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SESSION 22

THE ROLE OF FISH IN THE SOUTHERN OCEAN

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Modelling dispersal of Antarctic toothfish eggs and larvae in the Ross and Amundsen Seas – The impact of sea-ice, ocean currents and larval behaviour

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Antarctic toothfish in the Ross Sea spawn near seamounts, at depths of 1000-2000m during winter (July-August). The buoyant eggs float to the surface where they encounter near complete cover of sea-ice. They likely hatch after 40 days and juveniles are found after 2-3 years at the continental slope of Antarctica, typically thousands of kilometres from spawning locations. It remains unclear how the larvae travel from the spawning grounds to the continental slope, and how this process is influenced by the timing of the spawning, sea-ice motion, ocean currents, eddies, and larval behaviour. In this study we investigate the individual contributions of these factors distributions of toothfish larvae, using hydrodynamical data from a high-resolution ocean model hindcasts. The resolution of this model hindcast (1/15°) is fine enough to resolve mesoscale eddies in this region and model representation of the Ross Sea gyre circulation is realistic. Based on the scenario modelling, we find that a combination of all factors is necessary for larvae to reach the shelf within 2-3 years. We will also discuss interannual variability in transport routes and how these may be impacted by climate change and potentially affect recruitment in the future.

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Transport pathways structuring life history distributions of Antarctic toothfish

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In the Ross Sea, juvenile Antarctic toothfish are found in deep basins along the inner continental shelf, the result of isostatic depression by the continental ice sheet. The basins connect to the continental slope via glacial troughs exposed during ice sheet recession. Predictable transport along each trough offers opportunities for biophysical interactions with life history. Equatorward flow of dense, cold Low Salinity Shelf Water (LSSW) from the Glomar Challenger Basin mixes with inflowing modified Circumpolar Deep Water, eventually contributing to the formation of Low Salinity Antarctic Bottom Water. Deep outflow from the trough mouth sinks down the slope to join a western boundary current northward to the Iselin Bank. High Salinity Shelf Water (HSSW) flows from the Joides Basin along the Joides Trough, and down the slope into the Adare Basin. Further west, more saline HSSW forms gravity cascades down the slope from the Drygalski Trough. Two transport pathways connect northward from the Ross Sea slope to the Pacific-Antarctic Ridge where Antarctic toothfish spawn: an eastern one from the Iselin Bank, and a western one that turns cyclonically along the flank of the Southeast Indian Ridge. We compare the shelf basins and transport pathways connecting habitats currently used by toothfish over their life history. We consider which inshore basins are likely most important in contributing to adult spawning aggregations; how transport pathways from each may be expected to influence distributions along the Pacific-Antarctic Ridge; and how these biophysical interactions can be expected to change over the glacial cycle.

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Marine Ecosystem Assessment for the Southern Ocean (MEASO): Productivity and change in fish and squid in the Southern Ocean

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The Marine Ecosystem Assessment for the Southern Ocean (MEASO) aims to provide a forward-looking assessment of present and future ecological trends in the Southern Ocean ecosystems, as well as to identify gaps to address in research and management. The fish and squid MEASO chapter collates a synthesis of current knowledge, impact of drivers (past, present, and future), and prognoses. Focus is brought on major taxonomic and functional groups particularly relevant to ecosystem functioning, with case study-species illustrating impacts of important drivers on the ecosystems (e.g. fisheries, climate change). Data collection methods on fish and squid in the Southern Ocean are discussed (e.g. fisheries, scientific surveys) with respect to their inherent biases. Variations in fish and squid distributions and adaptations over glacial scales are examined, as well as impacts from more recent anthropogenic drivers (e.g. climate change, fisheries, pollution). Based on a synthesis of historical data and current knowledge, we developed a set of prognoses for fish and squid connectivity, distributions and biomasses throughout the Southern Ocean over the next 10 - 20 years and beyond. In this presentation we will describe the major conclusions regarding fish and squid emerging from this assessment, including the need to consider the synergistic impacts of concurrent drivers, as well as inter-population and inter-species variability across regions in regard to their response to drivers of change.

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Combined risk and quantitative assessment approach to Southern Ocean fisheries bycatch: Deep water skates (Bathyraja spp.) in the Patagonian toothfish fishery as a case study.

