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Past records and current distribution of seabirds at Larsemann Hills and Schirmacher Oasis, east Antarctica

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Research Article

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Abstract

Seabird populations in Antarctica serve as indicators to assess the impacts of global environmental change. Ecological data on seabirds in Antarctica are scarce due to limited knowledge on their distribution and abundance in most parts of the continent. In this study, we investigated the status of seabird species around the Indian research stations *Bharati* at Larsemann Hills, Prydz bay and *Maitri* at Schirmacher Oasis, central Dronning Maud Land located in east Antarctica. We conducted primary surveys during austral summers under the Indian Antarctic Program and compiled published as well as unpublished information on seabird distribution from these areas. We employed intensive area search methods to locate presence of seabird nesting and moulting sites. Ten species were recorded from Larsemann Hills with confirmed breeding of snow petrel, south polar skua and Wilson's storm-petrel. Only south polar skua and Adélie penguin were reported breeding at Schirmacher Oasis with unconfirmed breeding of Wilson's storm-petrel. This study presents the first detailed synthesis of status of seabirds from Larsemann Hills and Schirmacher Oasis regions in Antarctica and serves as a strong baseline for future ecological work on seabirds in the sector of operation of Indian Antarctic Program.

Introduction

Marine top predators such as seabirds are integral part of marine trophic webs in Southern Ocean and serve as key indicators of marine ecosystem health (Frederiksen, Edwards, Richardson, Halliday, & Wanless, 2006; Lascelles, Langham, Ronconi, & Reid, 2012; Paleczny, Hammill, Karpouzi, & Pauly, 2015). Over the last century, climate change has impacted Southern Ocean ecosystem processes, dependent trophic levels including seabird populations (Barbraud et al., 2012; Rogers et al., 2020) and their prey (Xavier, Tarling, & Croxall, 2006). In the Southern Ocean and along the Antarctic coastline, seabird breeding sites are thus being monitored using interdisciplinary approaches to assess impacts due to global climate change and to aid their conservation (Croxall et al., 2012; Friesen, 2007; Taylor & Friesen, 2012).

Presently, seabird monitoring and observations in Antarctica are conducted through National Antarctic Programs. The Biogeographic Atlas of the Southern Ocean provides large spatial scale distribution maps of seabirds and marine mammals using data obtained from at-sea sightings and by tracking studies (De Broyer et al., 2014). Further, through field surveys over several decades and remotely-sensed data, species distribution has been studied along Antarctic coast (Fretwell & Trathan, 2009; LaRue et al., 2014; Lynch, Fagan & Naveen, 2010; Lynch & LaRue, 2014; Mehlum, Gjessing, Haftorn, & Bech, 1988; Schwaller, Olson, Ma, Zhu, & Dahmer, 1989; Schwaller, Lynch, Tarroux, & Prehn, 2018). These studies utilising satellite imageries also need substantial ground validation to minimise statistical errors and provide robust estimates of the seabird populations (Fretwell et al., 2012). Further, satellite imagery would not be helpful in the case of less conspicuous species (like cavity-nesting species), thus necessitating field-based assessment of species' populations.

Given the remoteness and inaccessibility of most seabird colonies in the Southern Ocean and coastal Antarctica, the essential baseline data on population trends over spatio-temporal scales are scarce and challenging to obtain. In this study, we present a comprehensive inventory of seabird diversity of the Indian sector of operation in Antarctica considering there have been few and mostly anecdotal records from these regions. We ascertained the breeding distribution of seabird species around the Indian research stations *Bharati* at Larsemann Hills and *Maitri* at Schirmacher Oasis. In addition, we present a detailed compilation of seabird occurrence records in these regions by collating past records.

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Methods

Permits

All surveys were conducted under the "Biology and Environmental Sciences" component of the Indian Scientific Expeditions to Antarctica with appropriate approval (No: NCAOR/14(159)/13/BES-3) from National Centre for Polar and Ocean Research, Ministry of Earth Sciences, Government of India, Goa, India.

Study area

This study was conducted around two overwintering Indian Research Stations in east Antarctica *viz.* Larsemann Hills, Prydz Bay, site of Indian Antarctic Research Station *Bharati* and; Schirmacher Oasis, Central Dronning Maud Land, site of Indian Antarctic Research Station *Maitri*.

Larsemann Hills, Prydz Bay

Larsemann Hills (69° 20′ S to 69° 30′ S; 75° 55′ E to 76° 30′ E) is an ice-free Oasis on the Ingrid Christensen Coast, Princess Elizabeth Land. It consists of about 50 islands located between the eastern extremity of the Amery Ice Shelf and the southern boundary of the Vestfold Hills (Fig. 1). These islands spread over an area of about 50 km^2 to form the second largest ice-free Oasis along east Antarctica's 5000 km long coastline (Hodgson et al., 2005). Larsemann Hills is flanked on both sides by two large peninsulas, the western Stornes and the eastern Broknes, which enclose a group of variously sized rocky outcrops, islands and peninsulas. The geomorphology of the Larsemann Hills includes glacial striae, tafone and glaciofluvial sediments created by erosion from ice, water and salt; the weathering being higher on islands located towards the sea than the continental ice sheet (ANARE, 2000; Hodgson et al., 2001; Stüwe, Braun, & Peer, 1989). One of the peninsulas within Larsemann Hills, the Grovnes Peninsula, is the site of *Bharati* (69°24′ S, 76°11′ E), the 3rd Indian overwintering research station in Antarctica. Two other Antarctic stations, viz. the *Progress II* (Russia) and *Zhongshan* (China) are located on the north-eastern edge of the Broknes Peninsula (also sometimes referred to as Mirror Peninsula) separated by Stepped Lake.

