

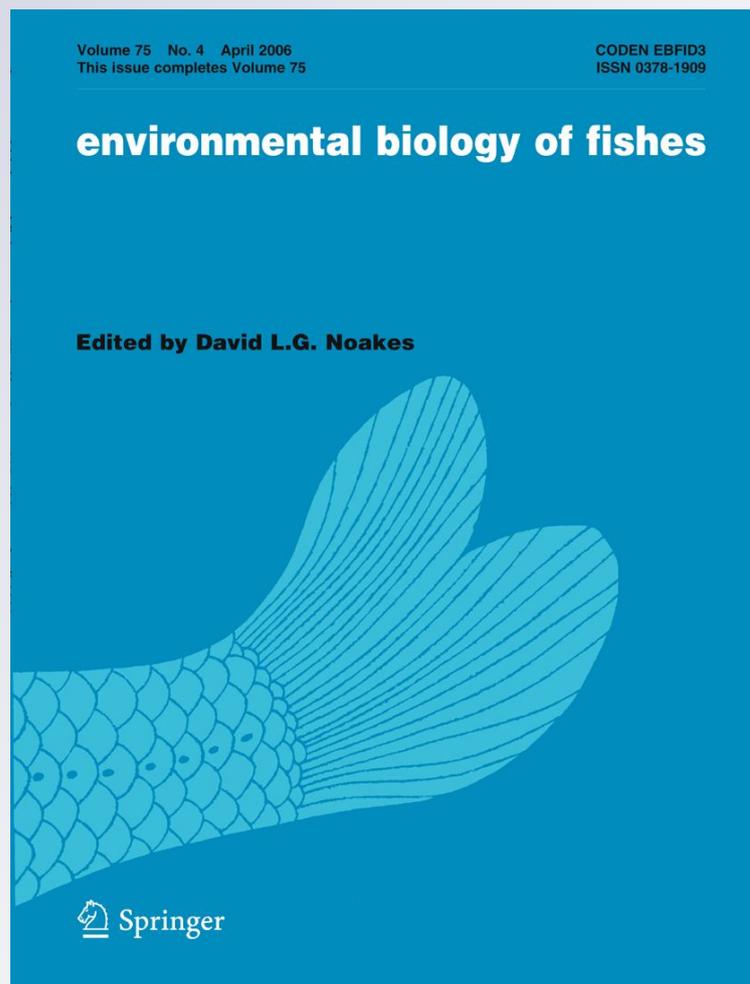
Larval fish distribution, growth and feeding in Patagonian fjords: potential effects of freshwater discharge

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Larval fish distribution, growth and feeding in Patagonian fjords: potential effects of freshwater discharge

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Abstract In fjord systems, freshwater inputs occur by ice melting and river discharge, affecting seawater salinity along fjord and adjacent waters, and potentially the ecology of early life stages of marine fish occurring in the area. During austral spring 2008, a bio-oceanographic cruise was carried out in southern Chile between 47°00' and 50°09'S, an area influenced by Baker River discharge and ice melting of Northern and Southern Ice Fields, the largest glaciers from Patagonia. Surface salinity and temperature ranged from 1.22 to 32.80, and from 8.11 to 10.68°C, respectively. Larval lightfish *Maurolicus parvipinnis* (Sternoptychidae) and Falkland sprat *Sprattus fuegensis* (Clupeidae) were the dominant species, with abundances of 2.2–39.9 larvae 10 m⁻² and 3.4–77.1

larvae 10 m⁻², respectively. Postflexion stages of both species were collected mainly in surface density fronts. Otolith-based growth analyses estimated linear growth rates of 0.136 mm day⁻¹ for *M. parvipinnis* of 4.1–15.1 mm, and 0.448 mm day⁻¹ for *S. fuegensis* of 5.4–20.5 mm. Recent Otolith Growth Index (ROGI), based on the residual analysis of the relationship between increment width of outermost five micro-increments and otolith radius, indicates that larval *M. parvipinnis* collected in low salinity waters showed a reduction of its recent growth rate compared those collected in saltier waters. Also, ROGI was positively correlated with salinity of the water column for larval *M. parvipinnis*. Gut content analysis showed that large larvae collected near sources of freshwater had lower number of prey in its guts and preyed on different items than fish larvae collected in saltier waters. Therefore, freshwater inputs from rivers and glaciers from Patagonia affected horizontal distribution, recent growth and feeding of larval fish in fjords and channels of southern Chile.

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Introduction

Fishes inhabiting fjord ecosystems have developed several adaptive mechanisms to feed and reproduce in such a variable environment, even with a tendency in

some fish species for population differentiation in the inner and outer part of a fjord (Goodson et al. 1995; Olsen et al. 2002; Kaartvedt et al. 2009). In fjord ecosystems, freshwater runoff and forceful mountain winds set up estuarine circulation patterns that may transport zoo- and ichthyoplankton into fjords, and possibly lead to entrapment of plankton there. The exposition to low-salinity surface waters of fish larvae and juveniles may result in osmotic stress that induces episodic massive mortality of potential food items from the plankton (Kaartvedt and Aksnes 1992; Eiane and Daase 2002), which in turn, may affect the fish somatic growth (Baumann et al. 2007; Husebø et al. 2007; Kristoffersen and Salvanes 2009). Furthermore, fishes may perform diel vertical migration in fjords, reducing its activity in deep waters and scanning the water for prey during ascent and descent (Kaartvedt et al. 2008).

The Magellan Zoogeographic Province in southern Chile is an extensive fjord-type estuarine system stretching from Puerto Montt (41°30'S) to Cabo de Hornos (55°58'S), 780 nautical miles in length and including many islands with innumerable channels and fjords. The area is characterized by a remarkable, permanent salinity minimum caused by high discharge of river fluxes. One of the largest rivers of southern Chile in terms of volume is the Baker River basin, 26 726 km² (Moya et al. 2009). It has a nival regimen with maximum freshwater discharge during the austral summer, when ice melting takes place (river flux around 100–250 m³ s⁻¹, Dávila et al. 2002). The river discharges to a narrow and deep channel (Baker Channel, from 30 to 860 m depth). Additionally, two prominent ice masses, the Northern and Southern Ice Fields, of 4,200 and 16,800 km², respectively, are also found in this extensive zone, feeding dozens of glaciers which melt during austral spring and summer.

Chilean fjords are largely utilized by fast growing, short life span small fishes, such as Falkland sprat *Sprattus fuegensis* and lightfish *Maurolicus parvipinnis* (Balbontín and Bernal 2005; Bustos et al. 2008, 2011). Falkland sprat forms dense schools in straits and channels along the Argentinean Patagonian coast (Sánchez et al. 1995) and recently it has been identified south 41°S in the Pacific Ocean (Aranis et al. 2007). It is a partial spawner whose reproductive activity tends to concentrate between September and October (Leal et al. 2011). Although a member of principally oceanic,

mesopelagic family, lightfish seems to be associated with land masses near upwelling areas (Landaeta and Castro 2002), seamounts (Boehlert et al. 1994) and fjords (Lopes 1979; Kaartvedt et al. 2008). There is no information about reproductive activity of this species; however, its eggs are highly abundant during austral spring along Chile (Landaeta and Castro 2002; Bustos et al. 2008, 2011).

