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SHORT NOTE

Unusual number of Southern Rockhopper Penguins, *Eudyptes chrysocome*, molting and dying along the Southern Patagonian coast of Argentina: pre-molting dispersion event related to adverse oceanographic conditions?

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Abstract
The annual molt of Southern Rockhopper Penguins, *Eudyptes chrysocome,* usually takes place at their colonies after a pre-molting foraging trip. In 2016, an unusual number of Rockhopper Penguins was found molting, and in part subsequently dying, along the southernmost portion of the Argentine coast, far from the main colonies. To report the extent of this dispersion and mortality event, a survey was conducted between February and May 2016 along the southern Patagonian coast. A total of 1039 molting Rockhopper Penguins were reported. The mortality, mainly attributed to starvation, varied between 40 and 89%, according to sites. Furthermore, as adverse oceanographic conditions are known to affect prey availability and penguin's survival, chlorophyll *a* concentrations (as a primary productivity index) and sea surface temperatures were analyzed at main foraging grounds. The results showed lower chlorophyll *a* and sea surface temperature values close to the main colonies during 2016 (compared to average 2003–2015). Although these values alone cannot explain such mortality (as similar low values already occurred in some of the previous year without inducing mortality events), our results support the hypothesis of a reduction in primary productivity close to the main colonies prior to the molt, inducing penguins to move towards more distant foraging grounds, which finally led them to molt later and away from their colonies. Although the oceanographic processes were not fully understood, this event highlights the serious effects that unusual conditions prior to molting can pose on the survival of this endangered penguin, in a context of climate variability.

Keywords *Eudyptes chrysocome* · Seabird mortality · Ocean productivity · Sea surface temperature · Southwest Atlantic Ocean · Climate change

Introduction

The Southern Rockhopper Penguin (SRP), *Eudyptes chrysocome,* is listed as Vulnerable by IUCN/BirdLife International due to a global decline of its population; potential causes and threats were identified as: habitat degradation, introduced mammals, disease and poisoning outbreaks, oil pollution, interactions with fisheries, and particularly climate variability and climate change (BirdLife International 2010; Trathan et al. 2015). In the Southwest Atlantic Ocean, the SRP breeds at several locations: Falkland Islands (Malvinas) (319,000 breeding pairs in 2010; Baylis et al. 2013), Isla de los Estados, Tierra del Fuego (aprox. 140,000 breeding pairs in 2010; Raya Rey et al. 2014) and Isla Pingüino, Santa Cruz (1200 breeding pairs in 2015; Gandini et al. 2016) (Fig. 1).

SRPs molt once a year. The molting period lasts between 3 and 4 weeks during which the penguins lose about 40% of their body mass (Brown 1986; Pütz et al. 2013). At the Falkland Islands (Malvinas) colonies and at Isla Pingüino, the molt of breeding adult penguins usually takes place between mid-February and mid-April, just after a post-nuptial/

