CCAMLR

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Commission pour la conservation de la faune et la flore marines de l'Antarctique
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Development of methods relevant to feedback management (FBM) for the krill fishery

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Abstract

The primary objective for this project is to develop knowledge on the marine environment essential for the implementation of a Feed-Back Management (FBM) system. In terms of FBM, Marine Protected Area (MPA) development in CCAMLR Planning Domain 1 encompasses the major krill fishing grounds. Thus, data supporting FBM as an integral part of the broader management strategies of the krill fisheries within Domain 1 are critical if the fishery is to be managed by an empirical understanding of krill density, distribution, availability and predator needs. A future developed FBM system, as presented in SC-CAMLR XXXVI/BG20 requires acoustic data to be collected, processed and reported continuously during the fishing season 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 (multiyear) intervals. The FBM process studies will take place during the Austral summer 2018-2019.

Background

The Antarctic krill fishery in Area 48 is managed by CCAMLR through two conservation measures regarding the determination of the trigger level and its interim distribution between subareas (CM51- 01 and CM 51-07, respectively). CM51-07 has repeatedly been reconsidered due to CCAMLR's inability to establish an agreed, operational feedback management (FBM) approach.

Due to large gaps in knowledge about this marine ecosystem and potential negative effects caused by fishery activities, precautionary catch limits for the Scotia Sea were set at 620 000 tons by CCAMLR in 1991 to avoid potential conflicts with predators dependent on krill as prey. As the trigger level of the fishery lacks any form of relationship with the actual stock condition, this approach is strictly not in line with the CCAMLR ecosystem approach to management. FBM has been considered an alternative approach for decades, but still lacks a plan that can be made operational within realistic cost and effort levels. Recently, an alternative management approach has been developed through the Marine Protected Area (MPA) proposal presented by Argentina and Chile in Domain 1 (WG-EMM-17/23, SC-CAMLR-XXXVI/18), which is currently under development and discussion by CCAMLR members. Krill is a key species in the Antarctic ecosystem and a systematic, scientifically appropriate and operationally realistic framework is required to set sustainable harvest levels and thereby ensure management in accordance with the CCAMLR convention. Thus, any Conservation Measure (CM) which proposes to manage the interaction between krill and its predators must be openly discussed and evaluated to ensure that CCAMLR chooses the most appropriate path. Considering discussions about FBM, krill risk assessment and MPAs, the present approach will provide with valuable information that will help these processes to reach a harmonized management of the krill fisheries in the area.

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 rapidly. Thus, development towards more optimal long-term dynamic fishery management principles such as FBM require fundamental knowledge about krill biology, population dynamics, spatial distribution and their interspecific and environmental synergies on appropriate temporal scales.

Research activities based at three land based sites in Bransfield Strait and from the RV Kronprins Haakon (KPH) will engage in a coordinated survey effort of krill hotspots with the aim of supporting development of the CCAMLR FBM approaches. This will strengthen the scientific basis for FBM and support development of autonomous data collection regimes in support of Subgroup on Acoustics, Survey and Analysis Methods **(**SG-ASAM) ambitions to establish a data collection regime facilitating near real-time monitoring, as required by FBM. This work is Co-led by the Institute of Marine Research and the Norwegian Polar Institute and involves the cooperation between Norway, Chile, US, and South Africa.

Methods

Land based monitoring of CCAMLR monitored krill predators and spatially-relevant prey field characteristics

The energetic costs and foraging needs of krill dependent predators in relation to prey availability (three-dimensional distribution and density) is poorly understood. The ultimate goal is to characterize the functional response of krill predators to changes in the prey field, at multiple location spanning the key krill fishing grounds. Specifically - what do predators require (prey sizes, swarm densities, when do they require it, where do they acquire it from in relation to potential overlap by traditional fishery grounds and what is the level of variability of these requirements between different predator colonies?