Fresher waters in the inner fjords and channels may reduce potential food items for larval and juvenile fish. In southern Chile, Landaeta and Castro (2006) demonstrate that calanoid and cyclopoid copepods smaller than 500 µm were more abundant near freshwater sources and large calanoid copepods (>500 µm) dominates prey field in oceanic mixed waters. Furthermore, the presence of frontal areas which are a product of the convergence of freshwater and saltier, oceanic waters create retention zones off fjords and along channels where it concentrates floating kelps (*Macrocystis pyrifera*, Hinojosa et al. 2010), attracting early life stages of marine invertebrate and fishes (Kingsford 1995; Landaeta and Castro 2006; León et al. 2008). Therefore, these areas may be utilized by larval and juvenile fish as feeding grounds, increasing recent growth rates at local scale.

We hypothesize that freshwater discharge from river inputs and ice melting from two major glaciers affects spatial distribution, recent growth and feeding of larval fish found in fjords of southern Patagonia. Therefore the main goal of this study is to analyze spatial distribution, recent larval growth through otolith microstructure and larval feeding by gut content analysis of fish larvae collected in areas near freshwater input and zones with oceanic influence of Patagonia, southern Chile.

Methods

Field work

An oceanographic cruise was carried out between 1 and 18 November 2008 (austral spring) onboard the R/V Vidal Gormaz between 46°48'S and 50°09', and comprised 45 stations (Fig. 1). At each station, environmental data of the water column (temperature, salinity, density) were collected from the surface to 800 m depth or 10 m above the bottom with a Seabird SBE-19 CTD profiler. Plankton samples were collected

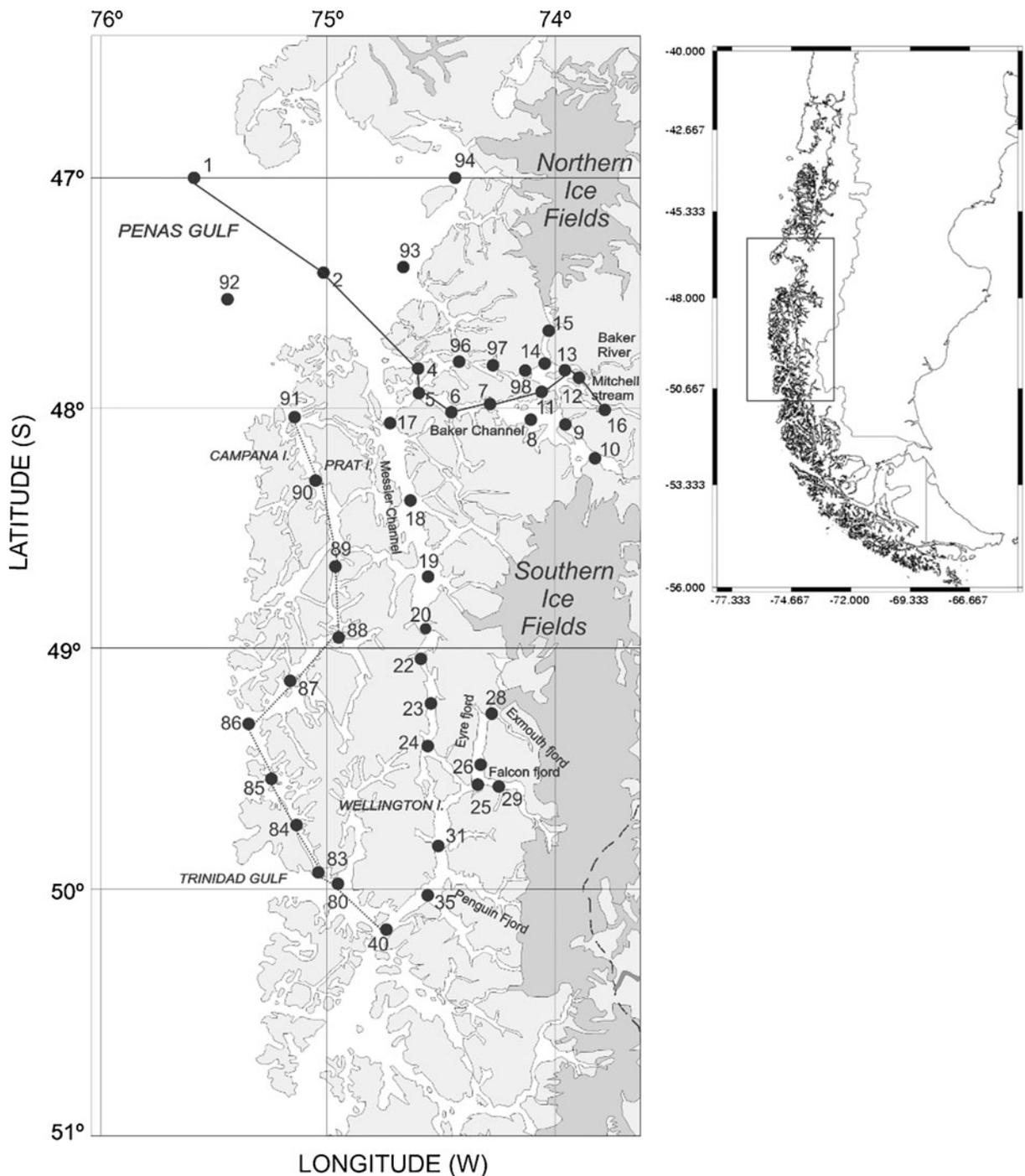


Fig. 1 Map showing the location of the stations sampled in November 2008. Lines correspond to transects showed in Fig. 2

from 200 m depth or 10 m above the bottom to the surface through oblique tows with a Bongo net (66 cm diameter, 300 μ m mesh size) with a TSK flowmeter mounted in the frame of the net to estimate the volume of

the seawater filtered. Towing speed was ~2–3 knots. The volume filtered in each tow (range=101.9–881.6 m³/tow, mean \pm standard deviation=419.9 \pm 151.1 m³/tow) was calculated from flowmeter counts. Once over the

vessel, the nets were washed and one sample was fixed in 5% formalin buffered with sodium borate for gut content analysis and other was preserved in 90% ethanol for studies of larval growth.

Laboratory analysis

All fish larvae were removed from all samples and identified to the lowest possible taxon; larval lightfish *Marolicus parvipinnis* and larval Falkland sprat *Sprattus fuegensis* were identified following de Ciechomski (1971). From ethanol samples, all undamaged larvae were measured to the nearest 0.01 mm (notochord length, NL, or standard length, SL) before extraction of otoliths under a stereomicroscope Olympus SZ-61 with a video camera Moticam 2500 (5.0MPixel) connected to a PC with Moticam Image Plus 2.0 software. Larval measurements were not corrected for shrinkage. Larvae were classified according to their developmental stages as pre- and postflexion (inflexion larvae were included in postflexion). Larval counts were converted to integrated abundance in the water column (larvae 10 m^{-2}).

Left and right sagitta otoliths were removed using insect needles from 100 larval *M. parvipinnis* (4.14–15.10 mm SL) and 42 larval *S. fuegensis* (5.44–20.47 mm SL) (Fig. 2). Otoliths were embedded in epoxy resin on a glass slide. Age was determined by counting the number of daily otolith increments with a light microscope Motic BA310 at 1,000 \times magnification under oil immersion; the longest radius of the sagitta was measured three times and the average was utilized; perimeter and area of otoliths were measured one time using Moticam Image Plus 2.0 software.

Three independent readings were made on each sagitta; where increment counts between three readings were within 5% of each other, one measurement was randomly selected for analysis. If readings varied >5% of each other, the otolith was discarded. Sagittae are considered ideal because we found that age estimates using the left and right sagittae within individuals were the same (Wilcoxon sign test, $p=0.563$, $N=54$ for *M. parvipinnis*; $p=0.093$, $N=34$ for *S. fuegensis*).

