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***Climate change direct effects on Antarctic fish and indirect effects on ecosystems and fisheries management***

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Abstract/executive summary (ca. 200 words):

Climate change has direct effects on the physiology of Antarctic fish. These polar fish, predominantly from *Notothenioidei*, are well adapted for the stable, cold environmental conditions of the Southern Ocean. Physiological adaptations include antifreeze glycoprotein (AFGP) and a narrow tolerance to temperature change. Climate change does not impact evenly around Antarctica, in areas of warming there are predicted negative effects on fish stock and survivability, habitats and indirectly ecosystems. In turn fisheries and their management must also take into account the direct impacts on the Antarctic fish they harvest. This critical review identifies specific areas of weakness of fish species, habitats and the Antarctic marine ecosystem. Whilst also identifying current fisheries issues that need to be addressed due to the direct influences on the Antarctic fish.

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## Introduction

Fisheries in the Southern Ocean are the longest continuous human activity in Antarctica and have had the greatest effect on the ecosystem up to this point (Croxall & Nicol, 2004). Now we are seeing the effects climate change is having on its ecosystem and fish, identifying it now as the current and future threat to them. Marine systems are changing due to changes in the environment, in particular climate change, but also recovery of stocks and current exploitation impacts (Croxall & Nicol, 2004). The increasing carbon emissions and warming of the oceans, such as the Southern Ocean, influence the spatial range in which marine fish can survive. Fish living in the Antarctic environment are exposed to a relatively stable environment temperature and are specialised to live in the cold. There are multiple studies confirming that there is a change in spatial ranges of marine fish with warmer temperatures, this is likely to be due to the impact of water temperatures and compositions on the physiological functions of these cold water fish (Peck et al., 2004, Portner et al., 2008, Tomanek 2008). They need to maintain internal temperatures for body functions to work and temperature changes in the environment make this difficult for the cold water fish. Comparing papers on the physiological limits of fish and the possibility of adaptations will enable future predictions of the influences of climate change on the fish. This in turn can be applied to ecosystem functioning, fisheries and management. An example of this if stocks decline or move to colder waters they may influence prey and predator stocks and behaviours in the new areas (Rolland et al., 2010), with further flow on effects to fisheries in regards to their catch sizes (Plaganyi et al., 2011) and management (Trathan & Agnew, 2010) that may need to adapt in response.

Examples of some of the impacts of climate change include warmer water temperatures, increased ocean pH and changing ocean ion compositions. Colder water holds more oxygen, which is an integral supply for the fish in the Antarctic cold waters. As waters warm, fish may need to migrate into cooler water further south and towards the continent. They already have a small distribution, any heat induced damage may affect the organism's organs and cell function, affecting chances for survival of the species. Atmospheric carbon dioxide levels are increasing and effects the oceans pH levels, this occurs as increased atmospheric amounts that are taken into the ocean through phytoplankton. With more carbon dioxide in the water the pH changes, making it more acidic, and it may reach lethal limits preventing physiological functions with cells and organs.

In this critical review the focus is on the direct impacts of climate change on the physiology of Antarctic fish. Further influences of climate change will be mentioned, such as habitat change. These effects of climate change also have indirect effects through ecosystem changes, which flow on to influence the fisheries and their management. As the environment changes there needs to be adaptation not only from the marine life but also the anthropogenic element, with fisheries having to approach the ecosystem with greater understanding and management.

## Climate change

Future climate predictions are highly uncertain for the Southern Ocean (Plaganyi et al., 2011). The International Panel on Climate Change (IPCC) has current models and trends of climate change, identifying the greatest long term threat to poles as climate change due to impacts such as sea ice change from atmospheric and ocean changes, although this spatially variable (IPCC, 2007). An example of this is that warming is more pronounced in the Peninsula region then elsewhere in Antarctic (Moline et al., 2008). Ocean acidification is a concern for marine ecosystems (IPCC, 2007) where models suggest seawater pH is decreasing becoming more acidic due to increased atmospheric carbon dioxide levels, however there is no solid Antarctic data yet. The South Annular mode (SAM) is a climate driver in the Southern Ocean and with a change from being negative to

