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Multi-method observations suggest recolonization of the Crozet Islands by southern right whales with links to different coastal calving grounds

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Introduction

The recovery of southern right whale (*Eubalaena australis*, SRWs) populations from overexploitation has been monitored over the past few decades in several calving grounds, including Argentina, Aotearoa New Zealand, Australia, Brazil, and South Africa. These long-term studies have provided a wealth of information on behaviour, population abundance and trends, and from the outset in the modern era have shown mostly steady population growth (e.g. Payne 1986, Bannister 2001, Best et al. 2001, Burnell 2001, 2008, Carroll et al. 2011, Cooke et al. 2001, 2015, Brandão et al. 2018, Bannister 2018, Charlton et al. 2019, Smith et al. 2019, Renault-Braga 2020, Stamation et al. 2020, Watson et al. 2014, 2021). However, in the past decade, notable changes have occurred in many of these populations, including elongated calving intervals (Marón et al. 2015, Charlton 2017, Vermeulen et al. 2018, 2019), shift in foraging strategy (Derville et al. 2023, van den Berg et al. 2021) and a reduction in maternal body condition (Vermeulen et al. 2023). Due to the long-term nature of these databases, they provide a unique opportunity to explore potential environmental drivers behind these observed changes. Therefore, IWC-SORP Theme 6 was established in 2018 with the aim to leverage long-term data on SRW demographics to assess the impact of foraging ground variability on population dynamics of the species. This research project, based on four pillars (foraging ecology, population demographics, health and impacts of climate variability) has shifted research focus from coastal calving grounds to the Southern Ocean foraging grounds.

Based on historical whaling records, the Crozet Islands are known as a historical Southern Ocean foraging ground (Maury 1851, Richards 1990, Townsend 1935, Tormosov et al. 1998). However, there is little data on contemporary SRW presence at the Crozet Islands. To further deepen our understanding on the importance of this region for SRWs, this report collates all available information on the occurrence and habitat use of SRWs around the Crozet Islands, and identifies data sources for further exploration.

Study area

The Crozet Islands (46°22'48" S / 51°40'12" E) are a sub-Antarctic archipelago of islands in the southern Indian Ocean, and one of the four administrative districts of the French Southern and Antarctic Lands. From a total of five islands covering a total surface of 352 km², the three largest islands are Pig Island (Ile aux Cochons), Possession Island (Ile de la Possession) and East Island (Ile de l'Est).

Data collation

Opportunistic sightings at the Crozet Islands

Opportunistic SRW sighting data were collated from three platforms: fishing vessels, the supply/research vessel *R/V Marion Dufresne* and the shores of Possession Island. From fishing vessels, which are longliners targeting Patagonian toothfish (*Dissostichus eleginoides*) at the edge of the oceanic shelf (beyond the 500m isobath), sightings were made by fishery observers during or between fishing operations and accessed from the PECHEKER data base (Martin et al. 2021). Data from the *R/V Marion Dufresne* were collected through the at-sea observation programme coordinated by the Centre d'Etudes Biologiques de Chizé (CEBC - programme #109 of the French Polar Institute, coordinator: C. Barbraud) during logistic or oceanographic cruises (on average 4 cruises per year) between La Réunion Island, Crozet Islands and Kerguelen, in both inshore and offshore waters. Data from the shores of Possession Island were collected by field crew from both the programme #109 of the French Polar Institute and from the National Nature Reserve of the French Southern Lands. All cetacean sighting information included the date, time, and location, and for most sightings an estimate of the number of individuals present. Additional information such as predation by killer whales on SRWs was recorded through the long-term photo-identification monitoring programme of killer whales around the Crozet Islands conducted opportunistically and dedicatedly from the same three platforms (programme coordinated by the MARine Biodiversity, Exploitation & Conservation unit (MARBEC) and the CEBC – Tixier et al., 2021).

Opportunistic data of SRWs in the Southwest Indian Ocean

At the last IWC SRW assessment (IWC 2013), it was restated that the SRWs of Mozambique (and Madagascar) should be regarded as a separate population until evidence shows otherwise. Due to the geographical proximity to the Crozet Islands, and possible links between the regions, information was collated from literature and unpublished observations on SRW contemporary presence around Mozambique and Madagascar.