Land based teams will deploy to three sites throughout Bransfield Strait (CCAMLR subarea 48.1); 1) Deception Island (Bailey Head) (62º 57' 52.90" S, 60º 29' 50.43" W), 2) Nelson Island (Harmony Point) (62º 17' 56.19" S, 59º 12' 56.76" W) and 3) Kopaitic Island off O'Higgins Station (63º 18' 53.99"S, 57º 54' 39.44" W). These sites are key colonies for CCAMLR monitored krill predator species during their breeding season (Kokubun *et al.*, n.d.; Naveen *et al.*, 2012). Each site is manned from late November 2018 with 2-3 people on each station. Logistic support for the deployment of personnel is provided by the Norwegian cruise ship Hurtigruten (www.hurtigruten.no) for Deception and the Instituto Antártico Chileno (INACh) and the Chilean Navy for Nelson and Kopaitic Islands. The INACH/Chilean Navy and the Norwegian RV Kronprins Haakon will provide the return of personnel from the field sites during late February 2019. Through collaborative agreements with the US-AMLR program and the British Antarctic Survey, an additional 2-3 field camps will be run concurrently, focusing on broadly the same species and data collection protocols, providing a hitherto unparalleled predator tracking dataset spanning the vast majority of the krill fishery.

A combination of electronic tag deployments and biological sampling will be conducted on breeding and non-breeding adult and fledgling Gentoo and chinstrap penguins, male and female Antarctic fur seals and crabeater seals (considered to be one of the largest consumers of krill in Antarctica, yet relatively unstudied in this context), at each location to determine where and on what they forage during the summer and into early winter. Utilizing these electronic instruments (including HD video cameras), data collected will look at the movement of predators in relation to their prey and what their preferred prey actually is.

Specifically, telemetry data will be used to reconstruct the underwater movement of predators, identify what prey are captured and where, and measure the age size class distribution of krill taken to determine overlap with the fishery at spatial scales that are relevant. Additionally, video footage from animal-borne cameras will provide insight into the relative distribution of foraging effort throughout foraging trips to sea, and to characterize the prey field individuals utilized and avoided. 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 proposed cruise. Krill are known to vary in their isotope signal along the west Antarctic Peninsula based on their age size distribution (Polito et al. 2013). The signals from predators will be compared to those from different age classes of krill and other prey identified from animal-borne cameras which will be taken during local ship-based sampling. These data will aid to further quantify the overlap between predator demand and the fishery across the three sites covering the majority of the krill fishery.

We will also be developing a basic bioenergetic model for each field site, in order to estimate the krill requirements of the breeding component of each penguin species population. To achieve this, estimates of basal and field metabolic rates (BMR and FMR) are required, as well as the size of the breeding population. Recent studies have demonstrated that accelerometry data, in conjunction with spatially explicit estimates of behavior (e.g. area restricted searching, transiting), can be used to accurately resolve the field metabolic rate (FMR) of individuals (Elliott *et al.*, 2012; Jeanniard-du-Dot *et al.*, 2017). Breeding adult penguins from each species at each site will be instrumented with high resolution GPS, TDR and magnetometer accelerometers from which FMR will be derived. It is our intention to estimate the basal metabolic rate (BMR) of a subset of individuals under controlled conditions (e.g. in the Bernardo O'Higgins research station, or at a later date). In parallel, remotely piloted aircraft systems (RPAS) will be flown over *a priori* designed transects, recording photographic images at set intervals. These images will be stitched together to produce a single contigious image from which nest counts will be conducted, and subsequently an estimate of the breeding population size will be derived.

The tracking studies will be conducted between late November and late February, and the resultant predator distribution data will be used to guide research vessels during the fine-scale "krill hot spot" surveys to at-sea areas important for predator foraging. These data will provide essential information on prey field exploitation by individuals from different krill predator species and underpin efforts to understand functional responses of predators to changes in their prey field. An opportunity also exists for a Chilean coastal research vessel to be dedicated to conducting acoustic surveys in the immediate vicinity of one land based field site for the duration of the season.