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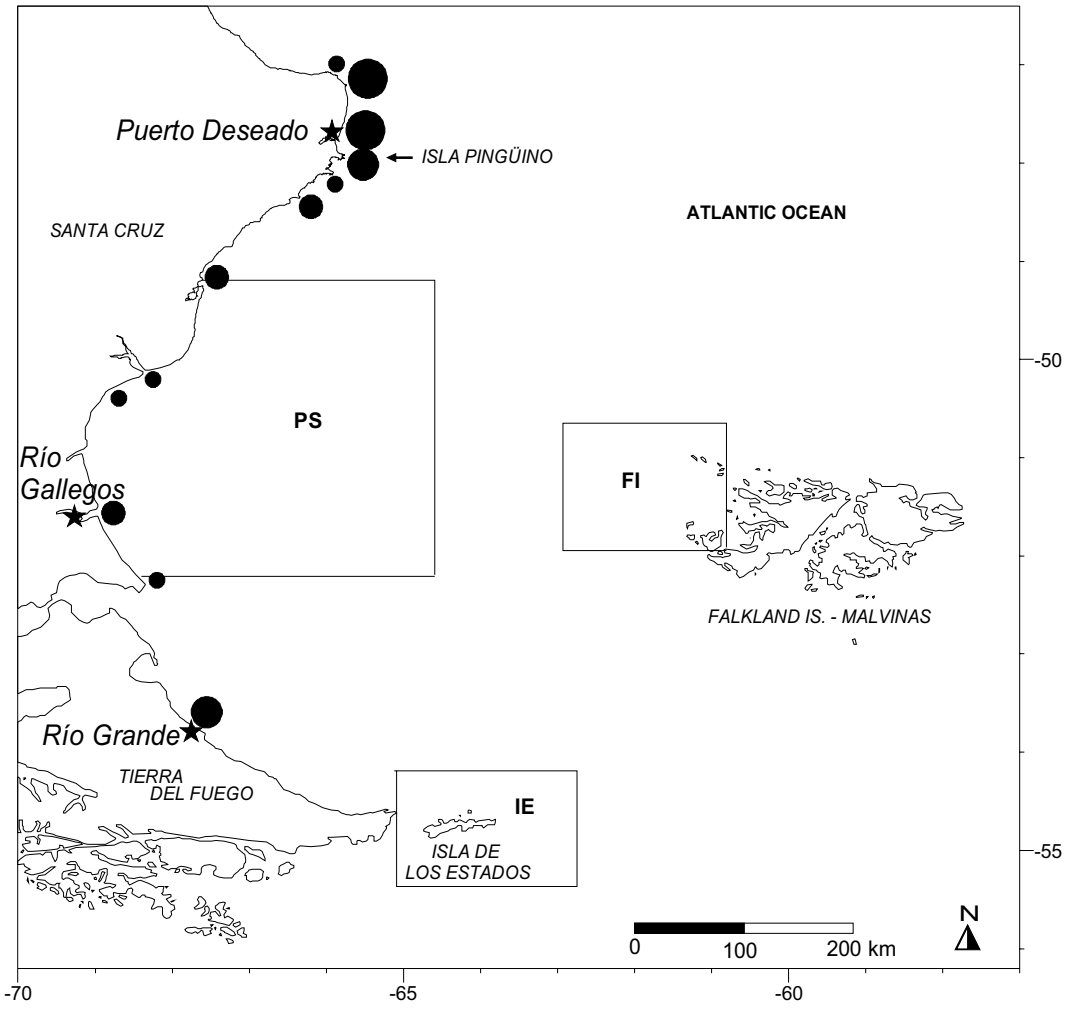

Fig. 1 Abundance of molting Southern Rockhopper Penguins, *Eudyptes chrysocome*, observed along the shores of Santa Cruz and Tierra del Fuego, Argentina, (●: 1–30, ●: 31–100, ●:101–200, ●: 201–320), with main nearby towns (stars). The highest counts recorded at each site were considered (see "Methods"). The three polygons show the areas used for chlorophyll *a* and SST analysis: *PS* the Patagonian Shelf off Santa Cruz, *IM* Northwest of Falkland Islands (Malvinas), *IE* Around Isla de los Estados

pre-molt foraging trip. Juveniles and non-breeding penguins typically molt in January–February after being at sea for the whole year (Schiavini et al. 2005; Pütz et al. 2013). At Isla de los Estados, the corresponding molting periods are taking place 2–3 weeks earlier (Raya Rey et al. 2007a). Molting can be delayed by several weeks in years of reduced food availability (Keymer et al. 2001). SRP seem to present a high fidelity to natal nesting sites for breeding and molting (Schiavini et al. 2005; Denhard et al. 2014). The diet of the SRP from the South Atlantic Ocean is composed mainly of small-sized crustaceans, cephalopods and fishes (Clausen and Pütz 2002; Raya Rey and Schiavini 2005, Frere and Millones unpublished data). The foraging areas are characterized by high chlorophyll *a* concentration and a tendency towards the neritic zone of shallow and shelf slope waters rather than oceanic waters during the breeding period (Masello et al. 2010; Rosciano 2016).

