



Larval fish feeding ecology, growth and mortality from two basins with contrasting environmental conditions of an inner sea of northern Patagonia, Chile



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ABSTRACT

During austral spring 2011, a survey was carried out in the inland sea (41°30'–44°S) of north Patagonia, South Pacific, studying a northern basin (NB: Reloncaví Fjord, Reloncaví Sound and Ancud Gulf) characterized by estuarine regime with stronger vertical stratification and warmer (11–14 °C) and most productive waters, and a southern basin (SB: Corcovado Gulf and Guafo mouth), with more oceanic water influence, showed mixed conditions of the water column, colder (11–10.5 °C) and less productive waters. Otolith microstructure and gut content analysis of larval lightfish *Maurollicus parvipinnis* and rockfish *Sebastes oculatus* were studied. Larval *M. parvipinnis* showed similar growth rates in both regions (0.13–0.15 mm d⁻¹), but in NB larvae were larger-at-age than in SB. Larval *S. oculatus* showed no differences in size-at-age and larval growth (0.16 and 0.11 mm d⁻¹ for NB and SB, respectively). *M. parvipinnis* larvae from NB had larger number of prey items (mostly invertebrate eggs), similar total volume in their guts and smaller prey size than larvae collected in SB (mainly calanoid copepods). Larval *S. oculatus* had similar number, volume and body width of prey ingested at both basins, although prey ingestion rate by size was 5 times larger in NB than in SB, and prey composition varied from nauplii in NB to copepodites in SB. This study provides evidence that physical–biological interactions during larval stages of marine fishes from Chilean Patagonia are species-specific, and that in some cases large size-at-age correspond to increasing foraging success.

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1. Introduction

The Chilean Patagonia is an extended area with large spatial heterogeneity. Fjords therein usually range between 100- and 500-m depth, from 10- to 70-km long, and have a two-layer structure that is vertically separated by a strong halocline between 4- and 20-m depth. The primary production regime is reported to be highly seasonal and may result in the efficient export of carbon to sediments in austral spring (Iriarte et al., 2007; González et al., 2010). During spring, the food web structure of the Patagonian fjords is

mainly sustained by large chain-forming diatoms that are favored by increased solar radiation, an extended photoperiod, a constant supply of silicate (input via freshwater discharges), orthophosphate and nitrogen (provided from below the pycnocline). Zooplankton biomass is more abundant in northern, more protected zone, than the southern, more exposed area (Palma and Silva, 2004). Most recently, it has been determined by modeling that in the inner sea of the northern Patagonia had 61% higher biomass, 44% more biomass consumed and a 17% greater efficiency in the transfer of energy in the pelagic food web than areas characterized by relatively shallow, small-sized fjords and channels of Chilean Patagonia (Pavés et al., 2014).

The Patagonian area is also utilized by several marine fish species as a spawning, nursery and feeding zone throughout their life

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cycle (Bustos et al., 2007, 2008; Castro et al., 2011; Landaeta et al., 2011). Recent studies in Patagonian fjords have shown that strong surface salinity gradients (from 10 to 32) may have an important impact over growth and recent condition of marine larvae (Landaeta et al., 2012), but surface temperature gradients (from 1.4 to 9.5 °C) caused by ice melting near fjord heads do not have the same effect in terms of recent larval growth (Zenteno et al., 2014).

Spatial variability of oceanographic conditions can cause not only changes in growth rates, but also in the feeding ecology of fish larvae (Dower et al., 2009; Young et al., 2010; Ochoa-Muñoz et al., 2013). Because both vital rates are not sampled on the same temporal scale, the linkage between them is unclear. Feeding success is estimated from stomach content, representing at most the last hours of foraging before capture, while growth derived from otolith microstructure integrates events experienced during the days before capture (Robert et al., 2014). Nonetheless, it is important to look for integrative approaches in order to establish potential roles of the physical oceanography in the ecology of early stages of marine fishes at different spatial and temporal scales.

Two abundant fish species throughout Chilean Patagonia are the lightfish *Maurollicus parvipinnis* (Vaillant, 1888) and the rockfish *Sebastes oculatus* (Valenciennes, 1833). The lightfish *M. parvipinnis* is a mesopelagic species distributed along the South Pacific Ocean and utilize the Patagonian fjords and channels of southern Chile as spawning, nursery and feeding grounds (Bustos et al., 2008, 2011; Landaeta et al., 2011). It is known that larval feeding and recent growth is affected by freshwater input (Landaeta et al., 2012) and mixing conditions of the open ocean (Zenteno et al., 2014). The rockfish *S. oculatus* is a bottom-dwelling fish that inhabits shallow and rocky areas. Females retain eggs until maturation, when embryos are extruded throughout most of the year (Sabatés and Olivar, 1990). Pelagic larvae have been collected in coastal waters of the southern tip of South America, where fjords and channels dominate the coasts (Bustos et al., 2011). Ontogenetic differences in the distribution of larval *S. oculatus* in Chilean Patagonia and differences in microincrement widths of sagitta otoliths suggests that different habitats are utilized during its early life stages (Landaeta and Castro, 2006).

