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Research Priorities as exercised from the Norwegian RV *Kronprins Haakon* during the Multinational Large-Scale Krill Survey in CCAMLR area 48, 2018/2019

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Abstract

The objective for this research was two-fold: (i) to provide updated estimates of the biomass and distribution of krill in the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Statistical Area 48, and (ii) to develop knowledge on the marine environment essential for the implementation of an adaptive management system for Antarctic krill. Survey design followed the transects of the CCAMLR 2000 Krill Synoptic Survey of Area 48 and of national surveys performed in the South Atlantic sector of the Southern Ocean by the People's Republic of China, the Republic of Korea, Norway, the United Kingdom and the United States of America. The survey also focused on high krill-density areas and employed state-of-the art methods and technology. The future management system will need standardised acoustic data from fishing vessels to be collected, processed and reported in near real-time as a measure of the available prey field. This information can be integrated with finer-scale knowledge of krill predator feeding strategies and updated through specific scientific studies at regular (multi-year) intervals. To aid such implementation and to encourage the development of future management tools, the survey took place during the austral summer of 2018/19. The work was coordinated by Norway and involved collaborative international efforts of six survey vessels provided by the Association of Responsible Krill harvesting companies and Aker BioMarine AS, the People's Republic of China, the Republic of Korea, Norway, Ukraine and the United Kingdom. This paper reports on the main research priorities and data collection performed on board the Norwegian research vessel *Kronprins Haakon* in January and February 2019, and the land-based predator work carried out between November 2018 and February 2019.

Résumé

L'objectif de cette étude est double : i) fournir des estimations actualisées de la biomasse et de la répartition géographique du krill dans l'aire statistique 48 de la Commission pour la conservation de la faune et la flore marines de l'Antarctique (CCAMLR), et ii) améliorer les connaissances en matière d'environnement marin essentielles à la mise en œuvre d'un système de gestion adaptative du krill antarctique. La campagne d'évaluation a été conçue en suivant les transects de la campagne d'évaluation synoptique du krill menée par la CCAMLR en 2000 dans la zone 48, ainsi que ceux des campagnes nationales menées dans le secteur Atlantique Sud de l'océan Austral par la République populaire de Chine, la République de Corée, les États-Unis d'Amérique, la Norvège et le Royaume-Uni. Cette campagne, qui a employé des méthodes et des technologies de pointe, s'est concentrée sur les aires de haute densité du krill. Le futur système de gestion nécessite que des données acoustiques standardisées soient collectées, traitées et déclarées en temps quasi réel par des navires de pêche, afin de mesurer le spectre alimentaire disponible. Ces informations peuvent être intégrées aux connaissances à échelle plus précise sur les stratégies alimentaires des prédateurs de krill et mises à jour grâce à des études scientifiques spécifiques réalisées à intervalles réguliers (pluriannuels). La campagne a été menée durant l'été austral 2018/19 afin de faciliter sa mise en œuvre et d'encourager le développement de futurs outils de gestion. Ces travaux ont été coordonnés par la Norvège et réalisés grâce aux efforts de collaboration internationale de six navires fournis par l'association des armements exploitant le krill de manière responsable et Aker BioMarine AS, la République populaire de Chine, la République de Corée, la Norvège, le Royaume-Uni et l'Ukraine. Cet article rend compte des principales priorités de recherches et de la collecte des données à bord du navire de recherche norvégien *Kronprins Haakon* en janvier et février 2019, ainsi que des travaux sur les prédateurs terrestres menés de novembre 2018 à février 2019.

Абстракт

Исследование преследовало две цели: (i) получение обновленных оценок биомассы и распределения криля в Статистическом районе 48 Комиссии по сохранению морских живых ресурсов Антарктики (АНТКОМ) и (ii) формирование знаний о морской среде, необходимых для внедрения системы адаптивного управления запасами антарктического криля. Схема съемок была составлена по разрезам Синоптической съемки криля в Районе 48 в 2000 г. и национальных съемок, проведенных в южно-атлантическом секторе Южного океана Китайской Народной Республикой, Республикой Корея, Норвегией, Великобританией и Соединенными Штатами Америки. Кроме того, съемки были сосредоточены в районах с высокой плотностью криля, и в них использовались самые современные методы и технологии. Будущей системе управления потребуется стандартизированная акустическая информация с промысловых судов, которая будет собираться, обрабатываться и представляться в режиме, близком к реальному времени, в качестве показателя зон наличия добычи. Данная информация может быть увязана с более точными знаниями о стратегиях нагула хищников криля и обновляться в ходе регулярных (многолетних) научных исследований. Для содействия подобной практике и поощрения разработки будущих механизмов управления съемки проводились австральным летом 2018/19 г. Работы координировались Норвегией и съемки проводились совместными усилиями шести международных судов, предоставленных Ассоциацией ответственных крилепромысловых компаний и компанией Aker BioMarine AS, Китайской Народной Республикой, Республикой Корея, Норвегией, Украиной и Соединенным Королевством. В данной работе сообщается об основных приоритетных направлениях исследований и сборе данных, выполненных на борту норвежского научно-исследовательского судна *Kronprins Haakon* в январе и феврале 2019 г., а также об исследованиях обитающих на суше хищников, проведенных в период с ноября 2018 г. по февраль 2019 г.

