Overview of the current FIFD research projects regarding Patagonian toothfish *Dissostichus eleginoides*

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This document provides an update on the research projects currently being undertaken by the Falkland Islands Fisheries Department (FIFD) on Patagonian toothfish biology, ecology and fishery:

1. Application of Bayesian spatial predictive models to describe juvenile Patagonian toothfish dynamics across the Falkland Islands shelf;
2. Recruitment and ontogenetic migration pathways for juvenile Patagonian toothfish using otolith elemental profiles;
3. Life-history strategies and connectivity in Patagonian toothfish in the SW Atlantic and SE Pacific;
4. Tag-recapture study using conventional tags to examine movement of Patagonian toothfish in the FICZ/FOCZ;
5. Genomic analysis of the Patagonian toothfish stock structure in SW Atlantic;
6. Investigation of the efficacy of '1.5% threshold for toothfish bycatch' management tool, and viability of the alternative options;
7. Insights into Patagonian toothfish demography using otolith microchemistry.

In addition, it includes preliminary findings of the Master thesis research on toothfish egg and larval dispersal in the Pacific and Atlantic Patagonian region, undertaken at University of Otago (New Zealand), co-supervised at South Atlantic Environmental Research Institute (SAERI, Falkland Islands) and partially funded by Consolidated Fisheries Ltd. (CFL, the MSC certification holder).

Summary of the research projects is given below, and the full reports /papers (if available at the time of writing) are provided as separate documents.

1. Application of Bayesian spatial predictive models to describe juvenile Patagonian toothfish abundance dynamics across the Falkland Islands shelf

As the fields of resource management and conservation continue to move towards more spatial and ecosystem-based approaches, there is a growing need for spatially explicit, quantitative information on species distributions and an understanding of the biotic and abiotic determinants of those distributions. Patagonian toothfish *Dissostichus eleginoides* exhibit high spatial and temporal variability in their distribution patterns along the Falkland Islands shelf. The extent to which this variability is a result of recruitment or habitat based oceanographic variables remains uncertain.

The dominant oceanographic features that characterise the region is the Falklands Current, an extension of the Antarctic Circumpolar Current (ACC) originating in the Drake Passage off the southern tip of South America and extending northwards to the west of the Burdwood Bank (Agnew, 2002; Arkhipkin et al., 2013). To the east of the Burdwood Bank, large eddies have also been observed splitting off the ACC and merging in to the Falklands Current off Beauchene Islands. The dynamics (velocity and direction) of the western and eastern components of this current are hypothesised to be a variable of primary importance for the dispersal of toothfish eggs and larvae onto the shelf from offshore spawning areas over Burdwood Bank (Laptikhovsky et al., 2006) and southern Chile (Arana, 2009).

Spatial and spatial-temporal models were implemented within a hierarchical Bayesian framework to estimate what ecological and oceanographic processes are driving the (1) presence and absence and; (2) abundance of age-structured juvenile toothfish populations across the Falkland Islands Shelf. Statistical models explored included components reflecting the dynamics of both branches of the Falklands Current as well as habitat-based oceanographic variables (bottom temperature, salinity, mixed layer thickness, current velocity), bathymetric features (depth) and ecological variables (abundance of prey, abundance of competitors).

Leading scientist: Brendon Lee, FIFD
Current status: Advanced stage of analyses - draft by September 2020.

2. Recruitment and ontogenetic migration pathways for juvenile Patagonian toothfish using otolith elemental profiles

Information on early life-history remains an elusive, yet critical period for many deep-sea fish species, particularly for those possessing a protracted egg and larval phase in conjunction with spatially distinct spawning and nursery areas. These characteristics provide opportunities for high levels of oceanographically derived regional connectivity, and associated spatial and temporal variability in recruitment patterns. Such variability has been observed in the early life-history for Patagonian toothfish *Dissostichus eleginoides* around the Patagonian Shelf of the south western Atlantic. Newly recruited toothfish, hypothesised to originate from two spatially distinct spawning areas, are known to settle in the shelf waters around the Falkland Islands. The timing and duration of recruitment as well as the fraction of the population originating from each area needs to be better understood for improved management.

