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Tracking ecosystem changes in Western Antarctic Peninsula to inform CCAMLR decision-making: insights from the ongoing ecosystem monitoring programme in Ardley Island's CEMP site

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Tracking ecosystem changes in Western Antarctic Peninsula to inform CCAMLR decision-making: insights from the ongoing ecosystem monitoring programme in Ardley Island's CEMP site.

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Summary

In western Antarctic Peninsula (WAP), one of the polar areas most affected by global warming, Adelie (*Pygoscelis adelie*) and Chinstrap (*P. antarticus*) penguin populations have declined since the 1970s. In contrast, Gentoo penguin (*P. papua*) populations are stable and even increasing. Population declines in the WAP have been linked to the reduction of total biomass and size of available Antarctic krill caused by regional declines in sea-ice extent and duration, fishing, and the population increase of natural competitors. In recent years, Bransfield Strait and the South Shetland Islands have become a hotspot for the krill fishery. Identifying foraging areas that are regularly used by penguins would provide valuable information for the small-scale management of the krill fishery and the design of a Marine Protected Area in WAP, currently under discussion in CCAMLR. Ardley Island, in the Fildes Region, southwest of King George Island/Isla 25 de Mayo is one of the few areas in Antarctica where the three Pygoscelis penguin species breed sympatrically. Due to its geographical position in the rapidly changing WPA, the establishment of a continuous monitoring programme in Ardley Island is relevant to understand the effects of long-term climate change and other sources of anthropogenic pressure such as tourism or fishing. In 2019 Uruguay initiated a monitoring programme of the breeding colonies of Gentoo and Adelie penguins in Ardley Island using standard CCAMLR methods. Since 2022 it is a CEMP site. In addition to standard population parameters, the programme aims to track changes in individuals' foraging ecology, use of space, trophic ecology, energy budgets, and physiological conditions. The most remarkable observation during the monitored period, is the sharp decline in the number of Adelie breeding pairs, and contrasting values for both Adelie and Gentoo penguins, in proxies of feeding energetic investment and individuals' conditions between seasons. This is likely linked to changes in krill availability. The consequences of these variations in resource availability, the carry-on effects of these variations, and the way the different species (with different ecological plasticity) respond to these changes, require further exploration. Understanding the predator-prey interactions at small scales is critical for ecosystem conservation planning and resource management. Using an accelerometry-data-based approach we identified the areas where Adélie penguins from Ardley Island forage. The core foraging area is located within Maxwell Bay, 10 km off the colony, with this area being systematically used by more than 60% of the population throughout the summer seasons and across seasons. Nearly 20% of the population also uses the area close to Orca Seamount for foraging (35 km from the colony), mainly during the late guard stage. Vessel movements in Maxwell Bay have increased significantly since the early 2000s during the summer season. This activity overlaps in space and time with the foraging areas of the Pygoscelid species that breed in Ardley Island. Our results emphasize the relevance of Maxwell Bay and Orca Seamount as critical foraging areas during the breeding season for Adélie and the other Pygoscelid penguins. Adelie penguins have also been tracked during the winter season since 2021. Areas used throughout the annual cycle are widely distributed across the region. During the breeding stage, penguins exploit

resources available in subarea 48.1, while they depend on resources available in subarea 48.5 for the post-breeding and moulting stage, and resources distributed across subareas 48.1, 48.2 and 48.5 during wintering. Their dependence on resources from different subareas in different times of the year in order to sustain their colonies also emphasizes the need of incorporating the temporal dimension of resources utilization when designing conservation measures for this region.

1. Introduction

Monitoring marine predators at sea, such as penguins, can identify areas of ecological importance. Areas with high concentrations of predators often indicate a high biodiversity and biomass at lower trophic levels and are, therefore, regions that may require special management (Hindell et al. 2020; Ropert-Coudert et al. 2020). As key predators of krill, penguins have been considered eco-indicating species, being highly sensitive to changes in the marine ecosystems (Boersma 2008; Hinke et al. 2014; Ropert-Coudert et al. 2018).

