Testing spatially-based population structure and life history connectivity of Antarctic silverfish (*Pleuragramma antarctica*) in the southern Weddell Sea

Report on the research activities carried out in November and December 2016, supported by the Antarctic Science Bursary

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Project background

The Antarctic Science Bursary supported an integral part of my PhD research on the population structure of a keystone forage species in the Southern Ocean, the Antarctic silverfish (*Pleuragramma antarctica*). The main portion of my research utilized population genetics techniques to address hypotheses regarding population structure and connectivity in silverfish. Using allele frequency distributions to define connectivity between sampling locations, we were able to define regions where significant obstructions to gene flow were resulting in differentiated populations (Caccavo et al. 2018a). However, there remained regions of the Southern Ocean where length distributions were indicative of differential mixing not detected in the genetics analysis.

One area of particular interest in this respect was the southern Weddell Sea, where sampling locations along different hydrographic features associated with the Filchner Trough system revealed divergent patterns of length distribution (Fig. 1). This prompted us to integrate otolith chemistry into our approach in order to utilize the variable of provenance as opposed to relatedness as a proxy for population structure (Campana 1999, Thorrold & Swearer 2009). While allele frequency distributions highlight population processes on a multi-generational timescale and length distributions can indicate spatial structuring at the time of sampling, otolith chemistry reflects environmental exposure over an individual's life history.

Otolith edge chemistry reflects environmental conditions directly prior to capture. Spatial discrimination has been tested between sampling areas around the maritime Antarctic and southern South America (Ashford et al. 2005), and across frontal systems within the Antarctic Circumpolar Current (Ashford et al. 2007), and along the continental slope off the Ross Sea (Ashford et al. 2012). By contrast, otolith nucleus chemistry records environmental exposure during early life, and has successfully tested population hypotheses in multiple notothenioid species: Patagonian toothfish (*Dissostichus eleginoides*) (Ashford et al. 2006), Scotia Sea icefish (*Chaenocephalus aceratus*) (Ashford et al. 2010), Antarctic toothfish (*Dissostichus mawsoni*) (Ashford et al. 2012), as well as Antarctic silverfish (Ferguson 2012).

Otolith chemistry therefore has the potential to resolve population structure where gene flow homogenizes genetic differences, and throw light on the mechanisms explaining spatial length distributions and genetic connectivity (Ashford et al. 2006).

Methods

During the fall of 2016, I travelled to the Center for Quantitative Fisheries Ecology at Old Dominion University in Norfolk, VA (USA), where I worked with Research Associate Professor Julian Ashford to prepare and then analyze trace element chemistry of Antarctic silverfish otoliths. These otoliths came from fish for which a genetics analysis had already been conducted (Caccavo et al. 2018a), thus affording a unique opportunity to compare the population structure implications from both techniques. The fish included in both the genetics and the otolith analyses were collected via benthic trawl from January – February 2014 during the research cruise PS82 (ANT-XXIX/9) by the RV *Polarstern*. CTD (Conductivity – Temperature – Depth) measurements were conducted throughout the region in order to identify predominant water masses. Species abundance and biodiversity data were also collected at trawl stations. The fish used in both studies represent a sub-sample of all silverfish collected during the cruise (see Fig. 2 for a map of sampling locations).

Over five weeks, I prepared 200 otoliths for trace element analysis by Laser Ablation-Inductively Coupled Plasma Mass Spectrometer (LA-ICP-MS). Otoliths were cleaned, ground and ultimately mounted onto petrographic slides for trace element analysis in a standard procedure described in Ashford et al. (2012). Trace elements were measured at the LA-ICP-MS located in the Plasma Mass Spectrometry Facility at Woods Hole Oceanographic Institution (WHOI) over one week. Otoliths were analyzed for ^{48}Ca, ^{25}Mg, ^{55}Mn, ^{88}Sr and ^{138}Ba and reported as ratios to ^{48}Ca.The Antarctic Science Bursary funded the use of the LA-ICP-MS at WHOI, which was the main expense of the project.