Satellite tagging of SRWs in Australia and South Africa

Satellite tags were deployed on SRWs off southwest Australia (2022, 2023), and in South Africa (2021, 2022 and 2023). In Western Australia, a total of 14 transdermal satellite tag were deployed on an adult SRWs (Wildlife Computers SPOT-372 and SPLASH10-373) to assess migratory patterns and foraging ground locations. Data were collected as part of the Mirnong Maat project (Sprogis et al. 2023a,b; Sprogis et al. 2024 (SC/69b/SH11); <https://tohoravoyages.ac.nz/welcome-to-mirnong-maat/>). In South Africa, a total of 25 transdermal satellite transmitters were deployed on adult SRWs (23 Wildlife Computers SPOT-372 and 2 SPLASH10-373) over 2021, 2022 and 2023 as part of a research program on foraging and migratory behaviour of South African population of SRWs (<https://www.mammalresearchinstitute.science/whale-unit>).

Tags were deployed with a modified pneumatic rifle (Heide-Jørgensen et al. 2001) at distances of approximately 3–5 m from the whales by an experienced tagger standing on a tagging platform installed at the bow of a 6-m inflatable boat. Tags were attached to a delivery carrier (Gales et al. 2009), which detaches from the tag at the moment of implantation and is recovered and reused in future deployments. Biopsy samples were obtained at the same time as tag deployment using a Barnett Panzer V (150 lb draw) crossbow or a Paxarms modified veterinary device (Krutzen et al. 2020). Photographs and video footage were also taken during the tagging approaches for photo-identification and tag placement assessment purposes. After tag deployment and biopsy sampling, the focal animal was followed and observed at a distance >500m for a period of up to 30 min to assess possible reactions to tagging operations and to obtain post deployment photos of the tag site. Instruments and methods for tag deployment and biopsy sampling were consistent with those approved by NOAA's Marine Mammal Laboratory Institutional Animal Care and Use Committee. Tagging work in Australia and South Africa were approved by the Macquarie University and Pretoria University Animal Ethics committees respectively.

Biopsy samples were either stored in 90% ethanol and/or frozen before analysis. DNA was extracted using standard phenol/chloroform protocols, modified for small tissue samples (Sambrook et al. 1989). The sex of the sampled individual was identified by amplification of the male specific SRY gene, multiplexed with an amplification of the ZFY/ZRX region as positive control (Aasen and Medrano 1990, Gilson et al. 1998).

Argos locations from the satellite transmitters were filtered using the “argosfilter” R package (Freitas & Freitas 2022; R Core Team, 2022), and modelled with a Bayesian switching state-space model (SSSM) (Jonsen, 2016; Jonsen et al., 2005). SSSM models infer a location estimate by considering measurement errors in observed Argos data and from the dynamics of the movement process by utilizing the joint estimate approach described by Jonsen (2016). The model was fit to filter Argos data using the “bsam” package in R (Jonsen, 2016; Jonsen et al., 2005; R Core Team, 2022), and Markov Chain Monte Carlo (MCMC) simulations were run using the software JAGS (Jonsen et al. 2013; Plummer, 2012; R Core Team, 2022). A time step of 12 hr was used to calculate predicted locations. A total of 40,000 MCMC simulations were run; the first 10,000 being discarded and every 10th sample of the remaining 20,000 samples were retained to reduce autocorrelation.

Optical satellite imagery

Submeter satellite imagery was used to assess a potential wider presence of SRW in the Crozet Islands, and to fill in spatial and temporal data gaps typical of remote regions. For this, an updated version of an automated SRW detection algorithm presented in Houegnigan et al. (2022) was deployed over approximately 41,540km² of Worldview 2 and Worldview 3 satellite imagery (respectively 46cm and 30cm ground sampling distance at nadir), of which 6,208km² corresponded to the vicinity of Possession Island and 37,924km² to the vicinity of Pig Island. Near the Crozet Islands, adverse yet not extreme meteorological conditions such as heavy cloud cover, heavy winds, and precipitation, as well as high sea states (Frenot et al. 2006) are factors that on the one hand limit the amount of exploitable amount satellite imagery and on the other hand can limit the efficiency of automated detection of SRWs in satellite imagery. The median cloud cover at the Crozet Islands for the processed imagery was 66%. For imagery where SRWs were detected, median cloud cover was 48.9%.

