wind, and is strongly influenced by the Equatorial Current system (Potemra *et al*. 1991, Shetye *et al*. 1996, Varkey *et al*. 1996). Surface circulation can enhance productivity through upwelling. In the BOB, upwelling is confined to the narrow continental shelf region (Shetye *et al*. 1991); central parts of the bay are characterized by the absence of upwelling and mixing (Dwivedi 1993). Some oceanic seabirds forage away from the coast, where they are largely independent of upwelling zones. Variations in seabird numbers could be associated with changes in oceanographic variables, particularly SST and ChlA, but their values were largely uniform throughout the BOB (Figs. 1A, 2A). Our limited data and the temporal mismatch between species and environmental data precluded detailed spatial analysis of fine-scale linkages between predators and oceanographic variables. As a result, we did not find correlations between environmental and species data. Additional investigations with greater survey effort are required to associate seabird and cetacean occurrences with environmental parameters in this region.

The BOB is deep, with weak bathymetric gradients (Sarma *et al*. 2000). Therefore, bathymetric characteristics appeared to have little impact on seabird distribution, although indirect effects through water circulation and stratification may exist. Therefore, facilitative association with subsurface predators, such as tuna *Thunnus* spp. and dolphins (Ashmole & Ashmole 1967, Au & Pitman 1986), and local enhancement (Poysa 1992, Buckley 1997, Grünbaum & Veit 2003, Silverman *et al*. 2004, Fauchald *et al*. 2011), could play a role in the distribution of seabirds in the BOB.

Major fishing zones in the BOB were limited to inshore waters, usually within 10 km of the coast (Devaraj & Vivekanandan 1999). However, we observed considerable deep-sea fishing in BOB waters, mainly longlining for tuna. We found substantial overlap between seabird occurrences and longline fishing areas in the BOB (Figs. 4A, 4B), with seabirds using these fishing zones for foraging.

Conservation Implications

Globally, seabirds are one of the most threatened groups of birds, and their conservation status has deteriorated rapidly over the last few decades (Croxall *et al*. 2012, Spatz *et al*. 2014). Cetaceans are equally challenged (Reynolds *et al*. 2009), with three species becoming extinct during the last 60 years; several

TABLE 4
Percentage share of country-wise fishing fleet employing pelagic longlines in the Bay of Bengal

Country	Total fishing effort, 1953–2014 (in thousands of hooks)	Percentage fishing effort	Gear[a]	Fishing effort period
Taiwan	1 561 646	59.6	ELL	1967–2013
Japan	790 648	30.2	FLL, LL	1953–2013
Korea	135 125	5.2	ELL, LLEX	1975–1987, 1992–1997, 1999–2005, 2007–2013
China	92 952	3.6	ELL	1999–2013
Seychelles	15 446	0.6	LLEX	2000–2001, 2003–2013
India	9327	0.36	LL	1991, 1994–1997, 2005–2012 1999, 2002–2012
Spain	8357	0.33	LL	1999, 2002–2012
Australia	929	0.04	LL	1999, 2002–2007, 2009, 2012–2013
Mauritius	692	0.04	ELL, LL	2002–2004, 2006–2008
Thailand	344	0.01	LL	2011
Portugal	303	0.01	LL	2008–2012
Maldives	150	0.01	LL, FLL	2012–2013

[a] LL = Longline, FLL = longline fresh, ELL = longline targeting swordfish, LLEX = exploratory longline (compiled from Longline fishing dataset of Indian Ocean Tuna Commission (IOTC), 1953–2014).

other species are on the brink of extinction (Turvey *et al*. 2007). Humans colonized the coast of BOB some 65 000 years ago, and their presence and pressure upon regional natural resources since has been substantial. Notably, in the first century AD, 33% of the world's GDP was generated by 75 million Indian people, far more than the whole of the Roman Empire (Maddison 2006). Today, the coastline of the BOB is more or less entirely occupied by people, with many fishing communities living permanently on the beach and participating in foraging activities (e.g., foraging for seabird eggs in virtually any accessible area, including supposedly protected zones and bird sanctuaries; Mondreti *et al*. 2018). The basin countries of the BOB are home to 25% of the world's human population (Kaly 2004, Preston 2004), with some 400 million people living along the BOB coast. Surveillance and enforcement of environmental regulations are weak (Mondreti *et al*. 2018). One of the central challenges to understanding the impact of fisheries on seabirds is the lack of at-sea monitoring. Continued at-sea and colony observations in this region over the next several decades would be desirable to monitor any improvement, or decline, in the situation for seabirds and cetaceans in the region.

