Evaluating climate change risks to Patagonian and Antarctic Toothfish

Summary of the project knowledge-base: a synthesis of information on Patagonian and Antarctic toothfish around South Georgia and the South Sandwich Islands

Background

Climate change is altering ecosystems with implications for how they are managed. Despite widespread recognition of the need to integrate climate change into fisheries management, in practice there are few examples, little progress and guidelines are lacking. Conveying climate change impacts in terms of risk provides valuable information for decision-makers. Drawing on our experience of the Southern Ocean, including South Georgia and the South Sandwich Islands (SGSSI), as a rapidly changing marine system, this project will undertake a risk assessment of climate-driven change to Patagonian (*Dissostichus eleginoides*) and Antarctic toothfish (*D. mawsoni*) in this region. Both species of toothfish are high-value deep-water species caught by longline fisheries throughout the Southern Ocean, including around SGSSI where their distribution overlaps.

SGSSI are an archipelago of sub-Antarctic islands that form part of the Scotia Arc, a predominantly submarine ridge that extends from South America to the Antarctic Peninsula. These islands are a globally important site of abundant and diverse marine fauna, including vast colonies of penguins, seals, nesting seabirds and recovering whale populations. The region's waters are protected by the SGSSI Marine Protected Area (MPA), which aims to conserve marine biodiversity, as well as allowing some sustainable fishing. Fisheries in the region are managed by the Government of South Georgia and the South Sandwich Islands (GSGSSI) within the framework of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). (Figure 1).

Understanding the relationships between toothfish and environmental parameters is foundational for considering the potential effects of climate change. Therefore, as a first step, this project has first addressed the need to synthesise relevant information from a range of disparate sources into a central "knowledge-base". We convened a workshop for expert scientists and stakeholders to pool knowledge on available information and sources for relevant environmental (e.g., temperature, climate indices), biological (e.g., toothfish distribution, life history parameters, physiology) and fishery (e.g., timing, location and management measures of the fishery) data. This document summarises the content of the knowledge-base and initial findings.

We will draw on the knowledge-base to undertake analytical and modelling approaches to develop robust species-environment relationship models, followed by projections of change. These analyses will underpin an ecological risk assessment of the effects of climate change on toothfish which we will translate into management recommendations to inform ecosystem-based fisheries management and other conservation priorities in the region.

Knowledge-base components

We have identified a range of relevant environmental, biological, and fishery information from disparate sources and synthesised this into a "knowledge-base" representing the current state of knowledge relevant to toothfish and their environment. In its current form the knowledge-base is internal to the project and will inform our analyses on toothfish-environment relationships and underpin our risk assessment of climate-driven change to toothfish in SGSSI. The knowledge-base comprises available data and literature relevant to both species of toothfish and the SGSSI environment, with three main components, synthesised in the form of spreadsheets with summary tables and plots.

1. Biological traits of both species of toothfish

Toothfish is the common name of both species of demersal notothenioid fish in the *Dissostichus* genera. Patagonian (*D. eleginoides*) and Antarctic toothfish (*D. mawsoni*) are both found on the continental shelves and slopes in the waters around SGSSI. SGSSI is one of the few regions in the world where the distributions of the two toothfish species overlap. Our understanding of toothfish biology is foundational to how we understand their relationship with the environment.

Much of what is known about toothfish biology and life-history comes from data recorded by CCAMLR fisheries as well as scientific surveys (see below). We have collated this data within the knowledge-base and it is also integrated within much of the literature that we have collated and reviewed. In our review of the peer-reviewed and grey literature (the latter being primarily CCAMLR reports and papers), we have explored known and hypothesised biological traits that determine how toothfish in the waters around SGSSI are influenced by their environment, and in turn, may be affected by climate change.

Both species have similar life-history and trophic strategies, being long lived generalist predators, with prolonged pelagic dispersal phases, followed by demersal juveniles that migrate to greater depths as they mature (Collins *et al*., 2010; Hanchet *et al*., 2015). The generalist trophic strategy and depth distribution of adults is cited as a likely source of their resilience to climate change (Constable et al., 2014), suggesting that juveniles are more exposed and sensitive to climate change because of their shallower distribution and lower trophic position respectively. The planktonic phase of toothfish (eggs and larvae) are the most exposed to environmental variability as they are found near the surface (Near et al., 2003; Parker et al., 2021). Furthermore, there is evidence that spawning toothfish are sensitive to environmental variability and will skip their already infrequent annual spawning events in sub-optimal conditions (Everson and Murray, 1999; Parker and Grimes, 2010).