Although we did not attempt to validate the daily periodicity of growth increments in *M. parvipinnis* and *S. fuegensis*, other authors have confirmed the daily nature of growth increments in *S. sprattus* (Alshuth 1988; Ré and Gonçalves 1993), and *M. stehmanni* (Belluco et al. 2004). Absolute ages and

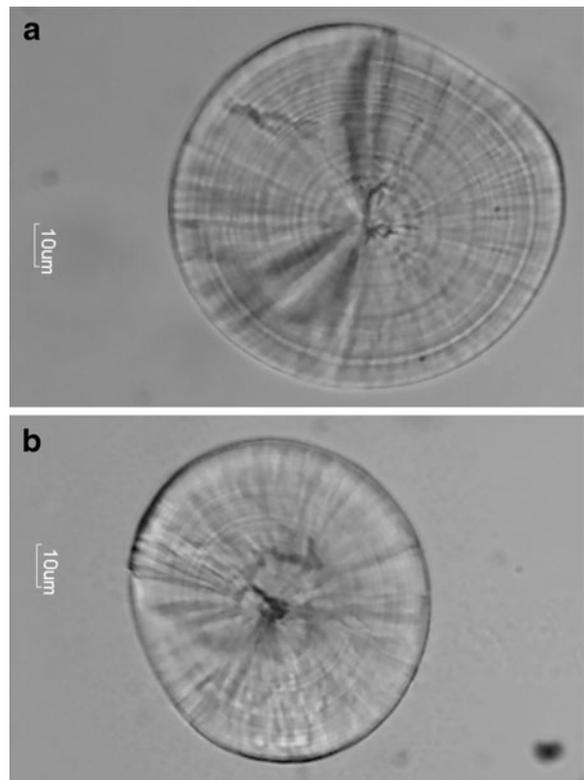


Fig. 2 Sagitta otoliths of **a** larval *Maurolicus parvipinnis* of 8.38 mm SL, **b** larval *Sprattus fuegensis* of 10.55 mm SL

dates of initial increment formation remain uncertain, though we do not consider it critical for the focus on growth rate estimations given the assumption that the time of initial increment deposition is constant for larvae of each species (Jeffrey and Taggart 2000).

From formalin samples, 75 larval *M. parvipinnis* were measured (notochord length for preflexion larvae, standard length for inflexion and postflexion larvae) and utilized for gut content analysis. The low number of larval *Sprattus fuegensis* preserved in formalin precluded the gut content analysis for this species. The gut of each larva was dissected from the body and opened lengthwise with fine needles. Prey items were counted and identified to the lowest possible taxon. The maximum body length and width of each prey item were measured to the nearest 0.01 mm, using a microscope with an ocular micrometer, along the maximum cross section that the larvae had to ingest (Sassa and Kawaguchi 2004). The volume of each prey was estimated using the three-dimensional shape that most closely resembled the item, following Cass-Calay (2003).

Data analyses

Least square linear regression analyses were performed between otolith measurements (radius, perimeter) and larval length for both larval species. Larval size and otolith area were related by potential models. Estimations of larval growth were carried out using least square linear regression models, where the slope corresponds to the population growth rate of each species.

Increment widths cannot be compared directly (Hovenkamp and Witte 1991). When increments which were formed at different radii are compared, the increment at the largest radius will on average be wider. To estimate a recent otolith growth index (ROGI), residuals of the relationship between the sum of the widths of the last five more recent increments and the radius of the otolith were calculated. The rationale for residual analysis is that since a residual is a measure of an individual's departure from the population, it can be viewed as an indicator of condition (Aguilera et al. 2009). According to this relationship, when increment width is larger than expected, the residuals of the regression will be positive, which means that otolith growth has been above average. When increment is smaller than expected, the residuals will be negative, which means that otolith growth has been below than average. Both variables (sum of five outer increment widths, excluding the last one, and largest radius of the sagitta otolith) were log transformed so that the variances would be independent of the mean.

To study the effect of freshwater discharges (salinity gradients), Spearman rank correlation and linear regression models were calculated for ROGI of *M. parvipinnis*, *S. fuegensis* and seawater salinity. Salinity values correspond to the average of first 50 m depth of the sampled water column, where most larval *M. parvipinnis* and clupeids occur in Chilean fjords (Landaeta et al. 2009).

Feeding incidence (FI) was calculated as the percentage of the total number of larvae examined having at least one prey in the guts. For gut content analysis, larval *M. parvipinnis* were separated into two groups: those collected along the Baker Channel (surface waters <20, stations 7, 8, 10, 13, 14, 15, 16 and 96; Fig. 1) and those collected outside the Baker Channel. Least square linear regression analyses were performed between larval length and number of prey items and prey volume. Also, for each group of

larvae, prey items were evaluated using the percentage of each item out of the total number of dietary items examined (%N), the percentage of volume of each item out of the total volume of prey items (%V), and the percent frequency of occurrence of each prey item (%F). An index of relative importance (IRI) was calculated as follows: $IRI = (\%N + \%V) \times \%F$. To readily allow comparisons among prey items, the IRI was then standardized to %IRI for each prey item *i* (Cortés 1997).

Results

Physical settings

Water column structure was variable depending on the coastal geometry and topographic features of the area: a) Open ocean: the most exposed area, Penas Gulf, was vertically stratified by temperature, ranging from 10.8°C at surface to 7.0 at 200 m depth (Fig. 3a). Salinity values were the highest and showed a slight variation with depth, around 33–34 (Fig. 3b); b) channels: at longitudinal channels, water column was vertically stratified by salinity, showing strong vertical gradients (i.e., halocline) at 20–25 m depth (Fig. 3d). Temperature inside channels was rather stable, from 8.5 to 9.5°C (Fig. 3c). Horizontal gradients (i.e., fronts) were generally observed above topographic constrictions, for example, around stations 85 and 86 (El Indio Constriction, Fig. 3c, d); c) area influenced by river discharge and ice melting. In the area near Baker River (stations 12 and 13) and Mitchell stream (station 16) salinity showed the lowest values (Fig. 3b); freshwater input caused strong vertical and horizontal gradients, with values as low as 10 found at 12 m depth (Fig. 3b). As a consequence, strong horizontal salinity gradient along the Baker Channel occurred (Fig. 3b).

Larval fish abundance and distribution

Abundance of fish larvae was low throughout the studied area. Larval *Maurolicus parvipinnis* at pre- and postflexion stages ranged between 1.79 and 16.50 ind. $\times 10^{-2}$ and 1.68 and 29.41 ind. $\times 10^{-2}$, respectively. There was no significant differences in larval abundance among stages (Mann-Whitney U-test, $U=206.5$, $p=0.927$). Spatially, the distribution of pre- and postflexion larvae was different (Fig. 4); preflexion stages were collected throughout the studied area, with