In the current study, longitudinal analyses of otolith microstructure and associated trace elemental composition were analysed for newly settled age 0+ toothfish (n=82) from three regions of abundance between 2014 and 2017 (defined from Project 1 above). Element:calcium ratios were extracted by laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) continuous line transects across growth layers from the nucleus (birth) to the otolith edge (point of capture). Otolith elemental profiles were quantified for 10 elements: Li, Na, Mg, K, Mn, Cu, Zn, Sr, Ba and Pb, which was followed by microstructure analysis to provide corresponding daily age estimates and to characterise key ontogenetic life-history events (hatching date, first feeding, settlement etc.). Otoliths extracted from progressive cohorts of age 1+ (2015-2018) and 2+ (2016-2019) year old toothfish (n=241) were sampled from four key regions of abundance that overlap with the recruitment areas, and processed for elemental analyses in the same way. A mixed modelling approach will be used to characterise individual elemental profiles and identify trends within and amongst these.

The results of this study should provide us with an improved understanding of the population structure of Patagonian toothfish across the shelf regions around the Falkland Islands. Specifically, this information should assist in determining what may drive variability in recruitment patterns of juvenile toothfish; and to improve our understanding of the subsequent population linkages that occur during their ontogenetic migration pathways across the shelf into deeper waters along the Patagonian slope. Results may be useful in the identification of regions of relative importance or management units, and the development of appropriate measures to ensure the continued sustainable management of the Falkland Islands toothfish fishery.

Leading scientist: Brendon Lee, FIFD
Current status: Data processing has been completed. Data analysis is at an advanced stage. Completion of analyses and write-up will continue subsequent to the finalisation of Project 1.

3. Life-history strategies and connectivity in Patagonian toothfish in the SW Atlantic and SE Pacific

The aim of this study is to use otolith elemental profiles to identify patterns in life history strategies of Patagonian toothfish *Dissostichus eleginoides* in the southwest Atlantic and southeast Pacific to:

1. Improve our understanding of the ontogenetic migration patterns from shelf to slope waters and how variable these are within localised and regional populations.
2. Improve our understanding of the prevalence and extent of larger migration patterns fuelling connectivity with the region

Otoliths have been collected from Chile (northern and southern Region), South Georgia and the Falkland Islands (Burdwood Bank, eastern and northern Region) for trace element profiles taken from the core (birth) through to the edge (time of capture). Otoliths from each of these regions were collected to reflect two groupings:

1. Shelf vs. slope fish: This grouping consists of 'larger' (60-70 cm) shelf fish captured in waters <500 m depth (Shelf); and fish of the same size sampled at >1000 m depth (Slope). These will be compared for variable patterns within and amongst regions. Common trends will be used to inform profile characterisation for the second sample grouping as described below.
2. Adult/mature slope-caught fish of 90-100 cm length. These are to be characterised according to 2-4 categories: Shelf phase, transition phase, slope phase and an 'event'. The results of section 1 are to be used to characterise the first three components of the otolith elemental profiles. An 'event' is considered as something unusual that has occurred in an otolith elemental profile, for example a sharp spike in the strontium ratios (Figure 6).
3. In addition to these two groupings, otolith elemental profiles will be extracted for seven toothfish that were tagged in various areas in the Falkland Islands and recaptured (1) in the same area within which they were tagged, showing limited movement (n=2); (2) within a different localised region to which they were tagged, showing medium levels of movement (n=2) and; (3) within a different region to which they were tagged showing large-scale movements (Chile: n=1 and Scotia Shelf: n=2). These elemental profiles with known movement patterns will be used to assist in describing these so called 'events' (Figure 7).

Leading scientist: Brendon Lee, FIFD
Current status: Work will resume on this project following the completion of Projects 1 and 2.

4. Tag-recapture study using conventional tags to examine movement of Patagonian toothfish in the FICZ/FOCZ

In June 2016, a pulsed-tagging programme for Patagonian toothfish (*Dissostichus eleginoides*) within the FICZ/FOCZ was initiated with an aim to tag 3000 toothfish by December 2019. The primary aim of the program was to quantify the amount of exchange taking place between adults on the northern and eastern slope of the Falkland Islands, and the spawning grounds on the Burdwood Bank; thus providing further insights into the stock structure of the species across the south western Atlantic. Recapture rates have been relatively high (3.46%) and preliminary results indicate high site fidelity with 75% of fish being recaptured within 40 km of their tagging location. A further 10% of the recaptured individuals were observed undertaking large-scale migration patterns into different areas of the Falkland Islands or regions of the south western Atlantic.