Schirmacher Oasis, Central Dronning Maud Land

Schirmacher Oasis (70° 44′–46′ S and 11° 26′–49′ E) is an ice-free oasis situated on the Princess Astrid coast of Central Dronning Maud Land. It is located between the continental ice cap and the Nivlisen ice shelf and spread over an area of about 34 km^2. (Phartiyal, 2014; Singh, Singh, Singh, & Sharma, 2012). It consists of low-lying hills with an average elevation of 100 m, several glacial lakes interspersed with steep cliffs on the northern margins towards the ice shelf (Ravindra, 2001). The landscape is marked with widespread debris cover and glacial moraine deposits within undulating rocky areas (Phartiyal, Sharma, & Bera, 2011). The second permanent Indian research station *Maitri* (70°45′ S, 11°44′ E) is located on the south-eastern part of the Schirmacher Oasis near Zub lake (Fig. 1). The Russian station *Novolazarevskaya* is located on the eastern extremity of the oasis.

In comparison to Larsemann Hills, Schirmacher Oasis has been more frequently surveyed for the presence of seabirds being smaller in area (< 35 km^2), accessible over foot and a longer presence of scientific activities. Indian Antarctic program also has a longer presence at Schirmacher Oasis (since mid-1980s) in comparison with Larsemann Hills, where the Indian Antarctic research activities began almost 20 years later in 2006–2007.

Nivlisen ice shelf and Dakshin Gangotri station

We also compiled information on seabird occurrence from areas near the first manned station of India in Antarctica, *Dakshin Gangotri* (70° 04′ 50″ S, 12° 00′ 09″ E), located on the Nivlisen ice shelf on Princess Astrid coast (Nair & Gupta, 1986). This information was collated from previous Indian Antarctic Expedition reports from areas mentioned as India Bay, Russian Dump and Russian Bay (coordinates 69° 59' S, 11° 57' E) located on Nivlisen ice shelf. These areas correspond to locations frequently used by the Indian Antarctic expeditions for logistic activities conducted for year-round operations of *Maitri* station. *Dakshin Gangotri* station was operational from 1983 to 1988 after which it was decommissioned on 25 February 1990 due to high snow accumulation in the area and converted into a supply base (Ravindra, 1994).

Data compilation: literature review and informal interviews

In order to understand the seabird distribution in the study areas, we first gathered all available literature in addition to the ground surveys conducted at Larsemann Hills and Schirmacher Oasis. We compiled all systematic as well as anecdotal information on seabird occurrence from the study areas reported by previous studies. This past literature included published technical reports of Indian Scientific Expedition to Antarctica (available from 1981 to 2006 at NCPOR online repository http://14.139.119.23:8080/dspace/index.jsp; Bhatnagar, 1999; Chandra, 2007; Chattopadhyay, 1995; Mathew, 1986; Sathyakumar, 1998; Venkataraman, 1998) and from publications by German, Russian and Chinese expeditioners (Artem'ev, 1965; Gerbovich, 1964; Haendel et al., 1983; Richter, 1983; Richter & Bormann, 1995; Richter, Haendel, & Junghans, 1990; Wang et al., 1996; Wang & Norman, 1993a, 1993b; Wang & Peter, 2004).

Additionally, we conducted informal interviews with scientific and logistics team members of respective Indian Antarctic Expedition stationed at *Maitri* and *Bharati* station. Interviewees were asked to report any information on previous sightings of seabirds in the station vicinity during the field visits in 2013/14, 2014/15 and 2015/16. High-resolution photographs of common species and standard seabird field guide (Enticott & Tipling, 1997) were shown to the interviewees to ensure correct species identification. It provided us with data on seabird sightings in the period where field surveys could not be conducted (between October–February and after March) due to logistical issues.

Field sampling

Field surveys were conducted for assessing the status of seabirds at Larsemann Hills and Schirmacher Oasis under the "Antarctic Wildlife Monitoring Program" of Indian Scientific Expeditions to Antarctica. These surveys were conducted during three austral summers (November–March) of 2013/2014, 2014/2015 and 2015/2016 coinciding with the breeding season for the Antarctic seabird species. The field sampling was designed to sample all accessible islands, peninsulas and smaller rocky outcrops at Larsemann Hills. We conducted intensive surveys at 40 islands/peninsulas/rocky outcrops (henceforth islands) at Larsemann Hills. The smaller islands (<2 km^2) were surveyed completely while zig-zag transects (spaced 200–250 m apart) were walked on larger islands/peninsulas (Broknes Peninsula and Fisher island) to maximise detection of seabird presence. Zig-zag sampling was conducted to