Resumen

Esta investigación tuvo un doble objetivo: (i) proporcionar estimaciones actualizadas de la biomasa y de la distribución del kril en el Área estadística 48 de la Comisión para la Conservación de los Recursos Vivos Marinos Antárticos (CCRVMA); y (ii) mejorar los conocimientos del medioambiente marino indispensables para la implementación de un sistema de ordenación adaptativa para el kril antártico. El diseño de la prospección utilizó los transectos de la Prospección CCAMLR-2000 del Área 48 y estudios nacionales realizados en el sector del Atlántico Sur del océano Austral por las delegaciones de República Popular China, República de Corea, Noruega, Reino Unido y Estados Unidos de América. La prospección también se centró en áreas de alta densidad de kril y empleó métodos y tecnología de última generación. El futuro sistema de ordenación necesitará que los datos acústicos estandarizados de los barcos de pesca se recaben, procesen y notifiquen en tiempo casi real como una medida del espectro trófico. Esta información puede integrarse con un conocimiento a escala más fina de las estrategias de alimentación de los depredadores del kril y actualizarse a través de estudios científicos específicos a intervalos regulares (multianuales). Para contribuir con dicha implementación y alentar al desarrollo de futuras herramientas de ordenación, la prospección se realizó durante el verano austral de la temporada 2018/19. Noruega coordinó el trabajo e incluyó esfuerzos internacionales colaborativos de seis barcos de prospección proporcionados por la Asociación de Compañías de Explotación Responsable de Kril y Aker BioMarine AS, República Popular China, República de Corea, Noruega, Ucrania y Reino Unido. Este documento informa sobre las principales prioridades de investigación y la recopilación de datos realizada a bordo del barco de investigación científica *Kronprins Haakon* (Noruega) en enero y febrero de 2019, y el trabajo sobre depredadores con colonias terrestres realizado entre noviembre de 2018 y febrero de 2019.

Introduction

Antarctic krill (*Euphausia superba*) is a key species of the Southern Ocean and exists within a narrow band of cold waters not exceeding ~5°C (Marr, 1962; Atkinson et al., 2008; Mackey et al., 2012; Flores et al., 2012). It is a major prey item for a diverse suite of predators, including whales, penguins, seals, and fish, and is an important fishery resource (Everson, 2000; Atkinson et al., 2001; Hill et al., 2012; Nicol et al., 2012; Pikitch et al., 2012; Hill, 2013). The Antarctic krill fishery in Area 48 is managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) through two conservation measures that define the trigger level of catch (used as an interim catch limit) and its interim spatial distribution among management subareas (Conservation Measure (CM) 51-01 and CM 51-07 respectively). CM 51-07 has repeatedly been reimplemented due to CCAMLR's inability to establish an adaptive management approach.

To determine sustainable harvest levels for Antarctic krill and thereby ensure management in accordance with the CAMLR Convention, a systematic, scientifically robust and operationally realistic framework is required. A CCAMLR-coordinated survey in 2000 measured the krill density and distribution acoustically in the fishing areas in Subarea 48.1 and slightly beyond (Hewitt et al., 2004; Watkins et al., 2004), and the biomass of krill was calculated at 60.3 million tonnes (SC-CAMLR, 2010). Due to large gaps in knowledge about the role of krill in the marine ecosystem and potential effects caused by fishery activities, precautionary catch limits for the Scotia Sea were set at 620 000 tonnes by CCAMLR in 1991 to avoid potential conflicts with predators dependent on krill as prey. As the trigger level for the fishery does not index the actual stock status, this approach does not fulfil the CCAMLR ecosystem approach to management. A feedback management approach has been considered as an alternative approach for decades, but still lacks an operational plan within realistic cost and effort levels. It also needs to be considered how such a system could co-exist with the development of a marine protected area (MPA) such as the proposal presented by Argentina and Chile in Domain 1 (Delegations of Argentina and Chile, 2017a, b).

