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First *in situ* estimates of acoustic target strength of Antarctic toothfish (*Dissostichus mawsoni*)

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ABSTRACT

Antarctic toothfish (*Dissostichus mawsoni*) is a large nototheniid endemic in Antarctic waters. They are a top predator, and an important commercially fished species with a circumpolar distribution mostly south of the Antarctic convergence. Fisheries acoustics is a potential tool to estimate toothfish abundance and distribution, but previous studies have been limited by lack of information on the acoustic target strength (TS). In this paper we present the first *in situ* estimates of TS for Antarctic toothfish. Data were collected by deploying acoustic equipment through the sea ice in conjunction with vertical line fishing and baited underwater video (BUV) observations. Estimated mean TS from 250 tracked single targets detected *in situ* in Terra Nova Bay was −37.8 dB re 1 m^2 (95% confidence interval −38.2 to −37.5 dB). Estimates of toothfish length from BUV images of 42 individuals ranged from 92 to 201 cm total length (TL) with mean length 134 cm. Estimates from 15 Antarctic toothfish (104–153 cm TL, average 131 cm) captured using vertical lines in McMurdo Sound gave a lower mean TS of −40.2 dB (range of individual fish means −38.3 to −43.7 dB). Although estimates from hooked fish have a number of potential biases, due to unnatural orientation and acoustic interference from fishing gear and adjacent hooked fish, these results supported the conclusion from our *in situ* estimates that toothfish have higher TS than previously thought. *In situ* acoustic observations showed most toothfish within 100 m of the seabed.

1. Introduction

Antarctic toothfish (*Dissostichus mawsoni*) is a nototheniid fish with a circumpolar distribution mostly south of the Antarctic convergence (60°S) (Hanchet et al. 2015). Juveniles grow to about 100 cm total length (TL) after ten years (Horn 2002) and adults can reach over 200 cm. They are a top predator, feeding on a wide range of prey, including fish, cephalopods, and crustaceans (Fenaughty et al. 2003; Stevens et al. 2014). Although primarily a demersal species, individuals more than 100 cm TL can be neutrally buoyant and have been observed in the pelagic zone at times during their life cycle (Near et al. 2003). Spawning occurs during winter (Hanchet et al. 2015). Hanchet et al. (2008) postulated that in the Ross Sea, eggs and larvae become advected by gyres and settle to the seabed on the continental slope and shelf, ontogenetically migrating to deeper water as they grow. Mature fish are caught mainly on the continental slope and on seamounts in depths of 600–1500 m (Hanchet et al. 2015).

There is an important longline fishery for Antarctic toothfish in the Ross Sea, with smaller fisheries in other regions of the Antarctic. These fisheries are managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), which sets catch limits in each area. The current (2017/18) catch limit for the Ross Sea (CCAMLR Subareas 88.1 and 88.2) is 3157 t (CCAMLR, 2017). Toothfish stocks in the Ross Sea are assessed based on analyses using catch-at-age from the commercial fishery, tag-recapture estimates, data from an annual research longline survey on the continental shelf, and area-specific biological parameters (Mormede et al. 2015). CCAMLR adopted a Marine Protected Area in the Ross Sea Region, which came into effect on 1 December 2017, and closed large regions to commercial fishing, especially the continental shelf (CCAMLR, 2017).

Another potential tool to estimate toothfish abundance and distribution is fisheries acoustics (Simmonds and MacLennan, 2005). Acoustic surveys are used for krill (*Euphausia superba*) and mackerel icefish (*Champsocephalus gunnari*) in Antarctic waters (e.g., Hewitt and

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Demer, 2000; Kasatkina et al., 2002), but there has been little work on toothfish using acoustics. Kloser et al. (1999) carried out a trial acoustic survey for a closely related species, Patagonian toothfish (*D. eleginoides*), around Macquarie Island in January 1999. They concluded that acoustic estimation methods using echo integration were of limited use because of the low densities of toothfish in the survey area and the co-occurrence of toothfish (which are large but have no swimbladder) with smaller swimbladder bearing species such as morids and rattails. Similarly, O'Driscoll and Macaulay, 2003 and Hanchet and O'Driscoll (2004) concluded that it was not practical to estimate Antarctic toothfish abundance in the Ross Sea using hull-mounted acoustic systems due to a very low signal-to-noise ratio deeper than 1000 m, the large acoustic deadzone at those depths, and postulated weak acoustic target strength (TS).

O'Driscoll et al. (2012) suggested that there was potential to use acoustic methods to monitor grenadier (macrourid) abundance in the Ross Sea. They concluded that single targets detected near the seabed were probably grenadiers due to their high TS and the correlation observed between acoustic backscatter and trawl and longline catches of grenadiers. However, acoustic target identification is still uncertain. O'Driscoll et al. (2012) noted that aggregations observed using acoustics on the northern seamounts were similar to those from acoustic marks associated with grenadiers on the slope, but the longline fishery catches relatively few grenadiers, with high catch rates of toothfish, in the northern area.