becoming more positive an increase in fish length was identified, showing greater fitness (Ainley et al., 2013). This means increased winds from the south in the Ross Sea which extends the area of sea ice (Ainley et al., 2013), and persistence of coastal polynyas influencing Ross Sea processes (Jacobs et al., 2002). In comparison increased temperature causes decreased sea ice on the coastal West Antarctic, which also influences changes in frequency and intensity of cyclones below 40 degrees south (Barbraud et al., 2012). This change in the SAM coincides with the ozone hole, another climatic driver (Turner et al., 2005).

Habitat decreases occur as increased temperatures cause disintegration of sea ice, glaciers and ice shelves. Sea ice is present year round but coverage is seasonal,  $4 \times 10^6$  km<sup>2</sup> in summer and  $20 \times 10^6$  km<sup>2</sup> winter (Zwally et al., 1983). Sea ice is decreasing in the Bellingshausen Sea and an increase in the Ross Sea (Kawaguchi et al., 2013, Nicol & Allison, 1983). Sea ice and temperature are variable between years and areas. There is no evidence over the whole continent that sea ice extent has decreased (Zwally et al., 1983). Warming on the Peninsula is leading to the disintegration of the Wordie and Larsen Ice shelves (Vaughan et al., 2003). Scouring and calving increase leads to seafloor habitat destruction. There have been few data collections that suggest any temperature change in the Southern Ocean, they were from isolated observations making trends very hard (Clarke & Harris, 2003). Sea surface temperatures increased in the Peninsula area by approximately 3°C in 50 years (Turner et al., 2005). Winter temperatures increased by 5-6°C (Vaughan et al., 2003). Indication of warming trends deep in the Ross and Weddell seas (Ozaki et al., 2009, Robertson et al., 2002). A study by Gille (2002) using data from Autonomous Lagrangian Circulation Explore floats indicated an increase of 0.17°C from shipboard vertical temperatures profiles 1950s and those in 80s between 700-1000m, showing that the Antarctic Circumpolar current increased more than the global ocean increase.

In the Arctic the North Atlantic Oscillation (NAO) and ENSO influence cod stocks. There is a range contraction and movement of stock when there is a decrease in water temperature and increase in ice extent (Portner et al., 2008). Although NAO is a large scale variation in climate its effects vary spatially and temporally, as SAM does in the Antarctic. Wind stress alters the ice formation, effecting the salinity of the upper ocean and advective flows. This influences circulation, larval dispersal, while also changing recruitment stock exchanges and therefore catch size. Similar influences are likely to be seen with the effects of these climatic changes in Antarctica. Fish are impacted by both direct and indirect effects of climate change. Direct impacts include increased temperature, decreased salinity and an increase in carbon dioxide influencing physiology capabilities (Mintenbeck et al., 2012). Indirect effects include changes in food webs, changes in habitats as sea ice decreases and increased ice scouring on the seafloor. Now we will be discussed these impacts of climate change on the Antarctic fish, Antarctic ecosystems and the fisheries management.

#### Antarctic Fish

The Southern Ocean has 320 species of fish and 50 families (Eastman 2005). It is unique as it has a highly endemic fish fauna 88% (Eastman 2005) and communities are dominated by one taxonomic group, *Notothenioidei*, which account for 35% of Antarctic fish species (Eastman 1993). Non *Notothenioidei* fish species are deep sea groups such as *zoarcids*, *liparids*, *macrourids* and *myctophids* (Mintenbeck et al., 2012). Most *Notothenioidei* species are described into five families; *Notothenidae*, *Channichthyidae*, *Artedidraconidae*, *Bathydraconidae* and *Harpagiferidae*. Both demersal and pelagic fish communities are dominated by Antarctic silver fish *Pleuragramma antarcticum* (Mintenbeck et al., 2012). Sexual maturity is delayed in most species, reaching it at approximately 50-80% of their maximum age and size (Kock & Everson, 1998). Most, if not all, *Notothenioidei* larvae are pelagic and are exposed to the conditions of the Southern Ocean. A big

factor in the survival of these Antarctic species is recruitment, these early developmental stages are highly sensitive to the effects of climate change.