The goal of this work was to determine the growth and feeding ecology of fish larvae and its potential linkage with the oceanographic variability of two adjacent basins of northern Patagonia. We hypothesize that feeding success, growth rate and survival of marine fish larvae from northern Chilean Patagonia will show spatial variability at basin-scale, associated to basin oceanographic conditions. Under this scenario, it is likely that (1) fish larvae are more successful at prey ingestion at more vertically stable areas, (2) larval fish grow faster in warmer waters, and (3) size-at-age and survival will be larger in zones with high chlorophyll concentration.

2. Materials and methods

2.1. Field sampling

A quasi-synoptic oceanographic cruise was carried out during 16–26 October 2011 along a transect from Reloncaví Fjord (41°25'30" S, 72°17'36" W) to Guafo mouth (43°49'00" S, 74°23'42" W) (Fig. 1A), onboard the research vessel Abate Molina. At each station the hydrographic features of the water column were measured with vertical casts of a CTD Seabird SB-19 from surface to 400 m depth or to 10 m from the ocean floor. Ichthyoplankton was captured with a 1 m² mouth Tucker trawl (300 µm mesh size) equipped with a General Oceanics flow meter mounted in the frame of the net to estimate the filtered seawater, during day and night hours using oblique tows at 1–2 knots for 10–12 min from 100 m depth to surface. We used an algorithm for standardization

of the samples (# individuals 1000 m⁻³). Filtered seawater fluctuated from 99 to 361 m³ tow⁻¹ (mean ± standard deviation: 197.7 ± 63.7 m³ tow⁻¹). Once onboard, nets were washed and plankton samples were initially fixed in 5% formalin buffered with sodium borate and then preserved in 96% ethanol.

2.2. Laboratory work

All fish larvae were separated, counted and identified into the lowest possible taxon. Larval abundance was standardised to individuals (ind.) per 1000 m³, utilizing the flowmeter counts. The two most widely distributed and abundant larval species were selected, lightfish *M. parvipinnis* and rockfish *S. oculatus*, for further gut content and otolith analysis. The body length (BL), which corresponded to the notochord length (from the tip of the snout to the tip of the notochord in pre-flexion larvae) or the standard length (from the tip of the snout to the base of the hypural bones in flexion and post-flexion larvae) and upper jaw length (UJL, from the tip of the snout to the posterior end of the maxilla) were measured on all collected larvae to the nearest 0.01 mm under an Olympus SZ-61 stereomicroscope with a Moticam 2500 (5.0 M Pixel) video camera connected to a PC with the Moticam Image Plus 2.0 software. No correction for shrinkage was carried out for neither of the studied species.

A total of 191 larval *M. parvipinnis* (2.91–12.18 mm BL) and 89 larval *S. oculatus* (3.55–12.17 mm BL) were utilized for gut content analysis. The gut of each larva was dissected from the body and opened length-wise with fine needles. Prey items were counted, identified to the lowest possible taxon and categorized to major groups, except for indigestible prey remains such as setae, under a Motic BA310 microscope. The maximum BL (prosomal length for copepods; total length for nauplii and other prey) and width of each prey item (maximum prey width, MPW) were measured with the microscope and a Motic moticam 2500 camera (resolution 5.0 MPixel) using the Motic Image Plus 2.0 software. The volume of each prey item was estimated using the three-dimensional shape that most closely resembled the item, following Cass-Calay (2003).

The left and right sagittae otoliths were removed using insect needles from 306 individuals of larval *M. parvipinnis* (3.19–13.65 mm BL) and 82 individuals of larval *S. oculatus* (2.92–11.84 mm BL). The rationales for removing both sagittae are to detect potential differences in the reading of both otoliths, and in the case that one is missing (or it is unreadable) then it can be used the other sagitta. The otoliths were embedded in epoxy resin on a glass slide. The daily growth was determined by counting the number of otolith increments with a Motic BA310 light microscope at × 1000 magnification under oil immersion. The longest radius of a sagitta was measured three times and the average was used. The perimeters and areas of the otoliths were then measured once using the Moticam Image Plus 2.0 software.

Three independent counts were done blindly on the sagittae by the same person (JEC). When the coefficient of variation (CV = standard deviation/mean × 100) of the increment counts among the three readings was <5%, the mode (or average if all readings were different) of the 3 counts was calculated and utilized for the analysis. When the CV was >5%, the otolith reading was discarded.

2.3. Data analysis

We used monthly average Sea Surface Temperature and chlorophyll-*a* satellite data from the Moderate Resolution Imaging Spectroradiometer (MODIS project). These images of 4 km × 4 km of spatial resolution were provided by the Ocean Color Web (<http://oceancolor.gsfc.nasa.gov/>) and were displayed on a mercator

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