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REFERENCES

ABRAMS, R.W. & GRIFFITHS, A.M. 1981. Ecological structure of the pelagic seabird community in the Benguela Current region. *Marine Ecology Progress Series* 5: 269–277.

AFSAL, V.V., YOUSUF, K.S.S.M., ANOOP, B. ET AL. 2008. A note on cetacean distribution in the Indian EEZ and contiguous seas during 2003–07. *Journal of Cetacean Research and Management* 10: 209–216.

AINLEY, D.G. 1977. Feeding methods of seabirds: a comparison of polar and tropical nesting communities in the Eastern Pacific Ocean. In: LIANO G.A. (Ed.) *Adaptations within Antarctic Ecosystems*. Houston, USA: Gulf Publishing Company, pp. 669–686.

AINLEY, D.G., BALLARD, G., BLIGHT, L.K. ET AL. 2009. Impacts of cetaceans on the structure of Southern Ocean food webs. *Marine Mammal Science* 26: 482–498.

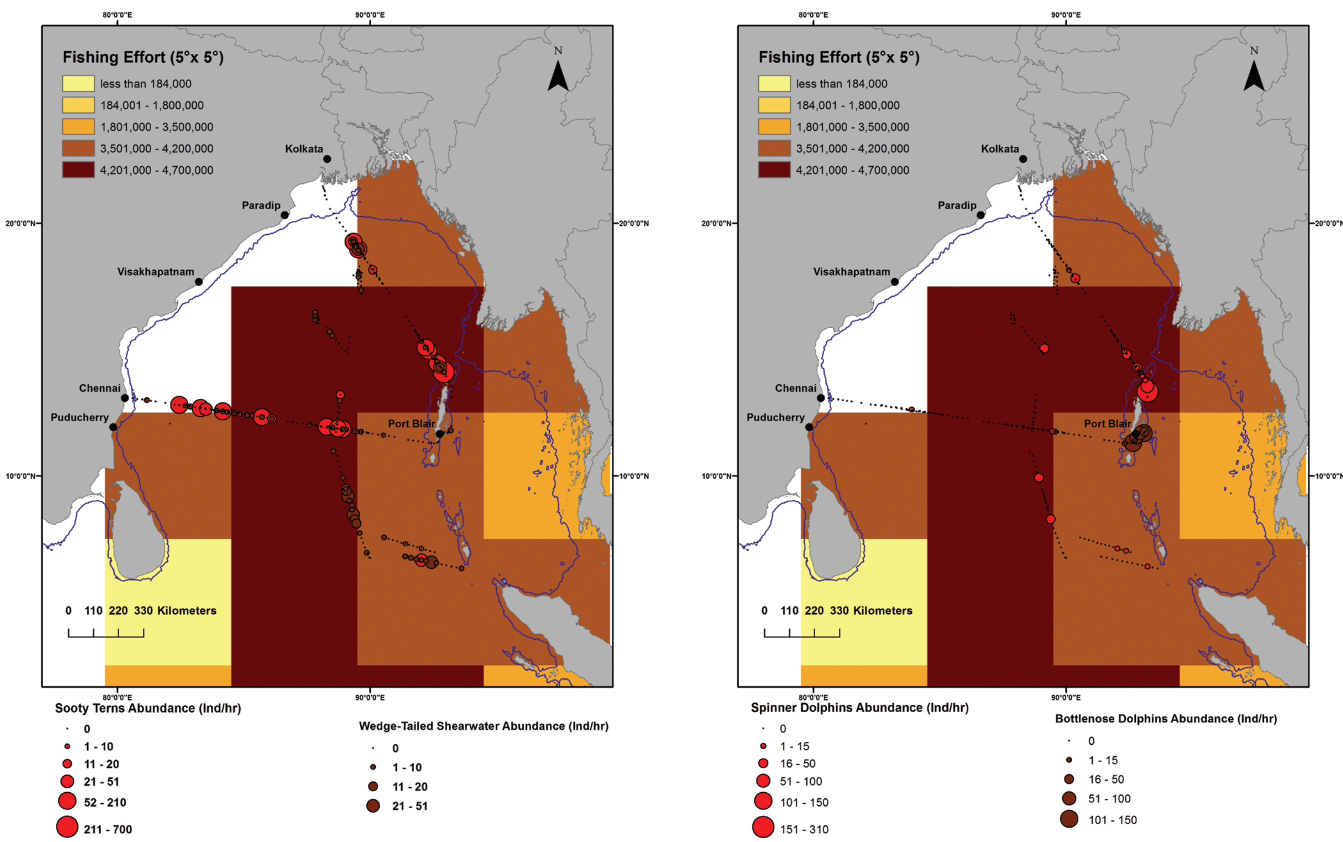

Fig. 4. Longline fishing effort overlaid on abundances of A) Sooty Terns and Wedge-tailed Shearwaters; and B) Spinner Dolphins and Indo-Pacific Bottlenose Dolphins. Fishing effort is expressed as mean number of longline fishing hooks deployed per year.

ALLING, A. 1986. Records of odontocetes in the northern Indian Ocean (1981–1982) and off the coast of Sri Lanka (1982–1984). *Journal of the Bombay Natural History Society* 83: 376–394.

ASHMOLE, N.P. & ASHMOLE, M.J. 1967. *Comparative feeding ecology of seabirds of a tropical oceanic island*. New Haven, USA: Peabody Museum of Natural History, Yale University, Bull 24.

ASHMOLE, N.P. 1971. Seabird ecology and the marine environment. In: FARNER, D.S. & King, J.R. (Eds.) *Avian Biology*, Vol 1. New York, USA: Academic Press, pp. 223–286.