Consistent water temperature of the Southern Ocean supported evolution of stenothermal animal life (Somero et al., 1986). Making these species more temperature sensitive as they have a narrow thermal window due to the cold adaptations they have accumulated (Somero et al., 1986). An adaptation of *Notothenioid* fish is antifreeze glycoproteins (AFGP), protecting the freezing of hypoosmotic body fluids as they adhere to each other and block ice crystal growth (DeVries 1971, Fletcher et al., 2001). AFGP concentrations differ among; species, temperature, depth, life cycle and activity (Mintenbeck et al., 2012). Temperature dependence on the viscosity of their body fluids means that increased viscosity occurs when there is a decrease in temperature (Hochachka & Somero, 2002). Cell membrane fluidity is maintained by a homeoviscous adaptation, where they have increased unsaturated fatty acids and specific membrane phospholipids (Eastman 1993). Blood viscosity increase is offset by a decrease in haematocrit and haemoglobin concentrations (Egginton 1996, Egginton 1997). Examples of species that have decreased haematocrit are *Notothenidei corriceps* and *Notothenidei rossi* from around the Peninsula (Beers & Sidell, 2011). The reason this is beneficial and not detrimental to aerobic performance is because there is low metabolic demands and an increase in physical oxygen solubility at cold temperatures.

Icefishes lack functional red blood cells, they have no haemoglobin in their blood (Montgomery & Clements, 2000). Instead they have increased; ventricle size, blood volume, cardiac output and skin vascularity (OBrien & Sidell, 2000, OBrien et al., 2003). Di Prisco (2000) tested the lack of haemoglobin and ability to uptake oxygen, in a carbon monoxide poisoned *T.bernacchii* it was found that carbon dioxide binds to haemoglobin with greater affinity than oxygen. The organism still survived so this suggests the cold stable environment means haemoglobin is not necessary for oxygen transport and it is possible to rely on oxygen physically dissolved in the blood. These metabolic adaptations help with the negative impacts of temperature and viscosity on enzymes and this counterbalances diffusion. The increased quantities and capacities of intracellular enzymes, decreased diffusion distance and an increased efficiency (Crockett & Sidell, 1990, Portner et al., 2008). The second is the mitochondrial proliferation, where there is increased abundance and ultra structural density (Guderley & Johnston, 1996). The rate of oxygen delivery to aerobic muscle fibres is a function of the fibre diameter together with factors that affect diffusion rate, such as temperature, distribution of mitochondria and lipid within the fibre as well as the metabolic demand (Guderley & Johnston, 1996). For large diameter muscle fibres to receive enough oxygen is probably only possible because of the low metabolism demand in Antarctic fishes in their low temperature environment (Clarke and Johnston 1996).

*Notothenioides* lack a swim bladder (Eastman & DeVries 1981), some of their skeleton is changed to cartilage which decreases their density therefore decreasing their weight (Eastman & DeVries 1981, Eastman & DeVries 1985). Very few species have neutral buoyancy such as *D.mawsoni*, *Aethotaxis mitopteuux* and *P. antarcticum* (Eastman 2005). Intracellular lipids are in high concentration for energy storage (Crockett & Sidell, 1990), gas diffusion and play a role in buoyancy. Increasing lipids means increased buoyancy, this is important metabolic fuel for aerobic respiration (Sidell et al., 1997). Lipids also have chemical properties that may increase oxygen flux through the cell, this may be crucial to Antarctic fish that lack or have very low concentrations of myoglobin (Sidell et al., 1997). *D.mawsoni* has lipid deposits in adipose cells, these make up approximately 23% of white muscle dry weight and are mainly triglycerols (Eastman & DeVries, 1981). These adaptations to their stable, cold environment allow the success of the Antarctic fish species but also limit them to adapt to

environmental changes. With all of these adaptations Antarctic fish have a narrow thermal tolerance making them vulnerable to climate change effects (Mueller et al 2011).

