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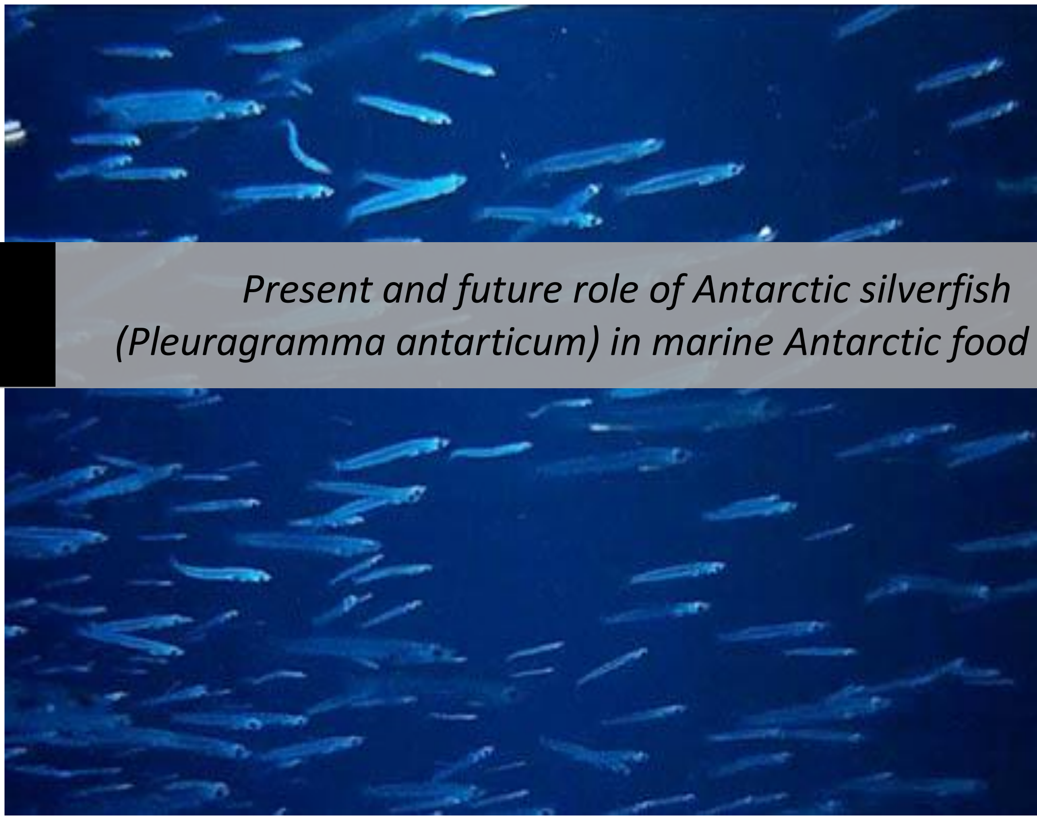

MASTER THESIS

Present and future role of Antarctic silverfish (Pleuragramma antarticum) in marine Antarctic food webs.

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Abstract

The Antarctic marine ecosystem hosts a fast range of species ranging from phytoplankton to blue whales. A significant number of Antarctic species are endemic, including the Antarctic silverfish *Pleuragramma antarcticum* which is abundant all through the Antarctic marine environment.

P. antarcticum is a pelagic fish in Antarctic waters, and have a fascinating life cycle that is distributed through the water column. Because of its high abundance and wide distribution, it is a key species in the Antarctic food web.

Climate changes have led to decrease in sea ice cover thus altering the distribution, community structure and abundance of species. Those changes ultimately disturb the food web interactions.

This report aims to comprehend what is the environmental significance of Antarctic silverfish and the role that it plays in the Antarctic food web. It is critical to comprehend what the potential threats to their population are. For example, climate change compromises vulnerable life stages and habitants as well as fishing which doesn't affect *P. antarcticum* directly however it affects its predators and prey species.

Keywords: Atlantic silverfish, Ross Sea, climate change, food webs

Introduction

An Introduction to Antarctica

Antarctica is more than 3,000m above sea level. Antarctica was covered with ice about 34 million years ago and became the coldest continent (Leer et al. 2016). The orbital distance contributes to the seasonal temperatures. During the winter, the earth is farthest from the Sun and closest during the summer. This leads to a colder winter and a warmer summer. One very important aspect of this region is the fact that it allows scientists from 28 countries to perform experiments that cannot be conducted anywhere else. In the summer more than 4,000 scientists operate experiments but this number decreases to just over 1,000 in the winter. The largest research station in Antarctica, called McMurdo Station, and host more than 1,000 scientists, visitors, and tourists.

Effects of global warming

The effects of global warming have been evident in Antarctica, particularly the Antarctic Peninsula. In West Antarctica measurements show increase in warmth by more than 0.1 °C per decade in the last 50 years. Increase in warmth is measured strongly in winter and spring (Steig et al. 2009). Though inconclusive (Steig et al. 2013), it has been suggested that warming is a result of human carbon dioxide emissions (Gillett et al. 2008). Noted that significant melting at the surface hasn't yet been observed. The inflow of the warm water from the deep ocean is believed to lead to the increase in glacier outflow. (Payne et al. 2004, Thoma et al. 2008). The net contribution to sea level from the Antarctic Peninsula is more likely to be a direct result of the much greater atmospheric warming there (Pritchard and Vaughan 2007).

A study published by Bromwich et al. in 2013 established the central West Antarctica as one of the fastest-warming regions on Earth. The highest temperature recorded in the region is 18.3 degree Celsius (February 2020). The previous highest temperature was recorded in March 2015 at 17.5 degrees Celsius.

