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The Australian Antarctic Science 10-year Krill and Krill Ecosystem Project (KaKE): A Long-Term Marine Ecosystem Monitoring Project Commencing in East Antarctica

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The Australian Antarctic Science 10-year Krill and Krill Ecosystem Project (KaKE): A Long-Term Marine Ecosystem Monitoring Project Commencing in East Antarctica

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Abstract

Antarctic krill are a fundamental component of Southern Ocean ecosystems and perturbations to krill populations have ramifications for the entire ecosystem. Krill are fished across the Southern Ocean and sustainable management of this fishery is a high priority for the Australian Government. A new Australian Antarctic Science project - *Managing Antarctic Krill and Conserving the Krill-based Ecosystems (KaKE)* – has been developed to design, develop and implement an integrated and comprehensive interdisciplinary program of scientific research and monitoring in East Antarctica that will provide new and important insights into krill biology and the Southern Ocean's krill-based ecosystem. This decade-long project will include annual interdisciplinary field surveys on *RSV Nuyina*, Australia's new icebreaker, as well as annual deployments of moored platforms to support autonomous echosounders and passive acoustics. The project will develop new capabilities for krill predator research including: new molecular methods to detect predators and determine their diet; the use of long and short-range uncrewed aerial vehicles for predator surveys, collection of whale biopsies and whale tagging; and the deployment of newly developed systems for the autonomous visual and infrared detection of whales. These activities will culminate in outputs to inform the ecosystem-based sustainable management of the East Antarctic krill fishery and quantify the current and projected impacts of climate change. The project welcomes expressions of interest from potential collaborators.

Background

The Antarctic krill fishery is the largest fishery in the Southern Ocean (Nicol *et al.* 2012). Krill catches have increased in recent years due to the development of more efficient harvesting and processing methods and interest in new products (Nicol and Foster 2016). While most krill fishing effort is currently centred around the Antarctic Peninsula region, krill fishing recommenced off East Antarctica in 2016 (Kawaguchi and Nicol 2020). The Australian Antarctic Strategy and 20-year Action Plan commits to setting in place a comprehensive policy and scientific approach to ensure the sustainable management of the krill fishery in waters off the Australian Antarctic Territory (AAT) (Australian Government 2016; Australian Government 2022).

Ecosystem-based management requires an understanding of both krill and krill predators. Krill cannot be sustainably managed without considering the needs of krill predators through knowledge of their abundance, distribution, phenology, prey requirements and foraging behaviour. Many krill predators are recovering from past exploitation and as such are actively managed by various international fora. Whilst the outputs associated with the krill fishery will be delivered into

Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), this project will also deliver evidence-based advice to the Australian Government, the International Whaling Commission (IWC), Agreement on the Conservation of Albatrosses and Petrels (ACAP), the Antarctic Treaty Consultative Meeting (ATCM) and other fora regarding the conservation and protection of krill predator populations in the Southern Ocean and East Antarctica.

The 2022 update to the Australian Antarctic Strategy and 20-year Action Plan states the Australian Government priorities in Antarctica and the Southern Ocean and the project described here has been specifically developed to deliver to these key priorities, which include:

- Scientific leadership in the CCAMLR, IWC, ACAP and the ATCM.
- Sustainable management of the krill-based marine ecosystem through integrated multi-year research into krill and krill predators; and more targeted and robust Southern Ocean ecosystem surveys.
- The design and build of a new krill aquarium to study ecological resilience of krill (a keystone species) and related species in the Southern Ocean to clarify climate change responses.
- Deliver science to support Australia's Southern Ocean fisheries including conducting research in the Southern Ocean to support ecosystem conservation and sustainable management of fisheries, and to secure a healthy ocean system (Australian Government 2022).

Project goals and objectives

The Australian Antarctic Science project – *Managing Antarctic Krill and Conserving the Krill-based Ecosystems (KaKE)* – will develop and implement an integrated and comprehensive interdisciplinary program of scientific research and monitoring in East Antarctica in order to provide new and important insights into krill biology and the Southern Ocean's krill-based ecosystem.