The potential harvest from the Scotia Sea and southern Drake Passage is equivalent to 7% of current global marine fisheries production (Grant et al., 2013). This marine resource is regarded as one of the most under-exploited fisheries in the world (FAO, 2005; Garcia and Rosenberg, 2010), and the interest in commercial activities targeting krill is increasing (SC-CAMLR, 2021). Thus, development towards long-term dynamic fishery management principles such as feedback management requires fundamental knowledge about predator needs, krill biology, population dynamics, spatial distribution and their interspecific and environmental synergies on appropriate temporal and spatial scales.

During the last decade, krill catches have doubled (SC-CAMLR, 2021). At the same time, there is a growing concern that global warming as well as the post-exploitation recovery of predator populations such as seals and whales (*sensu* the 'krill surplus hypothesis') might erode the ecological basis of krill as an exploitable resource with cascading effects through the ecosystem over the long term (Krüger et al., 2020; Watters et al., 2013, 2020). This is a concern also shared by the fishing industry, and it is expected that updates of the CCAMLR 2000 Krill Synoptic Survey of Area 48 coverage will provide feedback on ecosystem trends that will aid the evaluation of impacts on krill from long-term global trends, including the sustainability of its exploitation.

During the 2017 meeting of the CCAMLR Scientific Committee (SC-CAMLR-XXXVI), Norway announced the intention to take the lead in organising a full-scale repeat sampling of Area 48 based on the survey carried out in 2000, using both research vessels and commercial fishing vessels through international cooperation. Central to this effort would be the first Southern Ocean cruise of Norway's new polar research vessel RV *Kronprins Haakon*, in operation since mid-2018.

The CCAMLR-2000 Survey (Hewitt et al., 2004; Watkins et al., 2004), set out to estimate the biomass in Subareas 48.1, 48.2, 48.3 and 48.4, as well as the associated estimate of the combined sampling and measurement error (Demer, 2004). The intention of the 2018/19 Area 48 Survey (Krafft et al., 2021), was to repeat the CCAMLR-2000 Survey by visiting the same areas using similar data collection methods (Hewitt et al., 2004; Watkins et al., 2004) for comparative analysis. The survey involved six vessels: from the Association of Responsible Krill harvesting companies and Aker BioMarine AS, the People's Republic of China, the Republic of Korea, Norway, Ukraine and the United Kingdom (Figure 1). A separate communication and planning group was established on the CCAMLR website, and CCAMLR working group meetings in 2018 provided opportunities for planning, coordination and standardisation of methodologies (Krafft et al., 2018a, 2018b; Knutsen et al., 2018; Macaulay et al., 2018). Combined sampling and measurement error is estimated for the CCAMLR-2000 Survey acoustic estimate of krill abundance in the Scotia Sea.

For the monitoring of land-based krill predators, three key sites were deployed with personnel throughout the Bransfield Strait (CCAMLR Subarea 48.1) on Deception Island, Nelson Island and Kopaitic Island (Figure 2). These sites hold key colonies for krill predator species monitored by CCAMLR Members during their breeding season. Logistic support for the deployment and retrieval of personnel was provided by the Norwegian cruise ship *Hurtigruten* (www.hurtigruten.no), the Instituto Antártico Chileno, the Chilean Navy and RV *Kronprins Haakon*.

Research priorities

Both fishing vessels and research vessels were used for the 2018/19 Area 48 Survey. Facilities for collecting scientific data were limited on board the fishing vessels and setting a minimum requirement was important for standardised equipment such as acoustic equipment, as well as equipment for biological sampling. Scientists on board the vessels were trained in advance and prepared for tasks such as calibrating acoustic sensors, storing data, collecting standard biological material, taxonomic identification of invertebrates, fish and determining krill demographic status (body length measurements, sexual composition and assessing developmental stage) (Knutsen et al., 2018; Krafft et al., 2018b; Macaulay et al., 2018; Delegation of Norway, 2018).

This paper describes the methodologies implemented on the RV *Kronprins Haakon*, and although standardised methods were used among vessels, not all aspects of the research were conducted on all vessels. The survey was conducted between 8 January and 24 February 2019 (departure and return dates Punta Arenas, Chile) while the land-based predator research was carried out between 21 November 2018 and 20 February 2019 (Figures 2 and 3).

Hydro-acoustics

Using the CCAMLR-2000 Survey as a template, and with the commitments of nations and industry partners, it was feasible to sample large scale transects occupied during the CCAMLR-2000 Survey and additional specific sets of transects on a meso-scale (Figures 1 and 3). The acoustic krill survey was carried out as per the configurations, procedures and plan in Delegation of Norway (2019), also described in detail in Krafft et al. (2021).