One of the key limitations in our ability to evaluate the use of acoustics for estimating toothfish abundance, or to distinguish species based on acoustic properties, is lack of available information on Antarctic toothfish TS. Kloser et al. (1999) suggested a TS-length relationship for Patagonian toothfish of TS = 20 log L – 83.2, based on their results for orange roughy *Hoplostethus atlanticus*, an unrelated, much smaller, deepwater species without a swimbladder. This relationship would give TS of –47.6 to –39.7 dB re 1 m^2 for a toothfish with typical length range of 60–150 cm. In this paper we present the first *in situ* estimates of TS for Antarctic toothfish.

2. Materials and methods

2.1. Fishing experiment McMurdo Sound

As part of a research project to survey Antarctic toothfish under sea ice, vertical lines were set through the sea ice at seven sites in McMurdo Sound from 31 October to 13 November 2015. Lines consisted of a vertical mainline suspended from the sea ice by a clump weight lowered to the sea floor. Hooks were attached using a 30-cm polyester snood at 1.4 m spacing along the mainline using metal swivels, and the 15/O hooks were baited with squid (see Parker et al., 2016 for details).

Acoustic data were opportunistically collected on three occasions with a portable Simrad EK60 echosounder with an ES38-12 split-beam 38 kHz transducer (nominal 3-dB beamwidth 12.5°). The transducer was lowered through the fishing hole in the sea ice and held approximately 2 m below the ice-water interface. The ping interval was 1 s, and data were collected to a maximum range of 500 m with a power output of 1000 W and a pulse duration of 0.512 ms.

As the longline was retrieved, fish were held at several intermediate depths for periods of up to 10 min to allow recordings of TS of hooked fish at a constant known depth (Fig. 1).

2.2. Baited underwater video Terra Nova Bay

Acoustic observations were also made through the sea ice at four sites in Terra Nova Bay from 6 to 16 November 2017 while carrying out an exploratory survey for silverfish (*Pleuragramma antarctica*). Data were collected using the same portable Simrad EK60 echosounder and ES38-12 split-beam 38 kHz transducer used in 2015, with a power output of 1000 W, but using a longer pulse duration of 1.024 ms, and ping interval of 1.5 s.

A baited underwater video (BUV) system was deployed in conjunction with the collection of acoustic data in Terra Nova Bay and was used for target identification. The BUV consisted of a Mobius high definition (HD) video camera with an associated 5 W light emitting diode (LED) light in housings 40 cm apart with timing controlled by a microcontroller. The camera and light were configured to look downwards about 2.5 m above a 10 kg weight which was baited with squid. The camera and light were set to stay on for 4 h, then start cycling 1 min on, 5 min off.

2.3. Echosounder calibration

The echosounder was calibrated through the sea ice in McMurdo Sound on 7 November 2015 and in Terra Nova Bay on 9 November 2017 using a reference target (38.1 mm tungsten carbide sphere) following standard procedures (Demer et al., 2015).

2.4. Biological data collection

All toothfish caught on the longline were tracked by hook position so they could be linked to the acoustic data, and upon landing were measured (total length to the nearest centimetre) and weighed. Most fish were then tagged and released.

The size of toothfish identified on BUV was estimated by comparison with the weight which had known dimensions (33 cm long and 6 cm diameter) when the fish were close to the weight. Images were extracted from video and measurements of fish length were made with the Measure Tool in Adobe Photoshop. The precision of these measurements was evaluated by repeat measurements on the same fish.

2.5. Acoustic data analysis

Acoustic data were analysed to estimate toothfish TS in the echosounder analysis software ESP3 (Ladroit, 2017). Calibration coefficients were applied along with an estimated sound absorption of 9.9 dB km^{-1} and sound speed of 1440 m s^{-1}, which were based on mean water temperature between 0 and 500 m depth of −1.9 °C and mean salinity of 34 PSU. Automated single target detection and alpha-beta target tracking algorithms were then applied in ESP3, using the same equations as those documented for Echoview version 6.1 (Echoview, 2017). The single target detection and tracking parameters are given in Table 1. Mean TS for each track were calculated from the equivalent linear values, and the acoustic backscattering cross-section (σ_{bs} in m^2). Confidence intervals on mean TS were estimated by bootstrapping σ_{bs} values. Linear means and confidence intervals were converted to TS (in dB re 1 m^2, hereafter abbreviated to dB) using the relationship TS = 10 $\log_{10}(\sigma_{bs})$.

3. Results

3.1. Fishing experiment McMurdo Sound

A total of 16 Antarctic toothfish were caught on the three sets in which acoustic data were recorded, but the lower fish (of 12) on 11 November 2015 was excluded from further analysis as it could not be distinguished from the longline weight (Table 2). The TS distribution of the remaining 15 targets is shown in Fig. 2. Fish length was between 104 and 153 cm TL with weights from 11.6 to 46.4 kg. Estimated mean TS was between −38.3 dB and −43.7 dB. There was no clear relationship between TS and fish length, with the largest fish having the lowest mean TS (Fig. 2).

There was a relationship between fish position on the line and acoustic TS, with fish in lower positions having generally lower and more variable TS (Fig. 2). This may have been due to acoustic interference from higher fish on the line. The three uppermost fish (one on