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Impact assessments on bycatch species require a basic suite of life history parameters including information on age, growth and recruitment. However for many species in the Southern Ocean these parameters are not available. Due to their deep water demersal existence little is known about skates (Bathyraja spp.) caught in the Heard and McDonald Island (HIMI) Patagonian Toothfish (Dissostichus eleginoides) fishery. By combining multiple sources of data on Bathyraja eatonii, B. irrasa and B. murrayi we aim develop a best practice framework for establishing input parameters used in population projection models. We estimated age, growth and recruitment through an integrated analysis of species morphometric, reproductive, mark-recapture and ageing data collected between 1990 and 2019 during Random Stratified Trawl Surveys and commercial fishing operations on the Kerguelen Plateau. Where input parameters could not be determined we followed a qualitative stepwise approach to obtain quantitative estimates from other species based on taxonomic, ecological and life history similarities. In the face of uncertainty a precautionary risk based approach was implemented by selecting for more conservative parameters. Input parameters were then applied to a Generalised Yield Model (GYM) to produce a simulated projection to determine the probability of stock depletion. Furthermore, we tested multiple scenarios of fishing gear selectivity within the GYM to obtain a range of future population predictions. This study provides the first estimates of long term annual yield for individual skate species in the HIMI fishery and a framework for setting bycatch limits in other areas of the CCAMLR region.

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The impacts of climate change and krill fishing on Antarctic larval fishes

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The Western Antarctic Peninsula (WAP) is one of the fastest warming regions on Earth. In addition, there was a dramatic reduction in sea ice and retreat of marine-terminating glaciers during the late 20th century. Although the increase in temperature and decline in sea ice has reversed since the year ~2000, primarily due to natural variability and Antarctic ozone recovery, under high anthropogenic emission scenarios the WAP is expected to experience prolonged warming in the future. It is critically important to understand how rapid climate change effects the WAP ecosystem. Previous work indicates phytoplankton, zooplankton, and penguins are all significantly influenced by climatic variability. However, there is less information pertaining to the influence on the unique ichthyofauna of the region, especially during their early life stages. Larval fishes in the Northern Antarctic Peninsula region are also incidentally captured by krill fishing vessels, although little is known on the scope of this bycatch due to difficulties in identifying larval fishes. This project utilizes a 27-year, continuously running time series of larval fishes collected by the Palmer Antarctica Long-Term Ecological Research (PAL LTER) Program to model the environmental drivers of ichthyoplankton population dynamics. Fishes from the PAL LTER and Australian Antarctic Division collections are also used to develop a novel identification guide for scientific observers on krill fishing vessels. Model results and observer reports are immediately necessary to assess anthropogenic influences on larval fish mortality, manage krill fishing efforts, and assist in the development of marine protected areas in the Southern Ocean.

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Fishing for DNA to study predator prey interactions of Southern Ocean fish

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The use of DNA as a dietary tracer is becoming increasingly common and has great potential to improve our knowledge of trophic interactions in a broad range of ecosystems. This talk will focus on two DNA-based diet studies that refine our view of the ecological role of fish in the Southern Ocean. Both studies used high-throughput DNA sequencing of DNA barcode markers. In the first study we characterised stomach contents of four myctophid and one bathylagid fish species collected on the southern Kerguelen Plateau. The presence of DNA from coelenterates and other gelatinous prey in the stomach contents of all five species, which are largely missed with morphological analysis, suggests the importance of these taxa in the diet of Southern Ocean mesopelagic fish has been underestimated to date. In the second study we examined the fish DNA present in the scats of Adélie penguins at Signy Island (South Orkney Islands) during the breeding season over two years. Scat DNA showed an increased diversity of fish in the penguin diet compared to parallel data collected at the colony through conventional stomach flushing. Based on these two case studies the strengths and limitations of the genetic approach to studying diet will be discussed.

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Species connectivity - Hybridization potential between notothenioid species

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Interspecific hybridization or its prevention may have contributed to the diversification of notothenioid fishes, but data supporting these hypotheses is scarce. With many related species displaying parapatric distributions, and with Antarctic and sub-Antarctic regions rapidly warming, the potential for hybridization may be greater than previously hypothesized.

To understand hybridization possibilities and investigate reproductive isolating mechanisms among notothenioids, we performed in vitro fertilization experiments between two Nototheniinae species (a female Notothenia coriiceps and a male Notothenia rossii) and between two icefishes (a female Chaenocephalus aceratus and a male Chionodraco rastrospinosus).

Embryos from the interspecies Notothenia cross initially developed but none survived past the establishment of the embryonic axis at 21 days post fertilization. The sequencing of nuclear genes from this cross identified only maternal DNA in all of the tested offspring, suggesting that the obtained cross was gynogenetic and that the N.rossii sperm activated the eggs but did not fertilize them.