These studies will provide potentially the most comprehensive within-season predator dataset collected to date in the region, and the most appropriate measure of krill predator requirements for developing FBM of the krill fishery. Importantly, by conducting these surveys simultaneously, the confounding impact of broad scale environmental variability arising from El Nino Southern Oscillations (ENSO, sensu 2016 and 2018) on our understanding of predator movements can be accounted for.

Recent efforts have been made to extrapolate predator habitat utilization from areas of data availability to regions where data is either poor or absent (e.g Trathan et al. in review). Such modelling exercises are important, as there will likely never be sufficient logistic and financial capacity to empirically monitor every region. However, how krill predators exploit their habitat is a function of its physical and environmental characteristics, which almost certainly varies spatially, as well as between seasons. Consequently, the modelling framework of Trathan et al. provides an appropriate and testable hypothesis of predator foraging behavior across the fishery and the empirical data collected from the landbased field camps as part of this work will be used to test and refine these models for future usage.

These simultaneous ship and land-based studies will provide the necessary data to feed into and advance the Feedback Management model presented in SC-CAMLR XXXVI/BG20.

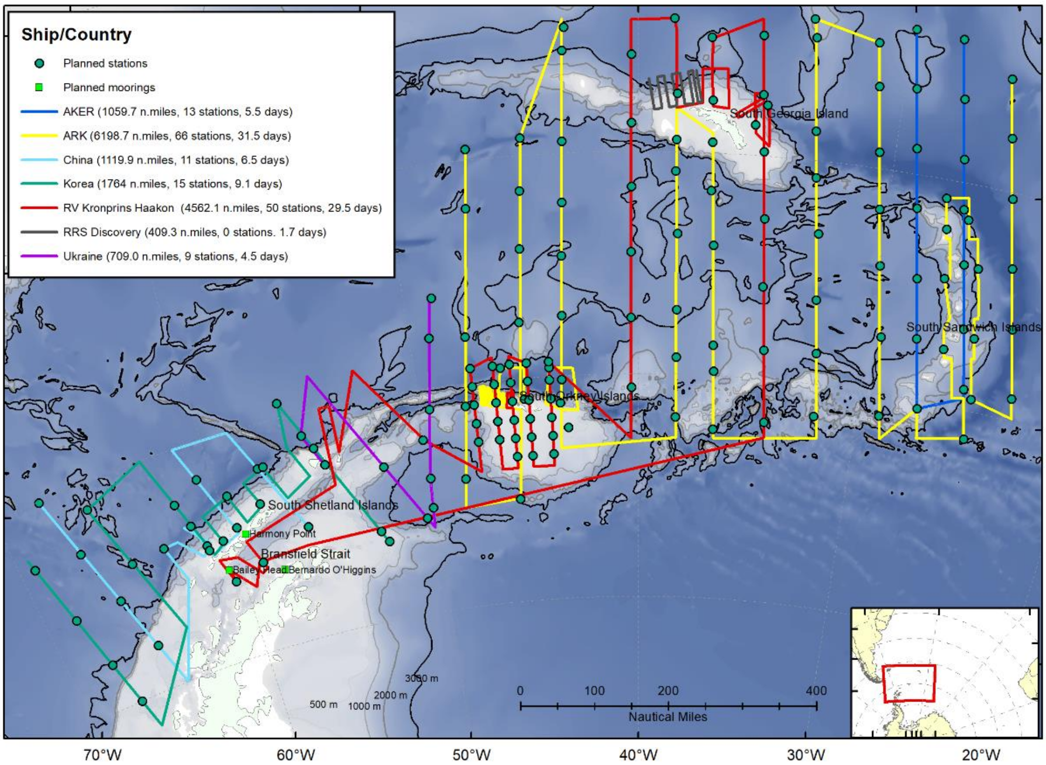

Figure 1. The location of the Large Scale synoptic survey transects covering area 48 and vessels allocated to specific regions.