The distribution of toothfish during their life-history stages and the ontogenic migrations they undertake determines the environmental conditions to which they are exposed and is summarised by the current stock hypotheses (Figure 1). The stock hypothesis for *D. eleginoides* at SGSSI is that they are a single, mostly self-contained population that carry out their entire life cycle within SGSSI with minimal connectivity to other populations (Evseenko et al. 1995; North et al., 2002; Shaw et al., 2004; Rogers et al., 2006; Roberts and Agnew 2007; Toomey et al., 2016; Lee et al., 2018; Arkhipkin et al., 2022; Soeffker et al., 2022). *Dissostichus mawsoni* at SGSSI on the other hand are likely transient and only spend a portion of their life cycle at the South Sandwich Islands for spawning, carrying out most of their life cycle in the Atlantic sector of the Southern Ocean as part of a Weddell Sea population/sub-population, with juveniles mostly found on the Antarctic shelf (Soeffker et al., 2018; Ceballos et al., 2021; Choi et al., 2021; Soeffker et al., 2022). The differences in the distribution of these two species throughout their life-history and at SGSSI (Hollyman *et* al., 2022; Soeffker *et al*., 2022) may be indicative of physiological differences, such as the presence of antifreeze proteins in *D. mawsoni* that are lacking in *D. eleginoides* (Eastman, 1990).

2. Toothfish presence and abundance observational data

Recorded observations of where and when toothfish have been found are available for both species from a variety of sources. Open access sources such as the Global Biodiversity Information Facility (GBIF) and the Ocean Biodiversity Information System (OBIS) contain observations of presence for both toothfish species over a large geographical and temporal extent. However, there are very few open access records of either toothfish species within the extent of the SGSSI stocks (CCAMLR Area 48, see Figure 1). Most of the observational data from SGSSI and the Southern Ocean are from CCAMLR. CCAMLR maintains comprehensive records of all toothfish catches within the Convention Area (https://www.ccamlr.org/en/organisation/convention-area), which includes SGSSI within Area 48 (see Figure 1).

Upon request we have obtained all CCAMLR fisheries records of toothfish within CCAMLR Area 48. This fisheries data consists of a large quantity of abundance data in the form of catch records for adult *D. eleginoides* and *D. mawsoni* since 1985 and 1992 respectively. While records of adult *D. eleginoides* significantly outnumber those of adult *D. mawsoni* and juvenile *D. eleginoides*, all three are well recorded. Biological data such as length, weight, and developmental stage of individual toothfish within the catch are also recorded. We have also compiled abundance data for juvenile *D. eleginoides* from bi-annual groundfish surveys carried out at South Georgia since 1986. This scientific survey also records biological measurements of the toothfish they catch in a way that is complementary to the CCAMLR fisheries data. The biological measurements collected by CCAMLR fisheries and the groundfish surveys underpin much of what we know of toothfish biology and ecology at SGSSI.

The combination of CCAMLR fisheries data and groundfish survey data represent the best available data in terms of reliability and distribution through CCAMLR Area 48 in space and time. This large quantity of abundance data for toothfish presents an opportunity to enhance our understanding of their environmental niche. Yet, data availability is highly variable among species and life stages, with little to none being available for the egg/larval stages. It is also important to consider biases in data collection. This is particularly relevant for fisheries data, the collection of which are restricted by fishery management measures and influenced by fishery fleet behaviours. Within CCAMLR, toothfish fisheries have undergone a series of changes to their fishable areas and seasons. Toothfish fisheries in SGSSI are currently restricted to depths of 700 – 2250m, and between the months of May and August for *D. eleginoides* and February to April for *D. mawsoni*. Additionally, fishery fleet behaviour tends to show a spatial bias due to a tendency to revisit the same or similar sites each year.

3. Environmental data relevant to toothfish around SGSSI

The two island groups have distinctly different environmental conditions, with South Georgia experiencing large inter-annual variability in temperatures and the South Sandwich Islands lower, more stable, annual temperature ranges and the presence of seasonal sea ice for a high proportion of the year (up to around 200 days) at the southern end (Hogg et al 2021). North-south gradients in environmental properties, such as temperature and sea ice conditions, exist along the South Sandwich Islands due to the oceanographic circulation (Duhamel *et al*., 2014; Hogg *et al*.,2021b; Thorpe and Murphy, 2023; see Figure 1). The region is also undergoing rapid climate-driven changes, including in ocean temperatures, acidification, winds, circulation, and sea ice (IPCC, 2019; 2022; Cavanagh *et al*., 2021). To evaluate the effects of climate-driven change on toothfish, we need to focus not only on those environmental conditions that are influenced by climate-driven change, but those that are ecologically relevant to toothfish. We have identified and sourced relevant environmental variables including topographic and oceanographic conditions (listed below), from a range of published and open-access data sources.

- Depth
- Topography
- Sea surface temperature
- Seafloor temperature
- Chlorophyll a concentration
- Particulate organic carbon
- Dissolved oxygen concentration
- Sea surface height
- Mixed-layer depth
- Sea-ice concentration

Summary

The knowledge-base brings to light the strengths and limitations of the available data and our current understanding of how toothfish interact with their environment. This will help us determine the most suitable analytical approaches that utilise these strengths while acknowledging the limitations to help us evaluate uncertainty. Using the knowledge-base we will determine species-environment relationships for both species and, where possible, for different life history stages, providing insights into important determinants of distribution. We will employ a range of analytical and modelling approaches to explore these relationships further and to extend our knowledge of the distribution of important areas of suitable habitat. Linking these analyses with research into oceanographic retention and connectivity of key life stages (eggs and larvae) will increase understanding of key drivers of distribution of both species. Results will be projected under future climate conditions to assess changes to suitable habitat. This will underpin a risk assessment of climate-driven change to toothfish, informing decisions, highlighting gaps and guiding future work.