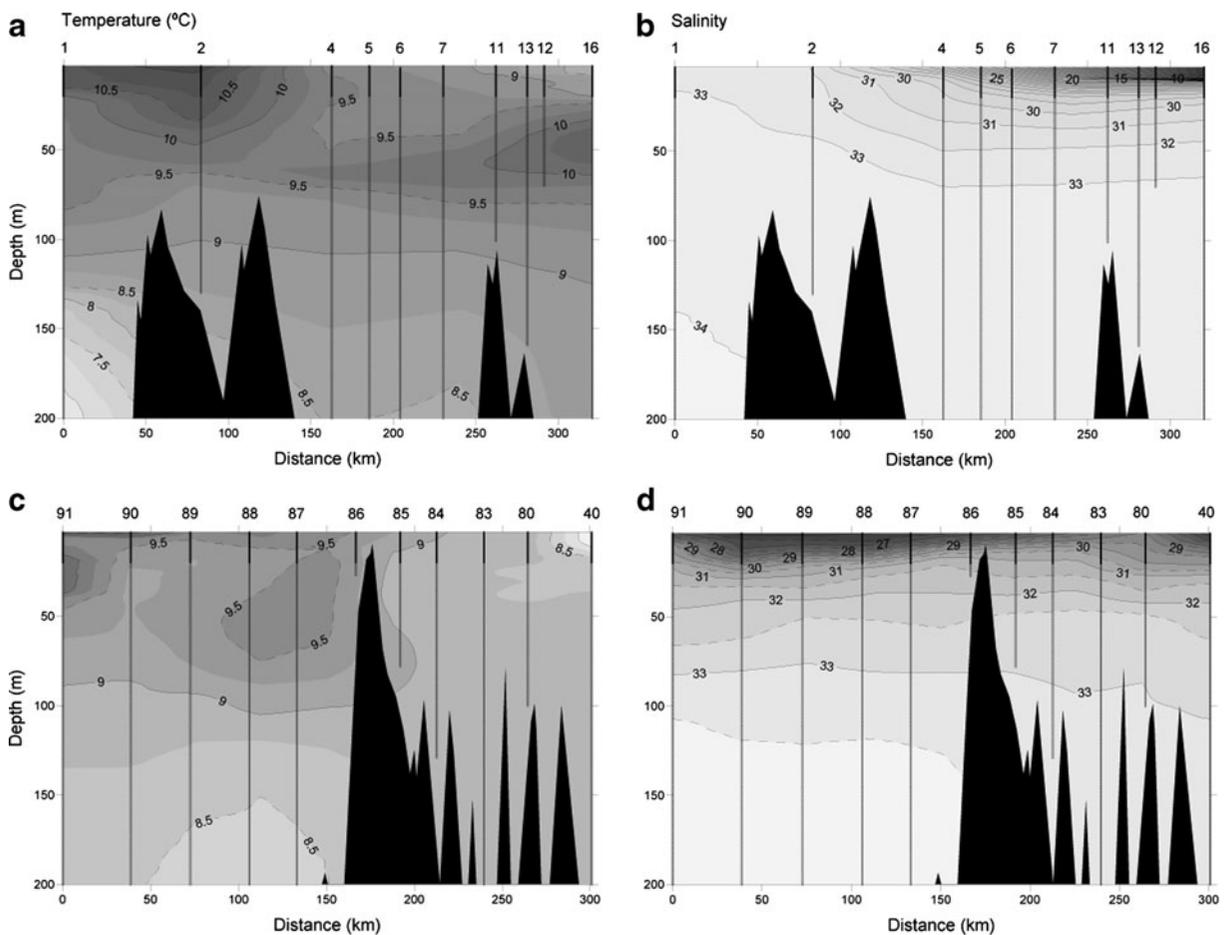


Fig. 3 Vertical sections transects of **a** and **c** temperature ($^{\circ}\text{C}$), and **b** and **d** salinity in southern Chile during November 2008. See number of stations in Fig. 1 for details

the highest abundance found along the Messier Channel (Fig. 4). Postflexion larvae of *M. parvipinnis* were found in higher abundance near sources of freshwater: off North and South Ice Fields, and Baker River, and also in mixed waters off Trinidad Gulf (station 80, Fig. 4). Abundance of pre- and postflexion larval *S. fuegensis* were similar ($U=34$, $p=0.593$) and ranged between 1.74 and 36.52 preflexion larvae $\times 10 \text{ m}^{-2}$ and from 1.68 to 5.71 postflexion larvae $\times 10 \text{ m}^{-2}$. Larvae were mainly located south Trinidad Gulf and along Baker Channel (Fig. 5).

Otoliths, recent larval growth and seawater salinity

Morphometrics of sagitta otoliths from both species showed that they grew proportionally to larval length (Fig. 6). Otolith radius and perimeter grew linearly in both species (Fig. 6a, b, d, e); sagitta area grew

potentially with the larval length for *M. parvipinnis* and *S. fuegensis* (Fig. 6c, f). These relationships also showed that sagittal otoliths of *M. parvipinnis* grew faster than otoliths of *S. fuegensis* though the size range was larger for the latter (Fig. 6). Otolith-based growth analyses estimated linear growth rates of $0.136 \text{ mm day}^{-1}$ for *M. parvipinnis* of 4.1–15.1 mm (Fig. 7a), and $0.448 \text{ mm day}^{-1}$ for *S. fuegensis* of 5.4–20.5 mm (Fig. 7b).

ROGI of larval *M. parvipinnis* and seawater salinity were positively correlated (Spearman rank analysis, 0.61, $p<0.05$) and a significant linear relationship was found ($F=9.05$, $p=0.008$) between both variables. Positive residuals were mostly found for larval *M. parvipinnis* collected in a water column with salinity >30 . Pre- and postflexion larval *M. parvipinnis* found at lower salinities showed recent growth slower than the population (Fig. 8a). ROGI of