AU, D.W.K. & PITMAN, R.L. 1986. Seabird interactions with dolphins and tuna in the eastern tropical Pacific. *The Condor* 88: 304–317.

BAILEY,R.S. 1966.The sea-birds of the southeast coast of Arabia. *Ibis* 108: 224–264.

BAILEY, R.S. 1968. The pelagic distribution of seabirds in the western Indian Ocean. *Ibis* 110: 493–519.

BALLANCE, L.T. 2007. Understanding seabirds at sea: why and how? *Marine Ornithology* 35: 127–135.

BALLANCE, L.T. & PITMAN, R.L. 1998. Cetaceans of the western tropical Indian Ocean: distribution, relative abundance, and comparisons with cetacean communities of two other tropical ecosystems. *Marine Mammal Science* 14: 429–459.

BALLANCE, L.T., PITMAN, R.L. & REILLY, S.B. 1997. Seabird community structure along a productivity gradient: importance of competition and energetic constraint. *Ecology* 78: 1502–1518.

BALLANCE, L.T., PITMAN, R.L., SPEAR, L.B. & FIEDLER, P.C. 2002. *Investigations into temporal patterns in distribution, abundance and habitat relationships within seabird communities of the eastern tropical Pacific*. Administrative report LJ-02-17. La Jolla, USA: NOAA Fisheries, Southwest Fisheries Science Center.

BIRDLIFE INTERNATIONAL. 2010. *Marine Important Bird Areas: priority sites for the conservation of biodiversity*. Cambridge, UK: BirdLife International.

BIRDLIFE INTERNATIONAL. 2014. Country profile: India. Available online at: http://www.birdlife.org/datazone/country/india. Accessed 03 June 2014.

BRISTOW, L.A., CALLBECK, C.M., LARSEN, M. ET AL. 2017. N_2 production rates limited by nitrite availability in the Bay of Bengal oxygen minimum zone. *Nature Geosciences* 10: 24–29.

