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Length–weight and otolith size to standard length relationships in 12 species of Southern Ocean Myctophidae: A tool for predator diet studies

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Abstract

Fish morphometric relationships are key tools for fisheries science and studies of food web dynamics and predator foraging behaviour, but parameterisations are limited for Southern Ocean myctophids (Family Myctophidae). New standard length (L_S) to total mass (M_T) relationships are therefore described for the 12 biomass-dominant myctophid fish species living in the Scotia Sea, Southern Ocean, using the most comprehensive data collected in the region to date. New linear regressions for otolith size (length; O_L and width; O_W) and L_S are also described. Significant ($p < .01$) L_S–M_T relationships were established for all species using simple non-linear regression. Significant ($p < .01$) relationships between L_S and both O_L and O_W were also determined for all species, with O_W being the best predictor of L_S in all but one species. Our study provides a comprehensive tool for reconstructing the myctophid component of marine predator diets that will improve future food web, predator behaviour and ecosystem studies in the Scotia Sea.

KEYWORDS
length–mass relationship, Myctophidae, otolith-body size relationship, otoliths, Southern Ocean

1 | INTRODUCTION

Myctophid fish (Family Myctophidae) are the most successful clade of mesopelagic fish in the Southern Ocean, with ~ 35 species and an estimated biomass that may substantially exceed 70–200 million tonnes (Hulley, 1981; Lubimova et al., 1987). Myctophids are crucial in Southern Ocean food webs, but there remains a need to evaluate their role in this system to resolve the impacts that ongoing environmental change will have on the local marine ecosystem (Atkinson et al., 2019; Murphy et al., 2007). Against this backdrop, recent studies have focussed upon the role of myctophids as consumers in Southern Ocean food webs (Saunders et al., 2019). However, their trophic role as prey for the many pelagic predators that inhabit the region is lesser understood, which has limited the assessment of Southern Ocean food web structure and resilience (Xavier et al., 2016).

The analysis of myctophid sagittal otoliths retrieved from predators can provide important information on their species, size, mass, and energetic content, which is a prerequisite for understanding predator trophodynamics. However, useful information can only be obtained from the otoliths if the species-specific relationship between otolith size (or mass) and fish size is established robustly.

Existing information on otolith size to fish size relationships are available for some Southern Ocean myctophids, but they are limited by relatively small samples sizes collected predominantly over limited spatial and temporal scales (Adams & Klages, 1987; Cherel et al., 1997; Reid, 1996; Williams & McEldowney, 1990). The available body length–mass relationships are similarly limited. Here, we examine the relationships between otolith size and standard length, and standard length and mass, for the biomass-dominant myctophids in the Scotia Sea to improve the accuracy of their parameterisation for Southern Ocean food web and ecosystem studies.

2 | MATERIALS AND METHODS

Mesopelagic fish were collected across the Scotia Sea (southwest Atlantic; 57.57°S, 40.07°W) during four multidisciplinary research cruises onboard RRS *James Clark Ross* in Mar–Apr 2004, Oct–Dec 2006, Jan–Feb 2008 and Mar–Apr 2009 (see Collins et al., 2008; 2012 for further details). Specimens were collected from discrete depth horizons (at ~200 or 300 m intervals) between 0 and 1,000 m using a 25 m^{-2} rectangular mid-water trawl net (RMT25, with 3 mm cod end mesh; Piatkowski et al., 1994). Net samples were sorted onboard to the lowest taxonomic level possible (Hulley, 1990). Standard length (L_S) and total mass (M_T) of each specimen was recorded to the nearest 0.1 cm and 0.01 g, respectively, and a random sub-sample of up to 10–25 specimens per haul was frozen at −20°C for subsequent otolith analysis. Additional samples of the rarer species *Gymnoscopelus bolini* and *Gymnoscopelus hintonoides* were obtained by a commercial sized demersal trawl (FP-120) deployed to ~200–500 m during a scientific survey around the South Georgia shelf-break onboard the fishing vessel *Dorada* in Jan 2003 (see Collins et al., 2004).