Results and relevance

Our results illustrate the utility of multidisciplinary approaches (Begg et al. 1999) for addressing population structure in Antarctic fish. While the previous genetics analysis found high levels of gene flow between locations in the south Weddell Sea, the chemistry in otolith nuclei indicated significant population structuring along the continental shelf. This discounted the null hypothesis of a single population of shared provenance in the region. Mediated by physiological processes like growth that are associated with changes in water properties in the Southern Ocean (Ashford et al. 2005, Ashford et al. 2006), $Mg{\cdot}Ca^{-1}$ and $Sr{\cdot}Ca^{-1}$ differentiated between fish from different cohorts as defined by their standard length (Fig. 3, 4). This suggested separate origins and a role for connectivity as well as local self-recruitment in structuring length distributions. Inter-annual variability may explain some of the difference between cohorts; nevertheless, even after accounting for this, $Mg{\cdot}Ca^{-1}$ showed differences between sampling locations in Halley Bay and Filchner Trough, consistent with spatially-based structuring along the eastern shelf.

This first set of results based on otolith nucleus chemistry culminated in a publication currently under review (Caccavo et al. 2018b), which integrates oceanographic data collected during the same research cruise in order to address physical-biological mechanisms of connectivity. A forthcoming publication and analysis based on otolith edge chemistry will address the differentiability of water masses based on trace element signature within the Weddell Sea. This will elucidate the extent to which variation observed in the otolith nucleus chemistry is related to population structure on the local or regional scale.

In addition to Caccavo et al. (2018b), this work was presented at the SCAR Biology 2017 Conference in Leuven. I aim to continue to integrate otolith chemistry techniques in addressing questions regarding population structure in Antarctic fish in my postdoctoral work. I am grateful to the Antarctic Science Bursary for affording me the opportunity to gain valuable training in this approach, and facilitate an integral component of my doctoral research.