As they usually molt at their colonies, sightings of molting SRP along the Argentine Patagonian shores are not very common (except at Isla Pingüino's colony) and generally only consist of isolated individuals (Darrieu et al. 2008). Nevertheless, these coastlines are very extensive, not densely populated and poorly visited (at this period of the year) so sightings could be underestimated. There is only one published record of numerous (thousands) SRP found molting, and in part subsequently dying, on the Patagonian shores, which occurred in the austral autumn of 1986 (Boersma 1987). That same year, a heavy mortality was recorded at several colonies of SRP from Falkland Islands (Malvinas), attributed to the starvation of adult penguins during the molt (Keymer et al. 2001). It has been hypothesized that the 1986 SRP dispersion and mortality event was related to a shortage of food close to the Falkland Islands (Malvinas) breeding/molting grounds possibly due to the adverse meteorological

(unusually long and hot summer) and oceanographic conditions, which were attributed to the El Niño phenomena (Boersma 1987; Keymer et al. 2001).

Warm Ocean temperatures affecting primary productivity and causing an inadequate food supply has been pointed out as the apparent mechanism of Rockhopper Penguin population decline at several breeding sites at the east of the species range (Cunningham and Moors 1994; Morrison et al. 2015). In the South Atlantic Ocean, even though the species has demonstrated some plasticity in its foraging behavior against inter-annual fluctuations of oceanographic conditions (Dehnhard et al. 2016), the foraging areas and the survival of SRP seem to be affected by changes in oceanographic conditions too (Keymer et al. 2001; Raya Rey et al. 2007b; Dehnhard et al. 2013). As this species feeds on low trophic level prey, it is more susceptible to changes in local primary productivity than other seabirds from the South Atlantic (Ciancio et al. 2008; Masello et al. 2010). Dehnhard et al. (2013) study (carried on during favorable conditions) suggest that SRPs survived best at slightly lower sea surface temperature (SST) anomalies (around − 0.4 °C), and that both, increased SST (above + 0.4 °C) and decreased SST (under − 1.1 °C), could negatively affect the survival rate of SRP. Reduced prey availability due to adverse oceanographic conditions just before and/or after molt (energetically highly demanding period) appear to be particularly critical for their survival (Raya Rey et al. 2007b).

During autumn 2016, between March and May, hundreds of molting SRP were sighted along the southern Argentine coast (Santa Cruz and Tierra del Fuego shores), and many of them died during or after their molt. The objectives of the present work were (1) to report the extent of this new dispersion and mortality event and, (2) to analyze and discuss potential oceanographic causes (variability in productivity and SST) related to this event.

Methods

Rockhopper penguin surveys

As soon as unusual numbers of SRP started to be reported along the southern Argentine coast (Patagonia) in late February, a monitoring program was implemented at the three main sites where SRP were first reported and which are situated at short distances from main towns (allowing regular visits): (1) Puerto Deseado (Santa Cruz): 3 km of urban and 3 km of provincial nature reserve shores, (2) Río Gallegos (Santa Cruz): 3 km of urban and 3 km of non-urban shores (Punta Loyola area) and (3) Río Grande (Tierra del Fuego): 3.5 km of provincial nature reserve shores at Cabo Domingo (see locations in Table 1). Direct counting of SRP (alive and carcasses) were performed at least once a week between end of February and end of May (when the latest alive penguins were seen) by walking the shores of each site. Moreover, the penguins found at the urban shores were relocated by rangers to more remote places (situated at 10 and 15 km from Puerto Deseado and Río Gallegos, respectively), in order to avoid dog attacks and human disturbance, and were monitored. The number of live penguins reported for each of the three monitored sites was calculated as the highest count of live penguins recorded at each non-urban shore during the whole monitored period, plus the sum of urban relocated penguins (when it applied). Most of the relocated penguins stayed at their new site for molting, so double counts were unlikely. Apart from the three monitored sites, unique counts were performed (or were provided by other observers; see acknowledgments) at other places and were reported. Around 5% of the very extensive (~ 1000 km) and mostly inhabited shores situated between Cabo Tres Puntas (47.09°S, 65.87 W) in the north and Rio Grande (53.78°S, 67.7 W) in the south were prospected (most accessible places situated close to the main towns and most visited protected areas).When possible, age (recorded as juvenile or adult, based on the plumage; Pütz et al. 2013) and body condition were recorded. The total number of dead penguins reported at each site was calculated as the highest count of dead penguins recorded, plus the number of dead penguins that we know for sure had died and disappeared before the highest count (i.e., washed by tide or taken away by animals) or died after the highest count. The percentage of mortality was calculated for each monitored site (based on total number of dead penguins over total number of live penguins).