In western Antarctic Peninsula (WAP), one of the polar areas most affected by global warming, Adelie (*Pygoscelis adelie*) and Chinstrap (*P. antarticus*) penguin populations have declined since the 1970s (Trivelpiece et al. 2011; Lynch et al. 2012). In contrast, Gentoo penguin (*P. papua*) populations are stable and even increasing (Herman et al. 2020). Population declines in the WAP have been linked to the reduction of total biomass and size of available Antarctic krill caused by regional declines in sea-ice extent and duration, fishing, and the population increase of natural competitors such as whales and seals (Trivelpiece et al. 2011; Lynch et al. 2012; Watters et al. 2020; Warwick-Evans et al. 2022). It has been pointed out that climate change as well as the spatio-temporal distribution and effort of krill fishing activities may affect penguin colonies (Santa Cruz et al. 2018; Kruger et al. 2020; Watters et al. 2020).

Antarctic krill is the main target of the Southern Ocean fishery, regulated by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). With a global biomass in the range of 340–540 million tons (Atkinson et al. 2009), this species is one of the last remaining under-exploited sources of marine protein, with the potential to contribute around 10% to all future marine landings (Trathan et al. 2022). Currently, this fishing activity is concentrated in the southwest Atlantic sector (FAO statistical Area 48) (Watters and Hinke 2022), and catches are considered relatively low, with limits set at < 1% of the regional biomass estimate. However, in recent years catches are both increasing, reaching in the 2019/2020 season the highest level recorded in the sector (450,781 tons), and intensifying, with the fleet repeatedly visiting fishing hotspots, particularly close to predator breeding colonies (Santa Cruz et al. 2018; Trathan et al. 2018).

Fishing might reduce the availability of krill to penguins through absolute reductions in krill biomass (exploitative competition) or by changing the structure of krill swarms or their distribution in the water column (interference competition) (Watters et al. 2020). When the temporal and spatial scales of catch limits are broader than the scales of predator-prey interactions, it is difficult to achieve ecosystem objectives that include predator conservation (Watters et al. 2020). Consequently, several works have pointed out the need for a krill exploitation framework that ensures small-scale precautionary protection to minimize negative effects on dependent predators (Santa Cruz et al. 2018; Watters et al. 2020; Trathan et al. 2022).

In recent years, Bransfield Strait and the South Shetland Islands have become a hotspot for the krill fishery (Santa Cruz et al. 2018), leading to interference competition with predators around the Antarctic Peninsula (Watters et al. 2020). Identifying foraging areas that are regularly used by penguins throughout the breeding seasons and across several years would provide valuable information for the small-scale management of the krill fishery and the design of a Marine Protected Area in the western Antarctic Peninsula, currently under discussion in CCAMLR (Hogg et al. 2020). Previous studies have described the spatial distribution and habitat use of breeding and non-breeding penguins from colonies in the South Shetland Islands (Wilson et al. 1994; Wilson 2002; Kokubun et al. 2010; Lee et al. 2021; Oosthuizen et al. 2022; Salmerón et al. 2023), and attempted to identify the degree of overlap between areas used by these birds and those harvested by fisheries (Hinke et al. 2017; Krüger et al. 2020; Watters et al. 2020; Warwick-Evans et al. 2022). However, detailed information on the at-sea foraging behavior of penguins during the breeding season is extremely limited for this region (but see e.g., Cimino et al. 2016 for other colonies in the WAP).

2. Study area and monitoring programme

Ardley Island, in the Fildes Region, southwest of King George Island/Isla 25 de Mayo (Fig. 1), is an Antarctic Specially Protected Area (ASPA N° 150) and is one of the few areas in Antarctica where the three Pygoscelis penguin species (Adélie, Chinstrap and Gentoo) breed sympatrically. In particular, this is an important area for the Gentoo penguin because a large number breed there, and in consequence, it is classified as 'Important Bird Area (IBA) N°48.