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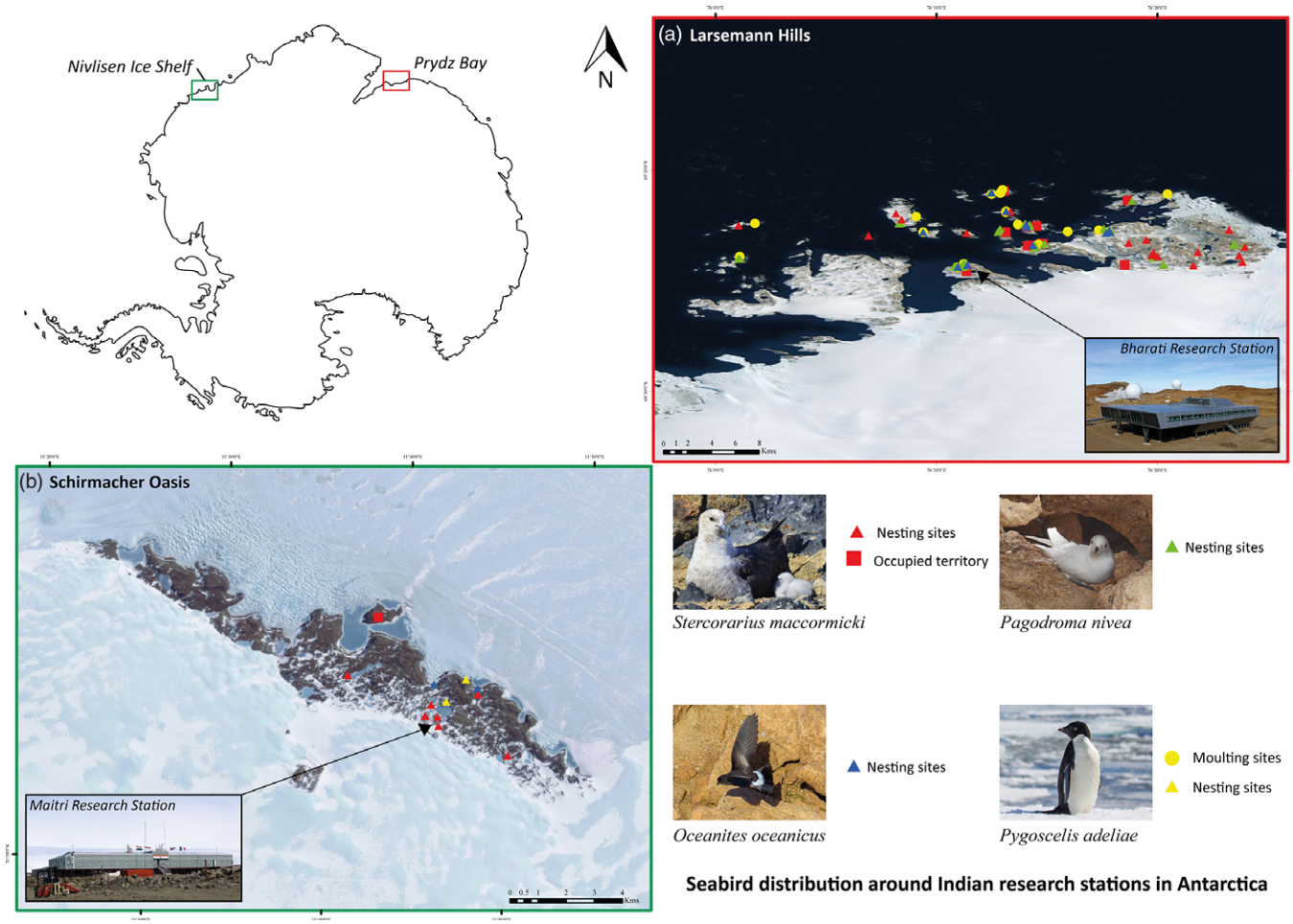

Fig. 1. Seabird distribution around Indian research stations in Antarctica. (a) Larsemann Hills, Prydz Bay; (b) Schirmacher Oasis, Princess Astrid coast, central Dronning Maud Land. Station images indicate the location of Indian research stations Bharati and Maitri. Nivlisen ice shelf location is indicated on the Antarctica inset map.

ensure maximum coverage of larger islands/peninsulas as linear transects over areas of permanent ice cover and steep coastal cliffs is not feasible especially under time constraint. We spent 8–10 h each day for a total of 53 days at the islands spread across the survey periods mentioned earlier. Most of the islands were covered in 1–5 days of effort, while a few larger such as Grovnes Peninsula and Broknes Peninsula were surveyed for 10 and 11 days, respectively, to implement the long-term nest monitoring programme (Pande et al., 2017, 2018). We did not conduct any survey at Stornes Peninsula (69°25′ S, 76°6′ E), an Antarctic Specially Protected Area (ASPA no. 174), as permission could not be obtained from the concerning authorities.

The entire ice-free landscape of Schirmacher Oasis and adjoining areas were surveyed over a period of 20 days. We also surveyed adjoining ice-free nunataks of Schirmacher Oasis, viz. Vetehia hills (70°47′30″ S, 11°37′43″ E), Palets rock or Veet/*Shivling* (70°46′46″ S, 11°36′01″ E) and Lanka (70°44′20″ S, 11°39′41″ E) for the presence of seabird signs. Most of this survey effort was towards the end of the austral summer period (March month) as visits to Schirmacher Oasis were made during the last leg of each expedition except for year 2014 (January and March).