The KaKE project has identified 2 main goals or themes each with its own specific scientific objectives:

Goal 1: Inform the sustainable and ecosystem-based management of the East Antarctic krill fishery

- Objective 1: Develop robust designs for ship-based surveys of East Antarctica's krill ecosystem
- Objective 2: Assess the spatial and temporal distribution and variability of krill biomass
- Objective 3: Assess the spatial and temporal composition and distribution of plankton consumed by krill
- Objective 4: Describe krill life history characteristics and spatial and temporal recruitment dynamics
- Objective 5: Identify biologically-meaningful management areas and area-specific catch limits for krill in East Antarctica
- Objective 6: Assess the spatial and temporal distribution and variability of krill consumption by penguins and flying seabirds
- Objective 7: Assess the spatial and temporal distribution and variability of krill consumption by whales
- Objective 8: Assess the spatial and temporal distribution and variability of krill consumption by seals
- Objective 9: Assess the spatial and temporal distribution and variability of krill consumption by other krill predators

Goal 2: Quantify the current and projected impacts of climate change on East Antarctica's krill-based ecosystem

- Objective 1: Use broad-scale, long-term monitoring data to develop species distribution models for krill and focal krill predators
- Objective 2: Apply climate model projections to produce future predictions of spatial distribution and habitat usage for krill and focal krill predators

Each objective will be addressed through the delivery of 26 key data streams (see Appendix 1).

Informing krill management

Krill abundance varies regionally and exhibits great inter-annual variability (Reiss *et al.* 2017). This variability combined with effects of climate change could have consequent impacts on krill predators and the magnitude of ecologically sustainable catch limits for the krill fishery (Klein *et al.* 2018; Veytia *et al.* 2020; McBride *et al.* 2021). Krill catches have increased in the recent years due to developments in both harvesting and processing methods, and interest in new products, and this fishery has recently recommenced off East Antarctica with a sign of further expansion in this region (Kawaguchi and Nicol 2020).

The krill fishery in Antarctica is managed by CCAMLR (Kelly *et al.* 2023). This international body implements a precautionary, ecosystem-based fisheries management approach, which aims to prevent adverse, irreversible long-term impacts from fishing activities on target species and the ecosystem (CCAMLR 2022). Catch limits are set with the aim of maintaining sustainability and the productivity of the krill stock with specific consideration of krill-dependent predators (Miller and Agnew 2000). The implementation of CCAMLR's ecosystem-based management and the associated risk assessment processes require three key information streams (Kelly *et al.* 2018; Kelly *et al.* 2023); these are:

i. Ship-based studies of krill abundance, demographics, distribution and biology;
ii. Distribution and abundance of krill predators and their rate of krill consumption, including the continued implementation of long-term land-based ecosystem monitoring program (CEMP) on krill-dependent and central place foraging seabirds; and
iii. The direct and/or remote acquisition and derivation of environmental data and parameters.

CCAMLR recently endorsed the use of a risk assessment (spatial overlap analysis) approach for distributing krill catch in smaller spatial management units. This approach for setting krill catch limits considers the needs of krill predators via the mortality component of the stock projection model and a high krill escapement target in the harvest control rules when determining the proportion of the krill population that can be taken each year with minimal risk to the predator populations. This risk assessment can also identify the catch distribution scenario with the lowest risk to krill and krill predator populations within the management unit.

The KaKE project will provide CCAMLR's risk assessment process with spatial estimates of prey requirements by the main consumers of krill in East Antarctica – whales, seabirds, seals, fish, squid and cnidaria (Objectives 5 to 8, see Kelly *et al.* 2018). These estimates will be informed by surveys of abundance together with studies of foraging distribution, behaviour, diet, morphometrics and physiology. These data will populate energetic models to derive consumption rates per capita within potential small-scale fishery management units.

The CCAMLR krill fishing risk assessment framework currently takes estimates of krill consumption by predators on a biomass-per-area basis, but it is likely that different taxa are targeting different life-stages and densities of krill. Future iterations of risk assessments could use these preferences, in

combination with information regarding spatial and temporal distribution of the krill population in East Antarctica to better spatially divide catch limits (Objective 4).

Spatial scale and ship-based surveys

The longitudinal extent of the AAT and the combined areas of CCAMLR Divisions 58.4.2 and 58.4.1 approximately coincide (Figure 1, Australian Government 2022; CCAMLR 2022). Adequate sampling coverage across this vast area is simply not possible for a single national program operating one or even two research vessels.

In this context, and to maximise benefits and efficiencies from current and future staff and operational resources, project survey efforts will be focussed; involving repeated broad-scale surveys in Division 58.4.2 where the nascent krill fishing effort is most likely to expand (Kawaguchi and Nicol 2020) while annual, targeted, smaller-scale surveys will also be conducted within Division 58.4.1.