Maurolicus parvipinnis

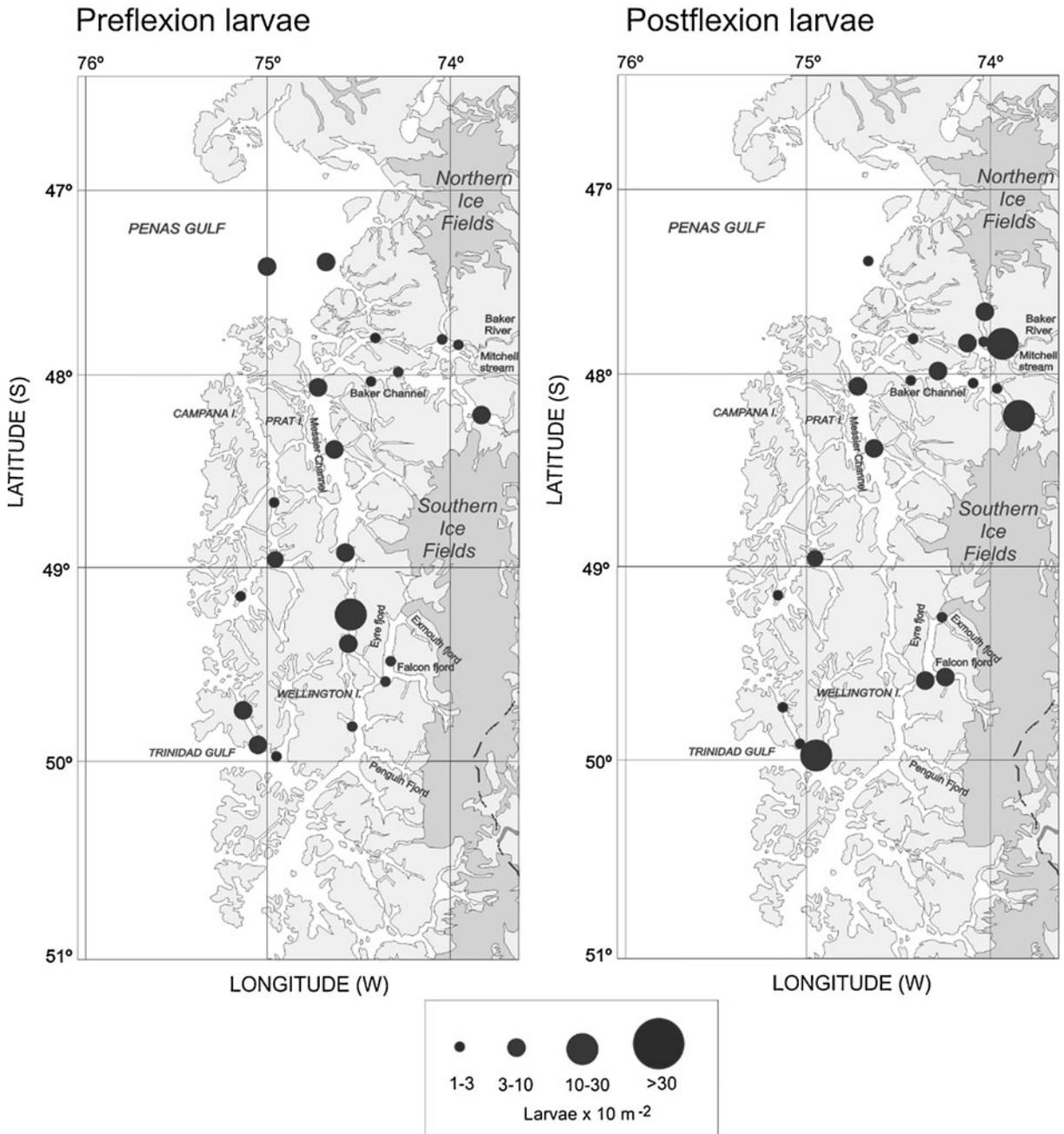


Fig. 4 Horizontal distribution of larval *Maurolicus parvipinnis* pre and postflexion stage. Abundances expressed as individuals $\times 10^{-2}$

larval *S. fuegensis* were not correlated with seawater salinity of the mixed layer of the studied area (Spearman rank analysis, 0.65, $p > 0.05$) and regression analysis showed that slope was not significant different of zero ($F = 2.77$, $p = 0.163$) (Fig. 8b).

Feeding of larval *Maurolicus parvipinnis*

Feeding incidence of larval *M. parvipinnis* was 63.6% ($n = 75$), and the smallest larval fish with content in its gut was of 4.08 mm length. Range of number of prey

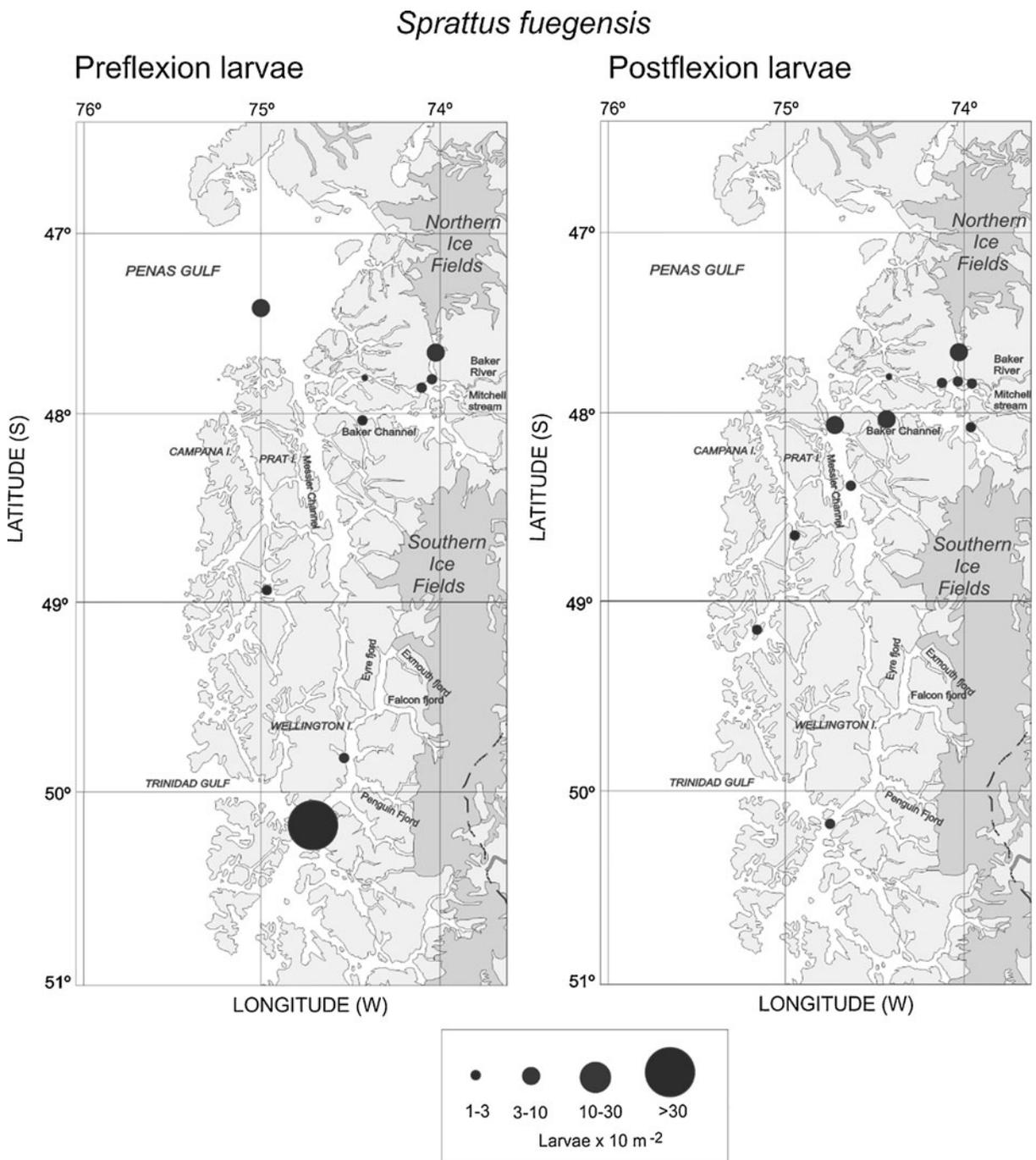


Fig. 5 Horizontal distribution of larval *Sprattus fueguensis* pre and postflexion stage. Abundances expressed as individuals $\times 10 \text{ m}^{-2}$

items in the guts was 0–11, with a mean of 2.70 ± 2.95 preys (excluding zeros, one standard deviation). Larval *M. parvipinnis* collected along Baker Channel and near Northern and Southern Ice Fields did not differ significantly in the ingested prey number nor in

total prey volume compared to those collected along exposed areas ($U=165$, $p=0.478$, and $U=117$, $p=0.238$, respectively), though the range was larger for larvae collected off Baker Channel (0–11 vs 0–3 preys, $0.001\text{--}0.617 \text{ mm}^3$ vs $0.005\text{--}0.097 \text{ mm}^3$;