Satellite survey effort is described in Fig. 1, intensity values correspond to the density of survey data points falling within a 1,000m radius circle. For simplicity, data points within each image are approximated to be sampled with a latitudinal and longitudinal step of 0.01 degrees. High intensity values are found where a larger number of image strips are overlapping and therefore where many data points are available, whereas lower intensity values correspond to a lesser amount of imagery.

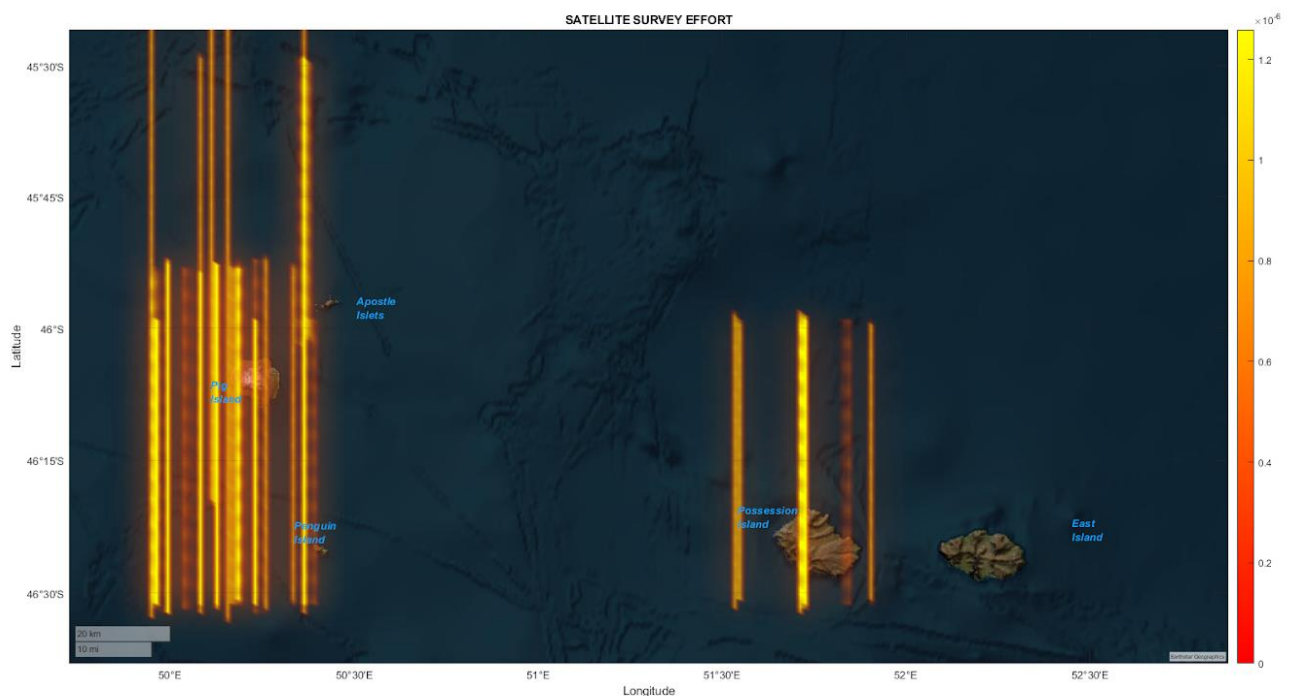


Fig. 1. Satellite imagery survey effort in the Crozet Islands

Results

Opportunistic sightings at the Crozet Islands

From the fishing vessels in the Crozet Islands, in total 37 sightings of SRWs were collected between 2012 to 2023. Most (62%) of the sightings occurred between 2021 and 2023, and the majority (97%) occurred between October and April. One sighting occurred in August, and according to the observer's comment, was the sighting with the largest number of individuals recorded (> 20). Among the 27 other sightings for which estimates of the number of SRWs were available, 60% included only one individual and 85% included 1 or 2 individuals. From data collated so far, 27 of the 37 sightings (73%) occurred to the north of Pig Island. The data from the other two platforms (*R/V Marion Dufresne* and land-based observations from Possession Island) are still in the process of being extracted and collated. However, at least 100 individual SRWs were seen in February 2023 in Crozet (N. Gasco pers. comm.).