Whale research and monitoring

Whale-focused research under this project will primarily aim to address:

Objective 7: Assess the spatial and temporal distribution and variability of krill consumption by whales

Key activities, actions and analyses under this objective will include:

- Design and conduct and coordinate Australian and multinational large-scale, ship-based campaigns possibly every 3 to 4 years, and annual, smaller-scale krill surveys
- Deployment of moored acoustic recorders from AAD, AWI, ENSTA, SANAP, NOAA/OSU, KOPRI at locations throughout the Southern Ocean. Coordinated and conducted in collaboration with IWC-SORP/SOOS Acoustic Trends Project & Southern Ocean Hydrophone Network
- Design & implementation of next-generation moored acoustic recorders (increased data collection capabilities, decreased requirements for engineering support & maintenance)
- Development of artificial intelligence (AI) for rapid processing of large acoustic datasets (including labelling of training & testing datasets, as well as application of deep learning methods to create novel detectors)
- Development of long-range UAV capability for the wildlife surveys in Antarctica
- Development of neural networks to detect cetaceans from long-range UAV imagery using existing labelled aerial image catalogues
- Development and implementation of the capability to deploy short-range UAVs from RSV Nuyina to biopsy and satellite tag cetaceans
- Development of small, low-impact satellite tags for cetaceans
- Development of double-platform wildlife survey methods from frequently used research vessels.
- Deployment and assessment of infra-red (IR) thermal imaging cameras for automated detection of cetaceans

Of the 26 data streams identified under this project (Appendix 1), the following will contribute to addressing Objective 7.

- A1 Satellite, remotely-sensed, and similar external synoptic environmental data and model outputs

- D10 Passive acoustics – calibrated hydrophones to describe distribution and trend of marine mammals
- D11 Cetacean telemetry data to determine movement, habitat use and foraging performance
- D12 Whale distribution, abundance, and behaviour from automated detections using infra-red (IR) thermal imaging cameras
- D13 Wildlife abundance and distribution from ship-based line transect sampling
- D14 UAV-derived cetacean data to assess condition, fecundity and foraging strategies
- D15 Long-range drones to determine abundance and distribution of Antarctic wildlife
- D16 Environmental DNA (eDNA) analysis to determine distributions and behaviours of krill, krill predators, and plankton
- D17 DNA analysis of krill and predator scats to determine diet

Logistics and key project activities

Almost all activities under this project rely heavily on financial and logistical support provided by Australian Government's Antarctic Program. The KaKE project is particularly dependent on the allocation of dedicated research days on the *RSV Nuyina*. *RSV Nuyina* is Australia's new Antarctic research and resupply vessel that is currently undergoing commissioning trials. While research time on this vessel is in high demand it is likely annual surveys related to the KaKE project will be facilitated each year, potentially as a component of resupply voyages to Davis and Mawson.

Major activities under over the 10 years of the KaKE project are provided below:

- Year 1 (2022/23): Head Office based – Planning, data stream prioritisation, survey and monitoring program design
- Year 2 (2023/24): Targeted krill and krill ecosystem surveys (Davis, Mawson)
- Year 3 (2024/25): Targeted krill and krill ecosystem surveys (Davis), Denman Marine
- Year 4 (2025/26): Targeted krill and krill ecosystem surveys (Davis), major KaKE synoptic voyage TEMPO2, Heard Island voyage
- Year 5 (2026/27): Targeted krill and krill ecosystem surveys (Davis, Mawson)
- Year 6-10 (2027/28-2031/32): Targeted krill and krill ecosystem surveys (Davis), analysis and syntheses

Capacity and collaboration

The Australian Antarctic Science 10-year Krill and Krill Ecosystem Project (KaKE) is a highly ambitious, long-term multidisciplinary project. To date it has been developed by a relatively small number of scientists based at the Australian Antarctic Division (AAD) and the University of Tasmania. However, it is likely this team will grow considerably with the allocation of new project-related positions at the AAD including a project manager, aquarium and sea-going technicians and scientists together with data analysts and modellers. While this additional capacity is much-needed, further collaboration remains essential. As the project and project team develops we hope to develop a network of international collaborators that can contribute to this project. Should any IWC's scientific committee members wish to contribute to the project or can identify synergies with their own research then we would warmly welcome further discussions about future collaborative research opportunities.