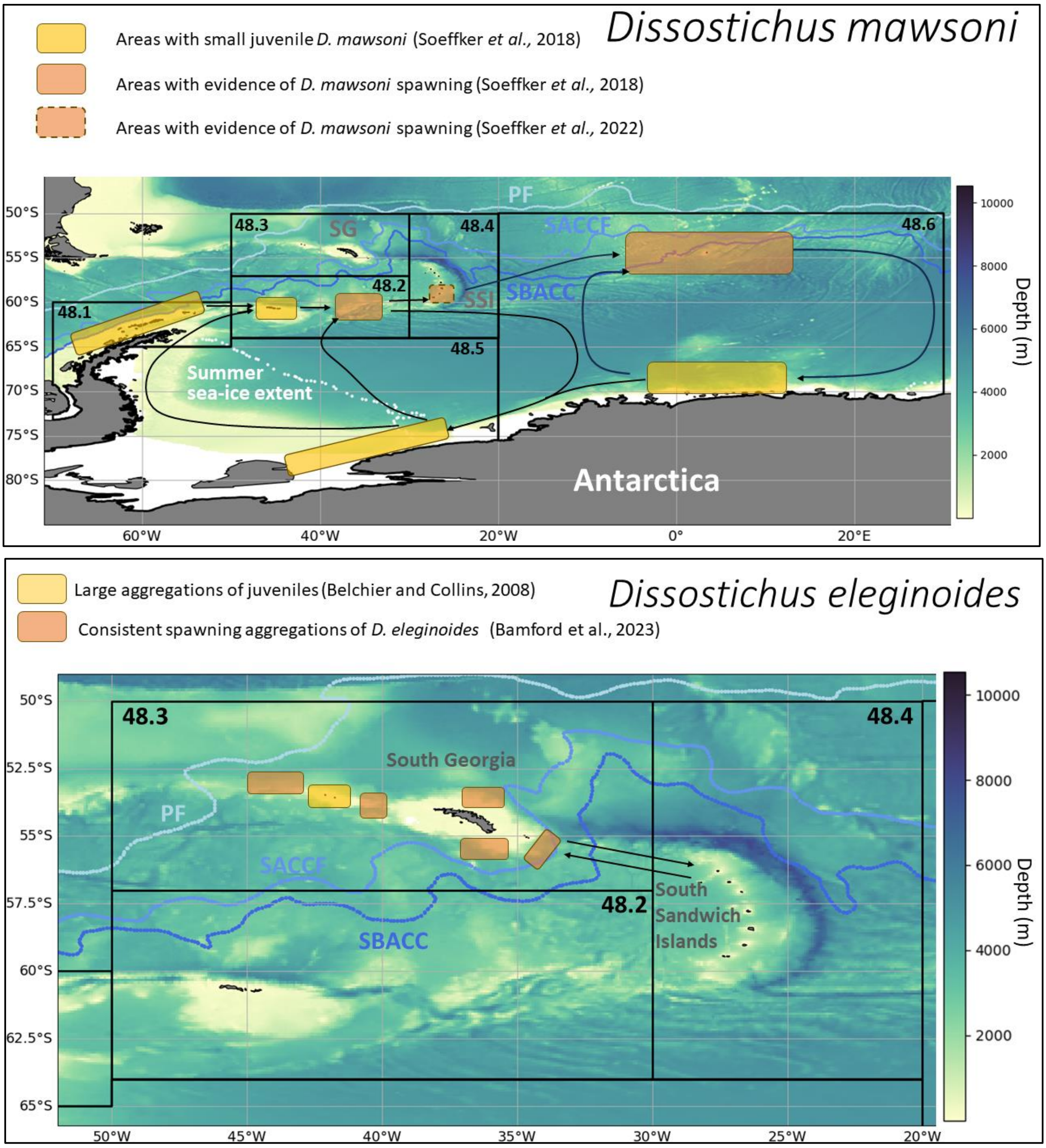

Figure 1: Stock hypotheses of *Dissostichus mawsoni* (top panel) and *D. eleginoides* (bottom panel) at SGSSI, based on existing literature. Hypothesised nursery (yellow shaded boxes) and spawning (orange shaded boxes) habitats are marked, along with migrations between habitats (black arrows). The distribution of the key habitats of both stocks are shown in relation to fishery management areas and oceanographic features. The extent of CCAMLR Area 48 and the Subareas are shown in black boxes. Summer sea-ice extent (white dotted line) is the median extent for February 1982-2010 (Fetterer et al., 2017). The mean positions of the Polar Front (PF), South Antarctic Circumpolar Current Front (SACCF), and Southern Boundary of Antarctic Circumpolar Current Front (SBACC) were calculated using satellite data from 1993-2012 (Park and Durand, 2019). Seafloor depth data is from E.U. Copernicus Marine Service Information; https://doi.org/10.48670/moi-00021

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