Predation on adult SRWs by killer whales (*Orcinus orca*) have been observed in inshore and offshore waters of the Crozet Islands, including at Baie du Marin (Guinet and Jouventin 1990, Guinet 1992, Tixier et al. 2019a, 2021, Table 1, Fig. 2). Stable isotope analyses confirm that SRWs are a prey species for Crozet killer whales (Tixier et al. 2019b).

Table 1. Records of killer whales attacking southern right whales off the Crozet Islands.

Year	Observation	Location	Reference
1920	Predation attempts were depicted in an artwork, where the killer whales were attacking an adult SRW, and the killer whales can be observed biting the lips of the SRW	Crozet waters	Guinet and Jouvetin 1990
1978	Two killer whales are observed in a photograph attacking a SRW	East Possession Island (Baie du Marin)	Guinet and Jouvetin 1990
2012	One predation attempt from killer whales (group CR013/CR111) was on a group of SRWs, on 8 February, as observed by fishery observers as part of a photo-identification monitoring program on killer whales and sperm whales	North-west Pig Island	Supplementary material in Tixier et al. 2021
2018	Predation attempt on a mother-calf pair with a possibly successful kill of the calf observed by fieldworkers from the shore of Possession Island in May.	East Possession Island (Baie du Marin)	This report
2023	Harassment from killer whale groups (CR002 and CR018) of an adult SRW on January 8 th , with a defensive behaviour from the SRW. Killer whales eventually moved into the bay foraging on penguins and elephant seals.	East Possession Island (Baie du Marin)	This report



Fig. 2. Image taken on 8th January 2023 of two killer whales (CR002 and CR018) surfacing next to a southern right whale near Baie du Marin, Possession Island (photo credit: Jeanne Abbou).

Opportunistic SRW sightings in the Southwest Indian Ocean

Within Mozambique, Banks et al. (2011) reports on the first confirmed SRW sightings (5 confirmed and 5 unconfirmed) between 1997 and 2009 since the cessation of whaling.

Vermeulen (unpublished data) received report (with photographs) of a SRW sighting in Ponta do Ouro (Mozambique) on 16 July 2023, as well as two SRW sightings on the coast of KwaZulu-Natal (South Africa) in 2022, >600km north of the well-established South African calving ground. These latter two sightings included one cow with a young calf observed on the 17 July 2022 at Mdumbi (-31.94, 29.22) and a single adult observed on 27 August 2022 at Sheffield Beach (-29.45, 31.01). In both cases, animals were observed travelling north along the coast in the direction of Mozambique. Photo-identification matching of both adults did not result in a match with the extensive South African photo-identification catalogue.

In Madagascar, Rosenbaum et al (2001) reports on two sightings of SRWs on the north- and south-east coast in the late 1990s, including one cow-calf pair and one male which showed genetic linkages to the Atlantic populations. Cerchio et al. (2022) further reports on another seven sightings in the 2010s predominantly cow-calf pairs, and states that the species is infrequent yet regular on both the west and east coast of Madagascar. Due to the presence of young calves, calving in the area and the possibility that this may relate to a remnant (sub-) population that was near-extirpated cannot be excluded (Rosenbaum et al. 2001, Cerchio et al. 2022).

Satellite telemetry of Australian and South African SRWs

Seven SRWs, six from the South African calving ground, and one from Australia, were tracked and displayed Area Restricted Search (ARS), i.e. presumed foraging, in the vicinity of the Crozet Islands (Table 2; Fig. 3).

Table 2. Details of whales tagged off Australia and South Africa, displaying the date (dd/mm/yyyy) and latitude/longitude of the tag deployment location, sex determined from skin biopsy sample (Male) or based on close association with a calf (Female), transmission end date (dd/mm/yyyy) and total days of transmission.