#### Direct effects on fish

The size, activity level and habitat of an organism impact their thermal tolerance with smaller individuals being more tolerable to thermal change (Somero 2010). The upper lethal limit of bottom dwelling *Teratomus* (species *T. bernachii*, *T. hansonii*, *T. pennellii*) is between 4-6°C (Somero & DeVries, 1967). Few species compensate exposure to high temperatures through long term warm acclimation. An example of a species that can acclimate is *P. borchgrevinki* which was acclimated to 4°C, this resulted in a shift of its thermal tolerance window (Robinson & Davison, 2008) by metabolic compensation (Seebacher et al., 2005). Long term warm acclimation of the Antarctic eelpout *Pachyura brachycephalum* involves metabolism rearrangements (Lanning et al., 2005). It includes improvement of hepatic metabolism and a shift of energy sources from lipids to carbs (Brodte et al., 2006). This acclimation is not across all species and does not completely compensate for the increase in temperature (Mintenbeck et al., 2012).

Beers and Sidell (2011) assessed the thermal tolerance of white and red blooded Antarctic *Notothenioidei* fishes. They did this by finding the organism's critical thermal maximum which was defined to be the temperature at which the animals lost their righting response. The white blooded icefish *Chionodraco rastrospinosus* and *Chaenocephalus aceratus* had significantly lower thermal tolerance than the red blooded *Gobionotothen gibberifrons* and *Notothenioidei coriiceps*. The lowest red blooded *Nototehnioidei* fish was *Lepidonotothen squamifrons*, as it has low haematocrit. The critical thermal maximum and haematocrit levels had a strong correlation, as oxygen carrying capacity in the blood influences the lethal temperature. Icefish (family *Channichthyidae*) are more sensitive to temperature increasing due to the fact that they lack haemoglobin (Sidell et al., 1997). Icefish are large, have extensive vasculatures, greater blood volume, larger hearts and numerous cardiac mitochondria's compared to similar sized red blooded *Notothenioidei* (Sidell et al, 1997). Low metabolic rates in well oxygenated waters mean that there is enough supply of oxygen to survive without haemoglobin and/or myoglobin. An increase in temperature leads to an energetic shift in cellular processes, such as an increase in resting metabolic rate (Enzor et al). Species with low or no haemoglobin have less capacity to adjust their haematocrit. As environmental temperature increases oxygen demand also increases, organisms therefore must increase oxygen consumption otherwise their tissue may become hypoxic (Enzor et al). Studies on non Antarctic fish show full compensation of increased oxygen demand at mitochondrial level after warm acclimation occurred (Dahlhoff & Somero, 1993). But there are limitations of mitochondrial acclimation especially in Antarctic fishes (Mark et al., 2006). Icefishes will be increasingly more vulnerable to warming than red blooded species as they cannot increase the oxygen carrying capacity of their blood (Mintenbeck et al., 2012). Antarctic fishes with increased haematocrit levels then possess a greater temperature acclamatory capacity than species with lower levels (Beers & Sidell, 2011). Icefishes and *P. antarcticum* are both the most vulnerable to temperature change (Mintenbeck et al., 2012).

Increased carbon dioxide effects across many fish species (Ishimatsu et al., 2005). An increase of carbon dioxide can cause a decrease in hatch rate and delayed embryonic development (Kawaguchi et al., 2013). Elevated carbon dioxide environment means that fish spend more energy of physiological responses such as acid base regulation and ventilation rates (Ishimatsu et al., 2005). Energy spent on acid base regulation is likely being taken away from energy that would be put on growth and reproduction (Portner et al, 2008). Salinity changes that effect directly on Antarctic fish species are rare (Mintenbeck et al., 2012). OGrady and DeVries (1982) researched the capacity of osmoregulation of adult organisms of *P. borchgrevinki* and *Trematomus* species at salinities between

25-200% of the natural salinity which is 35 psu. The results identified a tolerance between 50-175% of normal salinity. Salinity does not appear to be of great concern for its direct effect on Antarctic fish species, especially in comparison to temperature and other changing factors. Almost all physiological sensitivity tests of *Notothenioidei* fish with changing abiotic pressures have been on adults. Testing has not been thoroughly completed on the most sensitive stages of their life history, such as larval and hatching stages.