Ozone depletion

There is a large area over Antarctica that has been labeled as "ozone_hole". It is an area where low ozone concentration has been detected and it is covering almost the whole continent. The largest "ozone_hole" was measured in September of 2008.
The emission of chlorofluorocarbons or CFCs into the atmosphere is the reason behind the formation of the "ozone_hole". The emission of CFCs decomposes the ozone into other gases. In 2019, the ozone hole was at its smallest in the previous thirty years, due to the warmer polar stratosphere weakening the polar vortex. This reduced the formation of the 'polar stratospheric clouds' that enable the chemistry that leads to rapid ozone loss.

There have been scientific studies that propose that ozone depletion may have a principal role in climate change in Antarctica (Schiermeier and Quirin 2009). Ozone absorbs large amounts of ultraviolet radiation in the stratosphere. Ozone depletion over Antarctica can cause a cooling of around 6 °C in the local stratosphere. This cooling tends to boost the westerly winds which flow around the continent. Therefore, the cooling prevents outflow of the cold air near the South Pole. As a result, the continental mass of the East Antarctic ice sheet is held at lower temperatures, and the peripheral areas of Antarctica, especially the Antarctic Peninsula, are subject to higher temperatures, which promote accelerated melting (Schiermeier and Quirin 2009).

Ice shelves are ice that originated on land. Melting of ice shelves does not in itself contribute much to sea-level rise (since the ice displaces only its own mass of water). However, it is the outflow of the ice from the land to form the ice shelf which causes a rise in global sea level. This effect is offset by snow falling back onto the continent. Recent decades have witnessed several dramatic collapses of large ice shelves around the coast of Antarctica, especially along the Antarctic Peninsula. Concerns have been raised that disruption of ice shelves may result in increased glacial outflow from the continental ice mass (Rignot et al. 2004).

On the continent itself, the large volume of ice present stores around 70% of the world's fresh water. This ice sheet is constantly gaining ice from snowfall and losing ice through outflow to the sea.

Ecosystem changes in the Antarctic

In part because of the heat and nutrients supplied by the Circumpolar Deep Water, the West Antarctic Peninsula hosts an extremely productive marine ecosystem supported by large phytoplankton blooms (Prezelin et al. 2000, Schofield et al. 2010). However, over the past 30 years the magnitude of these blooms has decreased (Montes-Hugo 2009, Schofield et al. 2010). There is evidence that the algal community composition has shifted from large to small cells (Montes-Hugo 2009, Moline et al. 2004, and Schofield et al. 2010). These changes are not uniform across the Peninsula, areas in the south that were previously mostly covered with sea ice now have open water, allowing local ocean productivity rates to increase (Montes-Hugo 2009, Clarke et al. 2009, Schofield et al. 2010). The shift in phytoplankton biomass and size has direct consequences for grazer communities, especially the Antarctic krill, which are inefficient at grazing small cells (McClatchie et al. 1983, Quetin et al. 1985, Schofield et al. 2010). Because krill form a critical trophic link between primary producers and upper-level consumers, the shift in zooplankton community structure suggests that there should be dramatic changes in the higher trophic levels (fish, seals, whales, and penguins and other seabirds) (Frazer and Hofmann, 2013, Schofield et al. 2010). These changes have been documented most dramatically in Antarctic penguins. In the past 30 years in the northern Antarctic Peninsula Atlantic, populations Adélie penguins have decreased (Ducklow et al. 2007, Schofield et al. 2010). Declines in the polar species have been related to decreasing sea ice cover and its possible effects on prey availability (Ducklow et al. 2007, Schofield et al. 2010). Penguins breed in locations with predictably abundant food, al-lowing them to forage and return to their colonies to feed chicks (Frazer and Trivelpiece 1996, Schofield et al. 2010).

The increase in ocean warming has led to lower total ocean productivity and decreased winter sea ice cover, which is a critical habitat for the spawning of krill (Quetin and Ross, 2001, Schofield et al. 2010) and Antarctic silverfish. Changes in climate have had a cascading effect, with reshaped sea ice distributions, disrupting the life strategies of resident species, leading to changes in community structure and in the abundance of populations, and ultimately altering the nature of local and regional food webs (Schofield et al. 2010).

Pleuragramma antarcticum

Pleuragramma antarcticum, commonly known as Antarctic silverfish is the most abundant pelagic fish throughout the Antarctic marine system. The scientific classification is as such: Kingdom: Animalia, Phylum: Chordata, Class: Actinopterygii, Order: Perciformes, Suborder: Notothenioidei, Family: Nototheniidae, Genus: Pleuragramma. Its conservation status is set to Least Concern according to the IUCN 3.1. This species is especially abundant in the Ross Sea (DeWitt, 1970; Guglielmo et al., 1998, Pinkerton 2017).