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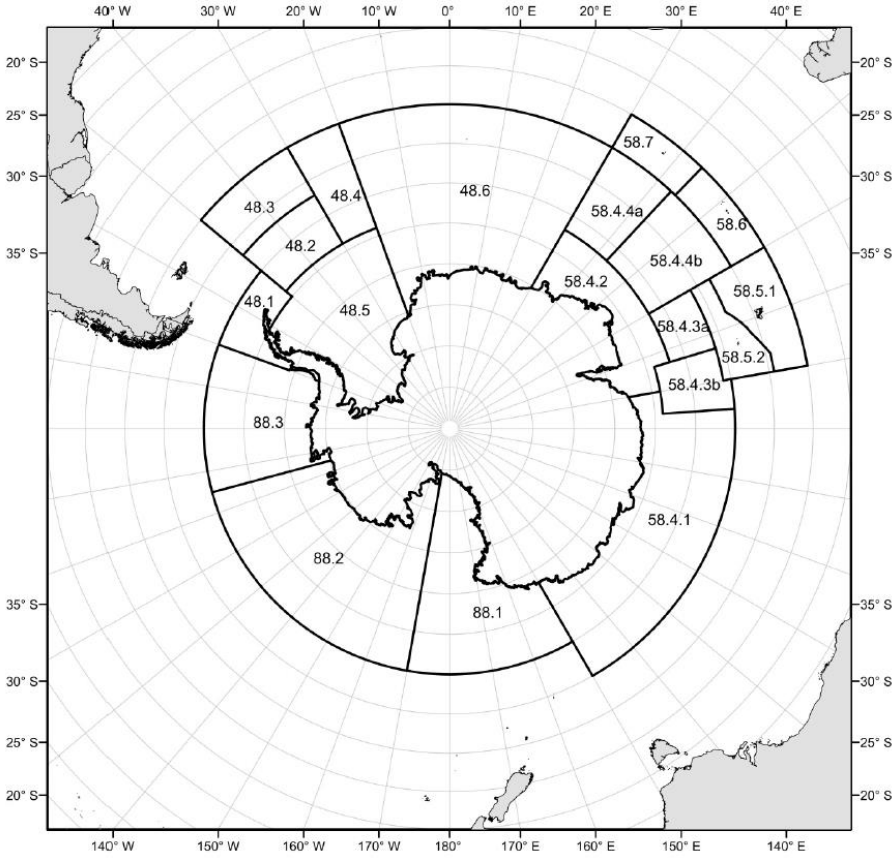

Figure 1 CCAMLR Area with Statistical Subareas and Divisions.

Appendix 1: Key data streams of the AAS Krill and Krill Ecosystem project

Data stream code	KaKE principal data stream
A1	Satellite, remotely-sensed, and similar external synoptic environmental data and model outputs
B1	Ship-based sampling to infer the spatio-temporal distribution of phytoplankton and primary production
B2	Continuous Plankton Recorder sampling to monitor abundance, species composition and distribution of the plankton communities
C1	Active acoustics and supporting samples to determine krill biomass and swarm characteristics
C2	Temporal observations of Antarctic krill from moorings and gliders
C3	Ship-based sampling and experiments to assess krill demography and population dynamics
C4	Aquarium experiments to assess the impacts of environmental change on Antarctic krill
C5	Aquarium-derived data to determine life history characteristics of Antarctic krill
C6	Genomics of Antarctic krill: signatures of different life stages and response to elevated CO2
D1	Ship-based sampling to infer the spatial distribution, variability and diet of mesopelagic fish, cephalopods and cnidarians
D2	Population surveys to determine abundance and trend of emperor penguins (AAS 4564)
D3	Satellite imagery and aerial surveys to determine distribution of emperor penguins (AAS 4564)
D4	Ice-breeding seal population surveys to estimate abundance and prey consumption
D5	Seabird population surveys for assessing distribution, abundance and population change (AAS 4518)
D6	Seabird survival, diet and mass change for assessing foraging success and demographic changes (AAS 4518)
D7	Seabird foraging distribution, abundance and behaviour (AAS 4518)
D8	Seabird camera network for assessing spatio-temporal variation in breeding success, phenology and nest attendance (AAS 4518)
D9	Seabird surveys and research campaigns at remote breeding sites (AAS 4518)
D10	Passive acoustics – calibrated hydrophones to describe distribution and trend of marine mammals
D11	Cetacean telemetry data to determine movement, habitat use and foraging performance
D12	Whale distribution, abundance, and behaviour from automated detections using infra-red (IR) thermal imaging cameras
D13	Wildlife abundance and distribution from ship-based line transect sampling
D14	UAV-derived cetacean data to assess condition, fecundity and foraging strategies
D15	Long-range drones to determine abundance and distribution of Antarctic wildlife
D16	Environmental DNA (eDNA) analysis to determine distributions and behaviours of krill, krill predators, and plankton
D17	DNA analysis of krill and predator scats to determine diet