In contrast, embryos from the interspecific icefish cross successfully developed and hatched into active larvae. The sequencing of nuclear genes confirmed that the larvae were true hybrids, demonstrating gamete compatibility and viability of resulting embryos. Due to logistic constraints, long-term hybrid viability, fertility, fitness, or hybrid dysgenesis could not be tested. Analysis of fishing records and literature, however, suggests that some hybridization barriers between icefishes or between other notothenioid parapatric species may be behavioral.

These results confirm previous observations of hybrids in the wild and suggest that some notothenioids species may be able to hybridize if appropriate conditions are met.

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Fisheries acoustics to study keystone species in the pelagic ecosystem of the Ross Sea region marine protected area

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On 1 December 2017, the world's largest Marine Protected Area (MPA) was established in the Ross Sea region of the Southern Ocean. At over 1.55 million km2 in size, tracking change and evaluating the value of the Ross Sea MPA is a highly complex, technical, and unprecedented scientific challenge. A first step is to improve our understanding of the key components of the Ross Sea ecosystem, and how these respond to pressures, including climate change and human activities. The open-ocean pelagic ecosystem of the Ross Sea is dominated by micronekton. Micronekton play a key role linking primary and tertiary consumers, and are thought to be a keystone group within the Ross Sea. Despite their importance, our knowledge of micronekton is still very limited. As part of the MPA research monitoring programme, research and fishing vessels have been used to collect active acoustic data in the Ross Sea region that can be used to monitor micronekton distribution and abundance. Dedicated research surveys have provided biological samples using midwater trawls to describe the community composition and ground-truth acoustic data. Future research is planned using an acoustic optical system (AOS) to estimate target strength of dominant micronekton species (i.e. lanternfish, family Myctophidae). Target strength values are required to convert acoustic densities to estimates of biomass. Together these data will help to develop explanatory and predictive models for micronekton in the Ross Sea MPA.

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Using new satellite datasets modelling egg and larval transport of Antarctic Toothfish (D. mausoni) in the East Antarctic region

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Antarctic Toothfish (D. mausoni) is one of the fishery targets with economically high valued in the Southern Ocean. CCAMLR assesses Toothfish fishery to continue the sustainable fishery and evaluate its ecology and the role of toothfish in the Southern Ocean foodweb system. To manage a stable population size and understand the life cycle of toothfish, the behaviour of the early stage of toothfish (i.e. egg and larvae) is essential knowledge.
In the East Antarctic region, Banzare Bank (BB, South part of Kerguelen Plateau) and continental slopes are hypothesized as main spawning grounds, and continental shelves are estimated as nursery grounds. However, egg and larval transport mechanism of toothfish in the East Antarctic region is still poorly known. We present the first result of particle tracking model for the oceanic transport of the early stage of toothfish released from (i) the BB and (ii) continental slopes with key ocean dynamics inducing the successful transports in the East Antarctic region. This model uses 8-year multiple satellites derived datasets to advect particles over altimately ice-free velocity filed.
Our result indicates the BB is the weak source of larvae for hypothesized nursery grounds, and continental slopes are strong sources by quick local inner-shelf transports through three-year simulations. The changes in oceanic positions and structures of cyclonic gyres and series of eddies affect the level of successful connections between spawning and nursery grounds over continental slopes and shelves.

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Larval and transformation-stage growth rates of Electrona antarctica (myctophid fish) in the Southern Ocean

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Myctophid fish provide important trophic links between zooplankton and higher predators in the Southern Ocean. Electrona antarctica is the most abundant myctophid in the high Antarctic zone, with its larvae found abundantly in the upper layer of the circumpolar deep-water during summer. However, the hatching season of E. antarctica has heretofore remained unelucidated. We analysed growth rates of E. antarctica during the larval and transformation stages using otolith increments to estimate hatching dates. Fish were collected using a ring net (mouth diameter: 1.60 m, mesh size: 500 µm) off Wilkes Land (East Antarctica) during January 2017-2020. Samples were preserved in 90% ethanol. The body length (BL) of fish was measured before fixation. Sagittal otoliths were extracted from seventy-four larvae. Daily rings in the otoliths were counted under a light microscope to estimate age in days (Age). The growth rate was estimated using regression analysis. The relationship between the BL and Age of larval E. antarctica (5.7-16.9 mm BL) was expressed by a linear equation: BL = 5.3 + 0.67×Age (R^2 = 0.82). The estimated hatching dates of E. antarctica in 2017 were between late December 2016 and mid-January 2017. A previous study estimated the growth rate of juvenile and adult E. antarctica to be 0.063 mm/day. This disparity between results implies a decrease in growth rate after the transformation stage (19-21 mm BL). In this presentation, the growth rate from larval to juvenile stages through transformation will be shown by adding transformation stage fish sampled in 2018-2020.