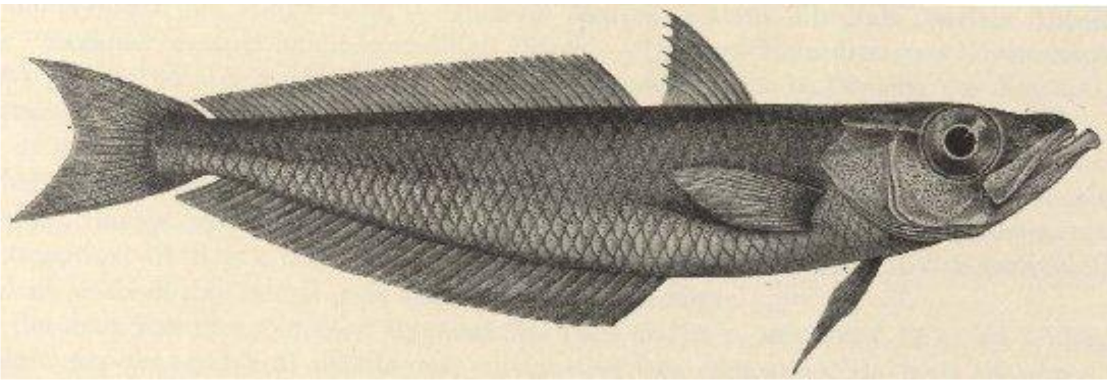


Fig 1: Pleuragramma antarticum (drawing by Louis Dollo)

P. antarcticum (Fig. 1) is a keystone species in the Ross Sea, providing one of the major links between lower and higher trophic levels (La Mesa et al. 2004, Smith et al. 2007, Pinkerton et al. 2013, Vacchi et al. 2017, O'Driscoll 2018). Even though the Antarctic silverfish is highly important in Antarctic food chains, there is not much research done about its abundance and spatial distribution in the Ross Sea (Pinkerton et al. 2010, O'Driscoll 2018). Silverfish are unique among notothenioid fish because they live throughout the water column in all stages of their life (La Mesa & Eastman 2012, O'Driscoll 2018).

Their eggs are spawned during winter or early spring. *P. antarcticum* (Fig. 2) is distributed around the whole of Antarctic waters, both in open waters and pack ice ranging from the surface down to 700 m (La Mesa & Eastman 2012, Moline et al. 2008, Rodgers 2016). *P. antarcticum*'s habitat is described by low temperatures and seasonal differences in ice cover, light and primary production (Rodgers 2016).

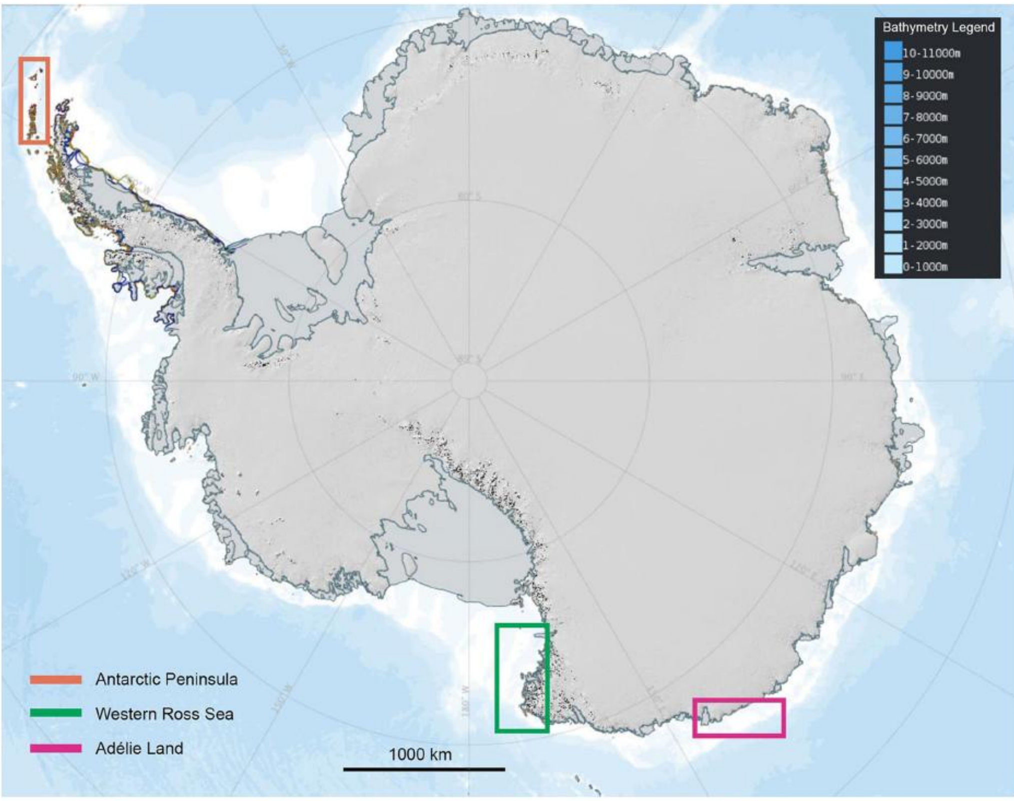


Fig 2: Spatial distribution of Antarctic silverfish along the Antarctic coast (frames) (Carlig et al.2019)

Main research question

In this report I will be presenting the role of *Pleuragramma antarticum* (Antarctic silverfish) in the food webs of the Ross Sea and how or will this be affected by climate change. To this end, I will be exploring the life stages and environmental adaptation of *P. antarticum.* Then I will be presenting the Ross Sea's food webs. Moreover I will be discussing the effects of climate change and commercial fishing on those food webs.

Results

Life stages of *P. antarcticum*

The different life stages (Fig. 4) utilize separate vertical sections of the water column. More specifically: early post-larval silverfish are found in the water column down to at least 700 m and late post-larvae, mostly in the surface at 100m (Granata et al. 2002, O'Driscoll 2018). Metamorphosis of larvae to juvenile stages occurs at 2–3 years old (30–40mm). Juveniles move to the deeper water column (Hubold 1985, Kellermann 1986, O'Driscoll 2018). Both juveniles and adults are largely pelagic. The larger fishes (over 60mm) live at greater depths than juveniles (Hubold 1985, O'Driscoll 2018). They can reach sexual maturity at the age of 6-7+ and then reach their maximum size of approximately 130mm (Faleyeva & Gerasimchuk 1990, Sutton & Horn 2011, O'Driscoll 2018). In table 1 a conclusive size guide of the different life stages is presented.