BROOKE, M. D. 2004. The food consumption of the world's seabirds. *Proceedings of the Royal Society of London B* 271: S246–S248.

BUCKLEY, N.J. 1997. Spatial-concentration effects and the importance of local enhancement in the evolution of colonial breeding in seabirds. *American Naturalist* 149: 1091–1112.

BURGER, J. & GOCHFELD, M. 2004. Marine birds as sentinels of environmental pollution. *EcoHealth* 1: 263–274.

BUGONI, L., MANCINI, P.L., MONTEIRO, D.S., NASCIMENTO, L. & NEVES, T.S. 2008 Seabird bycatch in the Brazilian pelagic longline fishery and a review of capture rates in the southwestern Atlantic Ocean. *Endangered Species Research* 5: 137–147.

CAMPHUYSEN, K.J., FOX, A.D., LEOPOLD, M.F. & PETERSEN, I.K. 2004. *Towards standardised seabirds at sea census techniques in connection with environmental impact assessments for offshore wind farms in the U.K.: a comparison of ship and aerial sampling methods for marine birds, and their applicability to offshore wind farm assessments.* Report to COWRIE (BAM – 02-2002). Texel, Netherlands: Netherlands Institute for Sea Research.

CAMPHUYSEN, C.J. & GARTHE, S. 2004. Recording foraging seabirds at sea. Standardised recording and coding of foraging behaviour and multi-species foraging associations. *Atlantic Seabirds* 6: 1–32.

COPELLO, S. & QUINTANA, F. 2009. Spatio-temporal overlap between the at-sea distribution of southern giant petrels and fisheries at the Patagonian Shelf. *Polar Biology* 32: 1211–1220.

CROXALL, J.P., BUTCHART, S.H.M., LASCELLES, B. ET AL. 2012. Seabird conservation status, threats and priority actions: a global assessment. *Bird Conservation International* 22: 1–34.

CUTHBERT, R., HILTON, G., RYAN, P.G. & TUCK, G.N. 2005. At-sea distribution of breeding Tristan albatrosses *Diomedea dabbenena* and potential interactions with pelagic longline fishing in the South Atlantic Ocean. *Biological Conservation* 121: 345–355.

DELORD, K., COTTE, C., PERON, C. ET AL. 2010. At-sea distribution and diet of an endangered top predator: relationship between white-chinned petrels and commercial longline fisheries. *Endangered Species Research* 13: 1–16.

DEVARAJ, M. & VIVEKANANDAN, E. 1999. Marine capture fisheries of India: Challenges and Opportunities. *Current Science* 76: 314–332.

DUNLOP, J.N., WOOLLER, R.D. & CHESHIRE, N.G. 1988. Distribution and abundance of marine birds in the eastern Indian Ocean. *Australian Journal of Marine and Freshwater Research* 39: 661–669.

DWIVEDI, S.N. 1993. Long-term variability in the food chain, biomass yield and oceanography of the Bay of Bengal ecosystem. In: SHERMAN, K., ALEXANDER, L.M. & GOLD, B.D. (Eds.) *Large Marine Ecosystems: Stress, Mitigation, and Sustainability*. Washington, USA: AAAS Press, pp. 43–52.

ESRI. 2012. ArcGIS Desktop and Spatial Analyst Extension: Release 10.1. Redlands, CA: Environmental Systems Research Institute.

FAUCHALD, P., SKOV, H., SKERN-MAURITZEN, M., HAUSNER, V.H., JOHNS, D. & TVERAA, T. 2011. Scale-dependent response diversity of seabirds to prey in the North Sea. *Ecology* 92: 228–239.

FEARE, C.J., JAQUEMET, S. & LE CORRE, M. 2007. An inventory of Sooty Terns (*Sterna fuscata*) in the Western Indian Ocean with special reference to threats and trends. *Ostrich* 78: 423–434.

GARTHE, S., MARKONES, N., HÜPPOP, O. & ADLER, S. 2009. Effects of hydrographical and meteorological factors on seasonal seabird abundance in the southern North Sea. *Marine Ecology Progress Series* 391: 243–255.