Name	PTT ID	Location	Lat/long	Sex	Deployed date	Transmit end date	Total days transmit
Augusta Whale 1	235410	Augusta, Australia	34°19'26"S 115°11'31"E	F	9/09/2022	24/03/2023	196
Canopus	87636	Hermanus, South Africa	34°24'51"S 19°14'55"E	F	12/10/2023	Still active	-
Chameleon	174063	Hermanus, South Africa	34°24'51"S 19°14'55"E	M	12/10/2023	Still active	-
Chenin	222172	Hermanus, South Africa	34°24'51"S 19°14'55"E	F	12/10/2021	01/07/2022	262
Disa	225992	Hermanus, South Africa	34°24'51"S 19°14'55"E	F	16/10/2022	21/05/2023	217
Indigo	236905	Hermanus, South Africa	34°24'51"S 19°14'55"E	F	16/10/2022	18/12/2022	63
Senecio	236908	Hermanus, South Africa	34°24'51"S 19°14'55"E	F	16/10/2022	23/10/2023	372

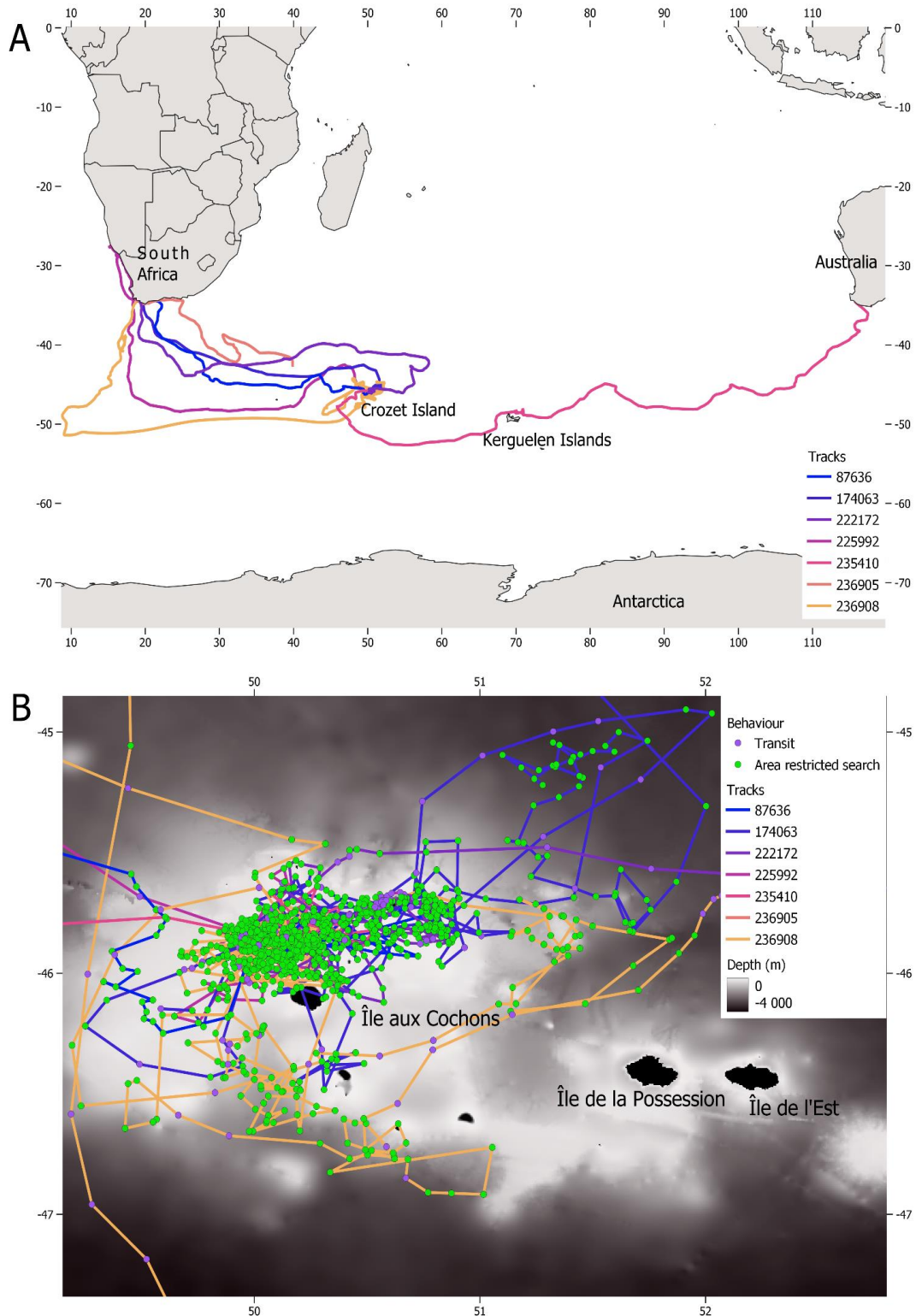


Fig. 3. A map of Crozet Islands (French sub-Antarctic Islands) showing A) Australian and South African southern right whale tracks. And B) Behaviour assignments around the Crozet Islands