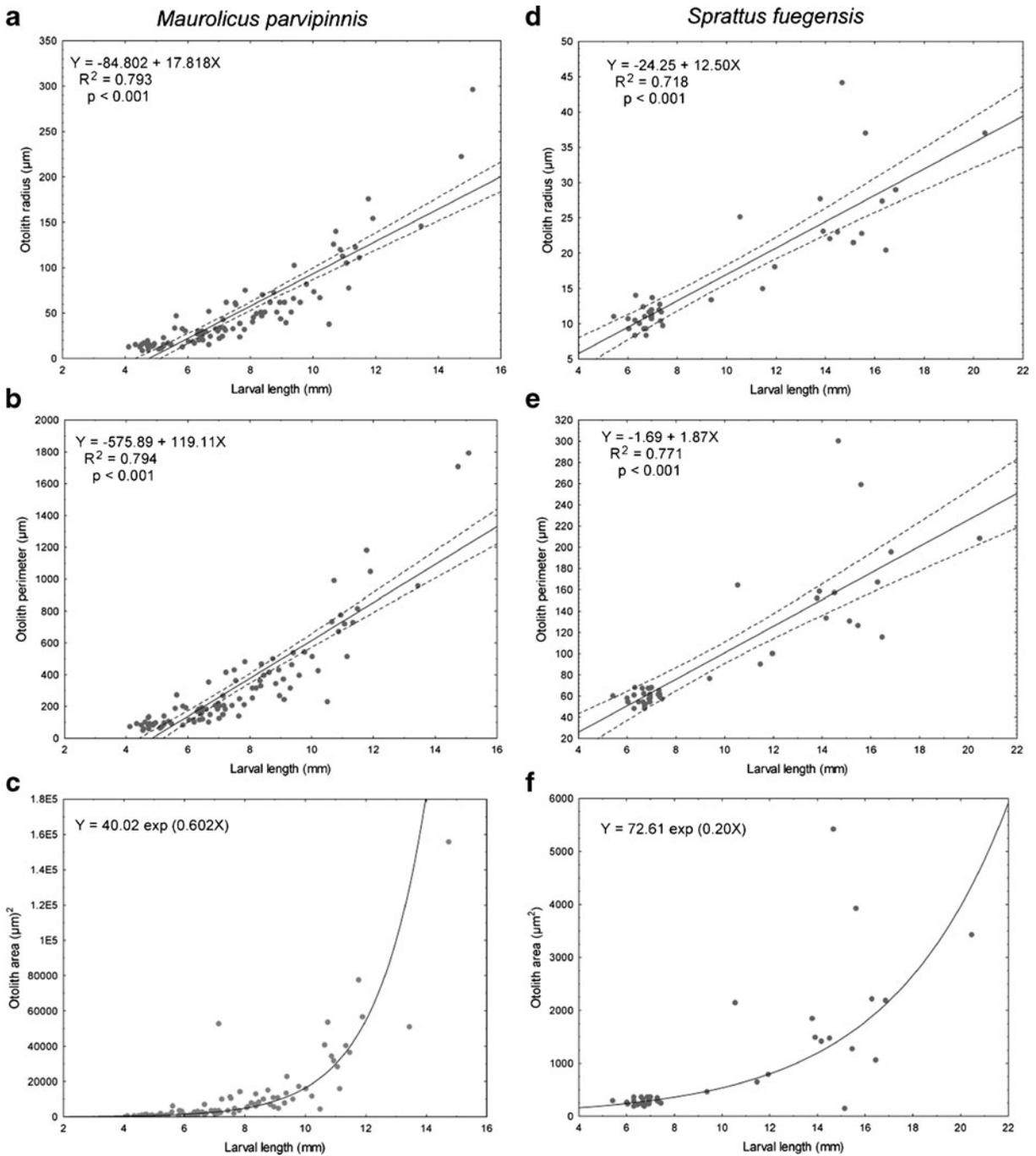


Fig. 6 Otolith morphometrics of larval *Maurolicus parvipinnis* and *Sprattus fuegensis*, respectively. **a, d** otolith radius (μm) vs larval length (mm), **b, e** otolith perimeter (μm) vs larval length (mm), and **c, f** otolith area (μm^2) vs larval length (mm)

Fig. 9). When compared by larval size, only larval *M. parvipinnis* collected outer Baker Channel showed significant positive relationship with prey numbers ($F=6.12$, $p=0.01$; Fig. 9). Differences in prey items

were also noticeable between areas (Table 1). Larval *M. parvipinnis* collected in fresher waters along Baker Channel preyed mostly on Ostracoda (%IRI=33.79%), *Paracalanus parvus* copepodites (%IRI=23.82%) and

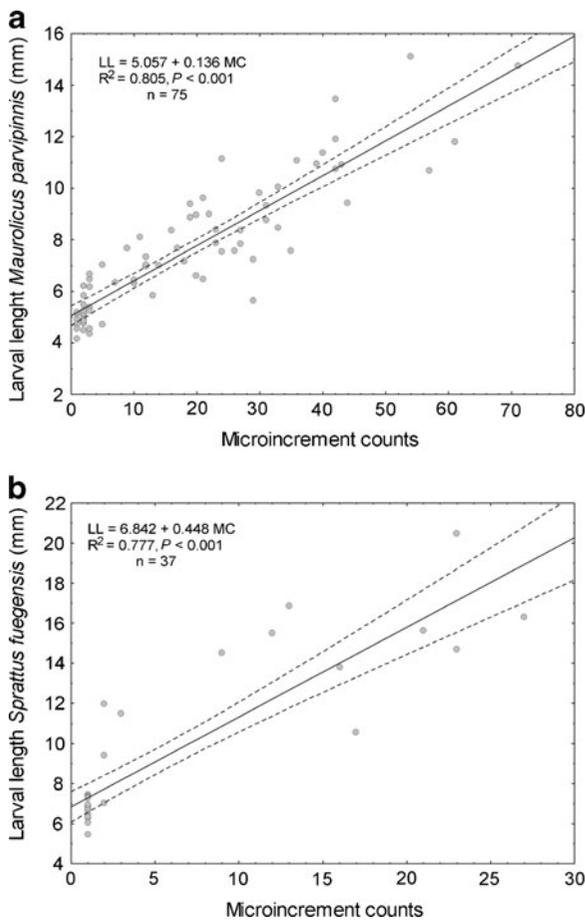


Fig. 7 Larval growth estimation based on microincrement counts of sagitta otoliths of **a** *Maurolicus parvipinnis* and **b** *Sprattus fuegensis*

mussel larvae (*Mytilus chilensis*, %IRI=10.44%); on the other hand, larvae found outside Baker Channel fed mainly on *P. parvus* copepodites (%IRI=36.23%), unidentifiable taxa (%IRI=18.49) and *Acartia tonsa* copepodites (%IRI=15.69%) (Table 1).

Discussion

Fjords are productive ecosystems which connect the open sea with freshwater derived from land drainage and ice melting, and consequently they are characterized by strong fluctuations and spatial variability in salinity. Plankton and nekton segregate along salinity gradients and differences in salinity alone can potentially affect recruitment success by causing changes in growth rates of fish larvae and juveniles (Peterson et al. 1999; Landaeta and Castro 2006) and

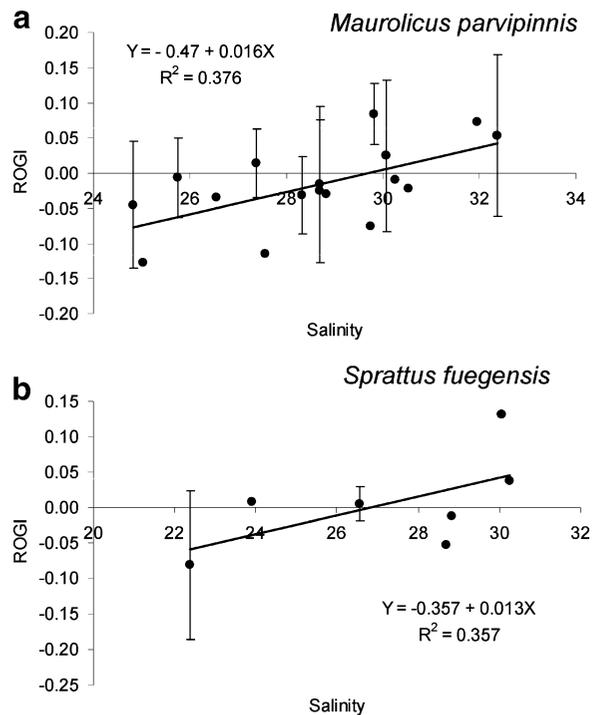


Fig. 8 Relation between recent otolith growth index (ROGI) and average surface seawater salinity (0–50 m depth) for larval **a** *Maurolicus parvipinnis* and **b** *Sprattus fuegensis*

other species with meroplanktonic stages (i.e., squat lobster, León et al. 2008).