Stage	Period	Size (mm)	Age (years)	Growth rate (mm per day)	Site	Source
Larvae	January–February	8–24	0	0.18–0.24	WS	1, 2
Larvae	December–February	7–19	0	0.15–0.21	RS	3, 4
Post-larvae	January–February	25–39	1	0.06	WS	2
Post-larvae	December–February	20–57	1	0.08	RS	3, 4
Post-larvae	February	33–54	1	0.07–0.08	AP	5
Juveniles	December–February	53–82	2	0.07	RS	3
Juveniles	February	65–82	2	0.07	AP	5

Site: AP, Antarctic Peninsula; RS, Ross Sea; WS, Weddell Sea.
Source: 1, Keller 1983; 2, Hubold 1985a; 3, La Mesa *et al.* 2010; 4, Guglielmo *et al.* 1998; 5, Kellermann 1986b.

Table 1: Growth rate of early life stages of the Antarctic silverfish from different high Antarctic areas (La Mesa and Eastman 2012)

The eggs are pelagic, and newly hatched larvae and eggs have been found under the sea-ice cover in the Ross Sea (Vacchi et al. 2004, Rodgers 2016). A way to reduce predation is for the eggs to flow under the sea ice (La Mesa et al. 2010, Vacchi et al. 2004, Rodgers 2016). The reproductive cycle is closely linked with the seasonal zooplankton production.

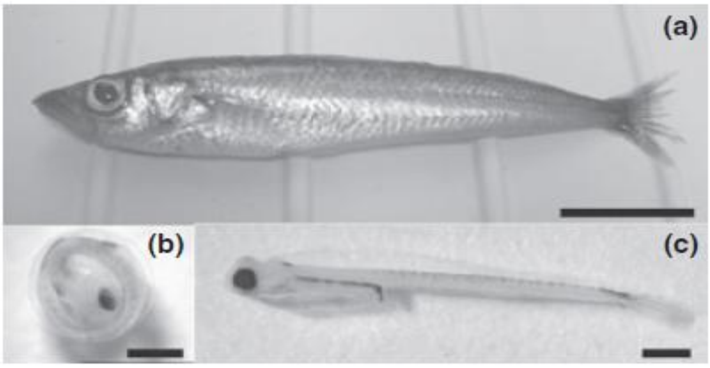


Fig 3: Life stages of the Antarctic silverfish (Pleuragramma antarticum).(a) Adult, (b) egg with embryo and (c) newly hatched larva (La Mesa and Eastman 2012)

Larvae can hatch from November until December. As larvae grow into juveniles they are slowly transported to offshore waters which is where *P. antarcticum* starts to differentiate through the water column and horizontally. This result in decrease in cannibalism and competition for resources (La Mesa et al. 2010, Rodgers 2016). The competition for food is also reduced by different life stages having different diets. In the second year lipid deposits grow and juveniles recruit to the adult population between the ages of 3-5 years. They have a low growth rate which allows them to feed on mesozooplankton, and direct most of the energy into reproduction, antifreeze and lipid production (Hubold & Tomo 1989, Rodgers 2016). They sexual mature at age of 7-9 years old. They can live until they are 21-35 years old (Hubold & Tomo 1989, Moline et al. 2008, Rodgers 2016). In Fig. 4 the length frequency distribution by sex can be observed.

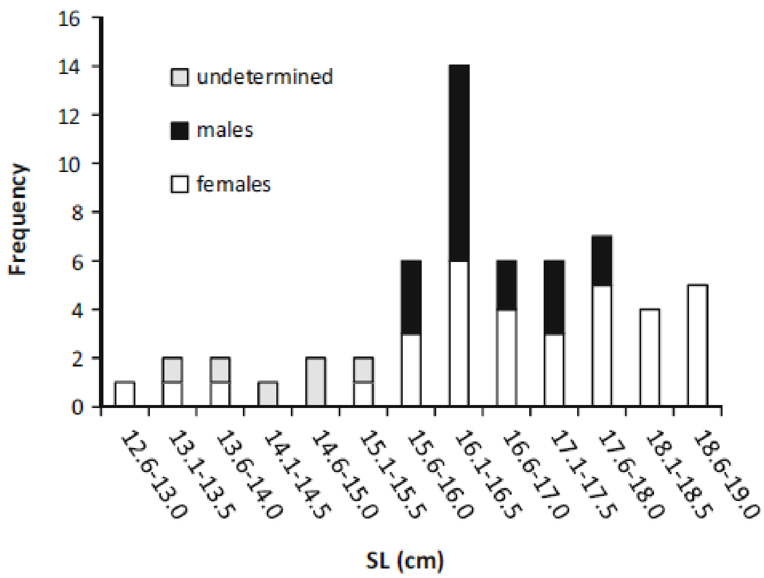


Fig 4: Length frequency distribution of the Antarctic silverfish sample by sex (Ghigliotti et al. 2017)

Evolving from benthic to pelagic waters

The Antarctic silverfish acts like a link between the plankton and the predators due to its high abundance and distribution (La Mesa & Eastman 2012, Rodgers 2016). The current stock status of the total population is unknown. There is no interest on commercial fishery for *P. antarcticum*. The only time that fishing of *P. antarcticum* was listed has been the 1980's by Soviet Union vessels (Kock 2007, Rodgers 2016).