To obtain data with the purpose of enhancing the ability to locally describe krill flux and overall improve our understanding of environmental change during the austral summer season, nine acoustic/oceanographic moorings were also deployed for the duration of the cruise in the Bransfield Strait. Two of these were deployed adjacent to Nelson Island, while the remainder were deployed southeast of Deception Island. The moorings contained a mixture of instruments: three were echosounder moorings (Simrad WBATs), three were Nortek Signature 100 Acoustic Doppler Current Profiler (ADCP)/echosounders, and the remainder each held two Nortek Signature 250 ADCPs (arranged as an upward- and a downward-looking pair). Selected moorings also included Seabird SBE37 conductivity, temperature and depth (CTD) profilers and one a SeapHOx pH sensor (Figure 4). An autonomous wind-driven platform (ASV Sailbuoy, Offshore Sensing AS) equipped with a Simrad EK80 broadband echosounder, with a 200 kHz transducer mounted in the keel was also deployed in the Bransfield Strait, from 19 January to 16 February to measure krill biomass. An iridium satellite link was used for the control and communication with the sailbuoy. It sailed approximately 1200 n miles during deployment and the depth range of the transducer was 300 m. The sailbuoy track plan was to overlap with the transects of the RV *Kronprins Haakon* to compare acoustic measurement as well as with the acoustic data from moored echosounders. This will be crucial to develop alternative platforms and methods for collecting acoustic data to be used for management purposes.

Sightings of cetaceans

Large cetaceans such as blue whales (*Balaenoptera musculus*), fin whales (*B. physalus*), humpback whales (*Megaptera novaeangliae*) and minke whales (*B. acutorostrata*) (also denoted as rorquals or Balaenopteridae) are major predators of krill in the Southern Ocean. To provide estimates of the potential for krill removal by these predators in the survey area, standard visual observation approaches were used to determine the relative abundance and distribution of key cetacean krill predators along the transects (Baines et al., 2021; Biuw et al., 2022; Viquerat et al., 2022).

Estimation of krill requirements for cetaceans

Baleen whales in the Southern Ocean consume substantial amounts of krill, yet although some species are recovering from human exploitation, there is very little quantitative information on how they interact with the krill prey distribution, or how much of the krill biomass they consume throughout their months-long foraging season in these waters. Similar to land-based predators, information on preferred krill swarm structure, locations and densities as well as how swarms are impacted by cetaceans is important to estimate spatial, temporal and functional overlap with key fishing areas. Traditional ship-based sightings was supplemented for estimation of abundance and distribution with moored acoustic recorders for identification of vocalising species and their abundance as well as arrival and departure times from the examined areas (Åsvestad et al., 2022). Skin/blubber tissue was sampled for genetic analyses using a small boat during the survey when time permitted to determine population memberships. The biopsies will also provide material for stable bulk and compound-specific stable isotope analyses to determine dietary preferences. Satellite tags were deployed on individual whales at key feeding grounds to quantify their consumption rates, describe their impact on krill swarm structure and determine the temporal and spatial overlap potential at relevant spatial scales with fisheries (Goldbogen et al., 2013).

Prey field requirements of krill predators

Land-based teams were deployed to three sites associated with the Bransfield Strait (Bernardo O'Higgins, Bailey Head and Harmony Point) for a focused study on populations of Adélie (*Pygoscelis adeliae*), chinstrap (*P. antarcticus*) and gentoo (*P. papua*) penguins throughout their entire breeding cycle, within the suite of CCAMLR ecosystem monitoring program (CEMP) sites (Figure 2). These concurrent studies provide potentially the most comprehensive within-season predator dataset collected to date in the region and will provide useful estimates of krill predator requirements for developing an understanding of the potential effects of the krill fishery. Importantly, by conducting these surveys simultaneously, the potential impact of broad-scale environmental drivers such El Niño and La Niña can be considered.

Various electronic tags were used on breeding adult penguins at each location to determine where they forage during summer and into early winter. Data from the electronic instruments (including high-definition video cameras) attached to krill predators were used to examine the movement of predators in relation to their preferred prey. Additionally, the video footage from animal-borne cameras will provide insight into the relative distribution of foraging effort throughout foraging trips to sea, and to characterise the ambient prey field within which individuals operate. Biogeochemical analysis (stable isotopes of carbon and nitrogen) of sampled predator tissues (blood plasma, whole blood, feathers etc.), taken on completion of foraging trips, provide information on prey intake at the scale of several days to months and provide data beyond the timescales of the fieldwork.