#### Ecosystem effects

The Southern Ocean food web is complex and non linear. Fish are important in the food web as they are a trophic link connecting small invertebrates to top predators (Mintenbeck et al., 2012). Species survival is usually determined by changes in balance of ecological factors and direct effects of alterations to the physical environment (Mintenbeck et al., 2012). *P.borchgrevinki* are adapted for cryopelagic life (Eastman & DeVries., 1985), such as hiding in crevices (Davis et al., 1999). Sea ice gives refuge, habitat and feeding availability of copepods (Davis et al., 1999). *P.antarcticum* uses sea ice for feeding (seen by Daniels 1982), also for spawning (La Mesa & Eastman, 2012) even though it usually occurs in the water column. It is the only *Notothenioidei* species that has all life stages in the water column, it also comprises 90% of the local fish communities in numbers and biomass in the Ross and Weddell Seas (Mintenbeck et al., 2012). In the Weddell Sea they mainly feed on copepods, ice krill, amphipods and euphausiids. The immature fish prefer copepods and mature fish euphausiids, this helps to mitigate food competition (La Mesa & Eastman, 2012). In the Ross Sea population they eat mainly krill (La Mesa & Eastman, 2012), this shows that they change diets to what is available in their habitat. Their eggs float freely into the platelet ice under sea ice cover which decreases the risk of predation (La Mesa & Eastman, 2012). A decrease in silverfish in other locations has seen an increase in myctophid fish that replace them (Moline et al., 2008).

As habitats are effected and temperatures warm range shifts are likely to occur as have been seen already by Peck et al (2004) and Portner et al (2008). Range shifts are limited by the habitat in which each species can survive in. Composition of demersal fish faunal differs between recently disturbed and undisturbed sites, with increased species and diversity occurring in undisturbed sites. *T.scotti*, *C.antarcticus* and *Pagetopsis maculatus* are typical in undisturbed habitats (Mintenbeck et al., 2012). *T. pennellii*, *T. Nicolai* and *Prionodraco evensii* are specialized for survival in disturbed sites. Structurally different habitats allow coexistence of trophically similar species (Brenner et al., 2001). Decreased habitat and heterogeneity means a decreased habitat, refuge for demersal fish (Moreno et al., 1982) and increased predator risk at all development stages. Decreased habitat diversity means increased competition for overlapping niches, currently not occurring by present disturbance levels (Brenner et al., 2001). To follow the colder temperatures species will continue to move further towards the continent, decreasing the spatial variation between species leading to increased competition for resources (Rolland et al., 2010). Increased disturbance levels along with temperature change mean an increase in future loss of species diversity.

Prey change effects the energy content of a fish, such as changes from diatoms to cryophytes which is a size shift and decrease in nutrient value (Gili et al., 2006). ). Salinity and surface water stratify, creating a depth mixed layer determining phytoplankton composition. Large diatoms moved to small cryophytes as salinity decreases on the Peninsula (Moline et al., 2004). Also seen in the Arctic is the community structure change as a decrease in krill in South West lead to an increase in salps (Atkinson et al., 2004), ultimately altering the structure of food webs (Woodward et al 2004). Krill play a large role in supporting the Antarctic marine food web, prey change for them flows on to toothfish and other predatory fish (Kawaguchi et al., 2013). Impacts on krill production are also from changes in sea ice (Barbraud et al., 2012), as krill abundance is correlated with sea ice extent on the

Antarctic Peninsula (Barbraud et al., 2012). A decrease in sea ice means a decrease in krill abundance (Atkinson et al., 2004). Population responses to projected climate change using population dynamics and models is challenging as other environmental factors influence them (Barbraud et al., 2012).