The suborder Nototheniodei are primarily benthic species. *P. antarcticum* evolved from benthic and has evolved to specialize in the Antarctic pelagic waters. Adapting to the pelagic zone meant that *P. antarcticum* had to utilize the adaptations associated with Notothenioids with more specialized adaptations (Wöhrmann et al. 1997, Rodgers 2016). This evolution provided *P. antarcticum* with abundant food sources with little competition (La Mesa & Eastman 2012, Rodgers 2016). In order to successfully evolve to pelagic waters *P. antarcticum* developed a plethora of adaptations such as buoyancy (La Mesa & Eastman 2012, Rodgers 2016). *P. antarcticum* is close to neutral buoyancy, despite not having a swim bladder. This is achieved by reducing skeletal ossification and retention of cartilage and accumulation of lipids (La Mesa & Eastman 2012, Rodgers 2016). *P. antarcticum* is very lipid rich, the amount of lipids increases with the length of individuals. Eastman and DeVries (1989) suggested that the lipid sacs acts like a buoyancy mechanism due to the low cell membrane surface area compared to the volume of the sacs (Rodgers 2016). *P. antarcticum* has many physiological features to suggest limited activity, such as a small amount of red muscle compared to other aerobic species (Rodgers 2016). The neutral buoyancy allows the *P. antarcticum* to use a similar feeding style to benthic species and allows them to conserve energy (La Mesa & Eastman 2012, Wöhrmann et al. 1997, Rodgers 2016). La Mesa & Eastman (2012) described *P. antarcticum* as an "ecological and physiological paradox, being a pelagic water column species with an inactive energy-conserving lifestyle" (La Mesa & Eastman 2012, Rodgers 2016).

Adaptations to environmental conditions

To cope with intense environmental conditions, Antarctic silverfish has developed a number of biochemical and physiological adaptations (Wöhrmann et al. 1997, Rodgers 2016). In order to survive in the cold waters of Antarctica *P. antarcticum* has antifreeze glycopeptides. Those glycopeptides protect *P. antarcticum* by lowering the freezing point of the body to below the freezing point for sea water (-1.9oC) (La Mesa & Eastman 2012, Rodgers 2016). Specifically, *P. antarcticum* also has a unique 'Pleuragramma antifreeze glycopeptide', which has a different carbohydrate and amino acid composition (Andreas Wöhrmann 1995, Rodgers 2016). The presence of the two antifreeze compounds varies between life stages, with adults and post larvae having the highest concentrations as they inhabit the coldest waters (La Mesa & Eastman 2012, Rodgers 2016). The early larval stages employ a barrier mechanism to prevent freezing and they are described as having low levels of antifreeze. (La Mesa & Eastman 2012, Wöhrmann et al. 1997, Rodgers 2016).

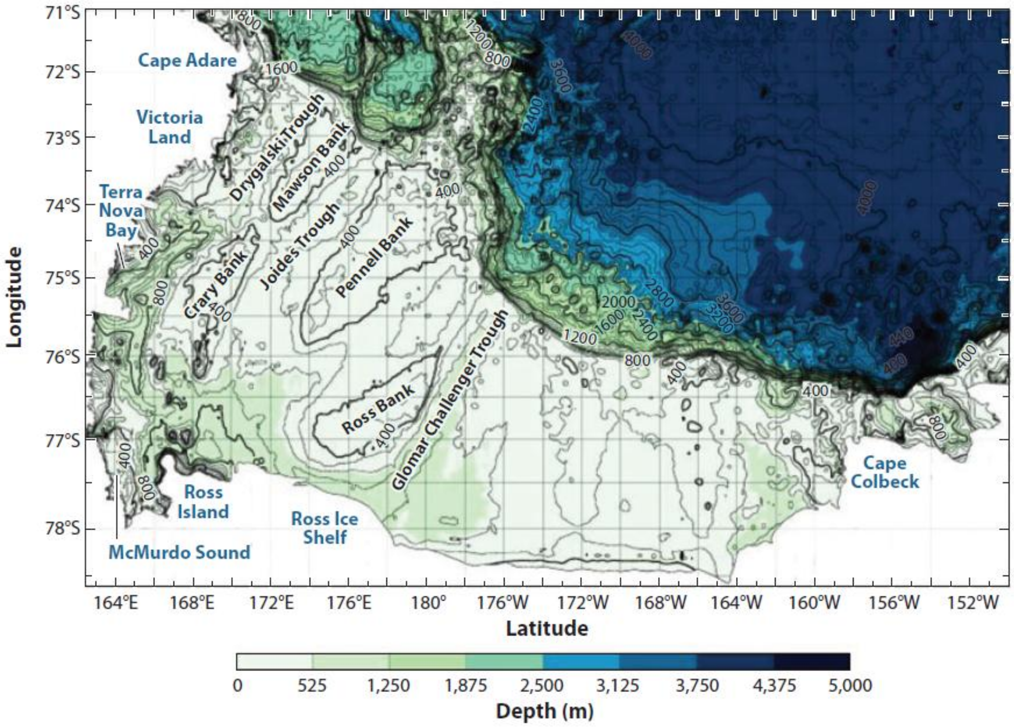
The Ross Sea

The Ross Sea (Fig. 5) is a deep bay in the Southern Ocean in Antarctica. It is located between Victoria Land and Marie Byrd Land and within the Ross Embayment. The Ross Sea is named after the British explorer James Ross who visited this area in 1841.