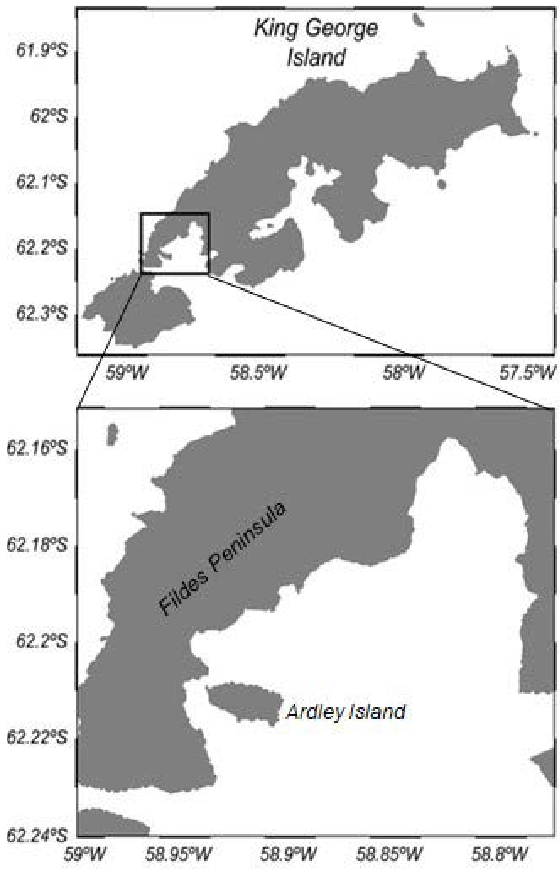

Fig.1. Ardley Island in King George Island/Isla 25 de Mayo, South Shetland Islands.

Fildes Peninsula, separated from Ardley Island by an isthmus of approximately 400 m, is one of the largest ice-free areas in Antarctica.. Because of this, its proximity to South America, and the construction of the Chilean airfield in the 1980s, it represents an important logistical hub for the South Shetland Islands and the Antarctic Peninsula. Consequently, this area has one of the highest densities of scientific stations and shelters in Antarctica, and a high level of shipping activity, both tourist and logistical (Braun et al. 2014; Soutullo et al. 2022a).

Therefore, due to its geographical position in the rapidly changing WPA, in an area that is exposed to strong anthropogenic impact and within the proposed MPA in the Domain 1 (Hogg et al. 2020), a continuous monitoring of penguin colonies in Ardley Island is relevant to understand the effects of long-term climate change and other sources of anthropogenic pressure such as tourism or fishing. A research group from the University of Jena has been monitoring seabirds in the island since the 80s. According to Braun et al. (2017), the number of breeding pairs of Chinstrap penguins have decreased by more than 90% since counts began, and more than 30% for Adelie penguins. In contrast, Gentoo penguins increased over the same time period by more than 80%.

In 2019 Uruguay initiated a monitoring programme of the breeding colonies of Gentoo and Adelie penguins in Ardley Island using standard CCAMLR methods (Machado-Gaye et al. 2021). Since 2022 the island has been incorporated as a CEMP site in the CCAMLR Ecosystem Monitoring Programme (identification denomination: ARD). In addition to standard population parameters, the programme aims to track changes in individuals' foraging ecology, use of space, trophic ecology, energy budgets, and physiological conditions, in order to understand population consequences of large-scale and local environmental changes, with the purpose of informing decision-making for CCAMLR and other instances of the Antarctic Treaty System. Tables 1 and 2 summarize collected information on some of the monitored parameters.

Table 1. Breeding parameters of Adelie and Gentoo penguins in Ardley Island. Reported weights correspond to adult birds.

Season	Species	Breeding pairs	Nest with chicks	Mean ± SD weight (kg)
2019-2020	Adélie	303	262	6.45 ± 0.71
	Gentoo	6695	5768	6.70 ± 0.64
2020-2021	Adélie	-	353	3.85 ± 0.39
	Gentoo	-	6107	5.37 ± 0.41
2021-2022	Adélie	200	163	3.90 ± 0.39
	Gentoo	7121	-	4.98 ± 0.63
2022-2023	Adélie	184	168	4.09 ± 0.48
	Gentoo	-	5057	5.16 ± 0.45

Table 2. Foraging range parameters of Adelie and Gentoo penguins during the chick-rearing stage in

Ardley Island.