Figures

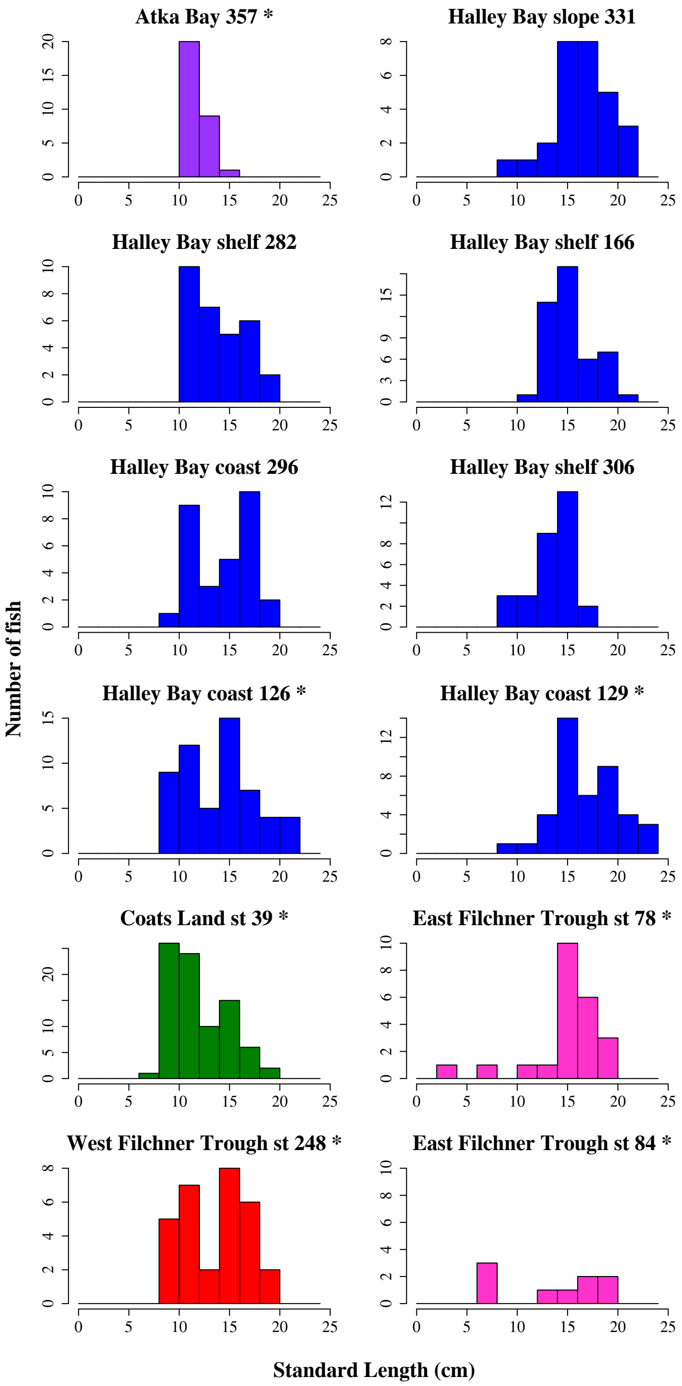

Figure 1 Standard length (SL) distributions of Antarctic silverfish in the Weddell Sea. Sampling locations are specified above the graphs. Asterisks (*) indicate stations sub-sampled for otolith chemistry. Left column highlights bimodal stations, right column highlights unimodal stations. Station, st.