Fig 5: Antarctica: Location of the Ross Sea

A low number of trophic relationships between species and key-species characterize Antarctic food webs and therefore they are considered very fragile and poorly resilient (Corsolini et al. 2017). The Ross Sea specifically is characterized by a remarkably large number of marine predators, such as marine birds and mammals that feed on a limited number of preys (Ballard et al. 2012, Corsolini et al. 2017). The Ross Sea was established as a Marine Protected Area (MPA) in 2016 due to its distinctive habitat and interactions between the species and the peculiar ecosystem integrity (Ballard et al. 2012, CCAMLR 2016, Corsolini et al. 2017).

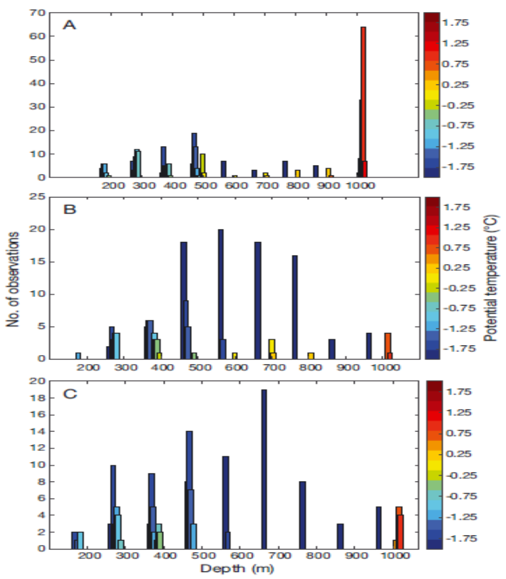
Fig 6: Bathymetric map of the Ross Sea. Based on the ETOPO1 bathymetry, with a contour interval of 100m (Smith Jr. et al. 2014)



Ross Sea's Food webs

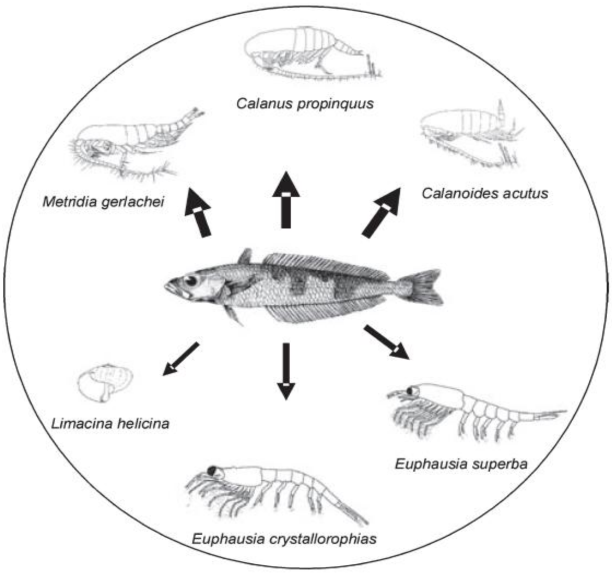
A diverse food web can be found in the Ross Sea (Pinkerton et al. 2010, Ballard et al. 2012, Smith et al. 2012, Davis et al. 2017). It consists of two species of krill, the Antarctic *Euphausia superba* and crystal *Euphausia crystallorophias* and the fish species, Antarctic silverfish *Pleuragramma antarcticum*. Those three species comprise the majority of the mid-trophic level biomass in the Ross Sea (Daly & Macaulay 1988, Ainley et al. 2006, Smith et al. 2007, Pinkerton et al. 2010, Davis et al. 2017). In Fig. 7, the histograms show the distribution of (A) Antarctic krill, (B) crystal krill and (C) Antarctic silverfish in different depths.

Fig 7: Frequency distribution of (A) Antarctic krill, (B) crystal krill and (C) Antarctic silverfish (Davis et al. 2017)



Predators such as penguins, seals, cetaceans and fish can be also found in the Ross Sea. Below, I will be presenting the trophic cascades in the western part of the Ross Sea. Adelie penguins feed on the egg stage of the breeding cycle of the crystal krill (Ainley 2002b, Ainley et al. 2006), while silverfish (Fig. 8) feed on larger krill (DeWitt and Hopkins 1977, Eastman 1985, Ainley et al. 2006). Minke whales feed on krill (Ainley et al. 2003, Ichii et al. 1998, Ainley et al. 2006) while killer whales feed on toothfish and silverfish. Toothfish also feed on silverfish (Eastman 1985, Ainley et al. 2006).

Fig 8: Main prey in the diet of adult specimens of the Antarctic silverfish (La Mesa and Eastman 2012**)**



Penguins and minke whales reduce krill. When the krill population is significantly reduced, penguins, minke whales and the killer whales, begin to feed on silverfish (Ainley et al. 2003; Ichii et al. 1998, Ainley et al. 2006). The older age classes of silverfish begin to feed on younger silverfish (Eastman 1985, Ainley et al. 2006). Year 0 silverfish is also preyed upon by penguins and seals (Ainleyetal.2003, Burnsetal.1998, Ainley et al. 2006). When silverfish availability declines, penguins begin foraging in different areas, both horizontally (Ainley et al. 2004, Ainley et al. 2006) or they dive deeper (G. Ballard and D. G. Ainley, unpublished data). Minke whales are also foraging elsewhere (Brodie et al. 1978, Piatt and Methven 1992, Ainley et al. 2006). As penguins and killer whales reduce fish density below that needed for efficient foraging, the whales depart the area.

