ORIGINAL PAPER

# Age, growth rates, sex change and feeding habits of notothenioid fish *Eleginops maclovinus* from the central-southern Chilean coast

**Roberto R. Licandeo · Claudio A. Barrientos · María Teresa González**

**Abstract** The róbalo, *Eleginops maclovinus*, a protandrous hermaphrodite species, is an important component of the ichthyofauna in the coastal areas and estuaries of southern Chile. However, there are many aspects about its life history that are unknown. Three hundred and eighty-three specimens of *E. maclovinus* (19–79 cm total length, TL) were collected between November 2002 and December 2003 from central-southern Chile. Marginal increment analysis from sagittal otoliths showed a single annual minimum in March, demonstrating that a single growth ring is formed each year. The growth of *E. maclovinus* was described by the von Bertalanffy growth model by following parameters: $L_\infty$ = 105.4 cm TL, $K$ = 0.08 per year, and $t_0$ = –1.03 years. *E. maclovinus* can live for 10 years. The length and age at which the 50% of the males in the population transformed into females was estimated at ~36 cm TL and ~5-years old. A total of 27 prey items were identified. The most important prey items were the crustaceans *Hemigrapsus crenulatus* and *Emerita analoga* associated with estuarial and marine habitats respectively. Ontogenetic changes in the diet were related to the spatial distributional pattern of males (1–4 years old, in the estuary) and females (5–8 years old, in the sea). Also, diet changes are associated with the type of available prey in each habitat occupied, indicating a generalized opportunist strategy.

**Keywords** *Eleginops* · Protandrous hermaphroditic · Age · Growth · Sex change · Diet

R. R. Licandeo (✉)
Sección Pesquerías, Departamento de Oceanografía, Universidad de Concepción, PO box 160-C, Concepción, Chile
e-mail: rlicandeo@hotmail.com

C. A. Barrientos · M. T. González
Instituto de Ecología y Evolución, Universidad Austral de Chile, Casilla 567, Valdivia, Chile

M. T. González
Instituto de Investigaciones Oceanológicas, Universidad de Antofagasta, Casilla 170, Antofagasta, Chile

## Introduction

The róbalo, *Eleginops maclovinus* (Cuvier & Valenciennes 1830), is a notothenioid belonging to the family Eleginopidae and is the only species of its genus. It is endemic to the coastal temperate and sub Antarctic waters of South America, distributed from Valparaiso (33°S) to the Beagle Channel (54°S) in the Pacific Ocean (Guzmán and Campodonico 1973; Pequeño 1989), and from the Beagle Channel to Uruguay (35°S) in the Atlantic Ocean (Lopez 1963; Eastman 1993). It is

also found in coastal waters around the Falkland Islands (Hart 1946).

*Eleginops maclovinus* frequently inhabits coastal areas, river mouths and estuaries, showing characteristics of a euryhaline and eurythermic species (Pequeño 1989), and it is a common member of the ichthyofauna of southern Chile. *E. maclovinus* has been described as a protandrous hermaphrodite (Calvo et al. 1992; Panoso 1996; Brickle et al. 2005a). Aspects related to its growth rates have been studied in different areas by Goztonyi (1974), Veas (1998) and Brickle et al. (2005b). Nevertheless, these authors used different models to describe growth and considerable variability has been recorded in growth rates between distant geographic areas. The feeding habits of *E. maclovinus* indicate that its diet usually consists of a variety of benthic organisms such as polychaetes and crustaceans (Guzmán and Campodónico 1973; Pequeño 1979; Pavés et al. 2005). However, there are no comprehensive studies focused on the relationship between feeding habits, ontogenetic changes or occupied habitats.

Traditionally, *E. maclovinus* has been an important food fish throughout much of its distributional range along the southern Chilean coast, supporting small fisheries (<200 tons per year). This species is captured mainly by commercial gill nets in estuaries and by recreational fishermen in the shallow waters of the coastline. However, in spite of its socio-economic importance as a fishery for some local communities (Re and Beron 1999), there are many aspects about its life history that are unknown. The objectives of this study were: (1) to estimate growth rates and age by growth ring counts on otoliths; (2) to estimate the size and age at sexual change; and (3) to analyse dietary habits and feeding strategies.