Once a seabird-nesting/moulting site or occupied territory was detected, its coordinates were marked on a Garmin etrex 30™ GPS unit and extensive search was conducted within a 100-m radius to locate other nesting sites (for snow petrel *Pagodroma nivea* and Wilson's storm-petrel *Oceanites oceanicus*). Being cryptic cavity nesters, snow petrels were detected by physically locating the nests using a hand-held flashlight (300 lumens). South polar skua *Stercorarius maccormicki* occupied territories were identified by the presence of prey remains (bones, carcass, regurgitated pellets, etc.) and confirmed to be occupied only if an adult is present.

Data processing

During field surveys, the spatial locations of seabird nesting, occupied or moulting territories were entered in MS Excel v.2016 and converted into comma separated value (CSV) files after the end of each field survey. These CSV files were later imported to Google Earth Pro v.7.1.8, converted as KML files and visualised on ArcGIS v.10.5 for creating spatial maps of the seabird distribution.

Results

Historical seabird records

We gathered a total of 146 independent records from past literature which listed Adélie penguin *Pygoscelis adeliae*, Antarctic petrel *Thalassoica Antarctica*, black-bellied storm-petrel *Fregetta tropica*, cape petrel *Daption capense*, chinstrap penguin *Pygoscelis antarcticus*, emperor penguin *Aptenodytes forsteri*, kelp gull *Larus dominicanus*, snow petrel, south polar skua, Wilson's storm-petrel in the study

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Table 1. Occurrence records and breeding distribution of seabirds from islands/peninsulas/rocky outcrops of Larsemann hills from 1986 to 2016

Site	Stercorarius maccormicki						Pagodroma nivea			Oceanites oceanicus			Pygoscelis adeliae		Survey Effort this study; in days)
	1986–1987[a]	1988–1989[a]	1989–1990[a]	1992–1993[a]	1993–1994[a]	***2014–2016[c]***	1989–1991[b]	1989–1994[a]	***2014–2016[c]***	1989–1991[b]	1989–1994[a]	***2014–2016[c]***	1989–91[b]	***2014–2016***	
	10 pairs	15 pairs	13 pairs	10 pairs	11 pairs	***12 pairs***	> 310 pairs	B	***255 nests***	40–50 nests	B	***B***	M	***M***	
Broknes Peninsula															***11***
Grovnes Peninsula	-	-	-	-	-	***O***	-	-	***92 nests***	-	-	***B***	-	***M***	***10***
Betts Island*	-	-	-	-	-	***O***	-	-	***6 nests***	-	-	***B***	-	***M***	***1***
Brattnevet Peninsula	-	-	-	-	-	***Nil***	-	-	***3 nests***	-	-	***-***	-	***-***	***1***
Breadloaf Island*	-	-	-	-	-	***1 pair***	-	-	***4 nests***	-	-	***B***	-	***Nil***	***1***
Butler Island	-	-	-	-	-	***1 pair***	-	-	***-***	-	-	***-***	-	***-***	***1***
Cook Island*	-	-	-	-	-	***Nil***	-	-	***9 nests***	-	-	***Nil***	-	***M***	***1***
Easther Island*	-	-	-	-	-	***1 pair***	-	-	***55 nests***	-	-	***B***	-	***M***	***4***
Fisher Island*	-	-	-	-	-	***2 pairs***	-	-	***36 nests***	-	-	***B***	-	***M***	***5***
Harley Island	-	-	-	-	-	***Nil***	-	-	***Nil***	-	-	***Nil***	-	***M***	***1***
Hill Island	-	-	-	-	-	***Nil***	-	-	***Nil***	-	-	***Nil***	-	***Nil***	***1***
Jesson Island	-	-	-	-	-	***Nil***	-	-	***Nil***	-	-	***Nil***	-	***Nil***	***1***
John Island*	-	-	-	-	-	***1 pair***	-	-	***Nil***	-	-	***Nil***	-	***Nil***	***1***
Knuckey Island	-	-	-	-	-	***Nil***	-	-	***Nil***	-	-	***Nil***	-	***Nil***	***1***
Lovering Island	-	-	-	-	-	***Nil***	-	-	***Nil***	-	-	***Nil***	-	***Nil***	***1***
Manning Island*	-	-	-	-	-	***O***	-	-	***4 nests***	-	-	***Nil***	-	***M***	***3***
McLeod Island*	-	-	-	-	-	***2 pairs***	-	-	***6 nests***	-	-	***Nil***	-	***M***	***4***
Osmar Island*	-	-	-	-	-	***1 pair***	-	-	***Nil***	-	-	***Nil***	-	***M***	***1***
Richardson Island	-	-	-	-	-	***Nil***	-	-	***Nil***	-	-	***Nil***	-	***Nil***	***1***
Sandercock Island	-	-	-	-	-	***1 pair***	-	-	***Nil***	-	-	***Nil***	-	***Nil***	***1***
Solomon Island	-	-	-	-	-	***Nil***	-	-	***Nil***	-	-	***B***	-	***M***	***1***
Stinear peninsula	-	-	-	-	-	***O***	-	-	***?***	-	-	***Nil***	-	***Nil***	***1***

Text and numbers in bold and italics indicate data from this study collected during austral summers (December–February of 2013–2014, 2014–2015, 2015–2016); Nil – indicates site surveyed but no activity detected; *indicates nearby rocky outcrops to the island/peninsula were surveyed; - indicates no data available from the year mentioned in column; ? – unconfirmed breeding; M – moulting site; O – occupied territory; B – breeding but numbers unknown; a – Wang and Peter, 2004; b – Wang and Norman, 1993a; c – this study.