Table 1 Total number of live Southern Rockhopper penguins (SRP), *Eudyptes chrysocome*, counted at each main area (in bold) and number of live and dead SRP with corresponding percentage of mortality obtained at each of the three monitored sites

	SRP alive	SRP dead	% mortality
Northern Santa Cruz	**715**		
Puerto Deseado	152	76	50
Southern Santa Cruz	**142**		
Río Gallegos	60	24	40
Tierra del Fuego	**182**		
Río Grande	182	159	89
Total	1039		

Oceanographic data analysis

Chlorophyll *a* concentration (mg/m^3) levels are used as an index of ocean primary production (Boersma et al. 2009). Along with sea surface temperature (SST), these oceanographic variables are often used as a proxy for environmental conditions reflecting prey availability (Raya Rey et al. 2007b). In order to analyze these variables at SRP

main pre-molting foraging grounds of the southwest Atlantic, three areas were defined as proxy of potential foraging ground (considering that these areas can vary between years and that the information for some colonies is scarce), based on a mixture of areas obtained between late summer and early winter by different authors (Pütz et al. 2006; Raya Rey et al. 2007b; Falabella et al. 2009; Dehnhard et al. 2013); PS: the Patagonian Shelf off Santa Cruz, FI: Northwest of Falkland Islands (Malvinas); IE: Around Isla de los Estados (Fig. 1). For each area and for 14 years (2003–2016), monthly average chlorophyll *a* concentration values (mg/m^3), with 0.1° spatial resolution, and SST values (°C), with 4 km resolution, were obtained from the Ocean Productivity Website (http://www.science.oregonstate.edu/ocean.productivity) and NASA ocean temperature images (ftp://podaac-ftp.jpl.nasa.gov/OceanTemperature/modis/L3/aqua/4um/v2014.0/4km/monthly/), respectively. Values of chlorophyll *a* concentration were directly obtained from the Ocean Productivity Website. For SST values, 500, 300 and 150 points were generated (according to the size of each zone PS, FI and IE), using the "create random point" tool in ArcGIS 10.3.1. Then, for each area, average chlorophyll *a* and average SST of both February and March of 2016 were compared with the respective average values from the previous 13 years (2003–2015) for those months. Differences were tested using Mann–Whitney *U*-test. Data from 2003 to 2015 were used as we are confident that no mortality event took place along the Patagonian coast during those years.

Results

Rockhopper penguin surveys

At least 1039 molting SRP were reported along the prospected shores (Fig. 1; Table 1). Two main separate concentration areas were detected (Fig. 1). The major area was the northern Santa Cruz Province, (totaling 715 individuals), and the second area was at Río Grande, Tierra del Fuego (182 individuals, Fig. 1). Only smaller groups (< 50) or isolated individuals were recorded between these two main areas, totaling 142 SRP (Fig. 1). Penguins were mostly found gathering together on rocky or sandy boulders and cliffs, and sometimes also on rocky, sandy or pebble beaches.

At the three monitored sites, the first SRP started to be seen during the last week of February/first week of March and the last ones had left or died by May 20th. Maximum numbers of live animals were recorded at mid-April. Before mid-April around 75% of the sighted penguins were juveniles and after mid-April the proportions of adults and juveniles were equal. Most penguins were molting and very emaciated. Site mortality varied between 40 and 89% with the highest mortality recorded at the southern site: Río Grande (Table 1). The peak of mortality occurred between the last week of April and the first of May in most places, except at Cabo Virgenes (south of Río Gallegos) where 12 out of 18 SRP died at the beginning of March (Jorge Serra pers. com.). At Puerto Deseado and Río Gallegos, rangers relocated respectively 152 and 5 penguins from the urban coastlines.

Oceanographic data analysis

The monthly mean chlorophyll *a* and SST values (for both February and March), from 2003 to 2015 and for all areas, were variable among years (Online Resource 1). The 2016 values felt within the maximum and minimum range of mean values obtained between 2003 and 2015 for each corresponding area and month (Online Resource 1). Nevertheless, chlorophyll *a* values were significantly lower at FI and IE potential foraging areas both in February and March 2016 compared to the averages of the previous 13 years (Table 2, all $p < 0.05$). At PS, chlorophyll *a* values were significantly higher ($p < 0.0001$) in February 2016, and there was no difference between March 2016 value and the average 2003–2015 (Table 2). The SST values were significantly lower (all $p < 0.0001$) for 2016 compared with the average 2003–2015, except for February at PS and FI (Table 2).