GOMES, H.R., GOES, J.I. & SAINO, T. 2000. Influence of physical processes and freshwater discharge on the seasonality of phytoplankton regime in the Bay of Bengal. *Continental Shelf Research* 20: 313–330.

GRÜNBAUM, D. & VEIT, R.R. 2003. Black-browed albatrosses foraging on Antarctic krill: density-dependence through local enhancement? *Ecology* 84: 3265–3275.

HEILEMAN, S., BIANCHI, G. & FUNGE-SMITH, S. 2009. VII-10 Bay of Bengal: LME #34. *In*: Sherman, K. & Hempel, G. (Eds.) *The UNEP Large Marine Ecosystems: A Perspective on Changing Conditions in LMEs of the World's Regional Seas, Vol. 82*. Nairobi, Kenya: United Nations Environmental Programme, pp. 237–251.

HOLMGREN, S. 1994. *An environmental assessment of the Bay of Bengal region*. BOBP/REP/67. Madras, India: Bay of Bengal Programme for Swedish Centre for Coastal Development and Management of Aquatic Resources.

HOSSAIN, M. M. 2004. *On sustainable management of the Bay of Bengal Large Marine Ecosystem (BOBLME).* National Report of Bangladesh, Institute of Marine Sciences and Fisheries and FAO of the UN, GCP/RAS/179/WBG. Chittagong, Bangladesh: Institute of Marine Sciences and Fisheries. [Available online at: http://www.boblme.org/documentRepository/Nat_Bangladesh.pdf. Accessed 31 Jan 2020].

HYRENBACH, K.D., VEIT, R.R., WEIMERSKIRCH, H., METZL, N & HUNT, G.L. 2007. Community structure across a large-scale ocean productivity gradient: marine bird assemblages of the Southern Indian Ocean. *Deep-Sea Research I* 54: 1129–1145.

INTERNATIONAL HYDROGRAPHIC ORGANIZATION. 1953. *Limits of Oceans and Seas, Special Publication No. 23, 3rd edition*. Monte-Carlo, Monaco: International Hydrographic Organization.

JAEGER, A., FEARE, C.J., SUMMERS, R.W., LEBARBENCHON, C., LAROSE, C. & LE CORRE, M. 2017. Geolocation reveals year-round at-sea distribution and activity of a superabundant tropical seabird, the sooty tern *Onychoprion fuscatus*. *Frontiers in Marine Science* 4: 394.

JAQUEMET, S., LE CORRE, M., MARSAC, F., POTIER, M. & WEIMERSKIRCH, H. 2005. Foraging habitats of the seabird community of Europa Island (Mozambique Channel). *Marine Biology* 147: 573–582.

JAQUEMET, S., LE CORRE, M. & QUARTLY, G.D. 2007. Ocean control of the breeding regime of the sooty terns in the South-West Indian Ocean. *Deep-Sea Research I* 54: 130–142.

JAQUEMET, S., POTIER, M., CHEREL, Y. ET AL. 2008. Comparative foraging ecology and ecological niche of a superabundant tropical seabird: the sooty tern *Sterna fuscata* in the southwest Indian Ocean. *Marine Biology* 155: 505–520.

JAQUMET, S., TERNON, J,F., KAEHLER, S. ET AL. 2014. Contrasted structuring effects of mesoscale features on the seabird community in the Mozambique Channel. *Deep-Sea Research II* 100: 200–211.

JOHANSEN, K.L., BOERTMANN, D., MOSBECH, A. & HANSEN, T.B. 2015. *Manual for Seabird and Marine Mammal Survey on Seismic Vessels in Greenland.* 4th revised edition, April 2015. Scientific Report from DCE – Danish Centre for Environment and Energy No. 152.(74 pp) http://dce2.au.dk/pub/SR152.pdf.

KALY, U.L. 2004. *Review of land-based sources of pollution to the coastal and marine environments in the BOBLME Region*. Bay of Bengal Large Marine Ecosystem (BOBLME) Theme Report. GCP/RAS/179/WBG.10 FAO-BOBLME Programme.