Table 2. Occurrence records and breeding distribution of seabirds from Schirmacher Oasis, its nearby hills and Nivlisen ice shelf area from 1961 to 2016

Area	Year	Stercorarius maccormicki	Pagodroma nivea	Oceanites oceanicus	Pygoscelis adeliae
Schirmacher Oasis	1961[ab]	-	-	-	1–6
	1963[a]	-	-	-	4*
	1979–1980[c]	10*	-	4*	-
	1979–1984[d]	-	-	2–6 pairs*	-
	1983–1984[cdef]	4–11 pairs	?	1–5	3*
	1984–1985[c]	10 nests*	-	-	-
	1988–1989[c]	9–11 nests*	-	-	4–20
	1990[d]	-	?	-	-
	1991–1992[g]	7 pairs*	5	2	4
	1994–1995[hlj]	8 – 15*	2	2	3*
	1996[hk]	14*	~80	2	6–11*
	1999[l]	9	-	-	1
	2002[m]	5 pairs*	?	-	-
	2008[o]	-	-	-	1 pair*
	2014–2016[o]	***7 pairs****	***12–15***	***3–4***	***1–2***
Vetehia nunatak	1984–1985[c]	1 nest*	-	-	-
	1996[k]	-	-	-	7 pairs*
	2014–2016[o]	-	-	-	-
Palets rock or Veet/Shivling	***2014–2016[o]***	-	-	-	-
Lanka	***2014–2016[o]***	**1 pair**	-	-	-
Orvinfjella mountains	1996[h]	1	8	-	-
India Bay, Nivlisen ice shelf	1983[n]	-	-	-	>100
	1991–1992[g]	-	-	-	~46
	1995[j]	9	16	62	24
	2002[m]	-	-	-	?*
Dakshin Gangotri, Nivlisen ice shelf	1995[ij]	8–26	15	6–7	3
Russian Bay, Nivlisen ice shelf	1995[ij]	-	-	-	14–105*
	1996[h]	6–16	1–16	2	24

Text and numbers in bold and italics indicate data from this study collected during austral summers (January & March 2014, March 2015, 2016); ? indicates confirmed sighting but numbers not known; - indicates no data available; *indicates breeding; a – Artem'ev (1965); b – Gerbovich (1964); c – Richter et al. (1990); d – Richter and Bormann (1995); e – Haendel et al. (1983); f – Richter (1983); g – Chattopadhyay (1995); h – Bhatnagar (1999); i – Venkataraman (1998); j – Sathyakumar (1998); k – Chaturvedi and Tripathi (1999); l – Hussain (2002); m – Chandra (2007); n – Mathew (1986); o – this study.

areas. Most of these records were made opportunistically, and thus the counts vary between years and observations for each species (see Tables 1 and 2).

Nivlisen ice shelf

The records from the Nivlisen ice shelf mostly come from Indian expeditioners when the vessels harboured at the ice shelf. Species such as Adélie penguin, chinstrap penguin, emperor penguin, Antarctic petrel, snow petrel, cape petrel, black-bellied storm-petrel, Wilson's storm-petrel and south polar skua have been reported from here. Unsuccessful breeding of Adélie penguins was reported near the Russian dump closer to India Bay, first by Chattopadhyay (1995; about 46 birds) and later by Sathyakumar (1998; 39 birds). Emperor penguins were reported on fast ice in various moulting stages by visiting expeditioners (Chattopadhyay, 1995; Sathyakumar, 1998; Venkataraman, 1998), including a breeding population (>500 birds – Bhatnagar, 1999; 57 birds – Venkataraman, 1998). Snow petrel, Wilson's storm-petrel and south polar skua were regularly recorded from the Nivlisen ice shelf (Table 2). Other seabird sightings at Nivlisen ice shelf include chinstrap penguin (Chattopadhyay, 1995; this study), Antarctic petrel, cape petrel (Chattopadhyay, 1995) and black-bellied storm-petrel (Venkataraman, 1998).

Status of seabirds at Larsemann Hills

We recorded 10 species of seabirds at Larsemann Hills with confirmed breeding of snow petrel, south polar skua and Wilson's storm-petrel (Table 1). Adélie penguin was recorded breeding in the unnamed island group ca. 8 km east of the Larsemann Hills. Emperor penguin individuals were also regularly recorded passing through the study area. Antarctic petrel, cape petrel, light-