Augusta whale 1, an adult female SRW tagged off Western Australia, travelled from Kerguelen Islands to the Crozet Islands around 2 March 2023 (174 days since leaving Western Australia), and showed ARS behaviour, i.e. putative foraging, for several weeks to the north of Pig Island ($-45^{\circ}48'S$, $50^{\circ}04'E$) near the 500 m depth contour (Fig. 3; Table 2). The whale remained in this location until the tag ceased transmission.

Five of the 25 adult SRWs tagged off South Africa migrated to the Crozet Islands and were frequently in an ARS behaviour, presumably feeding (Fig. 3; Table 2). Another individual, Indigo, travelled in the direction of the Crozet Islands but the tag stopped transmitting before reaching it (Fig. 3). All whales tagged were mothers with calves, except for Chameleon which was genetically sexed as male. The five individuals that reached the Crozet Islands spent several months in the region, with high and focussed use of the shallow (30 – 300 m depth) area north of Pig Island. Canopus and Chameleon reached the Crozet Islands on the 6 January 2024 and 11 November respectively and both tags are still active in the area to date (19 March 2024). Chenin arrived at the Crozet Islands on 17 December 2021 and was still in the area on 27 March 2022 when the tag stopped transmitting data. Disa and Senecio arrived at Crozet on 26 February and 14 March 2022 and were still in the region on 21 May and 23 October 2023 respectively when the tag stopped transmitting.

Optical satellite imagery

A summary of SRW the detections per month is presented in Table 3. Most significant survey effort was performed for March 2022 and 2023. In total, 115 detections were confirmed in the vicinity of Pig Island and 3 detections near Possession Island (see Fig. 4). Most of the detections were found north of Pig Island and spanned a range over 120km along the latitudinal axis. The distribution of detections per month is described in figure 4. March 2023 offered the largest number of exploitable imagery and the largest number of detections, a period which coincides in time with the presence of satellite tagged SRWS in the area.

Table 3. Summary of monthly satellite survey effort and southern right whale (SRW) detections.

	Number of SRW detected per period	Effort per period (expressed as km ²)
January 2018	0	1,457
April 2018	0	1,546
May 2018	0	1,522
May 2019	0	1,256
March 2020	3	2,668
March 2022	42	12,051
December 2022	1	1,224
February 2023	17	3,196
March 2023	35	10,987
April 2023	0	1,069
May 2023	18	3,357
July 2023	0	1,207