There have been many observations that the presence of those predators, whales and penguins, can modify the availability of prey in the western Ross Sea. There are 17 penguin colonies in the western part of the Ross Sea (Woehler 1993, Ainley et al. 2006). Abundance of minke and killer whales is observed, particularly within the pack ice of the western Ross Sea (Thomas et al. 1981, Ainley 1985; see also Ichii et al. 1998, Pitman 2004, Ainley et al. 2006). Furthermore, the diatom community in the western Ross Sea is ungrazed (Arrigo et al. 2003, Ainley et al. 2006). This observation can be explained by the absence of grazers such as krill by the predators. Researchers have also noticed cannibalistic behavior amongst silverfish in the southwest Ross Sea during late summer due to predators feeding on krill at the same time (DeWitt and Hopkins 1977, Eastman 1985, Ainley et al. 2006). Ainley et al. (2006) proposed a different hypothesis. They suggested that the diet shift could occur due to climatic changes in sea-ice cover. Those changes can have an impact on the availability of crystal krill (Ainley et al. 2003, Ainley et al. 2006).

Any changes in the availability of those three key species can ultimately affect all trophic levels. (Laws 1985, Kellermann 1986b, Daly & Macaulay 1988, Davis et al. 2017).

There have been multiple studies investigating the relationship between krill and different environmental variables (Witek et al. 1981, Weber et al. 1986, Siegel 2005, Atkinson et al. 2008, Murphy et al. 2017, Davis et al. 2017). However, it is unknown if these relationships are stable through different areas and through time. A complete understanding of the factors that affect krill and Antarctic silverfish distribution will allow estimations on how changes in environmental conditions can influence distribution (Smith et al. 2014b, Davis et al. 2017).

Discussion

Climate change effects

Although the Ross Sea has remained unimpacted by direct human effects such as fishing, changes in atmospheric composition (stratospheric ozone and greenhouse gases) have impacted the area (Smith Jr et al. 2014). The altered atmospheric composition leads to changes in winds and altered temperatures. Furthermore, sea ice concentrations have significantly increased in the Ross Sea and are responsible for the increase in ice concentrations found over the entire Southern Ocean (Smith Jr et al. 2014). A consequence of the increased ice concentrations is the decrease of open ice season by two months in the Ross Sea. The circulation of the Ross Sea is controlled largely by bathymetry. Freshening of waters is possibly occurring due to low-salinity water from the east. A large range in temperature influences the formation of dense water. The Ross Sea is characterized by high productivity, making it an important regional carbon sink. In the summer the productivity is influenced by iron input and availability (Smith Jr et al. 2014).

Changes in temperatures and the ozone hole are estimated to result in changes in the Ross Sea. The atmospheric temperature at the Ross Sea is projected to rise by 3^{o}C by 2100. The changes in air temperatures, winds, freshwater inputs, and amounts of offshore heat inputs will likely reduce summer ice cover. The changes will result in altered phytoplankton composition and production, changes in krill availability, and modified predator abundance and reproductive success (Smith Jr et al. 2014).

The environmental changes due to climate change in the Southern Ocean have been recorded in sea ice decline, temperature rise and ocean acidification (Flores et al. 2012, Rodgers 2016). Casini et al. (2008) stated that the impacts of climate change could have devastating effects to upper and lower trophic levels (Rodgers 2016).

The effects of climate change on *P. antarcticum* will not be expressed evenly throughout the Southern Ocean, and there has been significant regional variation in sea ice extent. The formation and duration of sea ice is dependent on the oceanic and climatic condition, these processes display annual variation and long term variation due to climate change. For example in the Ross Sea sea ice is increasing by 5% per decade, while in the west Antarctic ice extent is decreasing by around 7% per decade (Kwok & Comiso 2002, Turner et al. 2009, Rodgers 2016). *P. antarcticum* early life stages are closely linked to sea ice cover (Vacchi et al. 2004, Rodgers 2016), which makes this vulnerable life stages very sensitive to the changes in sea ice extent and timing. The timing and extent of coastal polynyas of the Ross Sea and Weddell Sea could affect the abundance and size of *P. antarcticum* larvae (La Mesa et al. 2010, La Mesa & Eastman 2012, Rodgers 2016), as the reproductive cycle is linked to seasonal zooplankton production which is strongly influenced by the timing and extent of coastal polynyas (La Mesa & Eastman 2012, Rodgers 2016).

The mid-waters of the Southern Ocean (to depths of 1000 m) have warmed more rapidly than other waters of similar depths around the world since the 1950's (Gille 2002, Rodgers 2016). Antarctic krill decline, as well as the decline of seabirds and seals has been linked to the warming of the Southern Ocean (Gille 2002, Rodgers 2016).The increased ocean temperatures will likely directly affect *P. antarcticum* since it has adapted to low, stable temperatures. They can also affect indirectly through the food chain, such as the changes to the abundance of Antarctic krill. Polar ecosystems are thought to be much slower to respond to environmental changes generally (Smith et al. 2007, Rodgers 2016).

La Mesa et al. (2015) found during their study in the West Antarctic that when sampling they were unable to find *P. antarcticum* in areas where they were historically abundant. They suggested that this population fragmentation was a result of rapid change in the shelf system, as the west Antarctic has already experienced declines in sea ice and rapidly warming water. Due to the recent declines in P*. antarcticum* population, predators have replaced them with other fish species such as myctophids (Moline et al. 2008, Rodgers 2016).

Climate change could impact *P. antarcticum* indirectly, through the food chain interactions. Phytoplankton is thought to change in abundance and composition of species which will impact on the whole Antarctic food web, as it relies on the abundance of primary production (Pinkerton & Bradford-Grieve, 2014). Phytoplankton have been reported in one study as a food source for early larvae but more research is needed to understand the importance of phytoplankton to *P. antarcticum* (Koubbi et al, 2007, Rodgers 2016).