Assay of mesopelagic organisms

In CCAMLR, much of the research on the effects of the fishery is centered on land-based, air-breathing predators. However, estimates suggest that in terms of predation on krill, fish and squid are major krill predators (e.g. Kock et al., 2012; Trathan and Hill, 2016). Therefore, these represent ecologically important predators that require increased attention. For a variety of reasons, fish and squid consuming krill in the Antarctic have received little research effort, and their biomasses and distributions are still poorly documented. If management of krill resources are to be ecosystem based, improved mapping and understanding of pelagic krill predators is of prime importance. These species also serve as food, either preferred or alternative to many of the krill predators. Mapping of densities and distributions of these are therefore also of direct interest to conservation measures for the air-breathing fauna.

As part of the krill research program, both the epi- and mesopelagic zones were sampled for fish and invertebrate predators of krill to map their biomass and distribution. These samples may also be used to study trophic connections in the area, and in combination with stomach and behavioural data from krill predators such as myctophids (Saunders et al., 2019; Dornan et al., 2022), could allow to parametrise important aspects of the active carbon pump (cf. Cavan et al., 2019).

The krill ambient zooplankton and fish environment

E. superba is considered the keystone ecosystem component in much of the Antarctic south of the Antarctic Convergence. However, its ambient biological environment also consists of a range of other zooplankton important for ecosystem function, and some of them could also act as direct competitors to *E. superba*. To get a broader understanding of the role of other mesozooplankton taxa, as well as their distribution and abundance, they were regularly sampled by a vertically hauled (0–200 m depth) 180 µm meshed double WP2-net (Unesco, 1968) on a joint frame and at selected stations, an identically meshed 1 m2 Multinet Mammoth was deployed and depth-stratified sampling conducted to a maximum depth of 1 000 m (see Krafft et al., 2019). In addition to these samples, the macroplankton trawl hauls used to target *E. superba* (0–200 m depth) also caught a range of other micronekton and macrozooplankton, including organisms such as myctophids (lantern fishes), bathylagids (deep-sea smelts), different species of icefish, and other krill species, particularly bigeye krill (*Thysanoessa macrura)*, pygmy krill (*Euphausia frigida)* and spiny krill (*Euphausia triacantha)*. Salps were also encountered, particularly *Salpa thompsoni*, which can be common in ice free-waters, and to some extent is considered a key competitor to *E. superba*. In addition to the sampling above, a larger pelagic Harstad trawl was used to obtain information on the deeper living nekton and macroplankton (0–1000 m depth) across the examined regions.

Through a novel approach applying two slightly different FlowCam systems, a FlowCam-VS1 ('Micro') and a FlowCam Macro, the applicability of the instruments as well as improving operational procedures for routine plankton monitoring research cruises were examined. A major aim of this work was to quantify and describe the microzooplankton and phytoplankton community in the photic zone. Samples were obtained from water bottles on the CTD, from the various plankton nets, while another set of samples were obtained via the thermosalinograph water inlet at 4 m depth at the vessel's hull.

Physical and chemical indicators of climate change and ocean acidification

Polar oceans are most sensitive to ocean acidification (OA), which is expected to affect calcifying zooplankton such as aragonite forming pteropods (Mekkes et al., 2021 and references herein). Moreover, increased upwelling of circumpolar deep water which is rich in CO_2 (low pH) and freshening due to break-off of marine outflowing glaciers may further enhance OA. The area surrounding the Antarctic Peninsula shows some of the largest ongoing effects of climate change. Studies of *Limacina helicina* in the Scotia Sea have indicated that OA is already affecting the shell condition of these organisms (see Bednaršek et al., 2012; Gardner et al., 2018; Mekkes et al., 2021), but could also have potential effects on krill egg hatch rates (see Kawaguchi et al., 2013). Here, water samples from the CTD-Rosette system were collected for the analysis of total alkalinity and pH, used to derive all other carbonate chemistry parameters such as $CaCO_3$ saturation and CO_2 in the water column and obtained in combination with net tows for sampling of calcifying plankton.

Physical drivers shape the krill habitat through sea-ice cover, water mass distribution and currents, all of which influence food availability, chemical environment and krill behaviour (e.g. swimming capability, on individual and swarm level). These features were studied during the survey using high-frequency underway measurements of salinity, temperature, pCO_2, chlorophyll-*a* and oxygen from instrumentation and sensors connected from the surface (~5 m) seawater intake on the RV *Kronprins Haakon*, the hull-mounted ADCPs and CTD and lowered ADCP casts. Physical mechanisms of cross-shelf exchange and retention are of interest in the region of the Antarctic Peninsula, as they shape transport pathways of krill, phytoplankton, inorganic nutrients and other particulates. Pathways of near-surface currents from the Weddell Sea into the Bransfield Strait and potential retention in a standing eddy in the strait have been described by Thompson et al. (2008), Renner et al. (2012) and Youngs et al. (2015). The region is characterised by highly complex topography influencing currents and local mixing. Water mass exchange and particle transport are thus subject to turbulent mixing induced by internal waves and current shear. Further investigation into associated water mass exchange using data from the acoustic/oceanographic mooring, the ship's sensors, and water samples will describe the physical characteristics of krill hotspots. Understanding the physical mechanisms and drivers is crucial for understanding krill distribution patterns and hence for effective management of krill fisheries.