Malzahn et al (2007) found that nutrient limitation of primary production propagates along a food chain, effecting the condition of fish feeding on herbivorous zooplankton. If zooplankton shift from crustaceans to salps then there is a decrease in energy and nutrients value from prey to consumers, such as fish (Mintenbeck et al., 2012). Fanta et al (2003) found that *N.coriiiceps* feed on crustaceans and within their absence they feed on macro algae. This means low energy food therefore effecting; survival, growth, body composition, reproduction ability and they become low energy food for predators (Kashkina 1986). An increase in gelatinous zooplankton has been observed in different marine systems (Malzahn et al., 2007). Gelatinous zooplankton such as ctenophores occasionally are eaten by fish (including *Notothenioidei*) but only when zooplankton are not in abundance (Kashkina 1986).

### Management and Fisheries

Commercial fishing in Antarctica started in late the 1960s and early 1970s (Kock et al., 2007). Krill exploitation began in the early 1970s and finfishing began in the mid 1960s. By the end of the 1980s marbled rock cod stock (*N.rossi*) was depleted, currently it is still at less than 5% of its pre-exploitation abundance (Clarke and Harris 2003, Constable). The reason for the slow recovery is low fecundity and slow development. This over exploitation pointed out the need for a governing body to monitor the Antarctic fisheries. CCAMLR was established in 1980, with the first meeting being held in 1982 (Constable). The main objective is to manage the exploitation of Antarctic marine living resources by taking in a holistic and ecosystem based view (Constable). In 1982 Southern Ocean fisheries began to be regulated by CCAMLR, many of them were closed due to over exploitation (Kock et al., 2007). Currently exploitation of the Patagonian toothfish (*D. eleginoides*) (Clarke & Harris, 2003) and mackerel icefish (*Champscephalus gunnari*) is still occurring (Constable et al., 2000). Illegal, unregulated and unreported fishing (IUU) catches are taken by vessels that do not cooperate under the CCAMLR obligations (Constable et al., 2000). Threats to the management is IUU (especially toothfish) (Constable et al., 2000). Over the years IUU catches have decreased but it still threatens the sustainability of fish stocks (Constable et al., 2000).

Ross sea toothfish management is based upon models from estimated stock size from industrial catch from CCAMLR, an assumption from this is that this is representative of the population in size and age distribution. Antarctic toothfish are a major piscine predator (Eastman 1993). It is reported that they spawn in winter but their spawn frequency, fecundity, larval and juvenile life history is unknown (Ainley et al., 2013). Often in these situations of uncertainty the fishery theory is applied. Fishery theory states that as large sized fish are removed then size and condition of the remaining fish increase as they are released from competition, these are the small fish, this is rarely demonstrated (Eastman 2005). Instead CCAMLR follow the precautionary approach, which includes conservative catch limits for different management areas combined with local catch limits to avoid over exploitation of localized stocks (Constable et al., 2000). Generalized yield models are used to estimate recruitments with uncertainties surrounding the assumptions made for this model of stocks (Constable et al., 2000). Monitoring programmes need to be applied to feedback from all kinds of data monitoring into the management (Constable et al., 2000). The issue with CCAMLR is that it is an international agreement between 23 states to set in management measures and it also needs the co-operation of the non-member states for ecosystem sustainability to be achieved (Constable et al., 2000).



## Discussion and Conclusion

*Notothenioidei* are well adapted to the Antarctic habitat and temperature, differences in these directly affect their physiological functions. Increased temperature and ocean acidification are a big threat to their persistence (Mintenbeck et al., 2012). Most *Notothenioidei* species are stenothermal (Mintenbeck et al., 2012). *P.borchgrevinki* and *notothenioidei* species have some physiological plasticity, allowing compensation for increased oxygen demand through mitochondrial proliferation and/or increased haematocrit, these adaptations are limited though. *Channichthyids* are very vulnerable to abiotic changes as they cannot adjust their blood parameters. Trophic vulnerability is low in fish that have a portion of benthic organisms in their diet, as they can adapt to prey availability. Plankton consumers have greatest vulnerability as they tend to specialise on plankton, making them sensitive to prey availability. Species with some of the highest trophic vulnerabilities include; *C.myesi*, *C.antarcticus* and *P. maculatus* as they specialise on only a few prey. Also *P. antarcticum* which has a few selected prey and is also the prey of many predators (Mintenbeck et al., 2012). These are the species that need close attention, in particular for any management of their abundances. The effects on these species are likely to effect the food web, as prey of inappropriate size and quality effects the nutrients and energy that are received by their predators, changing the condition of the fish (Beaugrand et al., 2003).