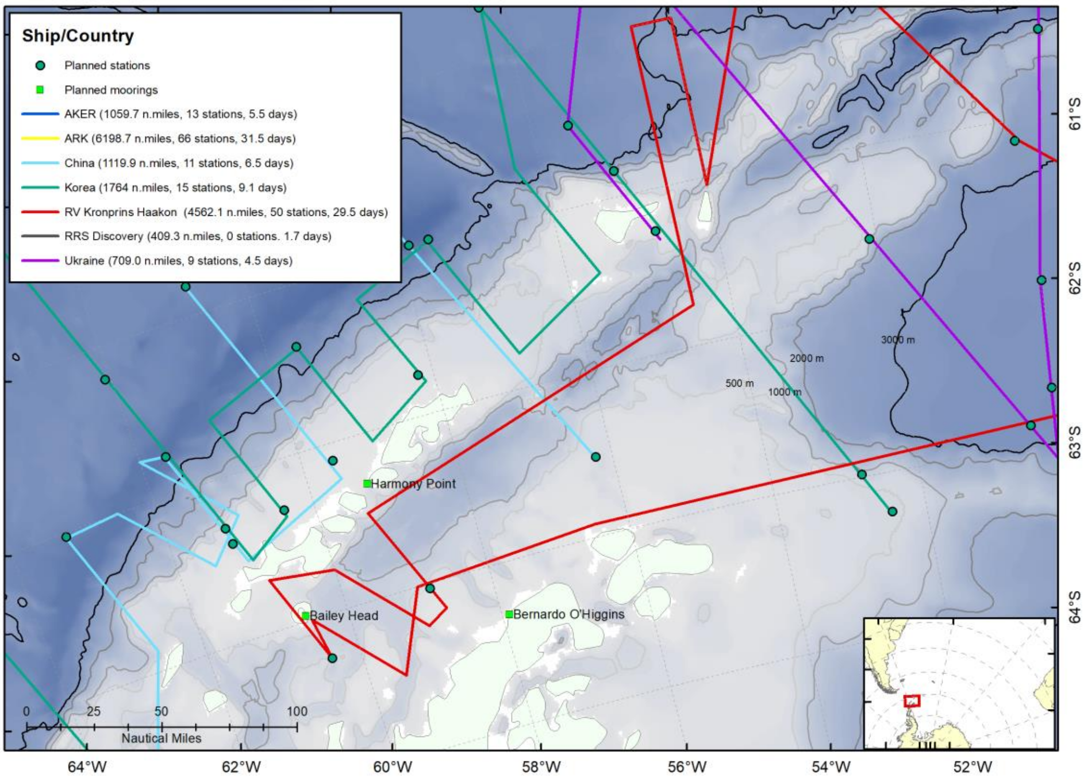

Figure 2. The location of the Land based predator field sites Bailey Head, Harmony Point and Bernardo O`Higgins and transects planned for the Large Scale Survey.

Vessel based approaches supporting development of the CCAMLR FBM

Acoustics

The RV Kronprins Haakon will depart Punta Arenas on the 13th January 2019. Acoustic and biological survey data (krill density, demography and zooplankton three-dimensional distribution) will be collected at the beginning (lasting approx. 5 days) and the end (lasting approx. 5 days) of the regional scale synoptic survey (lasting approx. 30 days). The first survey will be directed onto areas preferred by predators in near-real time. The second survey will be guided in a similar way, but will also incorporate the same areas surveyed at the beginning.