## Materials and methods

### Sampling

In total, 383 *E. maclovinus* were collected between November 2002 and December 2003 from central-southern Chile (ca. 40°S). The sampling locations were sited to encompass the local

distribution of *E. maclovinus* (Fig. 1); two areas were located in the estuarine zone of the Valdivia River (Cutipay River and San Juan Creek), a third area was semi-exposed to the sea (Niebla beach), and the other two areas were exposed to the sea (San Ignacio and Curiñanco beaches). More detailed descriptions of the Valdivia River system are given in Arcos et al. (2002).

Most of the *E. maclovinus* specimens were caught in the estuarial zone in commercial gill nets and landed in the port of Niebla. Specimens were also caught along the coast by recreational fishermen using hook and line, with *Tagelus dombeei* clam as bait. For each specimen, the total length (TL, to the nearest cm) and total body mass (TM, to the nearest g) were recorded. The length–weight relationship was estimated (in the form $TM = aTL^b$, where $a$ and $b$ are parameters and TM and TL are as above) by nonlinear least-squares parameter estimation. The otoliths (sagittal) were removed for ageing. Sex and maturity were recorded whenever possible, determined by macroscopic examination of the gonads on the basis of the maturity scale proposed by Oliva et al. (1986). Stomach contents were also obtained whenever possible from the sampling areas for laboratory analysis.

### Age and growth

In most cases, the left sagittal otolith was used for age estimation. Otoliths were observed using transmitted light and digitally photographed at 50× magnification. Two readers carried out an initial training exercise, counting growth rings on digital images with knowledge of the size. Then, two readers counted the growth rings on all the samples without knowing their size or date of capture. The average percent error index (IAPE; Beamish and Fournier 1981) was used to compare the reproducibility of growth ring counts between readers. The annual periodicity of growth rings was investigated using marginal increment analyses (MIA), with the following equation (Hayashi 1976): $MIA = (OR - R_n)/(R_n - R_{n-1})$, where OR is the otolith radius, $R_n$ is the radius to the last complete growth ring and $R_{n-1}$ is the radius to the previously completed growth ring. Measurements for MIA were made on an axis extending
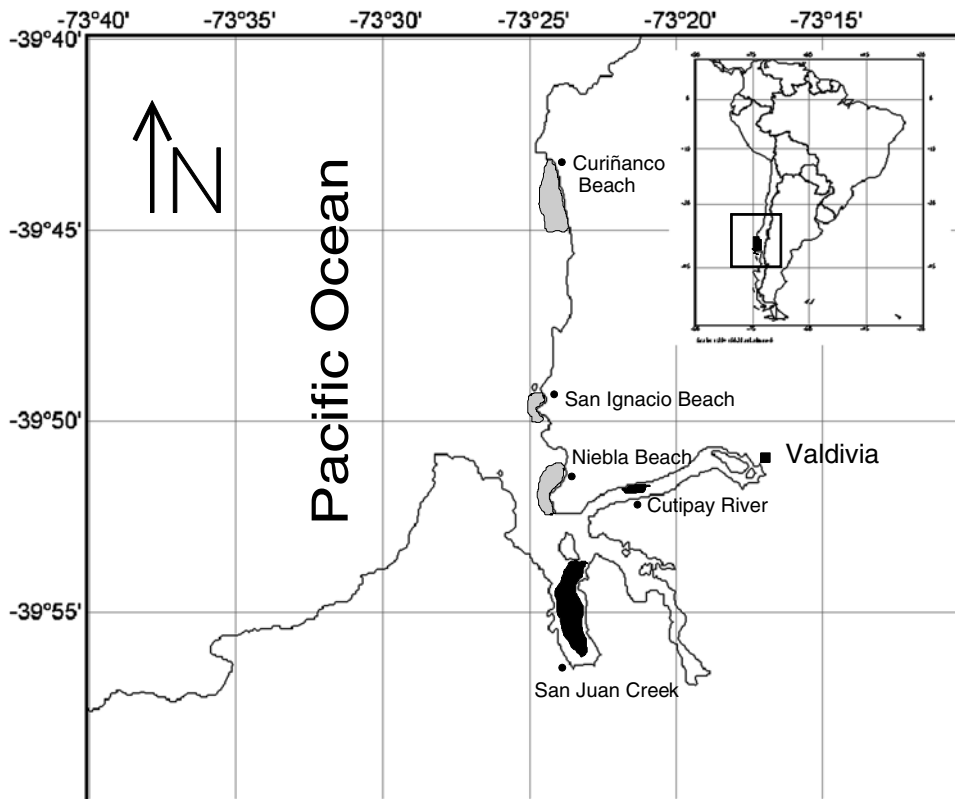
**Fig. 1** Study area on the central-southern Chilean coast, showing the location of sampling stations (see methods)

from the otolith's focus to the outer edge of each growth ring.