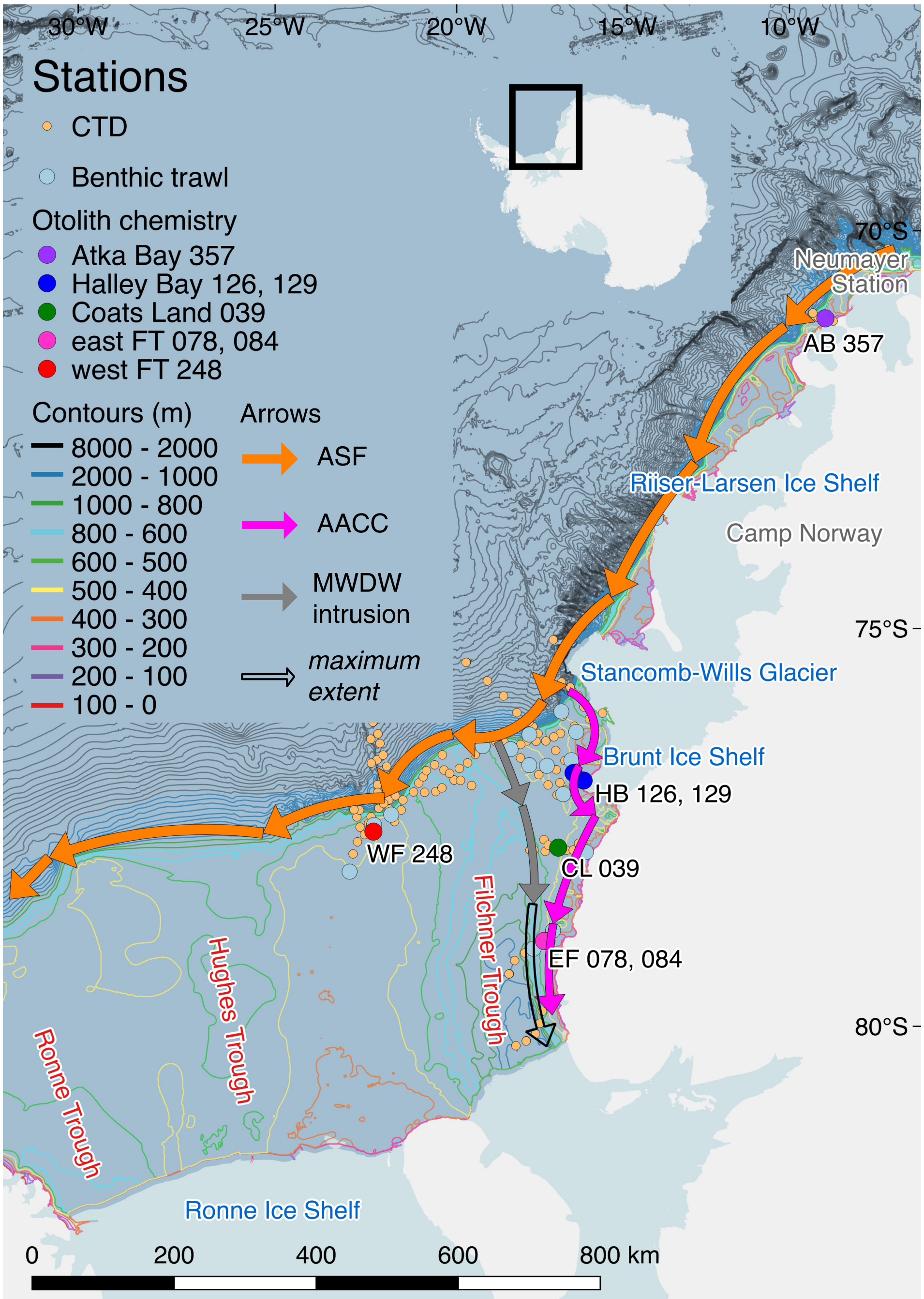

Figure 2 Sampling stations. Current positions based on Fig. 2b in Nicholls et al. (2009). Intrusion of MWDW along the eastern side of the Filchner Trough based on Fig. 1 in Ryan et al. (2017), with the maximum extent of MWDW indicated. ACC, Antarctic Circumpolar Current; ASF, Antarctic Slope Front; AACC, Antarctic Coastal Current. Map created using the Norwegian Polar Institute's Quantarctica 2.0 package (Matsuoka et al. 2018) in the software QGIS version 2.18.9 http://qgis.osgeo.org (QGIS Development Team 2018).