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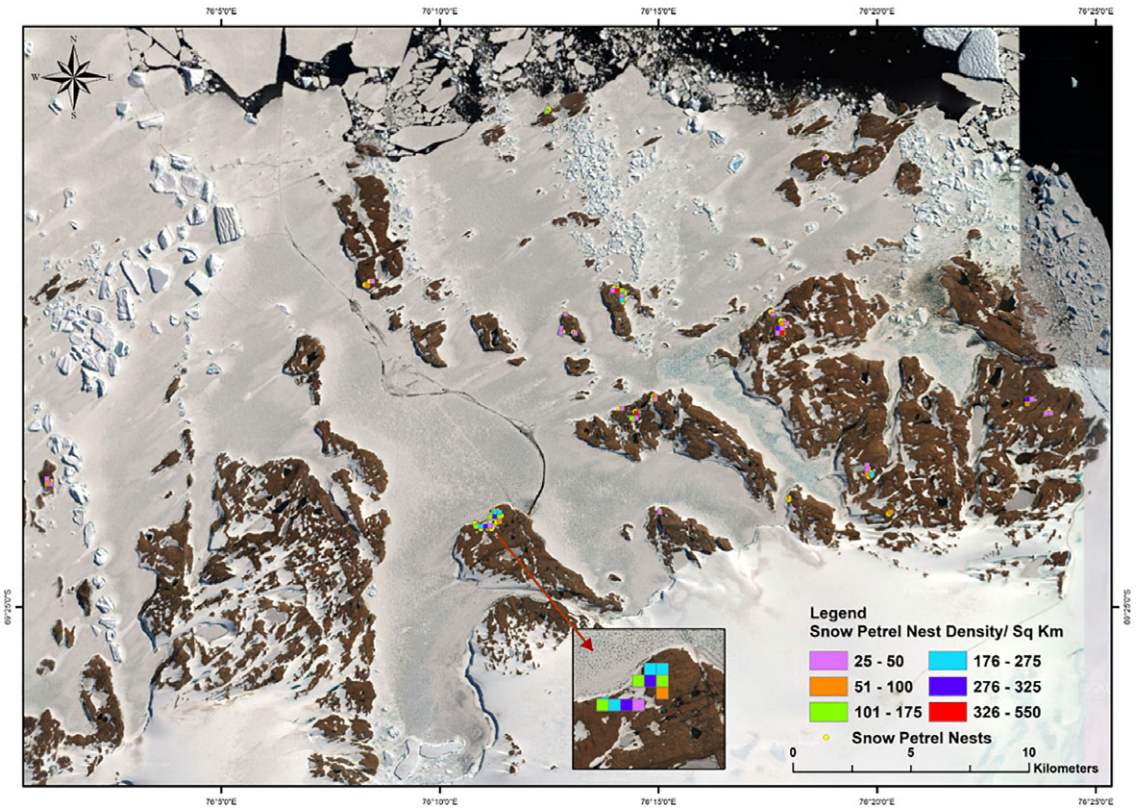

Fig. 2. Snow petrel nest distribution and density at Larsemann Hills, Prydz Bay.

mantled albatross *Phoebetria palpebrata,* southern fulmar *Fulmarus glacialoides* and southern giant petrel *Macronectes giganteus* were seen flying over the study area, but no breeding was recorded.

Snow petrel

Snow petrels were found to breed at 10 islands/peninsulas with unconfirmed breeding presence at Stinear Peninsula. High concentrations of occupied nests were found at Fisher island (36 pairs), Easther island (55 pairs), Grovnes (92 pairs) and Broknes Peninsula (255 pairs). Highest nest densities (mean nest density = 0.044 nests/100 m^2) were recorded in small pockets at Easther, Fisher and north-west Broknes followed by Grovnes (mean nest density = 0.03 nests/100 m^2; Fig. 2). Previously, snow petrels were recorded from only Broknes Peninsula (Wang & Norman, 1993a; Wang & Peter, 2004).

South polar skua

South polar skua were recorded nesting in eight islands/peninsulas, whereas they occupied territories in four more islands (Phillips, Silk, Massey, & Hughes, 2019; Wilson et al., 2017). A total of 22 pairs were recorded from the islands with active nests over 2014–2016 (Table 1). We also observed congregations of up to 25 skua individuals during the study period. Skua nests were found in close vicinity with snow petrel colonies at Broknes Peninsula, Easther as well as Fisher island. Previously, skua nesting had been reported at Broknes Peninsula (up to 15 pairs; Wang & Norman, 1993a) near *Progress-II* (Russia) or *Zhongshan* (China) stations.

Wilson's storm-petrel

Wilson's storm-petrel is known to breed in low abundance at the Larsemann Hills (Wang & Norman, 1993a). Due to lower detection of Wilson's storm-petrel nests, being narrower and more cryptic than the co-occurring snow petrels, we did not attempt to count nests during the island surveys (Gonzalez-zevallos et al., 2013). Nesting was found to occur at seven sites in close association with snow petrel nesting (Table 1 and Fig. 1).

Adélie penguin

We did not detect any breeding activity of Adélie penguins at Larsemann Hills. The nearest breeding colony was observed at Steinnes island group ca. 8 km east of Broknes Peninsula. Adélie penguin moulting areas were found on 11 islands, mostly on the northern slopes. Extensive moulting grounds were located at Cook, Mcleod and Grovnes (Fig. 1).

Status of seabirds at Schirmacher Oasis

Only south polar skuas were recorded breeding actively at Schirmacher Oasis. Sporadic sightings of Wilson's storm-petrel and stray Adélie penguin-nesting events were reported too. Direct sightings were also made of Antarctic petrel and snow petrel during early austral summer.

