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Extended abstract

Population dynamics and life-history plasticity of mackerel icefish (*Champsocephalus gunnari*) within the vicinity of Heard Island and the McDonald Islands

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Mackerel icefish (*Champsocephalus gunnari*) are found associated with sub-Antarctic islands and continental shelves in the Atlantic and Indian sectors of the Southern Ocean between the Polar Front and the Southern Boundary of the Antarctic Circumpolar Current. Mackerel icefish are one of the most common fishes encountered across the shallow (<500 m) Kerguelen Plateau north of 60°S. The species was targeted in this area by unregulated fisheries in the 1970s until fishing ceased due to low catch rates, the declaration of the French exclusive economic zone (EEZ) around Iles Kerguelen and the Australian Fishing Zone around Heard and McDonald Islands (HIMI). Commercial fishing of mackerel icefish by Australian vessels at HIMI commenced in 1997 and continues to this day. Catches are characterised by high interannual variability, due in large part to the population being dominated by a single year class, resulting from recruitment that occurs on a three-year cycle.

Populations of mackerel icefish show a high level of phenotypic plasticity throughout their range (Table 1), and even across the Kerguelen Plateau different cohort structures and growth rates have been observed between Skiff Bank and the north eastern plateau adjacent to Iles Kerguelen in the French EEZ and the shallow plateau, Shell Bank and Pike Bank in the HIMI EEZ (Figure 1) (Constable and Welsford, 2011; Duhamel et al., 2011). The drivers of plasticity observed in this species are not well understood. While they may be linked to the high levels of overfishing of multiple stocks in the 1970s and 1980s, it seems likely that the Kerguelen Plateau icefish also exhibited single cohorts dominating populations in the early stage of fishing by the USSR (Psheniknov, 2011). Furthermore, despite being unfished between 1981 when the Australian Fishing Zone was declared, and the commencement of Australian commercial fishing in 1997, the populations within the HIMI EEZ have not changed from being primarily single-cohort to multi-cohort. Therefore, an alternative hypothesis which remains to be evaluated, is the disparity between icefish populations linked to variation in local environmental conditions as has been observed in other species (Kock and Everson, 1997; Welsford, 2011; Maschette, 2014).

A unique opportunity to explore this hypothesis occurred in 2011, when the results of the annual trawl survey conducted at HIMI indicated that a total of five consecutive year classes where present simultaneously, including a relatively high number of fish older than three years (Welsford, 2011). For this population structure to have arisen, the 2007 year class had spawned, to produce the 2010 cohort, but unlike previous cohorts, not died post-spawning as seems to typically be the case (Figure 2).

To investigate any environmental relationship that may have enhanced survival of the 2007 year class, we fitted a length–weight function (of the form $W = aL^b$) by non-linear least-square regression (R Core Team, 2018) to all data available from surveys between 2001 and 2017, and then examined the residuals by year to see if fish were significantly heavier of lighter for a given length in a particular year. This analysis showed that median fish weight at length had increased during the period 2005–2009 to a statistically significant historical high in 2009 (as indicated by a lack of overlap in 95% percent confidence intervals), before dropping back to the average in 2010 (Figure 3). Hence the cohorts present in the 2011 survey had been in above-average condition for a sustained period. This period also corresponded to increasing average sea-surface temperature over the HIMI plateau (Figure 4). This indicates that quite small

Table 1: Variation in life history characteristics found in populations of *Champsocephalus gunnari* across its geographic range. Data drawn from Constable and Welsford, 2011; Duhamel et al., 2011 and Kock and Everson, 1997.