Environmental DNA profiling

Studies of the distributions of Antarctic marine species are inherently limited by the excessive logistical costs associated with sampling. Although significant efforts are undertaken to assess Antarctic marine resources, the spatiotemporal assessment resolution is coarse, and changes in spatio–temporal distributions may go unnoticed. Thorough surveillance by traditional approaches involves deployment of sampling gear and considerable efforts to process the collected material. Increasing surveillance by methodologies that require less effort on the vessel may allow alternative sampling platforms (e.g., fishing vessels, autonomous underwater vehicles (AUVs) or surface drones) to be utilised and may thus represent an alternative pathway of retrieving population-critical information.

A methodology that could provide for more comprehensive sampling in time and space in this regard is analysing environmental DNA (eDNA). This methodology relies on molecular identification of trace amounts of shed DNA present in the environment to indicate species presence. Water samples from the CTD-Rosette system were filtered on board. From the water sample filtrates, selected genetic regions were amplified from wide taxon groups (algae, crustacea, teleosts, marine mammals, and gelatinous zooplankton) and these amplified regions were sequenced. The resulting sequences will be analysed by comparing them to validated databases comprising species 'barcode' sequences. These databases contain most species and will allow species identification at high resolution. The barcode tag frequency may be indicative of its abundance, although this capacity is debated, and a realistic outcome to be likely is a semiquantitative abundance index. The results will be used to assess the spatial scale of the eDNA signal, compared to species distributions observed using conventional sampling approaches.

Conclusion

In conclusion, for many years, scientific assessments of the Antarctic krill resource in CCAMLR Area 48 made references to the only previous major coordinated survey effort carried out in 2000. Thanks to this international effort, there is now new and comparable information to inform management on the status and dynamics of krill in the Scotia Sea area (Krafft et al., 2021). The krill monitoring that takes place regularly through the meso-scale surveys does not indicate any significant changes in the abundance over the available time series (Hill et al., 2016). However, there is a concern that global warming in the long term might change the ecological dynamics of the krill resources with cascading effects through the ecosystem. The results from the 2018/19 Area 48 survey can contribute to increased understanding, as will regular surveys of defined transects off South Shetland the South Orkney Islands and South Georgia. However, it is necessary to standardise data for comparative analyses, and there is likely great potential to understand periodic fluctuations in population dynamics, the factors on which this depends and the processes interconnecting these regions. Analyses of the large amount of data from the studies that were carried out on board the RV *Kronprins Haakon* will contribute in the coming years to increase our understanding about the way physical parameters and biological organisms of different trophic levels interact. Such data will be essential for developing methods for a feedback management system that maintains a holistic and dynamic understanding of the ecosystem, and in which the fishing fleet must contribute to collect necessary data. An overarching goal of the sampling efforts outlined above has been to broaden the research approach – bringing an extended sampling scheme into an ecosystem approach to monitoring and management, a methodical approach actively undertaken by Norway in the Arctic and the Barents Sea for nearly 20 years (Michalsen et al., 2013).