Season	Species	N° Ind	N° Trips	Trip duration (h)	Max. distance from colony (km)	Total distance traveled (km)	Home range (50% UD) (km^2)	Home range (90% UD) (km^2)
2019-2020	Adélie	19	67	8.63 ± 3.66	6.6 ± 5.42	19.33 ± 12.33	31.59 ± 15.99	100.69 ± 51.48
	Gentoo	19	102	9.23 ± 3.46	16.26 ± 9.95	37.41 ± 20.25	100.52 ± 42.54	335.75 ± 129.04
2020-2021	Adélie	15	52	20.85 ± 11.01	25.16 ± 17.92	64.66 ± 40.40	149.65 ± 66.88	490.67 ± 185.41
	Gentoo	20	84	13.14 ± 11.76	22.82 ± 11.48	53.06 ± 26.23	137.94 ± 44.55	457.01 ± 136.14
2021-2022	Adélie	22	79	19.73 ± 11.43	18.14 ± 16.72	49.87 ± 39.22	102.73 ± 80.33	353.59 ± 231.50
	Gentoo	21	115	12.06 ± 4.41	18.55 ± 10.89	44.81 ± 23.28	133.90 ± 61.47	444.34 ± 195.01

3. Highlights and conclusions

The most remarkable observation during the monitored period, is the sharp decline in the number of Adelie breeding pairs, and contrasting values for both Adelie and Gentoo penguins, in proxies of feeding energetic investment (e.g., foraging trips duration or total distance) and individuals' conditions (e.g., body weight) between the season 2019/2020 and the other seasons (see Table 1). This is likely linked to increased krill availability in 2019/2020, as reported by Salmerón et al. (2023) for the vicinities of Ardley island. The consequences of these variations in resource availability, the carry-on effects of these variations, and the way the different species (with different ecological plasticity) respond to these changes, require further exploration.

As krill catches intensify in the Western Antarctic Peninsula, and sea-ice declines, there is an increasing need for ecological data at small spatial and temporal scales to inform potential overlap and conflicts. Understanding the predator-prey interactions at small scales is critical for ecosystem conservation planning and resource management (Watters et al. 2020; Trathan et al. 2022). We used an accelerometry-data-based approach to identify the areas where Adélie penguins from Ardley Island forage (Machado et al. under review). We showed that the core foraging area of the penguins is located within Maxwell Bay, 10 km off the colony, with this area being systematically used by more than 60% of the population throughout the summer seasons and across seasons. We also observed that nearly 20% of the population uses the area close to Orca Seamount for foraging (35 km from the colony), mainly during the late guard stage.