Furthermore, fjords are a source of suspended sediments and floating ice. The effects of ice-front melting are found to be overwhelmed by the influences of glaciofluvial discharge and iceberg calving (Syvitski 1989), and buoyant sediment-laden meltwater mixes with fjord water to produce a thick, brackish overflow (Cowan and Powell 1990). For visual plankton feeders such as larval fishes, turbidity may reduce search and reaction distances, resulting in lower feeding abilities and as a consequence, reduction in larval growth.

This study showed that larval *Maurolicus parvipinnis* collected near sources of freshwater input were in poorer conditions (lower ROGI index), have similar number of prey items as larvae grown and fed on different preys (mussel larvae, ostracods), compared to those collected off Baker Channel, which have higher ROGI index, preyed on larger number of preys as larvae grown, feeding mainly on copepod stages (copepodites, eggs and nauplii). Recently, for southern Patagonia, Bustos et al. (2011) suggested based on the spatial distribution, composition and size

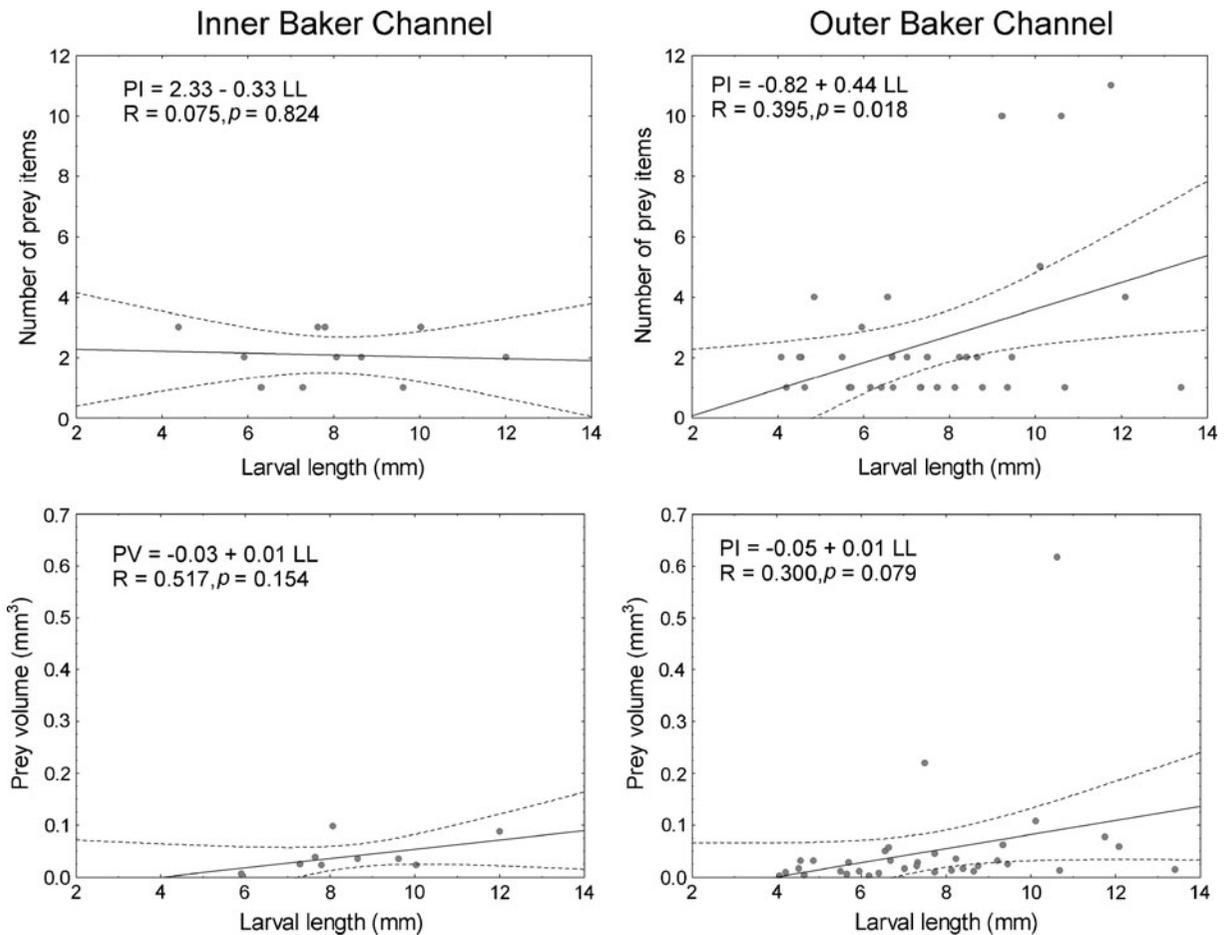


Fig. 9 *Maurollicus parvipinnis*. Relation between number of prey items (PI) and larval length (LL), and between prey volume (mm³, PV) and LL, in stations located inner and outer Baker Channel

structure of ichthyoplakton, that differences in size range of larval fish may be explained by differences in larval growth and survival between colder, turbid areas (upper fjords) and warmer, saltier and more mixed zones (open waters and channels). This hypothesis is partially supported by our results, particularly for larval stages of *Maurollicus parvipinnis* which showed differences in growth and feeding between areas. Instead, larvae of *Sprattus fuegensis* grew in a similar fashion at mixed and stratified coastal waters.

Two plausible explanations may be suggested for these results: i) reduced salinity of the water column affected physiology of fish larvae, prey field availability and recent growth; ii) low salinity is a proxy of high turbidity provoked by ice melting and suspended sediments transported by Baker River, causing a reduction of predator-prey encounter rates, and as a consequence, a reduction of ingestion and daily growth rates.

Differences in seawater salinity itself may not affect larval fish survival (flounders, Daniels et al. 1996) although it may affect larval and juvenile growth (weakfish, Lankford and Targett 1994; croaker, Peterson et al. 1999). A significant number of marine teleosts utilize estuaries as nursery ground in their early life history, and inevitably encounter brackish waters. Those species develop low-salinity tolerance by the interplay of prolactin and thyroid hormone activities (Hiroi et al. 1997), lower standard metabolic rate and an increase of food intake (Bœuf and Payan 2001). Clupeoid fishes, such as *Sprattus fuegensis* inhabit coastal waters of Chilean and Argentinean Patagonia (Sánchez et al. 1995; Bustos et al. 2008, 2011) and its early life stages may be adapted to tolerate low salinity waters, partially explaining lack of correlation between ROGI index and salinity in larval *S. fuegensis* (Fig. 8b). On the other hand, mesopelagic species such

Table 1 Summary of prey items in *Maurolicus parvipinnis* larvae collected in the inner and outer part of Baker Channel, southern Chile