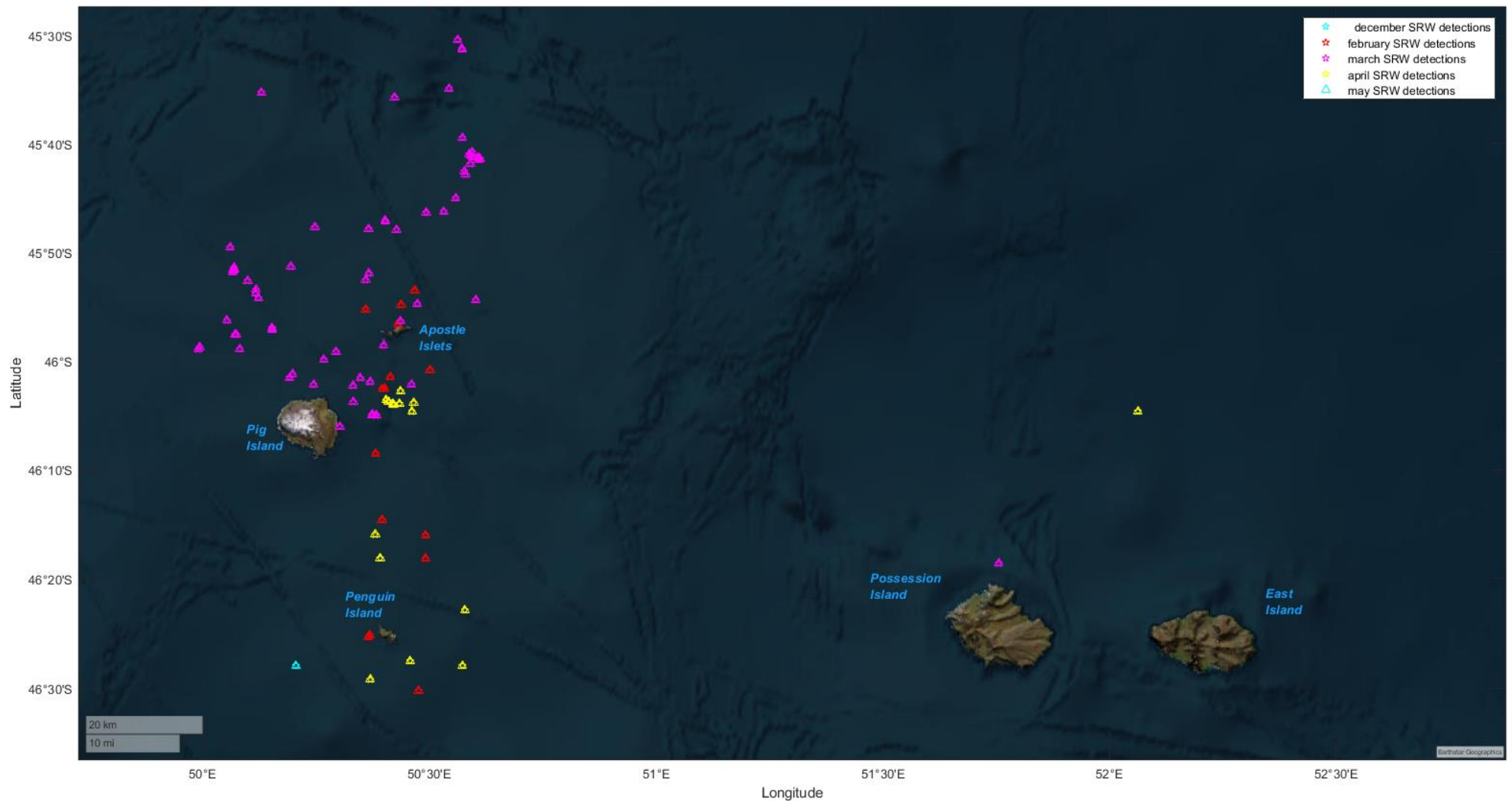


Fig. 4. Monthly detections of southern right whales off the Crozet Islands in optical satellite imagery (2018-2023).

Discussion

During the 1800s, SRWs were severely hunted near the Crozet Islands (Maury 1851, Richards 1990). In fact, it was stated that the exploitation in this region was so severe that the population was considered depleted by 1870s (Wray and Martin 1983). The more recent Soviet exploitation around the Crozet Islands likely further hampered population recovery in the area (Tormosov et al. 1998, Townsend 1935). A first effort to collate data on SRWs in this area indicates an increasing trend in sightings in recent years indicative of a recolonization of the Crozet Islands.

Considering most historical catches as well as recent sightings were made during the austral summer months, and telemetry data indicates putative feeding behaviour through ARS patterns, the Crozet Islands clearly continues to serve as an important summer foraging ground for the species (Best 2007). Telemetry data further showed that especially the area north of Pig Island seems to be used for foraging. Similarly, spatial data available from the Soviet catches indicates most SRW were taken north of Pig Island (Tormosov et al. 1998). In this broader area, the Subantarctic Front flows north between the Del Cano Rise and the Crozet Plateau (where Pig Island lies), from where it flows eastwards (Sanial et al. 2014), which may result in increased productivity. Although preliminary, these data warrant further in-depth investigation into the environmental variables triggering SRW foraging habitat selection in this sub-Antarctic Archipelago.