South polar skua

We recorded seven pairs of south polar skua breeding at Schirmacher Oasis. Four pairs were found nesting near *Maitri* station; one pair each at *Maitri* station workshop, near Ionosonde

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instrument, north of *Priyadarshini* or Zub lake and near the exit road to *Novolazarevskaya* station (Fig. 1). One pair each was found nesting near the long lake (70.758314° S, 11.647541° E), near big valley (70.757964° S, 11.769306° E) and near *Novolazarevskaya* (70.772716° S, 11.808691° E). We found the occupied territory of a pair of south polar skua at Lanka (70°44′20″ S, 11°39′41″ E) but no evidence of nesting.

Snow petrel

We found evidence of snow petrel in the Schirmacher Oasis in the form of predated carcasses at south polar skua nesting and occupied territories in accordance with previous reports (Mathews, 1986). The data from the interviews indicate that snow petrel and Antarctic petrel flocks are seen at *Maitri* for a short period during early summers (before November each year). Snow petrels have also been reported frequently by the *Maitri* station members flying over the oasis as late as first week of February (Table 2).

Adélie penguin

We recorded Adélie penguin at the Schirmacher Oasis during these surveys, but no breeding was observed. Two sightings were made of single individuals near the northern shelf of the oasis during January 2014. A single individual strayed near the *Maitri* station during February 2016 before succumbing to starvation. In previous expeditions, one pair of Adélie Penguin was observed nesting near the ice shelf towards the northern part of the oasis (70° 45′ 09.08″ S, 11° 45′ 21.68″ E; dated 24 November 2008; Fig. 3) by the team of Geological Survey of India. Informal interviews with station members at *Maitri* revealed breeding attempts by Adélie penguins north of *Priyadarshini* lake in 2005–2006 (no photographic evidence).

Wilson's storm-petrel

We recorded multiple sightings of Wilson's storm-petrel at the Schirmacher Oasis, but nest cavities could not be located. Most of these sightings were made towards the northern steeper shelf area of the oasis.

Fig. 3. Seabird species breeding or moulting around Indian research stations in Antarctica. (a) Snow petrel with egg, Grovnes Peninsula, Larsemann Hills; (b) south polar skua with chick, McLeod island, Larsemann Hills; (c) Adélie penguins moulting at McLeod island, Larsemann Hills; (d) Wilson's storm-petrel at nest site, Grovnes Peninsula, Larsemann Hills; (e) Adélie penguin with two eggs, Schirmacher Oasis (Photo: Prakash Shrivastava); (f) nesting pair of Adélie penguin at Schirmacher Oasis (Photo: Kailash Bhindwar).

Discussion

The current study is the first attempt to provide a comprehensive picture of the status of seabirds in the Indian area of operation in Antarctica. Previous records on seabirds from Indian Antarctic Program have come from surveys conducted mostly to record larger vertebrate fauna esp. seals and penguins since the early 1990s. These surveys have been temporally spaced over a period of 20 years and thus the existing information on seabird distribution in these areas has mostly been patchy or anecdotal in origin.

Status of seabirds at Larsemann Hills

Our study provides the first records of seabird occurrence from most islands/peninsulas of Larsemann Hills. Previous records of seabird diversity at Larsemann Hills are very few and have been restricted to only the eastern part of the area, i.e. Broknes Peninsula. The only long-term study on avifauna was conducted by Wang and Norman (1993a, 1993b), Wang et al. (1996), Wang and Peter (2004) on south polar skua breeding and foraging ecology near Zhongshan station in the early nineties.

We found a lesser number of nests of south polar skua in the area (12 pairs as compared to maximum 15 pairs at Broknes Peninsula) previously surveyed by Wang and Norman (1993a) at Larsemann Hills. South polar skua has been reported to nest in low densities (0.8 pairs/km^2) across the Broknes Peninsula (Wang & Peter, 2004). South polar skuas arrive in early summer (mid-October) and establish territories in close vicinity with snow petrel colonies. In the early breeding season, south polar skuas feed on placental remains of Weddell seals, which pup during October at Larsemann Hills. Snow petrel probably forms the main diet of south polar skua in the islands as snow petrel carcasses were commonly found at the occupied territories and nesting sites of south polar skua. However, south polar skuas were observed stealing station refuse on some occasions, and remains of human food items were also found in their regurgitated pellets (Anant Pande, personal observations).

Snow petrels were the most abundant seabird species at Larsemann Hills followed by Wilson's storm-petrels. Since counts were made in different years, we assumed that each nest was occupied by a unique pair, and total counts were given for each island/peninsula (Table 1). Broknes Peninsula (including Mirror) hosts the highest number of snow petrel-nesting sites (n = 255) followed by Grovnes Peninsula (n = 92). Previously, Wang and Norman (1993a) described the presence of snow petrels at Mirror Peninsula. They recorded approximately 300 nests near the south

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polar skua nesting sites while having observed about 850–900 pairs flying near Seal Cove (south-eastern fringe of Broknes Peninsula). However, the snow petrel population might yet be underestimated as several areas including the large western peninsula of Stornes need to be surveyed. Further, spatial classification of nest sites may reveal newer areas of snow petrel nesting in the Larsemann Hills.