The variability in distribution and density of kill in the high krill density areas near the three field sites in the Bransfield Strait will be quantified using a combination of stationary (moored) and mobile (ship-mounted) multi-channel broadband echo sounders. The spatial arrangement of the ship-based acoustic data collected will be designed to allow for testing of several survey strategies that may be useful for industry vessels to use in subsequent years as part of a CCAMLR FBM system. High resolution broadband echo sounders will provide detailed information on predator-prey interactions to compliment the foraging behaviour studied of the CCAMLR monitored krill dependant predators. The ship will also measure three-dimensional acoustic images of individual krill aggregations via multi-beam sonar systems for detailed behavioural studies. High-frequency backscatter information at depth will be obtained from a horizontally-operating echo sounder attached to all applicable CTD casts, providing high-frequency backscatter at depths beyond the range of the ship-mounted echo sounders. Three moored upward-looking acoustic echo sounders (WBAT, Kongsberg, Norway) arranged in a '+' deployment pattern will be used to estimate the krill spatial flux through hotspots. Echo sounders mounted on a dedicated probe will also be used to obtain detailed broadband backscatter characteristics of krill, including the estimates of krill target strength that are required to accurately convert acoustic backscatter into quantitative estimates of krill abundance.

As part of the FBM related efforts also 4 acoustic moorings will be deployed in and around the krill hotspot areas just north of the South Orkneys. These acoustic moorings contain ADCPs, as well as echosounders. The moorings are deployed as part of the IMR project "SWARM". As part of this effort IMR has deployed one or more acoustic moorings in the area since 2014. Data from the instruments give information on current speeds, krill biomass and biomass fluctuations in the krill fishery area, as well as data on dive activity of air-breathing predators, and provides a long-term context to evaluate the results of the scientific survey for this area. These data also provide, together with the data collected during the FBM activities in the Bransfield area, give the possibility to make comparative analysis of biomass and behavioral patterns in 2 ecologically and commercially important krill areas.

A Sailbuoy will also be deployed during the first cruise and recovered during the last cruise. This is a wind-driven autonomous surface vehicle, capable of continuous operation over several months. The Sailbuoy concept has demonstrated robustness and reliability under other rough conditions and will be tailored to support data for Feedback management and for eco-efficient fishery in the Antarctic. The system will be equipped with echosounder (Simrad EK80 333 kHz) and environmental sensors. The test program for the cruise is in order of priority 1) covering krill hotspots through a random track model, 2) repeated coverage of dedicated industry transects, 3) operation in areas with ice and 4) cruising between neighboring hotspots. The Sailbuoy is deployed from, and picked up by the RV Kronprins Haakon, with the Sailbuoy cruise plan adapted to fit the KPH cruise plan. Measurement data are processed on board and the results relayed to the user in near-real time through satellite communication. The experience gained during the cruise will be used to further develop and optimize the Sailbuoy for the Antarctic environment, and in the future equipping the Sailbuoy with an acoustic modem for collecting the data from the moored echosounders.