Although the area was already assumed to be a foraging ground for SRWs of the South African population based on historical whaling data (Best 2007), the use of the Crozet Islands by an adult female SRW of the Australian breeding population was more surprising (see Sprogis et al. 2022). The sharing of foraging grounds between both populations has implications regarding our understanding of population connectivity, and allocation of catch histories to breeding populations. Carroll et al. (2019) showed that, despite strong genetic differentiation between the Atlantic and Pacific populations, gene flow may be occurring. Population recovery and/or adaptive behavioural responses to altered environmental conditions in foraging grounds may furthermore increase such population connectivity (Carroll et al. 2020). The Crozet Islands may play a crucial role in this regard, and warrant attention in future research.

The possible link between the Crozet Islands and SRWs seen off Madagascar should also be considered (Rosenbaum et al. 2001, Cerchio et al. 2022). Whether or not the SRWs seen in this part of the Indian Ocean form part of a slowly recovering (sub-)population which was hunted to near extinction remains to be determined (Rosenbaum et al. 2001). Nonetheless, SRW numbers around Madagascar and Mozambique remain low and there has been no clear evidence of an increase in population number (Cooke and Zerbini 2018). Further collation of SRW sighting data for the broader area of the southwest Indian Ocean is ongoing, and photo-identification and genetic data collection and matching across regions should be prioritised where possible.

Considering the increased number of SRWs sightings off the Crozet Island it is not surprising to have recorded killer whale predation attempts on SRW adults. Killer whale predation on SRWs has also been recorded on multiple occasions off the calving grounds in Península Valdés, Argentina, with 80% of the attacks on adult SRWs (Reeves et al. 2006, Sironi et al. 2008). On the other hand, killer whale predation has been observed opportunistically only on rare occasions in the South African calving ground, with killer whale related predatory scarring in this population is rare (Vermeulen, unpublished data). When attacks do occur on large baleen whales, the tongue and lips are commonly targeted (Totterdell et al. 2022, Pitman et al. 2015). From the records in 1920 off the Crozet Islands, the killer whales were also biting the lip of the SRW. More detailed observations of killer whale attacks on SRWs off the Crozet Islands are required to determine hunting strategy, success rates, frequency, and any spatiotemporal trends.

Conclusion

This first compilation of data clearly shows a recolonization of the Crozet Islands by SRWs, suggesting the area should be considered as an important mid-latitude summer foraging ground for the species, with known connections to the South African and Australian calving grounds. Further work should also consider possible connections to the SRWs observed in the southwest Indian Ocean. Considering the observed changes in SRW foraging ecology and population demographics in response to climate change (e.g., van den Berg et al. 2021, Derville et al. 2023, Brandão et al. 2023), the importance of studying SRWs in their foraging grounds cannot be understated (e.g., Jackson et al. 2020, Kennedy et al. 2023). It is therefore considered that focussed research on SRWs in the Crozet Islands should be pursued, starting with a further in-depth collation and analyses of existing data. This includes, for example, a collation and processing of opportunistic sightings from other platforms and data sources (e.g., research supply vessel and coastal observations from the research base). An autonomous recorder was deployed at 100 m depth during 2018 in the south of Possession Island (46°31.70' S / 51°30.40'E)

related to a project to assess the occurrence of killer and sperm whales in the presence or absence of fishing operations (HADOCC project; <http://dx.doi.org/10.17600/18000973>), and other cetaceans at the Crozet Islands (sampling rate was 32,768 Hz and the duty cycle was 15 minutes every hour). This acoustic database should be interrogated (planned for May- June this year) to assess seasonal presence of SRWs among other cetacean species. Consideration should also be given to the establishment of dedicated research projects in the area on SRWs, including, for example, biopsy sampling, satellite tagging and aerial photogrammetry, to further investigate foraging ecology, fine- and broad-scale movement patterns in the area, health, and population connectivity. Such projects could coincide with existing cetacean research programs such as the long-term monitoring of killer whale and sperm whale populations (coordinated by MARBEC and CEBC, with support from the French Polar Institute, the National Nature Reserve of the French Southern Lands and the National Museum of Natural History of Paris), and be implemented as a French Polar Institute project of its own, or as specific actions of the 2018-2027 management plan of the National Nature Reserve of the French Southern Lands. Continued satellite tagging on the South African and Australian calving ground, as well as a continued exploration of readily available satellite imagery will allow to fill knowledge gaps on SRW distribution and seasonal presence around the Crozet Islands.

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