TABLE 1 Relationship of standard length (L_S)–total mass (M_T) for 12 myctophid species in the Scotia Sea. Specimens were obtained from a total of 204 net hauls between 2004 and 2009

Species	Location	*n*	L_S range (cm)	M_T range (g)	*a*	±95% C.I.	*b*	±95% C.I.	r^2
Electrona carlsbergi (Tåning, 1932)	Northern Scotia Sea	377	6.5–9.0	3.77–9.27	0.0183	0.00451	2.88	0.121	.856
Electrona antarctica (Günther, 1878)	All Scotia Sea	1,459	2.5–11.3	0.16–22.12	0.00510	0.000392	3.45	0.0339	.975
Gymnoscopelus bolini Andriashev, 1962	South Georgia	111	14.9–25.5	44.00–198.00	0.00560	0.00235	3.23	0.140	.954
Gymnoscopelus braueri (Lönnberg, 1905)	All Scotia Sea	884	3.4–16.2	0.24–19.49	0.00510	0.00059	3.21	0.0441	.976
Gymnoscopelus fraseri (Fraser-Brunner, 1931)	Northern Scotia Sea	100	3.9–11.5	0.34–11.75	0.00690	0.00157	3.22	0.104	.979
Gymnoscopelus hintonoides Hulley, 1981	South Georgia	20	10.2–14.5	12.00–38.00	0.0200	0.0192	2.80	0.368	.951
Gymnoscopelus nicholsi (Gilbert, 1911)	All Scotia Sea	53	3.4–16.0	0.27–48.17	0.00890	0.00627	3.06	0.261	.963
Gymnoscopelus opisthopterus Fraser-Brunner, 1949	All Scotia Sea	38	5.6–17.0	1.00–50.00	0.0777	0.0735	2.25	0.353	.964
Krefftichthys anderssoni (Lönnberg, 1905)	Northern Scotia Sea	605	2.7–7.4	0.14–4.16	0.0113	0.00137	2.97	0.0682	.963
Protomyctophum tenisoni (Norman, 1930)	Northern Scotia Sea	157	2.8–5.5	0.22–1.84	0.0193	0.00274	2.69	0.0933	.973
Protomyctophum bolini (Fraser-Brunner, 1949)	All Scotia Sea	376	2.5–6.6	0.19–3.58	0.144	0.00176	2.95	0.0774	.951
Protomyctophum choriodon Hulley, 1981	Northern Scotia Sea	48	5.6–8.4	1.69–6.61	0.0206	0.00745	2.75	0.188	.957

Note: The Northern Scotia Sea was defined as waters north of the South Antarctic Circumpolar Current Front, which occurs generally in the region at ~56°S.

Abbreviations: ±95% CI, 95% confidence intervals for *a* and *b*; *a*, intercept; *b*, slope; *n*, total number of specimens collected; r^2, coefficient of determination.

TABLE 2 Relationships of standard length (L_S), to otolith length (O_L) and otolith width (O_W) for 12 myctophid species in the Scotia Sea. Specimens were obtained from a total of 204 net hauls between 2004 and 2009

					L_S to O_L						L_S to O_W					
Species	***n***	**L_S range (mm)**	**O_L range (mm)**	**O_w range (mm)**	***a***	**±95% CI**	***b***	**±95% CI**	**r^2**	***F***	***a***	**±95% CI**	***b***	**±95% CI**	**r^2**	***F***
Electrona carlsbergi (Tåning, 1932)	134	65–90	2.96–3.92	2.63–3.50	17.0	4.69	20.2	1.57	.614	*	5.86	5.99	21.0	1.76	.577	*
Electrona antarctica (Günther, 1878)	173	36–109	0.88–2.32	1.64–2.68	−4.23	2.78	48.8	1.58	.876	*	−8.57	2.39	42.1	1.12	.913	*
Gymnoscopelus bolini Andriashev, 1962	50	174–255	6.00–9.20	3.33–5.25	49.2	17.8	37.5	4.16	.682	*	33.5	14.4	23.9	1.95	.799	*
Gymnoscopelus braueri (Lönnberg, 1905)	164	42–139	0.80–2.62	0.88–2.42	2.25	3.39	49.8	1.82	.854	*	−17.7	3.60	59.6	1.91	.884	*
Gymnoscopelus fraseri (Fraser-Brunner, 1931)	42	45–85	1.64–3.70	1.08–2.44	−9.74	8.07	39.8	3.90	.763	*	−0.0460	6.65	22.9	2.10	.787	*
Gymnoscopelus hintonoides Hulley, 1981	15	118–145	4.13–5.50	2.50–3.17	25.6	27.0	38.2	9.37	.615	*	57.9	13.1	16.0	2.69	.773	*
Gymnoscopelus nicholsi (Gilbert, 1911)	97	39–159	1.70–6.29	1.14–3.67	−25.8	3.54	50.8	1.21	.959	*	−17.5	3.29	28.2	0.66	.960	*
Gymnoscopelus opisthopterus Fraser-Brunner, 1949	20	82–166	1.68–3.52	1.28–2.84	17.3	11.4	53.6	5.72	.901	*	−0.600	9.01	58.5	4.24	.952	*
Krefftichthys anderssoni (Lönnberg, 1905)	94	27–71	0.90–1.74	0.82–1.48	−19.0	4.33	52.6	3.30	.810	*	−28.0	4.09	67.3	3.53	.859	*
Protomyctophum tenisoni (Norman, 1930)	45	29–53	0.98–1.42	1.14–1.62	−34.2	6.24	61.3	4.96	.815	*	−22.0	4.07	45.2	2.83	.880	*
Protomyctophum bolini (Fraser-Brunner, 1949)	140	28–66	1.24–1.94	1.48–2.46	−27.1	5.95	46.4	3.64	.599	*	−25.0	3.60	35.8	1.75	.795	*
Protomyctophum choriodon Hulley, 1981	24	59–98	1.85–2.25	1.63–2.18	0.482	28.5	34.0	13.8	.501	*	6.29	24.1	34.1	12.7	.532	*