KARNOVSKY, N.J., HARDING, A.M.A., WALKUSZ, W. ET AL. 2010. Foraging distributions of little auks *Alle alle* across the Greenland Sea: implications of present and future Arctic climate change. *Marine Ecology Progress Series* 415: 283–293.

KATONA, S. & WHITEHEAD, H. 1988. Are cetacea ecologically important? *Oceanography and Marine Biology* 26: 553–568.

KUMARAN, P.L. 2002. Marine mammal research in India: a review and critique of the methods. *Current Science* 83: 1210–1220.

LE CORRE, M., JAEGER, A., PINET, P. ET AL. 2012. Tracking seabirds to identify potential Marine Protected Areas in the tropical western Indian Ocean. *Biological Conservation* 156: 83–93.

LEGRAND, B., BENNEVEAU, A., JAEGER, A. ET AL. 2016. Current wintering habitat of an endemic seabird of Reunion Island, Barau's petrel *Pterodroma baraui*, and predicted changes induced by global warming. *Marine Ecology Progress Series* 550: 235–248.

LEWISON, R.L., FREEMAN, S.A. & CROWDER, L.B. 2004. Quantifying the effects of fisheries on threatened species: The impact of pelagic longlines on loggerhead and leatherback sea turtles. *Ecology Letters* 7: 221–231

MACÍAS LÓPEZ, D., GARCIA BARCELONA, S., BAEZ, J.C., MIGUEL DE LA SERNA, J. & ORTIZ DE URBINA, J.M. 2012. Marine mammal bycatch in Spanish Mediterranean large pelagic longline fisheries, with a focus on Risso's dolphin (*Grampus griseus*). *Aquatic Living Resources* 25: 321–331.

MADDISON, A. 2006. *The world economy. A millennial perspective and volume II: historical statistics*. Paris, France: OECD Development Centre.

MALAKAR, B., VENU, S., OJHA, C. ET AL. 2015. Recent sightings of marine mammals in Andaman Islands, India. *Journal of Threatened Taxa* 7: 7175–7180.

MALLORY, M.L., ROBINSON, S.A., HEBERT, C.E. & FORBES, M.R. 2010. Seabirds as indicators of aquatic ecosystem conditions: a case for gathering multiple proxies of seabird health. *Marine Pollution Bulletin* 60: 7–12.

MONDRETI, R., DAVIDAR, P., PÉRON, C. & GRÉMILLET, D. 2013. Seabirds in the Bay of Bengal Large Marine Ecosystem: current knowledge and research objectives. *Open Journal of Ecology* 3: 172–184.

MONDRETI, R., DAVIDAR, P. & GRÉMILLET, D. 2018. Illegal egg harvesting and population decline in a key pelagic seabird colony of the Eastern Indian Ocean. *Marine Ornithology* 46: 103–107.

NARVEKAR, J. & PRASANNA KUMAR, S. 2006. Seasonal variability of the mixed layer in the central Bay of Bengal and associated changes in nutrients and chlorophyll. *Deep-Sea Research I* 53: 820–835.

NASBY-LUCAS, N., DEWAR, H., LAM, C.H., GOLDMAN, J.K. & DOMEIER, M.L. 2009. White shark offshore habitat: a behavioral and environmental characterization of the eastern pacific shared offshore foraging area *PLoS One* 4: e8163.

NEWTON, I. 2003. *Speciation and Biogeography of Birds*. London, UK: Academic Press.

OLSEN, L.M., MAJOR, G., SHEIN, K. ET AL. 2013. NASA/Global Change Master Directory (GCMD) Earth Science Keywords. Version 8.0.0.0.0.

PAULY, D., TRITES, A.W., CAPULI, E. & CHRISTENSEN, V. 1998. Diet composition and trophic levels of marine mammals. *ICES Journal of Marine Science* 55: 467–481.

PETERSEN, S.L., PHILLIPS, R.A., RYAN, P.G. & UNDERHILL, L.G. 2008. Albatross overlap with fisheries in the Benguela Upwelling System: Implications for conservation and management. *Endangered Species Research* 5: 117–127.