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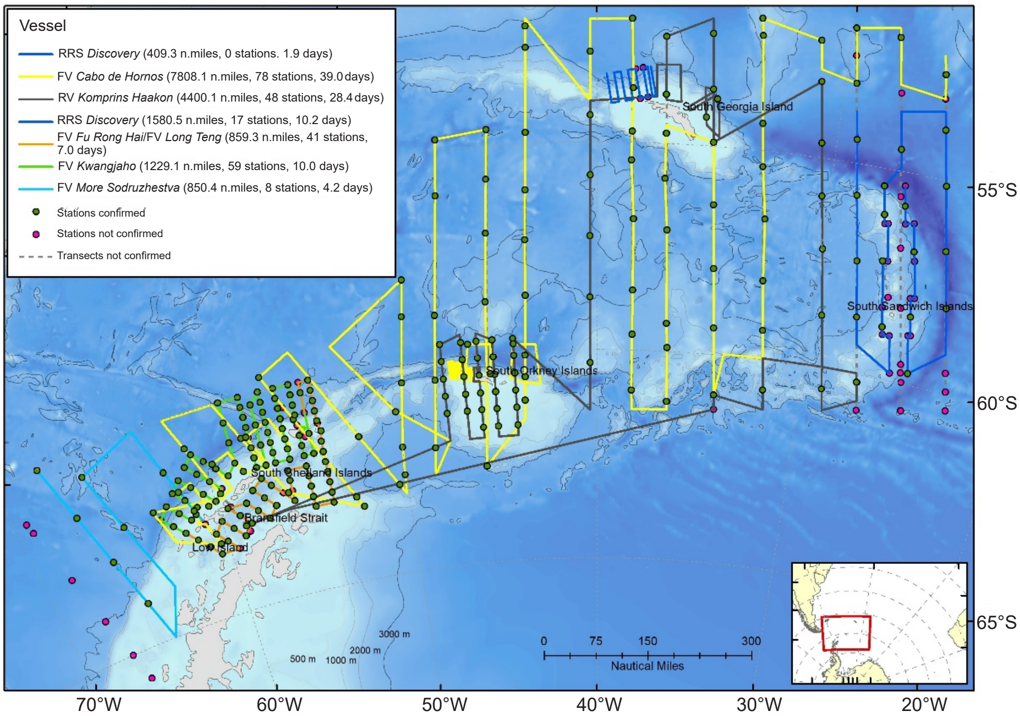


Figure 1: Transect plan by vessels taking part in the 2018/19 Area 48 Survey.

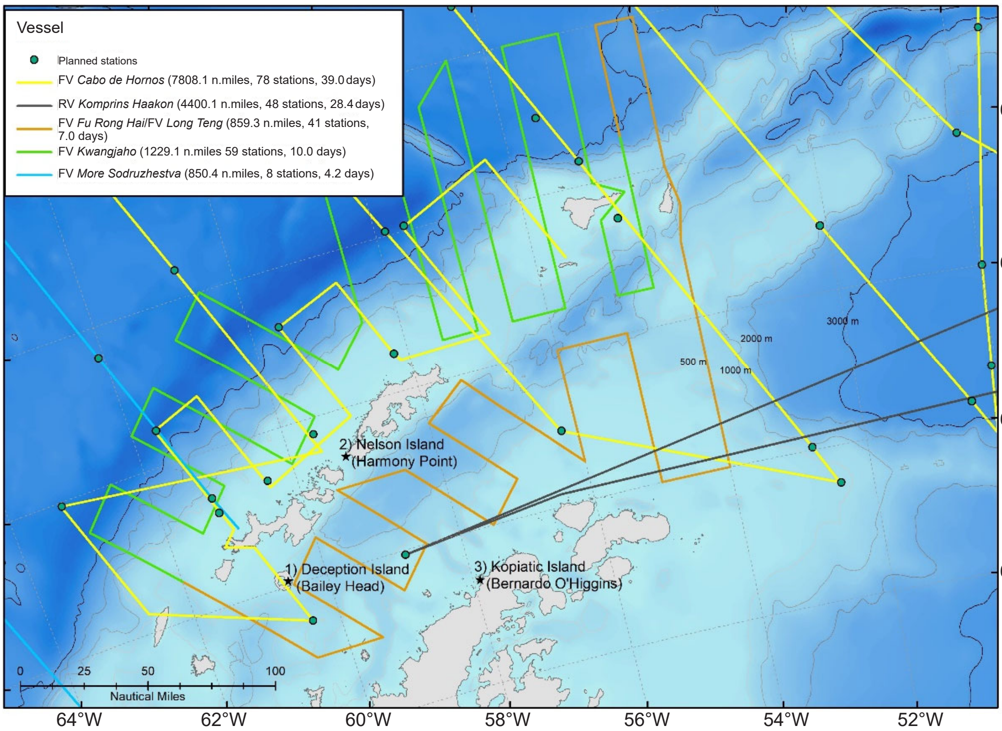
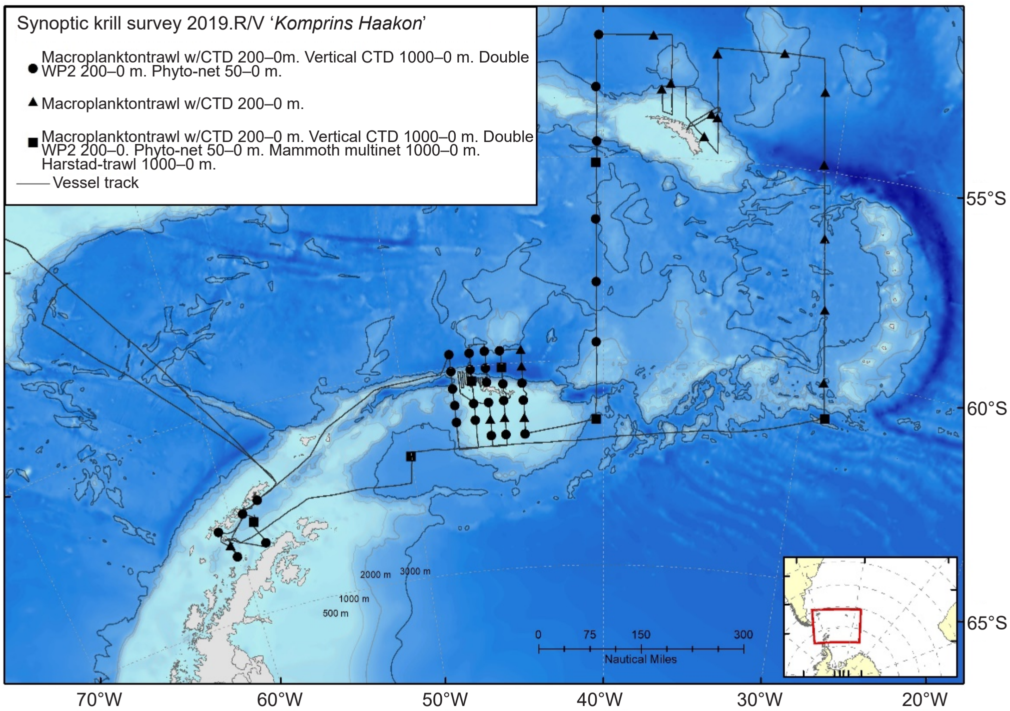