Leading scientist: Brendon Lee, FIFD
Current status: Report produced. Based on the success of the tagging program during the first phase of implementation, the program has been preliminary extended until November 2023.

5. Genomic analysis of the Patagonian toothfish population structure in SW Atlantic

This study is the first to employ Next Generation Sequencing (RADSeq) based methods to the analysis of Patagonian toothfish *Dissostichus eleginoides* population structure, adaptation and evolutionary history and provided unprecedented resolution in each case.

RADSeq confirms the strong differentiation and high level of demographic independence of Patagonian sites from waters south of the Antarctic Polar Front and provides the first empirical evidence than toothfish in these regions are differently adapted. These are vital considerations in predicting responses to future environmental change. RADSeq and mtDNA phylogeography reveal the Patagonian shelf to be a distinct and endemic evolutionary linage that diverged from the ancestral and widespread Southern Ocean clade. Accordingly the taxonomy should be reviewed. Genetic evidence supports the status of the Patagonian group as a distinct species though such elevation likely requires analysis of phenotypic variation. As a minimum the Patagonian shelf group should be recognised as a distinct Evolutionary Significant Unit.

A high level of genetic differentiation was reported between the South Georgia and South Sandwich Island sites. Restricted gene flow and dispersal between these areas may be due to a combination of physical (oceanography) and behavioural factors, and necessitates independent management in both areas.

Among the Patagonian samples there was significant differentiation between the Chilean and High Seas (Atlantic) samples with the Falklands site being not differentiated from either. Further spatial coverage will be needed to assess the dynamics of connectivity and isolation, however the results support the view that the species (i) should not be considered panmictic within the region and (ii) that population boundaries may not align with geopolitical operational boundaries. The enhanced resolution provided by RADSeq also provides a resource in the form of stock diagnostic markers that can be used for future high-throughput monitoring of stocks and fish traceability (fish forensics) analyses.

Leading scientist: Dr Alexander Arkhipkin, FIFD
Current status: Report produced.

6. Investigation of the efficacy of '1.5% threshold for toothfish bycatch' management tool, and viability of the alternative options

An emerging trend of increasing fishing effort in deeper waters during the last quarter of 2015 to 2017 culminated in record catches of grenadier and bycatch of Patagonian toothfish *Dissostichus eleginoides* being recorded in November 2017. The monthly grenadier catch and toothfish bycatch in November 2017 were the highest recorded since the establishment of the ITQ and current licensing system and came primarily from waters as deep as 840 m (mostly south of -52.75°). In response, the Falkland Islands Government Fisheries Department met in early December 2017 and acted swiftly by closing grid squares from -52.75° southwards until January 31st 2018 and then implementing new bycatch regulations for grenadiers (to a maximum of 10% of the total catch) and toothfish (to a maximum of 1.5% of the total catch) from February 2018.

The bycatch regulations were meant to be temporary until their efficiency could be reviewed and a long-term management strategy could be put in place. The objectives of this report are to: (1) evaluate whether the application of the 1.5% threshold for toothfish bycatch has proven to be an effective management tool; and (2) investigate whether alternative options might prove viable without disrupting commercial activities.

Using Generalized Linear Mixed Models, fishing depth was identified as the most important predictor of toothfish catch, proportion of effort exceeding the 1.5% toothfish bycatch threshold, and the proportion of the catch consisting of toothfish. Fishing effort (in hours) had a positive effect on the toothfish catch and the proportion of effort exceeding the 1.5% toothfish bycatch threshold, but not on the proportion of the catch consisting of toothfish. The proportion of the catch consisting of toothfish was negatively correlated with the total catch, suggesting that when target species, such as hake on A-licence, *Illex* on G-licence, hoki on W-licence, and *Doryteuthis gahi* on C- and X-licences are abundant, the proportion of toothfish in the catch decreased, even if the toothfish bycatch by weight is high. The total catch and effort in hours both had a positive influence on toothfish catch and the proportion of effort exceeding the 1.5% toothfish bycatch threshold. With toothfish bycatch decreasing by over 40% since the implementation of the new toothfish bycatch threshold and the enforcement of a move on rule when this threshold is exceeded, the new measures have provided a positive outcome without disrupting commercial activities.