Region	Maximum age (years)	First maturity (years)	Spawning
Kerguelen	3–4	2–3	Semelparous (?)
South Georgia	7+	2–3	Iteroparous (2–3)
Scotia Arc	12+	3–4	Iteroparous (3+)

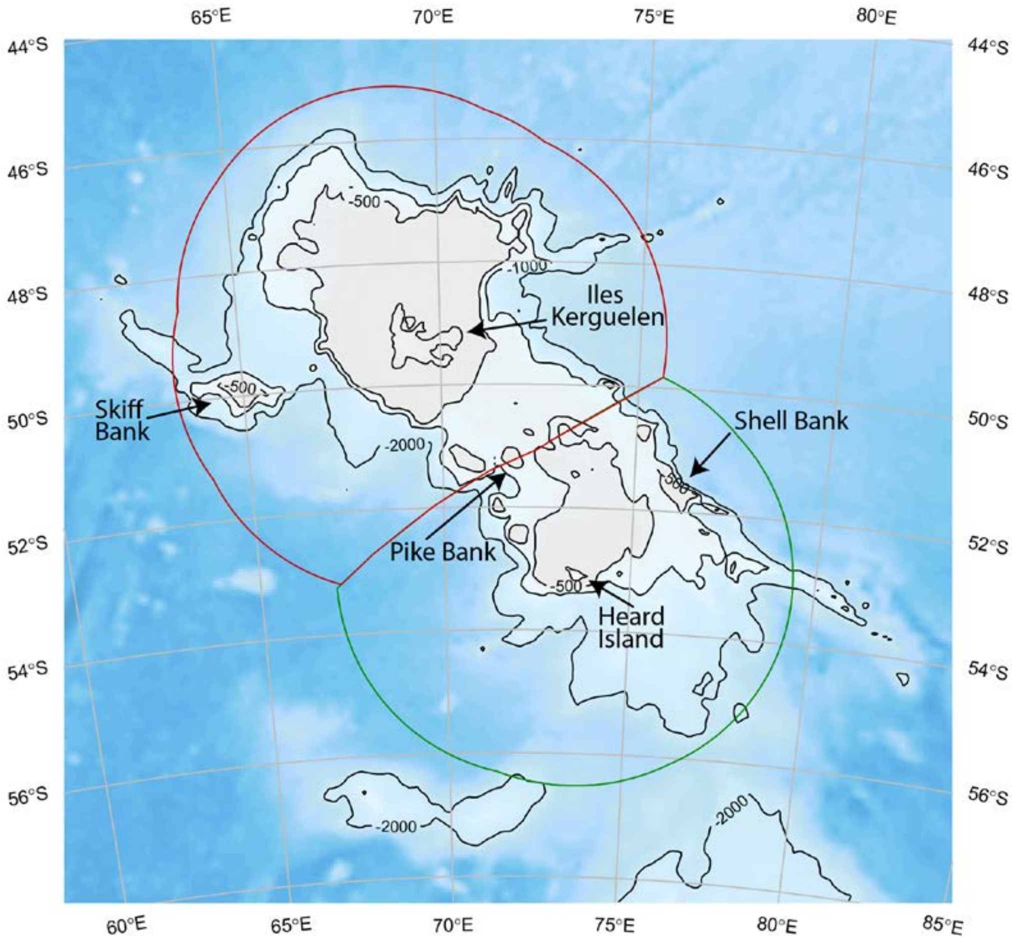

Figure 1: Australian (green) and French (red) exclusive economic zones around Heard Island and Iles Kerguelen, and the locations that support distinct populations of mackerel icefish.