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Hormonal analysis provides new insights on reproductive features in Antarctic notothenioids: a trial in Lepidonotothen nudifrons

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The knowledge of reproductive biology in notothenioids arises exclusively from macroscopic and histologic descriptions, without the complement of hormonal analysis. Our study provides for first time in Lepidonotothen nudifrons adult females, information on oocyte growth and change in testosterone and estradiol plasma levels throughout the ovarian growth. Sampling included near 100 specimens caught at Potter Cove (PC), South Shetland Islands (SSI), from November to late March of 2016-2018. Histological analysis confirmed the macroscopic characteristic of two distinct cohorts of oocytes: one leading clutch (Lc) of large orange vitellogenic oocytes, to be spawned in the upcoming reproductive season, and a second clutch of smaller whitish previtellogenic oocytes. In March, females (n=17) attained gonado-somatic index of 13-20% (16.73±4.20), total fecundity of 2196-4652 oocytes/female (3209±740) and Lc oocytes of 1.7-2.1 mm. The Lc oocytes growth was significantly associated with photoperiod, with no diameter variation until the summer solstice, when they began to grow linearly with an estimated rate of 0.01 mm/day. Testosterone and estradiol increased together with the oocyte growing throughout the analyzed seasons, with a higher rise rate during March. The significant plasma level increase of both sex steroids observed in March and the reproductive effort data suggest that: (1) specimens were at a late vitellogenesis stage just prior to the oocyte final maturation in March, and thus L. nudifrons spawning period might onset from this month at SSI; (2) PC is likely a spawning site for L. nudifrons, which reinforce the hypothesis that nearshore areas are spawning grounds for some notothenioids.

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Movements patterns of tagged Antarctic toothfish Dissostichus mawsoni

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Antarctic toothfish (Dissostichus mawsoni) and Patagonian toothfish (D. eleginoides) are generally considered to be non-migratory species, with previous tagging studies indicating individuals typically only move distances of less than 20 km from their initial point of observation. Most studies have focused on Patagonian toothfish with research on the distribution and behaviour of Antarctic toothfish being relatively limited. Toothfish tagging studies in the Southern Ocean have been designed and implemented as mark-recapture approaches to estimating population size data from 3835 recaptured D. mawsoni to analyse movements of patterns of this circum-Antarctic species. Results indicate that while the median distance between tagging and recapture was 22km, regardless of the time-at-liberty, 10% of individuals moved > 200km and 4% moved >500 km. The direction of movement for those fish that moved > 500 km shows a distinct bias towards an anti-clockwise direction around the Antarctic continent, possibly following the Antarctic coastal current. Tagging studies, although implemented for population size estimation, can also provide insights into movement patterns, population linkages and basic ecology of fish species, particularly where other sources of data are not available.

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Bycatch of fish in the krill fishery: insights into Southern Ocean pelagic fish assemblages

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The majority of fish research in the Southern Ocean is directed towards nearshore and commercially exploited species. As a consequence there is relatively limited sampling of pelagic fish assemblages. CCAMLR requirements for scientific observer coverage in the pelagic fishery for Antarctic krill have resulted in over 30 000 samples inspected for fish bycatch and over 90 000 fish identified and measured. This has increased the information available on fish bycatch around the Antarctic Peninsula, South Orkney Islands and South Georgia where icefish and nototheniids were found most frequently. Species-specific differences in geographic distribution patterns are apparent with some taxa such as Chaenodraco wilsoni found predominantly in the Antarctic Peninsula whereas others taxa, such as Lepidonothen larseni, have a more ubiquitous distribution. Length frequency distributions of bycatch fish typically have unimodal distributions with a modal length of less that 10cm although multi-modal distributions are apparent for some taxa. These data provide the basis for an improved understanding of the ecosystem impacts of the krill fishery as well as providing the basis for approaches to mitigate the bycatch of fish in the krill fishery. These data are collected throughout the year and provide a unique source of data on the pelagic fish assemblage in a key part of the Southern Ocean.

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Diet of the bald notothen (Trematomus borchgrevinki) in the fast ice zone of Terre Adelie

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Notothenioid fish are the dominant group of mesopredators in the high-Antarctic. Obtaining information regarding their ecological role is key for understanding potential success or failure under changing Antarctic conditions. Diet analyses can reveal information about a species' functional placement in the food chain and direct observations of predation events and use of resources. Trematomus borchgrevinki, the bald notothen, was collected in the coastal fast-ice zone of Terre Adélie, Antarctica, during summer. Stomach contents were identified, sorted, and analyzed using percent frequency of occurrence (%F). The calanoid copepod Paralabidocera antarctica was present in the highest number of stomachs (%F = 69) followed by krill (%F = 38). Larger prey occurred more frequently in the fish stomachs as standard length of fish increased. Comparisons with other diet studies indicate that T. borchgrevinki is plastic in its dietary choice and may cope well with changing Antarctic conditions, although this is contingent upon the continued presence of favourable prey.