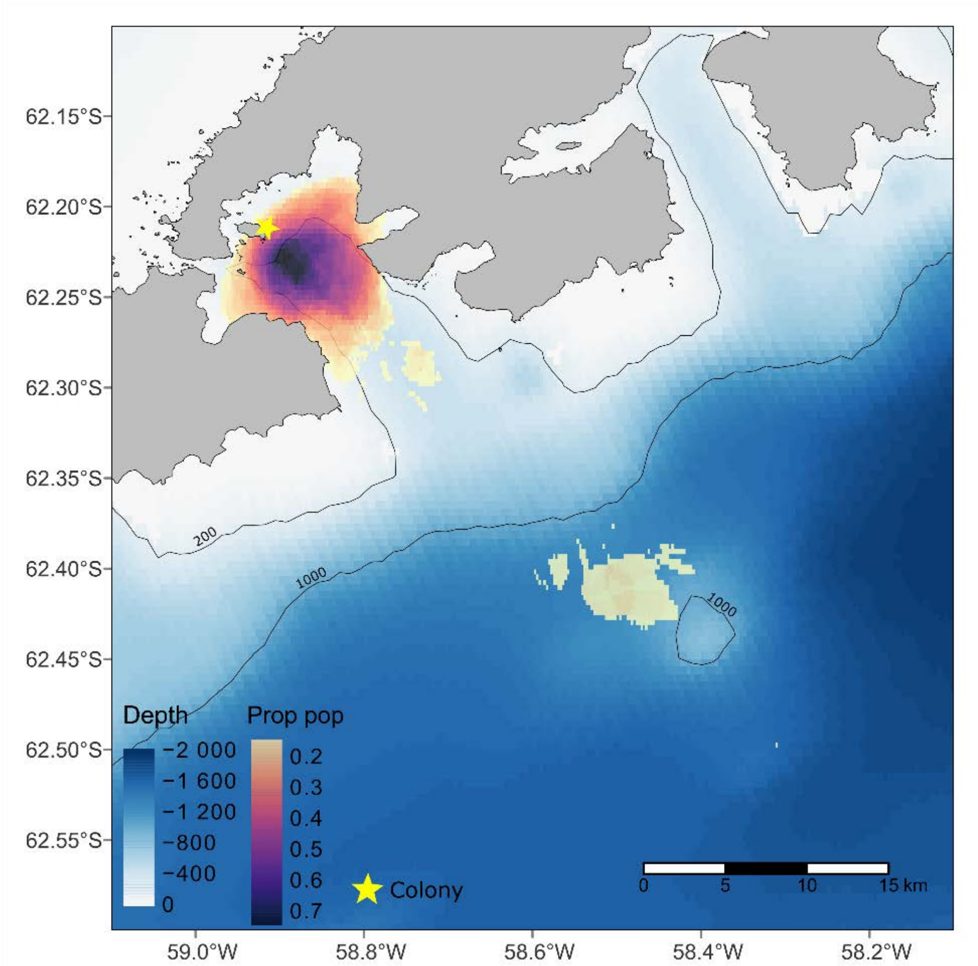

Fig. 2. Key foraging areas of Adelie penguins breeding in Ardley Island (57 individuals tracked between 2019/2020 and 2021/2022 during the chick-rearing stage in December)

The foraging activity of Adélie penguins in Ardley Island, as well as that of their conspecifics described by Lee et al. (2021) and Kokubun et al. (2015), has implications for the local management during the summer season of Maxwell Bay and the area around the Seamount located in Bransfield Strait. In recent decades, the number of ship arrivals in Maxwell Bay has increased from roughly 40 in the early 2000s (Braun et al. 2012) to a peak of about 120 arrivals during the 2021-2022 summer season (Braun pers comm). This activity within the Maxwell bay during the austral summer overlaps in space and time with the foraging areas described for the Pygoscelid species that breed in Ardley Island. However, up to now, no studies have examined the impacts that the transit of these ships may have on these colonies. Our results emphasize the relevance of Maxwell Bay and Orca Seamount as critical foraging areas during the breeding season for Adélie and the other Pygoscelid penguins, and therefore their relevance in terms of marine conservation.

Adelie penguins have also been tracked during the winter season since 2021. Fig 3. shows the distribution of 11 individuals tracked during the year 2021 (Soutullo et al. 2022b). Since 2021, 30 individuals have been tagged with GLS each year, to monitor year-round movements and activity patterns.