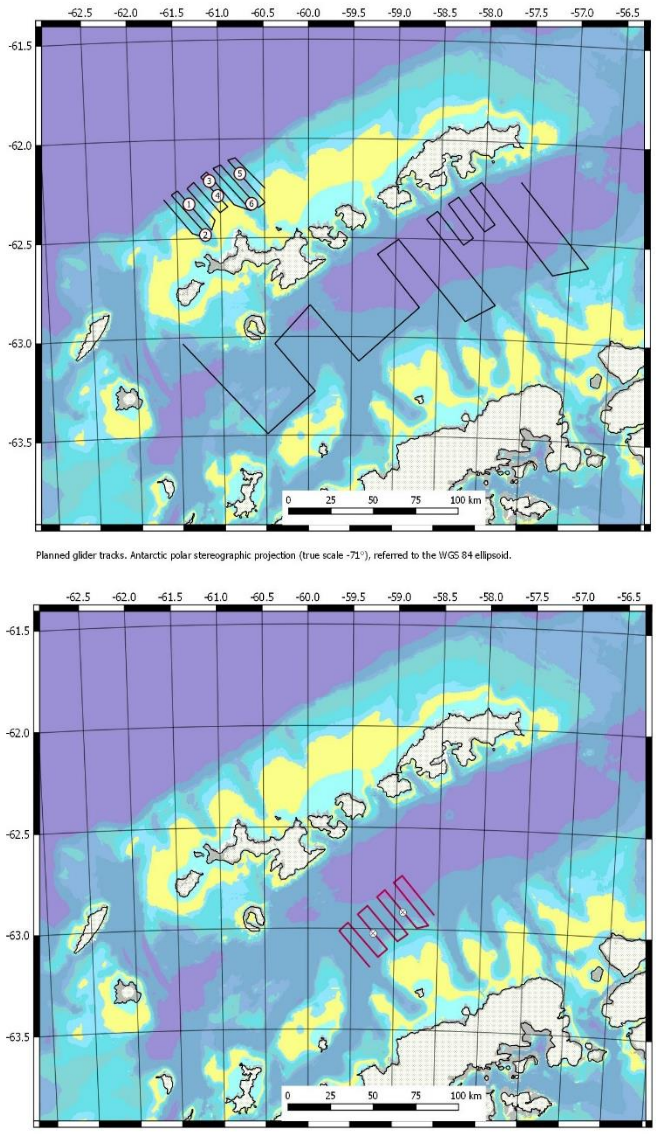

Figure 3. Transects covered by gliders and positions for ADCP moorings devoted for the US AMLR program in 2019 (upper figure) and additional coverage by glider and deployment of ADCPs for support of the FBM development project (lower panel).

The U.S. AMLR Program will be deploying two SLOCUM G3 gliders equipped with3-frequencies of active acoustics (38, 67, and 125 kHz; ASL Environmental Inc AZFP), Seabird CTDs, AANDERAA oxygen sensors and WetLabs Inc. Ecopucks (to measure water column fluorescence and particle backscatter) and six NORTEK 100kHz ADCPs with and integrated single beam wide-band scientific echosounder moorings to understand krill flux, and predator prey relationships around Cape Shirreff and within Bransfield Strait as part of their ongoing annual monitoring program (Figure 3, Upper figure).

As part of the scientific collaboration in this research proposal. The U.S. is proposing to provide two additional 100kHz ADCP/E's and an additional similarly equipped glider to focus on an important fishing area with Bransfield Strait, and an area where predator-prey-fishing overlap may be high. Coupling these two ADCP/E's with an additional mooring (Signature 55) could provide estimates of flux through the fishing area at a scale relevant to understanding the physical-biological properties in this region (Figure 3, Lower panel). The short duration of the deployments (~30 days) will mean that currents and krill biomass flux will be measured at extremely short timescales while the glider will provide a slightly broader context to the measurements. This deployment will free ship-time for the collection of acoustic and hydrographic data as outlined in other areas of this proposal. In addition to estimation of krill flux we envision collection of relevant comparative data on the acoustic properties of the various acoustic instruments an important overall goal for many programs.

Mesopelagic organisms

The CCAMLR protocol for krill biomass estimation has explicit focus on the upper 200 m (the epipelagic zone). Newer results have however demonstrated that krill are also ubiquitous at deeper depths, and *E. superba* have been observed down to ~3500 m depth (Clarke & Tyler 2008). It has been suggested that *E. superba* have a role in transporting iron from the seabed and into the epipelagic in this otherwise iron-limited (HNLC) environment (Schmidt et al. 2011), generating a positive feedback loop to Southern Ocean productivity. The practical effect of this feedback loop however hinges on (among other things) the actual flux of krill between shallow and deep waters, which, due partially to the focus on the epipelagic, is poorly parametrized. IMR has equipment at its disposal (e.g. lowered acoustics, depth rated quantitative trawls) that would allow us to address *E. superba* actual vertical distribution deeper than the epipelagic, which could lead to enhanced understanding of krill-mediated transport of nutrients.

In CCAMLR, much of the focus is also centered on charismatic megafauna, for krill management purposes this mostly translates into land-based, air-breathing predators. However, it has been suspected for a long time that in terms of predation on krill, fish and squid consume more krill biomass than air-breathing predators (Murphy et al. 2007). For krill then, these represent additional ecologically important predators that require study. For a variety of reasons, planktivorous fish and squid in the Antarctic have received little research effort, and their biomass and distribution are still poorly understood. If management of krill resources are to be ecosystem based, improved understanding of pelagic krill predators is needed.