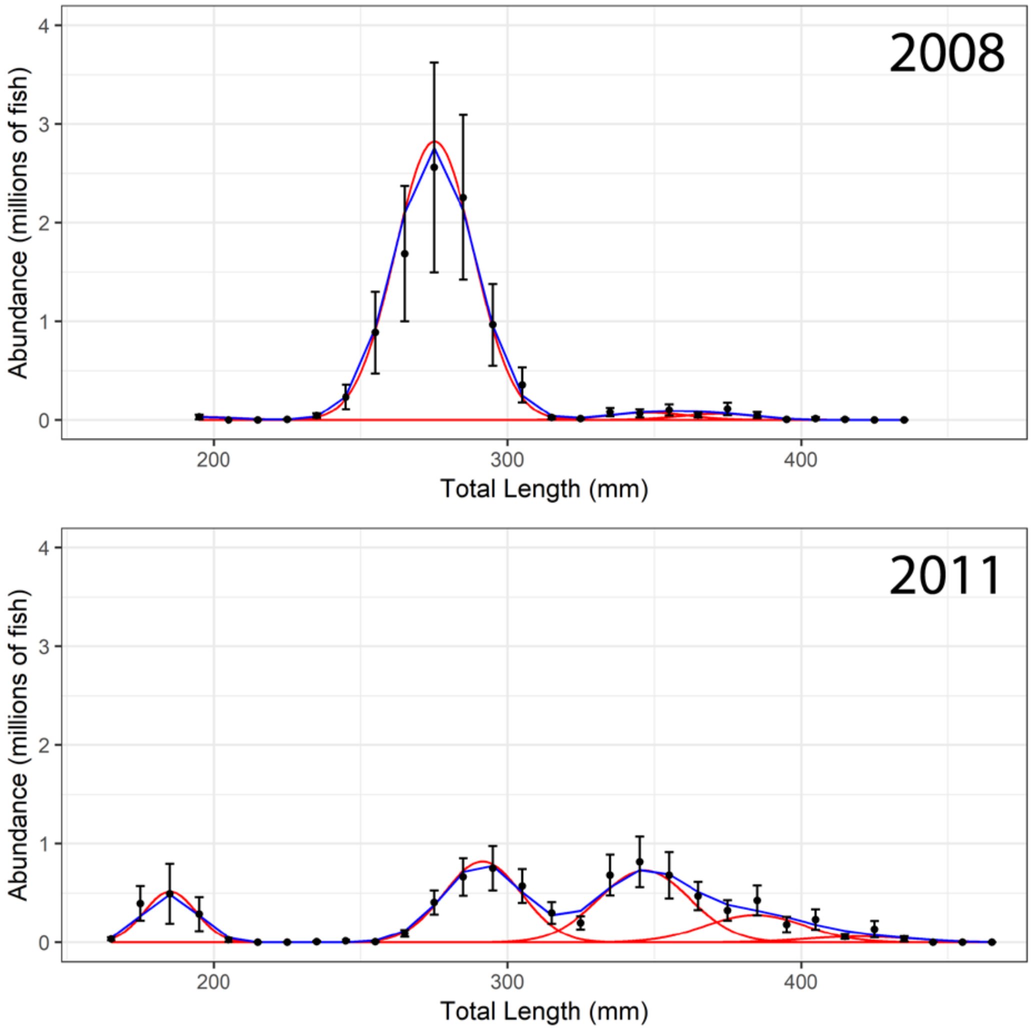

Figure 2: Cohort structure and abundance of *Champsocephalus gunnari* captured in the annual random stratified trawl survey conducted at Heard Island and McDonald Islands in 2008 and 2011, showing the 'typical' cohort pattern of a single dominant year class in 2008, and the unusual pattern in 2011 where at least five cohorts were present simultaneously, including a relatively large proportion of large fish in the 3–5+ age classes. Black points are the length densities estimated for the survey, red lines indicate individual cohorts and blue lines the sum of cohort densities estimated (Welsford, 2011).