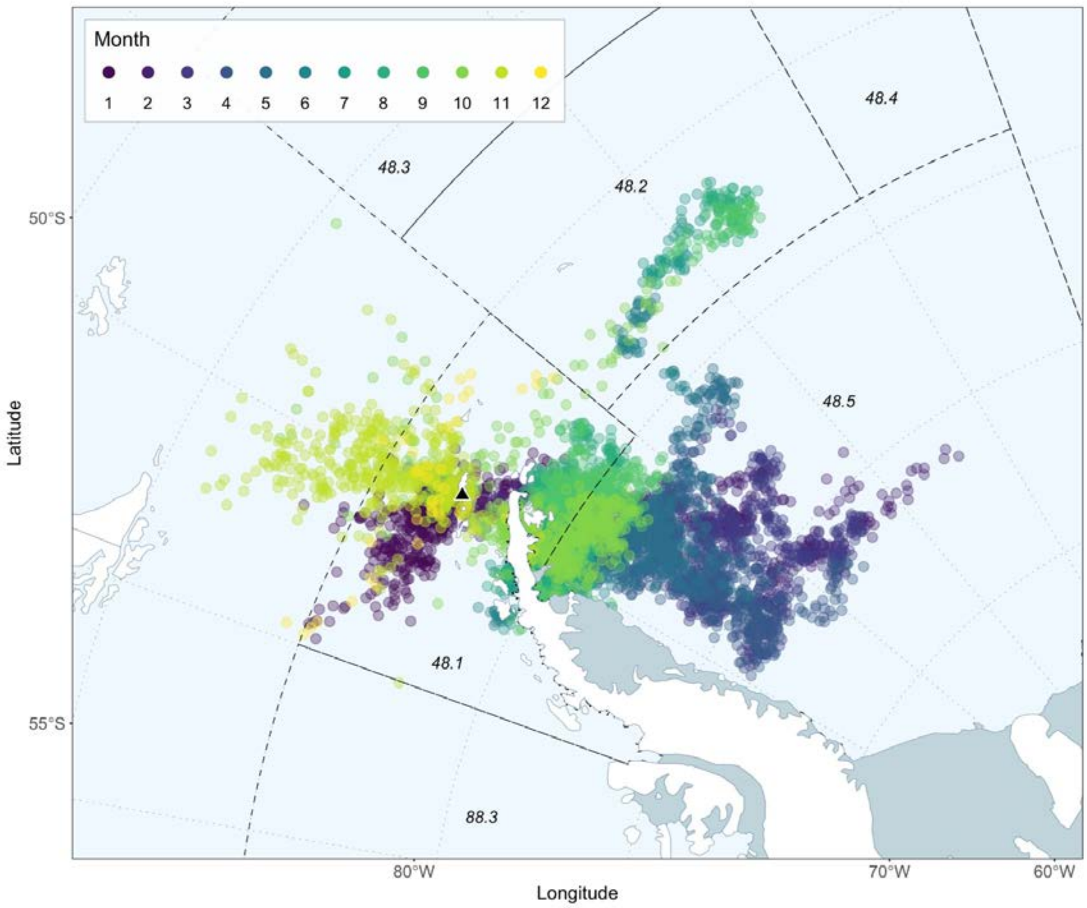

Fig. 3. Year-round location of Adelie penguins breeding in Ardley Island tracked during 2021.

Areas used throughout the annual cycle are widely distributed across the region. During the breeding stage, penguins exploit resources available in subarea 48.1, while they depend on resources available in subarea 48.5 for the post-breeding and moulting stage, and resources distributed across subareas 48.1, 48.2 and 48.5 during wintering. Their dependence on resources from different subareas in different times of the year in order to sustain their colonies also emphasizes the need of incorporating the temporal dimension of resources utilization when designing conservation measures for this region. It also highlights the relevance of accounting for connectivity when designing and managing MPAs, and hence the relevance of network-level considerations when designing and managing individual MPAs (Grorud-Kolvert et al., 2014). With an increasing pressure on Adélie penguin colonies in the western Antarctic Peninsula coming from a range of sources, long-term protection of Adélie penguins in the area might depend on well designed and managed MPAs both in the Domain 1 (Hogg et al. 2020) and the Weddell Sea (Teschke et al. 2021).

Overall, the information collected during the first 4 years of implementation of the monitoring programme in Ardley Island highlights the value of CEMP sites as a long term ecological monitoring network, with potential contributions that go beyond CEMP's initial purpose of providing a standardized approach to track changes in ecosystems. CEMP sites offer opportunities to better frame more precise ecological questions that are relevant for decision-making. Coordinated research involving several CEMP sites within a region, as currently ongoing in collaboration between Uruguay and Argentina in subarea 48.1, might result crucial for CCAMLR to inform current debates on small-scale fisheries management or the potential contribution and effectiveness of MPAs to enhance marine ecosystems resilience under current scenarios of climate change and local anthropogenic impacts.

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