Figure 2: The location of the land-based predator field sites. 1] Deception Island (Bailey Head) (62°57'52.90" S, 60°29'50.4" W), 2] Nelson Island (Harmony Point) (62°17' 56.19" S, 59°12'56.76" W) and 3] Kopaitic Island off Bernardo O'Higgins (63°18'53.99" S, 57° 54'39.44" W).



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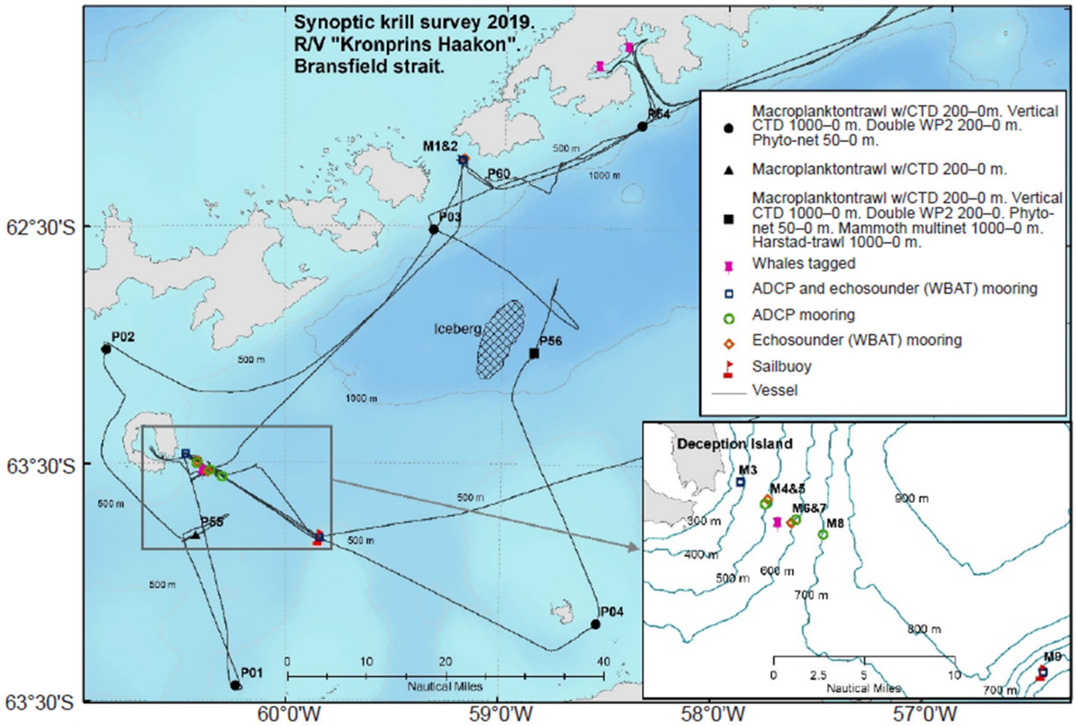

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