Climate change is likely to impact on *P. antarcticum* in a number of ways, however the resilience of *P. antarcticum* could be enhanced by having such a high fecundity (Rodgers 2016).

Effects of commercial fishing

Antarctic silverfish is affected by the commercial fishing of its food source, krill and predators, toothfish.

The krill fishery catches have increased over recent years, this combined with krill being effected by climate change, are thought to have resulted in a population decrease (Flores et al. 2012, Rodgers 2016). The decrease in the abundance of krill as a food source could negatively impact *P. antarcticum*, but due to the plasticity of feeding (mentioned earlier) the decrease in this prey species may not be as detrimental (Rodgers 2016).

Antarctic toothfish are a top marine predator in the Antarctic marine food web. A significant decrease in Antarctic toothfish population could release *P. antarcticum* of a significant predator pressure. However, (Pinkerton & Bradford-Grieve, 2014) found that toothfish did not have a high trophic importance using their modelling system. So the top down effect on *P. antarcticum* may not be large (Rodgers 2016).

The life histories of *P. antarcticum* (delayed sexual maturity, long life span, high mortality rates and low productivity) mean that any commercial harvesting needs to be very well managed, as this species would be very vulnerable to overfishing (La Mesa & Eastman 2012, Rodgers 2016). The importance in the food chain means that this species needs to be very well managed if there was ever a fisheries established.

P. antarcticum plays an important role in the Antarctic food chain, due to its abundance and circumpolar distribution. *P. antarcticum* demonstrates wide predation plasticity and can switch between preferred prey species, with the main prey type being mesozooplankton (Rodgers 2016). The preferred prey species changes between different locations and displays seasonal differences. La Mesa et al. (2010) found that Antarctic krill were the primary food source for *P. antarcticum* in the northern area of the Ross Sea, while ice krill were the primary food source for species living inside the Ross Sea (Rodgers 2016).

The preferred prey species also varies during life stages, presumably due to the vertical separation of life stages, which reduces intra-specific competition. For example Pinkerton et al. (2013) found that post larval *P. antarcticum* in the Ross Sea fed predominantly on copepods, as did juveniles. For adults, copepods were a minor prey species in terms of mass, while fish were an important prey type which increased in importance with the length of *P. antarcticum* (Rodgers 2016).

P. antarcticum are prey for a number of species including fish, marine mammals and birds in the Antarctic food chain (Pinkerton et al. 2013, Rodgers 2016). In the Ross Sea where *P. antarcticum* makes up 90% of the mid-water fish biomass (Smith, Ainley, & Cattaneo-Vietti 2007, Rodgers 2016), most top predators in this area feed on *P. antarcticum*. They are a prey species for petrels, Adelie and Emperor penguins, Weddell seals, Antarctic toothfish and other fish, Minke whales and Orca (Smith et al. 2007, Rodgers 2016). For example a study on Weddell seals found that *P. antarcticum* contributed between 70-100% of their diet (Burns, Trumble, Castellini, & Testa 1998, Rodgers 2016) and a study on a population of Emperor penguins found that *P. antarcticum* made up 95-100% of the fish component of their diet (Cherel & Kooyman 1998, Rodgers 2016).

Ainley et al. (2015) hypothesise that the predators such as whales and penguins regulate the prey (such as *P. antarcticum* and krill) vertical distribution and the abundance, which then reduces their impact on their prey species. This hypothesis is for the Ross Sea, where they describe the food chain as 'wasp-waisted' in that there is an abundance of top predators and primary production, but a relatively smaller abundance of mid-trophic level species such as *P. antarcticum* (Rodgers 2016).

P. antarcticum are a critical trophic link in the Antarctic food chain and are considered a keystone species (Ghigliotti et al. 2016, Rodgers 2016), creating a significant ecological importance to the Antarctic marine ecosystem. They channel the majority of primary production to the upper trophic levels. The high abundance of *P. antarcticum* significantly impacts the species they are predating on. Many species that utilize *P. antarcticum* as a prey source heavily rely on it either year round or at certain times of the year. In the Ross Sea based on Pinkerton and Bradford-Grieve (2014) quantitative food web model, *P. antarcticum* had a high trophic importance in the Ross Sea ecosystem along with two other species types (mesozooplankton and small demersal fish). Due to the importance of *P. antarcticum* in the trophic system, research such as the impacts of climate change and other effects should be a priority (Pinkerton & Bradford-Grieve, 2014, Rodgers 2016).

Conclusion

P. antarcticum have adjusted through stable natural conditions to use the pelagic zone, which is one of a kind for a species in the suborder Notothenioidei. The life stages of *P. antarcticum* are fascinating because of vertical and horizontal division of life stages. *P. antarcticum* assume a significant job in the Antarctic marine biological system as they are fundamental piece of the food webs (Rodgers 2016).

Because of the dependence on ocean ice in the early life stages (egg and larval stages) *P. antarcticum* are sensitive to changes in the ocean ice cover and timing. The progressions to the sea ice because of climate change will influence these life stages. So far sea ice changes has not been steady and all things considered, the effect to *P. antarcticum* will be variable (Rodgers 2016).

Understanding the environmental change that will happen because of anthropogenic effects on the Antarctic marine biological system is significant, as they react to environmental change and the expanded pressure from fisheries (krill and Antarctic silverfish). Future research should be centered on how *P. antarcticum* will be affected from both these pressures, and what this will mean for the food webs. The stock status should be built up, as without a population status it will make it hard to recognize and demonstrate population changes. Any adjustments in the abundance or distribution will probably impact the species that rely upon *P. antarcticum* as a food source, and the species that *P. antarcticum* predate upon (Rodgers 2016).

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