Taxa	Inner Baker Channel				Outer Baker Channel			
	%N	%V	%F	%IRI	%N	%V	%F	%IRI
Mollusca								
<i>Mytilus chilensis</i> larvae	13.64	9.57	20	10.44	–	–	–	–
Cladocera								
<i>Evadne nordmanni</i>	4.55	17.22	10	4.89	–	–	–	–
Ostracoda	13.64	36.45	30	33.79	–	–	–	–
Copepoda								
Eggs	4.55	0.07	10	1.04	20.22	0.25	11.43	5.31
Nauplii	–	–	–	–	1.12	0.32	2.86	0.09
Calanoid copepodite								
<i>Acartia tonsa</i>	4.55	4.51	10	2.04	13.48	16.74	22.86	15.69
<i>Calanoides patagoniensis</i>	–	–	–	–	2.25	4.16	5.71	0.83
<i>Paracalanus parvus</i>	18.18	17.13	30	23.82	15.73	30.82	34.29	36.23
Unidentifiable calanoid	13.64	5.71	20	8.70	3.37	0.66	2.86	0.26
Cyclopoid copepodite								
<i>Oithona</i> spp.	–	–	–	–	7.87	5.96	22.86	7.17
Unidentifiable cyclopoid	9.09	6.71	20	7.11	2.25	1.67	5.71	0.51
Copepoda fragments	13.64	1.90	20	6.99	15.73	8.34	25.71	14.05
Amphipoda	–	–	–	–	1.12	0.88	2.86	0.13
Unidentifiable egg	–	–	–	–	5.62	0.71	8.57	1.23
Unidentifiable taxa	4.55	0.73	10	1.19	11.24	29.49	20.00	18.49

%N, percentage of each prey item out of the total number; %V, percentage of each prey item out of the total volume; %F, percent frequency of occurrence of each prey item among larvae with food in their guts; %IRI, index of percentage relative importance; –, no occurrence

as lightfish *Maurolicus parvipinnis* may be more susceptible to be affected by osmotic stress caused by low salinity waters. Larval *M. parvipinnis* has been found in high abundance in lower salinity surface waters of northern Patagonia (>500 larvae 1,000 m⁻³ in the top 25 m depth; Landaeta et al. 2009), however, it is unknown the physiological consequences of its distribution.

Innermost parts of fjords are less productive and have less zooplankton biomass than outer coastal areas, which depends on advected biomass (Salvanes et al. 1995). A reduction of zooplankton biomass at inner fjords may reduce larval and juvenile fish growth, indicated by otolith microstructure (Baumann et al. 2007). However, because turbidity near the surface is higher in the fjords, larval fish may reduce predation mortality since the visibility at the long reaction distances of piscivores will decrease more than the visibility at the short reaction distances of zooplanktivores (Kristoffersen and Salvanes 1998).

In coastal waters off central Chile, larvae of *M. parvipinnis* perform diel vertical migration to be retained in the continental shelf (Landaeta and Castro

2002), but in fjords of southern Chile larvae seems to migrate at tidal scale (Landaeta et al. 2009). In Norwegian fjords, juvenile *Maurolicus muelleri* perform large vertical migrations at diel scale, preying on food items during ascent and descent, and particularly in surface waters (Giske and Aksnes 1992); similar trends probably may occur in larval *M. parvipinnis*. Therefore, why were larval *M. parvipinnis* found near sources of freshwater input? Negative results of ROGI (Fig. 8) and feeding in larval *M. parvipinnis* collected in areas influenced by fresher coastal waters (Fig. 9, Table 1), suggests that large larvae collected in the area near Baker River mouth were trapped by salinity fronts and/or subsurface estuarine currents rather than they perform tidal stream selective transport to stay near freshwater sources. In fjord ecosystems, tidal inflow advection may cause entrapment of zooplankton near fjord heads (Basedow et al. 2004), and subsequent surface offshore transport may concentrate the organisms at frontal areas, associated to floating kelps (Hinojosa et al. 2010). If larval *M. parvipinnis* were not advected to frontal areas because of its vertical migration at tidal time scale, than chances for

find prey items along Baker Channel will be reduced or they will feed on prey items other than copepods (ostracods, larval mussels), affecting its recent growth. It is well known that copepods, and particularly copepodites are rich in polyunsaturated fatty acids and wax esters, providing an important source of energy for fish larvae, juvenile and adults from fjord ecosystems (Falk-Petersen et al. 1986). A reduction or absence of copepods in the diet may probably be detrimental for the right larval fish development. On the other hand, one other plausible benefit for maintenance of larvae near freshwater inputs may be a reduction of predation by larger fishes, because turbidity reduces predator-prey encounters (Kristoffersen and Salvanes 1998).

Additionally, results of ROGI analyses indicate that sources of freshwater did not affect recent growth rates of larval *Sprattus fuegensis*, probably indicating a high tolerance of this species to reduction of seawater salinity. There are no previous estimations of growth for larval *S. fuegensis*. Sánchez et al. (1995) estimated growth parameters of juvenile *S. fuegensis* of 50–110 microincrements and around 20–40 mm SL from Argentinean Patagonia by adjusting Laird-Gompertz equation. Specific growth rate (A_0) estimated by parameters was $0.205 \text{ mm day}^{-1}$. Our study estimated a linear growth rate of $0.448 \text{ mm day}^{-1}$ for *S. fuegensis* of 5.4–20.5 mm SL. Similar results have been estimated for larval *Sprattus sprattus*. For the North Sea, Valenzuela and Vargas (2002) found growth rates of $0.36\text{--}0.40 \text{ mm day}^{-1}$ over an age range of about 30 days, and Ré and Gonçalves (1993) estimated a growth rate of 0.41 mm day^{-1} . Other clupeoid larvae inhabiting central Chile also show fast growth rates, such as anchoveta *Engraulis ringens* (0.66 mm day^{-1} , Herrera et al. 1985; 0.47 mm day^{-1} , Hernández and Castro 2000; $0.68\text{--}0.79 \text{ mm day}^{-1}$, Castro and Hernandez 2000) and sardine *Sardinops sagax* ($0.40\text{--}0.65 \text{ mm day}^{-1}$, Castillo et al. 1985).

For larval *Maurolicus parvipinnis* estimations of linear growth rates were of $0.136 \text{ mm day}^{-1}$ for larvae of 4.1–15.1 mm SL. No larval growth estimations were found for any *Maurolicus* species, irrespective of its cosmopolitan distribution. The smallest individual analyzed of *M. stehmanni* by Belluco et al. (2004) was of 14 mm SL and 44 microincrements. This means that larval growth may be as fast as $0.318 \text{ mm day}^{-1}$ and two times faster than larval *M. parvipinnis* from Patagonian fjords. Differences may arise from seawater

temperature; Brazilian waters are subtropical, around 23°C (Belluco et al. 2004) and in south Patagonia temperature was $\sim 9^\circ\text{C}$ (Fig. 3a, c). More recently, Savinykh and Baytalyuk (2010) described the otolith microstructure of *M. imperatorius*. They found that microincrements immediately at the nucleus were narrow, but in the course of growth their width rather increases; however, they did not estimate growth rate. The estimation of growth rate of larval *M. parvipinnis* was similar to an estimation made on larval rockfish *Sebastes oculatus* (= *S. capensis*; Landaeta and Castro 2006) collected in northern Patagonia.

The high variability of topographic and environmental conditions along Patagonia creates a series of microbasins consistent with the distribution of water properties, copepods and microzooplankton (Antezana 1999; Marín and Delgado 2001; Antezana et al. 2002). Therefore, it is plausible to say, study zone fish larvae were located in areas with different prey fields and variable environmental conditions which explain variations in recent growth of larval *Maurolicus parvipinnis*. This gives clues to the understanding of the success of this species and *Sprattus fuegensis*, a key species of the trophic web of southern Chile.

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