Adélie penguins as well as emperor penguins were frequently recorded from Larsemann Hills. Wang and Peter (2004) also reported the presence of small numbers of Adélie penguins on two small islands about 10 km away from Mirror Peninsula (north-east Broknes). Emperor penguins breed in large numbers (>6000 pairs) at Amanda Bay, a designated Antarctic Special Protected Area (ASPA no. 169) (Fretwell et al., 2012; Wienecke and Pedersen, 2009), which is about 25 km east of Larsemann Hills. We presume the penguin sightings at Larsemann Hills are mostly foraging individuals or those searching for moulting sites in the area.

Status of seabirds at Schirmacher Oasis

At Schirmacher Oasis, failed breeding attempts of Adélie penguins have been previously reported (Table 1) (Richter, Haendel, & Junghans, 1990). We recorded only one nest on 24 November 2008, but the fate of the eggs was unknown. Bhatnagar (1999) speculated the vagrant penguins at Schirmacher Oasis to be breeding pairs prospecting for a suitable nesting place. However, successful nesting of Adélie penguin might not have happened due to high south polar skua predation rates and a long distance of Schirmacher Oasis from the ocean for foraging during the breeding period for either of the partner.

South polar skua is the only continuously breeding inhabitant of the Schirmacher Oasis. South polar skua arrives at the oasis in October (Richter & Bormann, 1995; Venkataraman, 1998; this study) and leaves for open ocean at the start of April every year. Records maintained by *Maitri* station overwintering members reported south polar skuas to arrive between 6 and14 October (earliest date recorded in 2015 compared to previously reported dates of 25–31 October by Venkataraman, 1998) and depart in the first week of April after the breeding season is over. We found a lesser number of breeding pairs (7 pairs) at the oasis compared to 10 nests reported by Venkataraman (1998). Bhatnagar (1999) reported 13 south polar skua adults and about four nesting pairs around *Maitri* station area with a rough density of three south polar skua/km^2 in the oasis area. Further, our visits to the oasis were made late-season (mostly in early March except for January 2014), and thus failed nests might have been excluded or some birds might have departed from the area.

Snow petrel and Wilson's storm-petrel were both previously sighted by previous researchers (Bhatnagar, 1999; Sathyakumar, 1998; Venkataraman, 1998). Bhatnagar (1999) recorded ca. 80 snow petrels south of *Maitri* station. Earlier records also mentioned nesting of snow petrels at Orvin mountains (Bhatnagar, 1999; Mathews, 1986) more than 180 km inland from the sea and about 90 km southwest of Schirmacher Oasis and near Lake Untersee in the central Wohlthat Massif (Richter & Bormann, 1995). Bhatnagar (1999) reported two and six snow petrels, and one south polar skua each, from two sites previously identified by GSI team at Orvin mountains. No survey, however, observed or reported snow petrels to be nesting in the much closer, Schirmacher Oasis (90 km) where similar rock crevices are available. We assume it to be due to high south polar skua numbers in the oasis and subsequent predation on the nests. Wilson's storm-petrel, on the other hand, has been found to breed in the oasis between 1979 and 1984 along the northern escarpments (Richter & Bormann, 1995). We could not locate the nest sites of Wilson's storm-petrel reported earlier but had several sightings of 1–2 individuals around station area and around northern slopes of the oasis. In previous Indian expeditions, researchers have reported similar sporadic sightings of Wilson's storm-petrel from the oasis indicating that Wilson's storm-petrel might be breeding in small numbers at the oasis. Moreover, there were no Wilson's storm-petrel remains found at the nesting sites of south polar skuas probably due to higher dependence of south polar skuas on station refuse available from both *Maitri* and *Novolazarevskaya* (and earlier *Georg Forster* too) and lower abundance of natural prey (Bhatnagar, 1999; Chattopadhyay, 1995).

Improvements in the study design for future field surveys

This study generated valuable baseline data for conducting detailed long-term ecological experiments on seabirds in east Antarctica. Estimates of nest counts and distribution could be improved further by utilising spatial tools such as spectral analyses or very high-resolution imagery, though it has limitations with respect to birds breeding in low numbers and cavity-nesting species (Fretwell et al., 2015; La Rue et al., 2014). Tape playback methods (Burger & Lawrence, 2001) or habitat modelling techniques (Olivier & Wotherspoon, 2006) could also be utilised to identify probable seabird nesting sites in the region. Although time consuming, these techniques would help reduce biases emerging from traditional ground surveys and cover areas inaccessible on foot or missed during zig-zag transects.

Conclusion

This study presents the first detailed synthesis of status of seabirds from Larsemann Hills and Schirmacher Oasis regions in Antarctica. We have presented the best information available so far on the status of Antarctic seabirds and have laid a strong baseline for undertaking long-term ecological work in these regions. This study also underlines the objectives of the Convention on Conservation of Antarctic Marine Living Resources' (CCAMLR) Ecosystem Monitoring Program, which emphasizes upon the importance of monitoring key seabird and marine mammal species in Antarctica (https://www.ccamlr.org/). Long-term population monitoring of key indicator species, such as snow petrels identified through this study, would serve as a basis for their conservation and management in light of global climate change. The seabird-nesting areas at Larsemann Hills and Schirmacher Oasis identified though this study need to be regularly monitored to generate long-term datasets on breeding behaviour, genetic structuring and population dynamics. Overall, this study provides direction to undertake population-scale investigations to understand environmental fluctuations and changes in ecological parameters (such as breeding phenology) of seabirds over time.

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