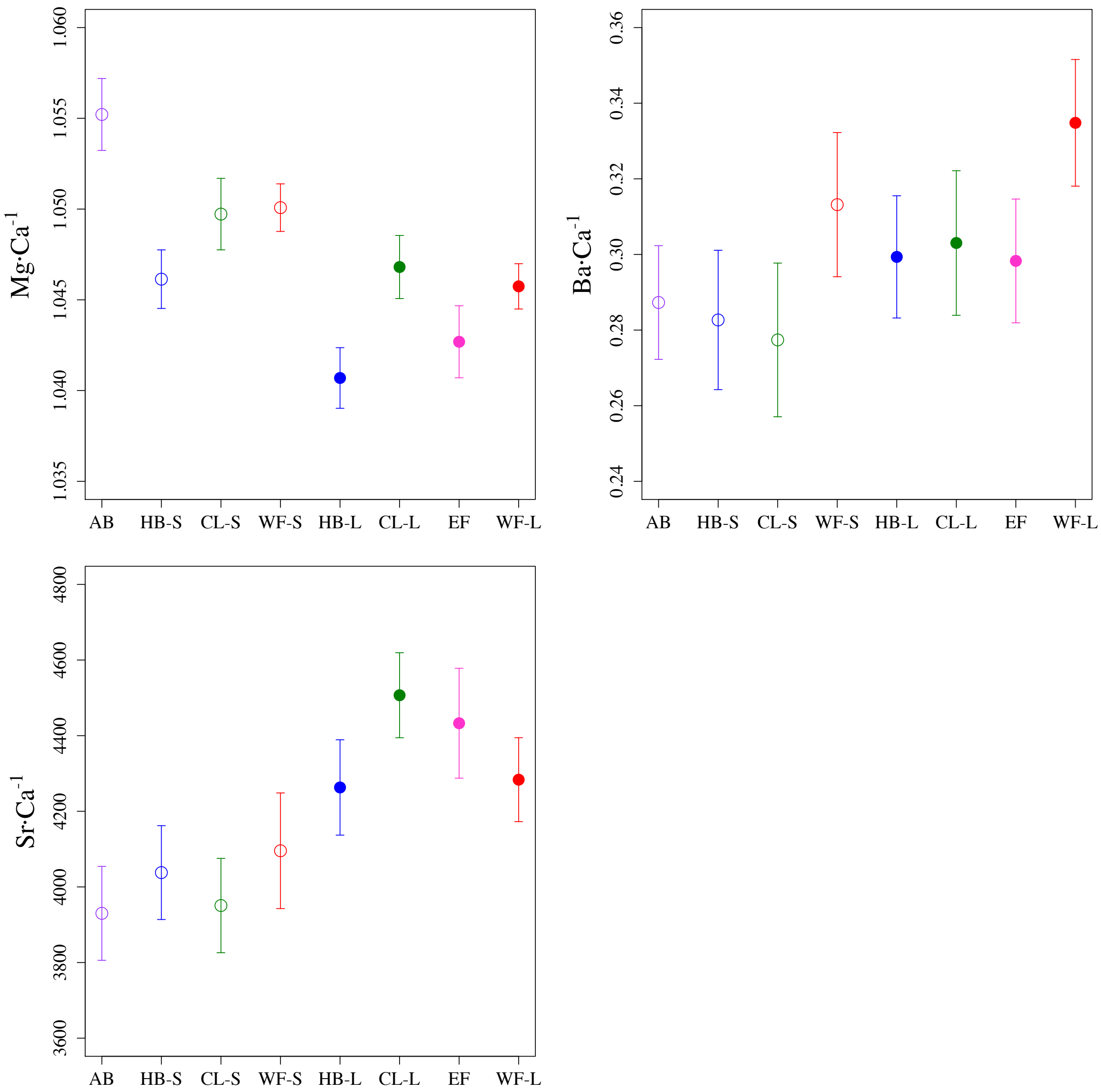

Figure 3 Mean concentrations of Mg·Ca^{-1}, Ba·Ca^{-1}; and Sr·Ca^{-1} of Antarctic silverfish, following transformation from µmol·mol^{-1}using $y^{0.01}$ for Mg·Ca^{-1} and y^{-1} for Ba·Ca^{-1}; no transformation for Sr·Ca^{-1}. Bars indicate standard error. Open and filled circles represent treatment groups composed of young and old cohorts respectively.