Sea ice duration and extent affect the life stages of the fish associated with sea ice such as *P.borchgrevinki* and *P. antracticum*. Habitat structure and heterogeneity are important for demersal fish communities as the loss of sea ice means loss of refuge and shelter for all developmental stages (Moreno et al., 1982). There is increased competition among tropically similar species sharing niches (Brenner et al., 2001). Model simulation completed by Mintenbeck et al (2012) on abundance data found that with increased ice scour there is a steep decrease in diversity and evenness leading to a decrease in species. This is a considerable threat for the Antarctic marine ecosystems, as well as already facing abiotic challenges they will now be under great pressure with biotic changes. In the short term there is very little we can do to mitigate climate change effects, currently fisheries are the major impact on the Antarctic ecosystem and something we can have some control over (Croxall & Nicol 2004).

Fisheries management need to consider the influence of changing environments on the condition and abundance of fish. In particular the toothfish that is currently being targeted. Concerns arise when we identify that the toothfish fishery has insufficient data to do stock assessments (Croxall & Nicol 2004).). As noted the Antarctic fish, *Notothenioidei*, are well adapted from the evolutionary time they have had to adapt to a stable cold environment. With climatic changes having direct and indirect effects on the fish species they may become increasingly vulnerable to predation, including predation by fisheries. Understanding their life history, abundance and role in the ecosystem are very important to be able to begin to identify how they may be influenced by abiotic changes. To make current fisheries sustainable there needs to be further research into Antarctic fish species, such as the toothfish, and the fishes life history characteristics. Uncertainty is one of the biggest challenges. Science and technology needs to be used to collect data with efficiency so that it can be conveyed successfully for management (Plagayni et al., 2011). The most critical changes are where it influences the vulnerable stages such as larval development and hatching (La Mesa & Eastman, 2012). CCAMLR needs to take this into consideration, such as the lack of data on climatic effects on the early life stages, when setting the sustainable limits for each fishing year.

Management allocations need to be assessed under a range of climate scenarios (Plagayni et al., 2011). It is important to integrate responses to environmental changes from individual organisms to communities at all levels (Plagayni et al., 2011). Management needs to be adaptive so that it permits

a rapid response to any short term changes. Also apply strategies to the fishing industry to allow flexibility for delayed responses of the fish species to environmental variations by understanding the links between physical environment and the marine organisms. Fisheries have variability annually with stock this should enable them to handle uncertainties. Continuous monitoring should allow information to be applied so adaptations can be made as necessary, as long as the rate of change does not exceed the response capabilities of the fisheries (Plagayni et al., 2011). Current efforts in modelling need to use the environment and data from fisheries, as ecosystem responses are complex and non linear (Plagayni et al., 2011).

Target species change when abundance is affected, as shown with the mackerel icefish that replaced fisheries as the marbled rock cod decreased in the mid 1970s (Constable et al., 2000). In the future we may see that current targeted fisheries are replaced with other species, such as silverfish as it has a high abundance. Climate change however will also be influencing their stock, as well as the other Antarctic fish species. Silverfish are also a key prey item for many predators but if fished sustainably could be a future fishery. Overall resources, habitat, species and ecosystems of the Antarctic marine environment will only survive if there is a true global effort to withdraw all IUU and pirate fishing, apply new systems of management based on ecosystems and increase the understanding of the environment and the living resources to decrease the scientific uncertainty.

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