These species, many of which are deep living, also serve as food, either preferred or alternative, to many of the charismatic megafauna in the Antarctic zone, and mapping of densities and distributions of these are therefore also of direct interest to conservation measures for air-breathing fauna.

As part of the krill research program IMR will sample both the epi- and mesopelagic zones for other pelagic macroplankton and micronekton, in order to map their biomass and distribution. These samples may also be used to study trophic connections in the Antarctic pelagic, and in combination with behavioral data from the land based studies, allow us to parametrize one important aspect of the active carbon pump (Davison et al. 2013, Klevjer et al. 2016, Anderson et al. 2018).

Cetacean sightings

Also baleen whales in the Southern Ocean consume substantial amounts of krill, yet although some species are recovering from human exploitation there is very little knowledge on how they interact with the krill prey field, 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. We will supplement traditional ship-based sightings for estimation of abundance and distribution with bottom rigged acoustic recorders for identification of species and their abundance in terms of their arrival and departure from Antarctic feeding grounds. Skin/blubber/muscle tissue will be sampled for genetics to determine breeding stock membership. Biopsies will also provide material for stable bulk and compound-specific stable isotope analyses to determine dietary composition.

Chemical indicators of climate change – ocean acidification and potential impacts

Polar oceans are most sensitive for ocean acidification and is expected to lead to detrimental effects in particular calcifying zooplankton such as aragonite forming pteropods. 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 enhance ocean acidification. The area surrounding the Antarctic Peninsula has observed some of the largest ongoing climate change. Moreover, studies of *Limacina helicina* in the Scotia Sea, Antarctica has indicated that OA is already affecting the shell condition on these organisms (Bednarsek et al., 2012). OA may also negatively impact krill and fish but that is largely unknown. Here, we propose to perform water sampling from the CTD-Rosette system for the analysis of ocean acidification (total alkalinity and pH, used to derive all other carbonate chemistry parameters such as $CaCO_3$ saturation and CO_2) in the water column in combination with net tow for sampling of pteropods using WP2/WP3 oblique tows in the upper 50 meters.

Surface water variability and fronts: Fronts are systems with high biological productivity. These features will be studied during the cruise using high-frequency underway measurements of salinity, temperature, pCO2, chlorophyll a, and oxygen will be performed from instrumentation and sensors connected to the surface seawater intake on KPH. These data will also be used to validate and develop remotely sensed abilities in the region similar to Chierici et al. (2012) and Mattsdotter et al. (2013).

Description of physical drivers of krill distribution with focus on understanding mechanisms for on-/off-shelf transport mechanisms

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). 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 and particles (e.g. nutrients). 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. (2009), Renner et al. (2012), and Youngs et al. (2015). The region is characterized by highly complex topography influencing currents and mixing. Water mass exchanges and particle transport are therefore likely subject to turbulent mixing induced by internal waves and current shear. Further investigation into associated water mass exchanges would help to shed light on the physical characteristics of krill hotspots. Understanding the physical mechanisms is an important component of understanding krill distribution patterns and is therefore needed for effective management of krill fisheries.

To investigate water mass exchange and water mass properties we will employ high resolution CTD, lowered ADCP, shipboard ADCP, and echo sounder transects for concurrent, full-depth observations of hydrography, currents, and krill distribution, around topographically complex regions such as canyons, and across front-associated jet currents in the northwestern Weddell Sea and the entrance to Bransfield Strait => link to water chemistry and (phyto-) plankton distribution (including satellite remote sensing data for ocean colour (Chl a & identification of eddies & fronts) & sea ice cover & drift, both prior to and during the cruise). On the KPH standard sampling also includes the collection of data for analyses of primary production, micro and meso zooplankton as well as numerous parameters describing the physical environment (e.g. water chemistry, CTD data, O2, light.

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