Abbreviations: 95% CI, 95% confidence intervals for *a* and *b*; *a*, intercept; *b*, slope; *F*, significance level of the ANOVA *F* test (*$p < .01$); *n*, total number of specimens collected; r^2, coefficient of determination.

Sagittal otoliths were removed by dissection, cleaned and dried. For each otolith, the maximum otolith length (O_L) and width (O_W) were measured to the nearest 0.001 mm using a microscope and a calibrated eyepiece graticule, recording the greatest distance from the anterior tip to the posterior edge (O_L) and the greatest distance between the otolith dorsal and ventral margins (O_W; Reid, 1996; Williams & McEldowney, 1990). Standard length–mass relationships were calculated for each species, using the simple non-linear regression model: $M_T = aL_S^b$; where the coefficients *a* and *b* are constants of the regression. Linear regression was used to relate L_S to O_L and O_W. These equations were first calculated for both left and right otoliths for each species and a *t* test was used to compare regression coefficients; when significant differences ($p < .05$) were not found, the H_0 hypothesis ($b_{right} = b_{left}$) was accepted. Where these equations did not differ statistically, a single linear regression was reported for each variable (O_L and O_W) and species.

3 | RESULTS

Significant ($p < .01$) length–mass relationships (L_S to M_T) and length–otolith size regressions (L_S to O_L and L_S to O_W) were established for 12 species and the model parameters are given in Tables 1 and 2. The *t* tests on the relationship between L_S and O_L and O_W did not show significant differences ($p > .05$) between left and right *sagittae*, so a single regression was used for each species. Based on the coefficient of determination (r^2), O_W was the best predictor of L_S for all species except *Electrona carlsbergi*.

4 | DISCUSSION

Our data represent a large proportion of the Southern Ocean myctophid fish assemblage and encompass the biomass-dominant species that reside in waters south of the Antarctic Polar Front (APF; Hulley, 1981). They also cover the species found most frequently in predator diets in the region (Reid et al., 2006). Myctophids are challenging to sample adequately at appropriate spatio-temporal scales in the remote Southern Ocean, which has hindered adequate parameterisation of their morphometric relationships. We examined data from greater sample sizes and more resolute spatio-temporal scales than previously available in the region, making our study the most accurate tool available to date for reconstructing the myctophid component of Southern Ocean predator diets. We also provide the most comprehensive standard length–mass relationships for myctophids that occur south of the APF, which are of high importance for many applications in a fisheries science, food web and marine ecosystem research context.

With respect to the standard length–otolith size relationships, our data are broadly characteristic of the size ranges caught in the Scotia Sea for each species. In general, few specimens <40 mm of any species have been found in the region across multiple years and seasons, using a range of different sampling gear (Saunders et al., 2019). The lack of data at smaller size classes is likely to be a prime contributor to the negative intercepts of the relationships for some species (Table 2), which indicates that data from waters north of the APF, where the smaller size classes probably occur (Hulley, 1981), may be needed to constrain the relationships more robustly. This is also true for the predominately expatriate species *E. carlsbergi*, where more data across its full size range are needed to establish a more accurate length–weight relationship (Table 1). Indeed, this is a problem common to previous studies in the Southern Ocean. We maintain that it is advisable to use the O_L–L_S and O_W–L_S linear regressions and the L_S–M_T equation within the fish size range limits reported in order to avoid errors in mass and size estimation, particularly when extrapolating to other regions of the Southern Ocean. Clearly, further studies are required throughout the Southern Ocean to put our parameterisations into context and facilitate regional comparisons in growth and morphometry. Other limitations to the use of this methodology include the rate at which the otolith increases in length may slow down, with otoliths increasing only in thickness at the maximum body size (Williams & Bedford, 1974), and a change in the otolith size and fish size relationship may be observed in larval and juvenile specimens (Bystydzienska et al., 2010).

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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