In this report, the strengths and weaknesses of the *Status quo* and three other approaches to managing the toothfish bycatch issue are discussed, namely managing it using a toothfish TAC, restricting fishing activity by depth, and a hybrid system. These are raised to inform internal discussions as we evaluate the best option available to implement a long term management strategy on the issue of toothfish bycatch.

Leading scientist: Dr Haseeb Randhawa, FIFD
Current status: Report produced, submitted to the Fisheries Committee for consultations.

7. Insights into Patagonian toothfish demography using otolith microchemistry

Patagonian toothfish *Dissostichus eleginoides* is one of the largest deepwater bentho-pelagic predators in the Southern Ocean. Two of its spawning grounds were identified in the southern part of South America, but their respective contribution to the recruitment inhabiting the Patagonian Shelf and slope remains unknown. To identify the recruitment provenance, we analysed trace element composition of otolith cores from 1,010 juvenile toothfish sampled between 2006 and 2017 and related these to oceanographic conditions of the spawning grounds and currents transporting larvae and juveniles to the South Patagonian Shelf.

Two spatially distinct spawning cohorts were revealed without seasonal differences in hatching times between them. Using temperature-dependent incorporation of strontium into the otolith matrix, it was suggested that the recruitment settling onto the shelf had originated from two areas with distinct environmental conditions. Recruitment proportions from both areas were influenced by SST during spawning (August) and by velocity of currents transporting respective cohorts onto the shelf during the larval and early juvenile dispersal phase (October and November).

Prior to this one, few studies on marine fishes have linked inter-annual variability of recruitment with oceanographic conditions. The revealed environmental mechanisms in source spawning grounds affect the inter-annual dynamics in demographic structure of adults in the sink areas of the Patagonian Shelf and slope, and contribute to developing appropriate management actions for sustainable fishing of the fish by the Falkland Islands long-line fishery.

Leading scientist: Dr Haseeb Randhawa, FIFD
Current status: Paper submitted, review in progress (First decision: major revision).

Master thesis research: 'Sources and Sinks: Toothfish egg and larval dispersal in the Pacific and Atlantic Patagonian region'

Research proposal

Patagonian toothfish are found around the Falkland Islands where an economically valuable longline fishery operates. There is currently no information available on the buoyancy of Patagonian toothfish eggs and larvae and the way oceanographic conditions influence recruitment processes around the Falkland Islands is unknown. This proposed study, identifying potential transport pathways of eggs and larvae can help to gain an understanding into the recruitment processes that are occurring around the Falkland Islands. It can also help to identify which fish populations (Falklands, Argentinian or Chilean) contribute to recruitment into the Falklands population of Patagonian toothfish.

This research aims to increase the knowledge of the spatial and temporal distribution of Patagonian toothfish eggs and larvae, and the oceanographic mechanisms associated with recruitment into the Falkland Island fishery stocks. This will be achieved by creating a particle-tracking simulation of toothfish egg and larval dispersal for the Patagonian shelf and slope.

Results

Buoyancy of eggs from toothfish being reared in captivity was estimated up to 21 days post fertilisation. Egg buoyancy followed a similar pattern to other species where buoyancy initially decreased and then began to increase again. It was assumed that eggs at FFFL were representative of wild eggs. Particle tracking simulations were undertaken using the Java tool ICHTHYOP, particles were released from areas with appropriate depth for spawning (800-1200m) in southern Chile and around the Burdwood Bank on the 31st in 2009 and 2012 which represented spawning events that corresponded to a good and poor recruitment year respectively. Retention areas on the Argentine Shelf and around the Falkland Islands were chosen based on the areas being at a depth suitable for retention (<200m) and were juvenile recruits have been seen in annual trawl surveys around the Falkland Islands. When incorporating buoyancy into particle tracking simulations the egg density and depth profile of the eggs position did not match with observations taken at sea. Due to the high uncertainty in the buoyancy results, a neutral buoyancy profile was used in the particle tracking. Results for the two years revealed that the Burdwood Bank is likely not contributing to retention around the Falkland Islands or the Argentinean Shelf. In 2009 there was a high level of connectivity between the southern Chilean spawning sites and the Argentinean Shelf which was not seen in 2012 indicated transport to this area may be important for successful recruitment of juveniles around the Falkland Islands. Further model development and further buoyancy experimentation should reduce the uncertainty in model development.

Undertaken by: Emma Harte, graduate student at the University of Otago, New Zealand
Current status: Thesis writing in progress.