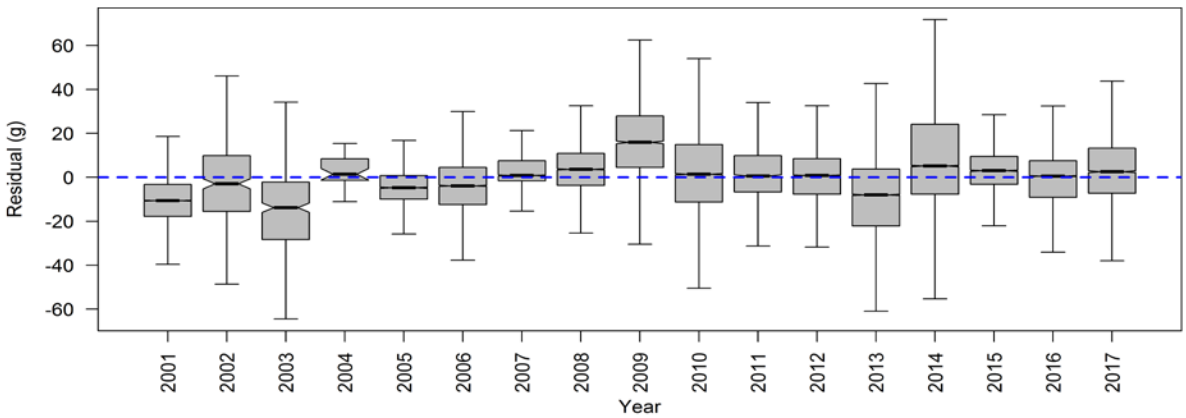

Figure 3: Box plot of residuals from a length–weight function (of the form $W = aL^b$) fitted by non-linear least-square regression to all *Champsocephalus gunnari* captured in the annual random stratified trawl survey conducted at Heard Island and McDonald Islands, 2001–2017. Box plots indicate the interquartile ranges of the length–weight residuals, and notches indicate the 95% confidence interval of the estimate of the median. The blue dashed line indicates the average weight-at-length where the residuals = 0.

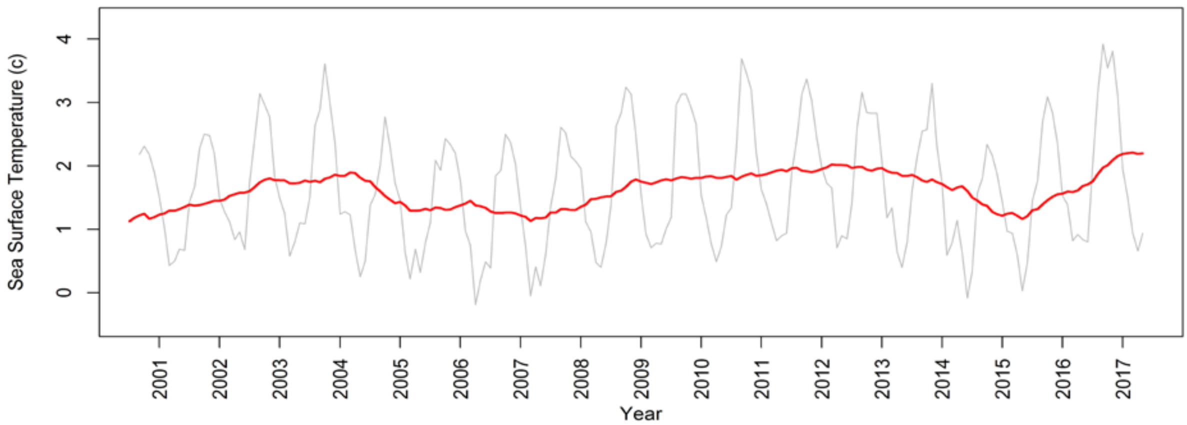

Figure 4: Average sea-surface temperature (°C) in a 1° × 1° grid square centred approximately at Gunnari Ridge near Heard Island and McDonald Islands (75°E 53°S). The grey line is monthly values and the red line is a LOESS regression fitted to the monthly values.

changes in environmental conditions may be sufficient to change the population structure of this species quite dramatically. However, it is seemingly contradictory that an increase in temperature led to the Heard Island population appearing more like that observed in cooler regions such as South Georgia and the Scotia Arc. This suggests that it is unlikely to be temperature alone that is driving the variation observed, and that it is being mediated by the different foodweb structures that are present on the Kerguelen Plateau. For example, Antarctic krill (*Euphausia superba*) is not a prey item that is available to *C. gunnari* at HIMI while it is common in the diet of *C. gunnari* in the Atlantic sector of the Southern Ocean.

Further exploration of the relationship between *C. gunnari* population dynamics, ecology and environmental conditions is likely to provide insights into the adaptive capability of sub-Antarctic marine species to environmental variability which will be increasingly important as the impacts of climate change manifest across the region.

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