Discussion

Around one thousand molting SRP were recorded along Santa Cruz and Tierra del Fuego Atlantic shores, in some cases several hundreds of kilometers away from the nearest colonies where the molt usually takes place. Considering that only around 5% of the total coastline of the study site was prospected, this might be only the tip of the iceberg and the true figure is likely to have been much larger and may have involved several thousands of SRP. The majority of these penguins were in poor body conditions (skinny and emaciated) and nearly half of them were juveniles (1–2 years old). The molt of these penguins was delayed compared with the molting periods at Falkland Islands (Malvinas) and Isla Pingüino (2–3 weeks delay) and Isla de los Estados (5–6 weeks delay) respectively. More than half of them did not finish molting and died before being able to regain the sea (site mortality rates ranged between 40 and 89%). The mortality was mainly attributed to starvation (although other causes as a primary agent like disease or harmful algae toxin poisoning cannot be discarded) and for a few individuals to predation by domestic dogs (Puerto Deseado and Río Gallegos). Chlorophyll *a* concentration values support the hypothesis of reduced prey availability close to the main colonies (significantly lower values in February and March 2016 than the average of the previous 13 years at FI and IE foraging areas), which could have induced a shift towards the

Table 2 Median values for chlorophyll *a* concentration (CL) and sea surface temperature (SST) of February and March 2016 and of February and March of the previous 6 years (2003–2015), at each studied area: *PS* patagonian shelf off Santa Cruz, *FI* Northwest of Falkland Islands (Malvinas), *IE* North of Isla de los Estados

Variable	Area	Month	2016	2003–2015	Test score (Z)	*P*	*N*
CL	PS	February	2.8	1.87	− 10.04	**< 0.0001**	1180
		March	1.73	1.71	− 1.45	0.23	1180
	FI	February	0.92	1.38	9.55	**< 0.0001**	288
		March	0.67	1.02	10.45	**< 0.0001**	288
	IE	February	1.14	2.45	3.42	**< 0.0001**	76
		March	1.14	1.54	2.09	**0.03**	76
SST	PS	February	11.56	11.32	− 1.65	0.09	500
		March	10.75	10.87	3.32	**< 0.0001**	500
	FI	February	10.55	10.42	− 0.62	0.53	300
		March	9.68	10.05	7.79	**< 0.0001**	300
	IE	February	6.19	7.13	6.99	**< 0.0001**	150
		March	6.3	7.04	4.2	**< 0.0001**	150

Test score (*Z*) values correspond to those obtained with Mann–Whitney *U*-test. Significant *P* values (< 0.05) are shown in bold. *N* is the number of values used to calculate the medians

more distant and productive foraging grounds of the PS (a known winter foraging area, where productivity was higher than average in February 2016). We suppose that, due to the biological imperative to molt (already delayed), they went ashore at the closest landform (Patagonian coast) but apparently their reduced amount of body fat was not always adequate to last the entire molt period. Nevertheless our results also show that productivity can be variable between years and that low late-summer productivity already occurred several times between 2003 and 2015 (Online Resource 1), without inducing massive mortality events. SST results for February and March 2016 showed lower values than average 13 previous years at all foraging areas (except for February at PS and FI). According to different sources (Falkland Islands Government 2017, and http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCDC/.OISST/.version2) strong negative SST anomalies were evident from March 2016 onwards at the Falkland (Malvinas) Current, whose main branch transfers cold and nutrient-rich waters northwards (Piola and Matano 2001). Therefore, the entire area receiving these waters (including the Patagonian Shelf) must have been affected by these negative anomalies, which seem to have produced variations in the distribution and availability of prey. In our case, considering that most of the SRP likely died from starvation, it could be assumed that primary productivity and prey availability was negatively affected by the occurrence of colder waters during late summer of 2016. This is in agreement with Dehnhard et al. (2013), who suggested that both increased and reduced SST could have a negative effect on SRP survival rates. Furthermore, it is postulated that optimal prey availability seems to be restricted to a limited range of environmental and oceanographic conditions, and any deviations from this range could reduce the survival rate of SRP (Raya Rey et al. 2007b; Dehnhard et al. 2013).