PETERSEN, S.L., HONIG, M.B., RYAN, P.G. & UNDERHILL, L.G. 2009. Seabird bycatch in the pelagic longline fishery off southern Africa. *African Journal of Marine Sciences* 31: 191–204.

PIATT, J.F., SYDEMAN, W.J. & WIESE, F.2007. Introduction: A modern role for seabirds as indicators. *Marine Ecology Progress Series* 352: 199–204.

PITMAN, R.L. & BALLANCE, L.T. 1992. Parkinson's petrel distribution and foraging ecology in the eastern Pacific: aspects of an exclusive feeding relationship with dolphins. *The Condor* 94: 825–835.

PHILLIPS, R.A., SILK, J.R.D., CROXALL, J.P. & FANASYEV, V. 2006. Year-round distribution of white-chinned petrels from South Georgia: relationships with oceanography and fisheries. *Biological Conservation* 129: 336–347.

POCKLINGTON, R. 1979. An oceanographic distribution of seabird distributions in the Indian Ocean. *Marine Biology* 51: 9–21.

POTEMRA, J.T., LUTHER, M.E. & O'BRIEN, J.J. 1991. The seasonal circulation of the upper ocean in the Bay of Bengal. *Journal of Geophysical Research* 96: 12667–12683.

POYSA, H. 1992. Group foraging in patchy environments: the importance of coarse-level local enhancement. *Ornis Scandinavia* 23: 159–166.

PRASANNA KUMAR, S., MURALEEDHARAN, P.M., PRASAD, T.G. ET AL. 2002. Why is the Bay of Bengal less productive during summer monsoon compared to the Arabian Sea? *Geophysical Research Letters* 29: 2235.

PRASANNA KUMAR, S., NARVEKAR, J., NUNCIO M., KUMAR, A. ET AL. 2010. Is the biological productivity in the Bay of Bengal light limited? *Current Science* 98: 1331–1339.

PRESTON, G.L. 2004. Review of the Status of Shared/Common Marine Living Resource Stocks and of Stock Assessment Capability in the BOBLME Region. Bay of Bengal Large Marine Ecosystem (BOBLME) Theme report. FAO-BOBLME Programme.

QASIM, S.Z. 1977. Biological productivity of the Indian Ocean. *Indian Journal of Marine Sciences* 6: 122–137.

REDDY, M.L., DIERAUF, L.A. &GULLAND, F.M.D.2001.Marine mammals as sentinels of ocean health. In: DIERAUF, L.A. & GULLAND, F.M.D. (Eds.) *Marine Mammal Medicine*, Second Edition. Boca Raton, USA: CRC Press, pp. 3–13.

REYNOLDS, J.E. III, MARSH, H. & RAGEN, T.J. 2009. Marine mammal conservation. *Endangered Species Research* 7: 23–28.

ROLLINSON, D.P., WANLESS, R.M. & RYAN, P.G. 2017. Patterns and trends in seabird bycatch associated with the pelagic longline fishery off South Africa. *African Journal of Marine Science* 39: 9–25.

SARMA, K.V.L.N.S., RAMANA, M.V., SUBRAMANYAM, V., KRISHNA, K.S., RAMPRASAD, T. & DESA, M. 2000. Morphological features in the Bay of Bengal. *Journal of Indian Geophysics Union* 4: 185–190.

SARMA, V.V.S.S., RAO, G.D., VISWANADHAM, R. ET AL. 2016. Effects of freshwater stratification on nutrients, dissolved oxygen, and phytoplankton in the Bay of Bengal. *Oceanography* 29: 222–231.

SCHIPPER, J., CHANSON, J.S., CHIOZZA, F., COX, N.A. & HOFFMANN, M. 2008. The status of the world's land and marine mammals: Diversity, threat, and knowledge. *Science* 322: 225–230.

SCHNEIDER, D.C.1997. Habitat selection by marine birds in relation to water depth. *Ibis* 139: 175–178.