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Myctobase: a circumpolar database of mesopelagic fish creates opportunities for new insights into mesopelagic prey fields

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Deep pelagic ecosystems are under-represented in databases of marine biodiversity, despite holding the largest biomass of organisms on Earth. Mesopelagic fishes dominate global biomass estimates possibly contributing up to 10% of the primary production at mesopelagic depths. In the Southern Ocean, the importance of mesopelagic fishes in alternative energy pathways has been established and can dominate the transfer of energy to pelagic top-predators in specific regions and seasons. The intensifying challenges posed by climate change has heightened the need for long-term datasets, on biomass-dominant species, across varying spatial domains and time scales, in addition to baseline data. Biodiversity informatics provides a powerful and timely tool for the integration of scattered and unpublished data. Here, we integrate existing catch data for mesopelagic fishes from survey voyages by SCAR nations to create a purpose-built database, Myctobase. We have collated species-specific data on life stage, length, weight, abundance and associated sampling methods from 13 different voyages. We aim to use this database to develop explanatory and predictive models of the environmental determinants of biomass for key myctophid species accounting for differences in survey methodology. Here, we present preliminary results from the Atlantic and Indian sector of the Southern Ocean. This research yields new insights into the biophysical determinants shaping patterns of biomass and abundance of mesopelagic fishes. We anticipate that Myctobase will continue to grow into a fully circumpolar database with continued collaboration from across the scientific marine community.

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Ontogenetic shifts in the diet of Bathylagus antarcticus (Microstomatidae) in the Indian Ocean sector of the Southern Ocean

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Mesopelagic fish play important roles in Southern Ocean foodwebs, linking zooplankton with higher predators. Although the Antarctic deepsea smelt Bathylagus antarcticus has a large biomass in the Indian Ocean sector of the Southern Ocean, its dietary habits remain unclear. The present study examined gut contents of larval to adult-stage B. antarcticus to reveal ontogenetic shifts in diet. Fish were collected off Vincennes Bay (East Antarctica) during January 2019 and 2020. The gut contents of the sixty-five fish (27.5 – 149.3 mm in body length, BL) analysed in this study included amphipods, chaetognaths, copepods, euphausiids, ostracods, polychaetes and pteropods. In the small fish size class (27 – 50 mm BL), copepods were the most important items both in volume and frequency of occurrence (61% and 73%, respectively). However, copepods were less important in volume (22%) and frequency (13%) in the larger 70-90 mm BL size class. Instead, other zooplankton including amphipods, euphausiids and pteropods comprised higher proportions of gut contents. The maximum size of B. antarcticus food items increased with mouth size growth. Therefore, 27 – 70 mm BL B. antarcticus mainly ate copepods, with the main trophic source changing to larger zooplankton at >90 mm BL. The dietary shift from copepods to larger zooplankton was related to increases in mouth size. Ontogenetic vertical migration from the upper mesopelagic to deeper layers is likely to explain this diet shift. We also present here results of DNA analysis applied to unidentified gut contents.

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Fisheries science at Heard Island and McDonald Islands on the Kerguelen Plateau

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Commercial fishing for Patagonian toothfish (Dissostichus eleginoides) and mackerel icefish (Champsocephalus gunnari) at Heard Island and McDonald Islands on the Kerguelen Plateau started in 1997. Patagonian toothfish is a large, long-lived and relatively late-maturing predator that can be found from 100 m to over 2500 m depth, while icefish is a medium-sized, short-lived zooplanktivore that lives on the shallow shelf up to around 350 m depth. The main focus of research has been to deliver management advice for CCAMLR on ecologically sustainable catch limits for target and bycatch species and mitigation of fishing impacts on the ecosystem. However, the comprehensive data sampling program from the fishery which includes logbook returns on catch and effort, an annual random stratified trawl survey (RSTS), a tagging program, and a variety of data collected by observers with 100% observer coverage on all vessels and fishing trips, has also allowed to improve our understanding of the biology of many species on the Kerguelen Plateau. Here, we summarise some insights into the distribution, movement patterns, ecology and population dynamics of fish and elasmobranch species on the plateau from this research.

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