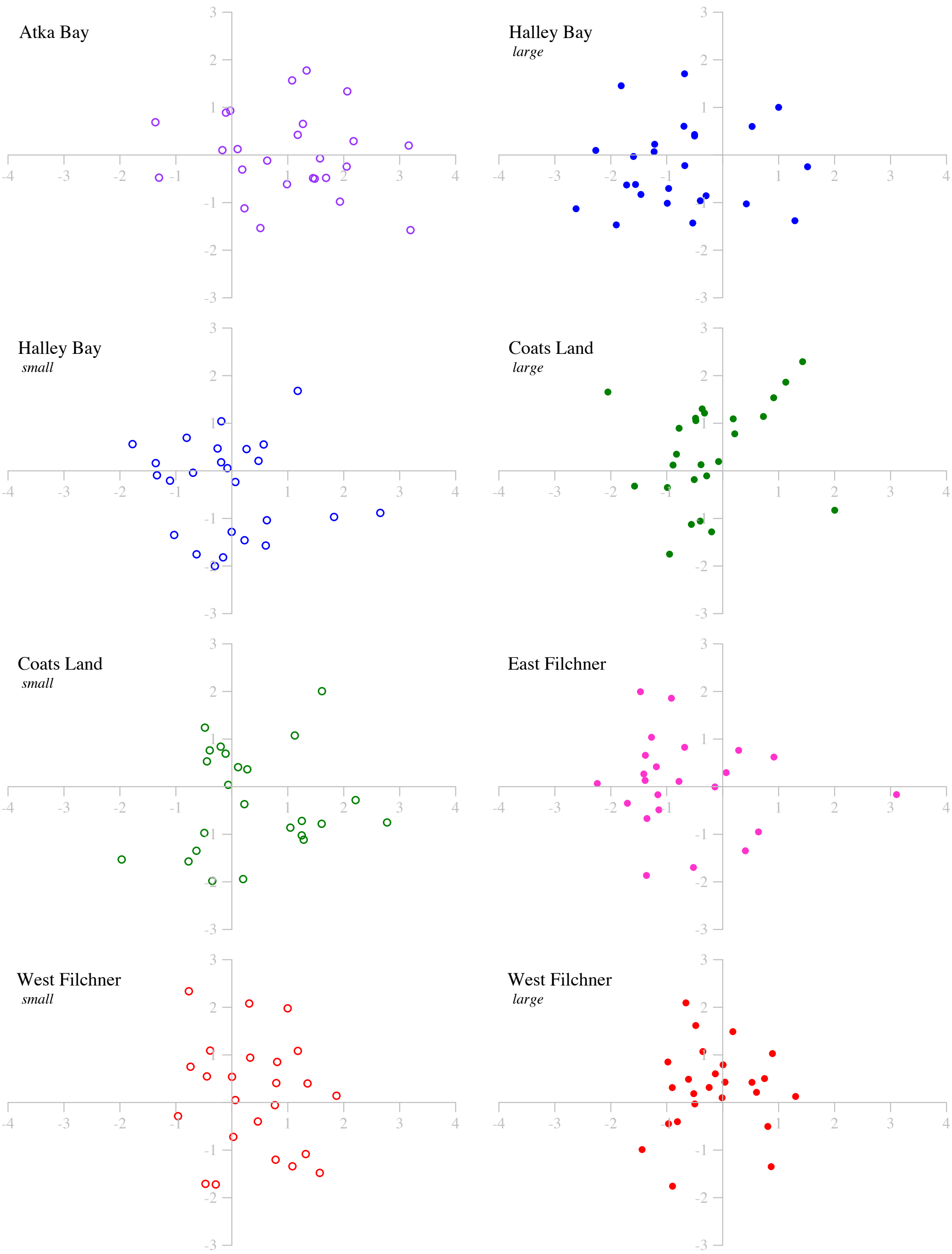

Figure 4 Relationships between Antarctic silverfish from the different treatment groups using canonical discriminant variates based on otolith nucleus chemistry. Open circles represent treatment groups composed of young cohorts, filled circles indicate treatment groups consisting of older cohorts.

References

Ashford J, Dinniman M, Brooks C, Andrews AH, Hofmann E, Cailliet G, Jones C, Ramanna N (2012) Does large-scale ocean circulation structure life history connectivity in antarctic toothfish (*Dissostichus mawsoni*)? Canadian Journal of Fisheries and Aquatic Sciences 69:1903-1919

Ashford J, la Mesa M, Fach BA, Jones C, Everson I (2010) Testing early life connectivity using otolith chemistry and particle-tracking simulations. Canadian Journal of Fisheries and Aquatic Sciences 67:1303-1315

Ashford JR, Arkhipkin AI, Jones CM (2006) Can the chemistry of otolith nuclei determine population structure of Patagonian toothfish *Dissostichus eleginoides*? Journal of fish biology 69:708-721

Ashford JR, Arkhipkin AI, Jones CM (2007) Otolith chemistry reflects frontal systems in the Antarctic Circumpolar Current. Marine Ecology Progress Series 351:249-260

Ashford JR, Jones CM, Hofmann E, Everson I, Moreno C, Duhamel G, Williams R (2005) Can otolith elemental signatures record the capture site of Patagonian toothfish (*Dissostichus eleginoides*), a fully marine fish in the Southern Ocean? Canadian Journal of Fisheries and Aquatic Sciences 62:2832-2840

Begg GA, Friedland KD, Pearce JB (1999) Stock identification and its role in stock assessment and fisheries management: An overview. Fisheries Research 43:1-8

Caccavo JA, Ashford JR, Ryan S, Papetti C, Schröder A, Zane L (2018b) Spatially-based population structure and life history connectivity of the Antarctic silverfish (*Pleuragramma antarctica*) along the southern Weddell Sea shelf. Marine Ecology Progress Series:*Under Review*

Caccavo JA, Papetti C, Wetjen M, Knust R, Ashford JR, Zane L (2018a) Along-shelf connectivity and circumpolar gene flow in Antarctic silverfish (*Pleuragramma antarctica*). Scientific Reports: *Accepted*

Campana SE (1999) Chemistry and composition of fish otoliths: Pathways, mechanisms and applications. Marine Ecology Progress Series 188:263-297

Ferguson JW (2012) Population structure and connectivity of an important pelagic forage fish in the Antarctic ecosystem, *Pleuragramma antarcticum*, in relation to large scale circulation. MS Thesis, Old Dominion University, Norfolk, VA.

Thorrold SR, Swearer SE (2009) Otolith Chemistry. In: Green BS, Mapstone BD, Carlos G, Begg GA (eds) Tropical Fish Otoliths: Information for Assessment, Management and Ecology. Springer Netherlands, Dordrecht