SHERMAN, K. & HEMPEL, G. 2009. *The UNEP large marine ecosystem report: A perspective on the changing conditions of the LMEs of the world's regional seas*. Nairobi, Kenya: United Nations Environment Programme.

SHETYE, S.R., SHENOI, S.S.C., GOUVEIA, A.D., MICHAEL, G.S., SUNDAR, D. & NAMPOOTHIRI, G. 1991. Wind-driven coastal upwelling along the Western boundary of Bay of Bengal during southwest monsoon. *Continental Shelf Research* 11: 1397–1408.

SHETYE, S.R., GOUVEIA, A.D., SHANKAR, D. ET AL. 1996. Hydrography and circulation in the western Bay of Bengal during the northeast monsoon. *Journal of Geophysical Research* 101: 14011–14025.

SILVERMAN, E.D., VEIT, R.R. & NEVITT, G. 2004. Nearest neighbours as foraging cues: information transfer in a patchy environment. *Marine Ecology Progress Series* 277: 25–35.

SMITH, B.D., AHMED, B., MOWGLI, R.M. & STRINDBERG, S. 2008. Species occurrence and distributional ecology of near shore cetaceans in the Bay of Bengal, Bangladesh, with abundance estimates for Irrawaddy dolphins *Orcaella brevirostris* and finless porpoises *Neophocaena phocaenoides*. *Journal of Cetacean Research Management* 10: 45–58.

SPATZ, D.R., NEWTON, K.M., HEINZ, R. ET AL. 2014. The biogeography of globally threatened seabirds and island conservation opportunities. *Conservation Biology* 28: 1282–1290.

SPEAR, L.B., BALLANCE, L.T. & AINLEY, D.G. 2001. Response of seabirds to thermal boundaries in the tropical Pacific: the thermocline versus the Equatorial Front. *Marine Ecology Progress Series* 219: 275–289.

TASKER, M.L., JONES, P.H., DIXON, T.J. & BLAKE, B.F. 1984. Counting seabirds at sea from ships: a review of methods employed and a suggestion for a standardized approach. *The Auk* 101: 567–577.

THIEBOT, J.B. & WEIMERSKIRCH, H. 2013. Contrasted associations between seabirds and marine mammals in four biomes of the southern Indian Ocean. *Journal of Ornithology* 154: 441–553.

THIEBOT, J.B., DELORD, K., BARBRAUD, C., MARTEAU, C. & WEIMERSKIRCH, H. 2016. 167 individuals versus millions of hooks: bycatch mitigation in longline fisheries underlies conservation of Amsterdam albatrosses. *Aquatic Conservation Marine and Freshwater Ecosystems* 26: 674–688.

TURVEY, S.T., PITMAN, R.L., TAYLOR, B.L. ET AL. 2007. First human-caused extinction of a cetacean species? *Biology Letters* 3: 537–540.

VARKEY, M.J., MURTHY, V.S.N. & SURYANARAYANA, A. 1996. Physical oceanography of the Bay of Bengal and Andaman Sea. *Oceanography and Marine Biology, Annual Review* 34: 1–70.

VILCHIS, L.I., BALLANCE, L.T. & FIEDLER, P.C. 2006. Pelagic habitat of seabirds in the eastern tropical Pacific: effects of foraging ecology on habitat selection. *Marine Ecology Progress Series* 315: 279–292.

WELLS, R.S., RHINEHART, H.L., HANSEN, L.J. ET AL. 2004. Bottlenose dolphins as marine ecosystem sentinels: Developing a health monitoring system. *Ecohealth* 1: 246–254.

WERNER, T.B., NORTHRIDGE, S., PRESS, K.M. & YOUNG, N. 2015. Mitigating bycatch and depredation of marine mammals in longline fisheries. *ICES Journal of Marine Sciences* 72: 1576–1586.

YEN, P.P.W., SYDEMAN, W.J. & HYRENBACH, K.D. 2004. Marine bird and cetacean associations with bathymetric habitats and shallow-water topographies: implications for trophic transfer and conservation. *Journal of Marine Systems* 50: 79–99.