The 2016 oceanographic conditions had other severe consequences as evidenced by the particularly low catches of shortfin squid, *Illex argentinus,* by Falkland Islands (Malvinas) fisheries that were attributed to negative water temperature anomalies starting in February 2016 (with near-bottom temperatures on the shelf about 1–1.5 °C colder than the normal) that spread all across the Southwest Atlantic (Falkland Islands Government 2017). Both SRP and shortfin squid feed on similar crustacean prey and thus can be negatively affected on a similar way to adverse conditions and reduced prey availability (Mouat et al. 2001; Pütz et al. 2002). Although the exact causes were not fully understood, the consequences were dramatic as evidenced by the number of dead penguins found along the Patagonian coast, and further confirmed by a drastic 30% reduction of 2016–2017 breeding pair numbers at several Falkland Islands (Malvinas) colonies and at Isla Pingüino (Crofts and Stanworth 2017; Morgenthaler et al. unpublished data).

The origin of the molting SRP found along the Patagonian shores is unknown; however it is likely that a great proportion of them came from some of the numerous colonies of the Falkland Islands (Malvinas) (totaling 320.000 breeding pairs). Indeed the Patagonian shelf off Northern Santa Cruz to Tierra del Fuego is known to be used as a winter foraging ground by SRP from Falkland Islands (Malvinas) (Pütz et al. 2002; Ratcliffe et al. 2014), and some of those colonies have shown reduced numbers of breeding pairs the season following the mortality event (Crofts and Stanworth 2017). Nonetheless, some individuals could also have come from Isla de los Estados (totaling 140.000 breeding pairs), as these are also known to use the sea adjacent to Tierra del Fuego during winter time (Pütz et al. 2006; Raya Rey

et al. 2007b). And finally, even though the colony of Isla Pingüino have seen a reduction of its size after the event (Morgenthaler et al., unpublished data), it is unlikely that a significant proportion of the penguins found on the coast came from this colony, due to its small population size (1200 breeding pair, Gandini et al. 2016).

This new mortality event is the second known record of SRP mass mortality along the Southern Argentine shore. The Santa Cruz and Tierra del Fuego coast is very extensive (~ 1000 km) and not very accessible (in part limited by ranch landowners), and therefore not thoroughly surveyed, so other mortality events could have happened and passed unnoticed (particularly before 2003 when the coast was less prospected by local biologists and naturalists). El Niño phenomena was pointed as the main cause behind the 1986 event, when thousands of SRP were found dead along the southern Patagonian coast and the Falkland Islands (Malvinas) (Boersma 1987; Keymer et al. 2001). During 2015 and 2016 one of the strongest El Niño event took place (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml), and the observed negative SST around Falkland Islands (Malvinas) in March 2016 are consistent with El Niño effects at the Falkland (Malvinas) Current (Severov et al. 2004).

This study highlights the serious effects that changes in oceanographic parameters prior to a critical period (molting) can have on SRP survival, and the need to improve our understanding of the oceanographic processes leading to reduced prey availability. Climate change and natural climate variability pose serious threats for this species, which in synergy with overfishing, pollution and invasive species could be catastrophic for their populations. These aspects should be taken into account when considering the population trends and IUCN status updates.

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Unusual number of Southern Rockhopper Penguins, *Eudyptes chrysocome*, molting and dying along the Southern Patagonian coast of Argentina. Pre-molting dispersion event related to adverse oceanographic conditions? Morgenthaler A, Frere E, Raya Rey A, Torlaschi C, Cedrola P, Tiberi E, Lopez R, Mendieta E, Carranza ML, Acardi S, Collm N, Gandini P, Millones A

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Online Resource 1: Mean values (± SE) for chlorophyll *a* concentration (CL) and sea surface temperature (SST), of February and March 2003 to 2016, at each studied area: PS: Patagonian shelf off Santa Cruz; FI: Northwest of Falkland Islands (Malvinas); IE: North of Isla de los Estados. Black dots indicate mean values for chlorophyll *a* concentration. White dots indicate mean sea surface temperature values. Error bars are ± SE