Growth for *E. maclovinus* was expressed using the von Bertalanffy (VB) growth model (von Bertalanffy 1938) fitted to the observed length-at-age data by the equation:

$$L_t = L_\infty \left(1 - e^{-K(t-t_0)}\right),$$

where $L_t$ is the predicted length at age $t$ years, $L_\infty$ is the asymptotic mean length, $K$ is the growth constant and $t_0$ is the theoretical age at zero length. The parameters of the model were estimated using Marquardt least-squares non-linear regression (Draper and Smith 1981).

Sex change

The size and age at sex change ($L_{50}$ and $A_{50}$ = size or age at which 50% are females) were calculated using the logistic model. Binomial sex data criteria (male = 0, female = 1) were fitted using the following equation: $P_L = 1/(1 + e^{\alpha+\beta L})$, where $P_L$ is the proportion of individuals that change from male to female according to their size or age, and $\alpha$ and $\beta$ are parameters. Mean size (or age) at sex change was expressed as $-\alpha/\beta$. The model parameters were estimated by maximum likelihood. Confidence limits (CL 95%) of $L_{50}$ and $A_{50}$ were calculated using a nonparametric bootstrap technique (1000 iterations) and percentile methods. The bias-corrected percentile confidence limits were applied (Efron and Tibshirani 1993).

Feeding

The prey items found in the stomachs were sorted, counted, weighed and identified to the lowest possible taxonomic level. Traditional methods of dietary analysis (Hyslop 1980) were used. In order to make dietary comparisons, the index of

relative importance (IRI; Pinkas et al. 1971) expressed as a percentage (IRI%; Cortés 1997) was calculated for each prey item. A loglinear model was used to determine that variables or interactions between them are more important to explain changes in the diet of *E. maclovinus*. The variables included in the model were: prey items (considering those with IRI > 1%), habitat (estuarine and marine), sexes, and classes age (class 1: 2–4 years and class 2: 5–8 years old). This analysis was made using the likelihood ratio Chi-square statistic (G) and the significance of the interaction terms was assessed by a hierarchical backwards elimination procedure (Vivanco 1999).

## Results

In total, 383 specimens were examined during the study period. Of these, 108 were females and 110 were males. The sex of the other 165 specimens was undeterminable, either due to immature gonads in small individuals ($n = 68$) or because samples of larger fish had been eviscerated after their commercial capture ($n = 97$). Fish size ranged from 16 cm to 58 cm TL (mean ± S.D = 34.9 ± 9.1, $n = 383$) and their weight varied from 378 g to 2787 g TM (514.1 ± 456.5, $n = 205$) (Fig. 2). Although an exceptional fish of 79 cm TL was captured, this was not included in the biological measurement indicated above. The length–weight relationship was represented with the following equation: $TM = 9.8E\text{-}03TL^{3.03}$ ($r^2 = 0.99$, $n = 205$).
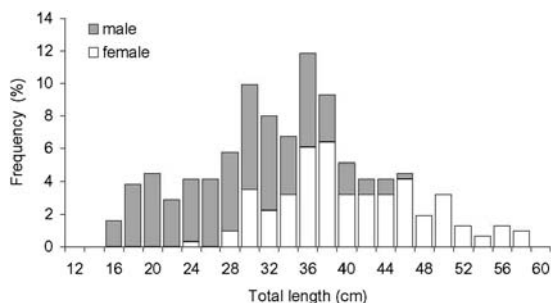
Age and growth

Sagittal otoliths of *E. maclovinus* showed the typical pattern of teleost fish. The first four pairs of growth rings were quite wide and subsequently became very regular. However, in the outer portions of the otoliths of larger fish, the growth rings decreased in width, becoming very irregular, and it was difficult to make age estimation in this zone. Counts were made in the post-rostral area where the pattern laid down was more uniform than in the rostral area (Fig. 3). The IAPE calculated from two readings provided results ranging from 0 to 0.33%. The IAPE for the whole sample was 9.43%. A mean of the two otolith counts was taken as an estimate and used for further analysis.

In order to investigate the annual periodicity of growth rings, otoliths with a high pattern of banding were selected, given that in general the otoliths were difficult to read. Monthly mean marginal increments were plotted for the combined group (Fig. 4) as the sample size was not large enough to plot the age-groups separately. MIA suggested that growth rings were formed in February, as there was a consistent seasonal minimum in March and April, followed by a peak in August and February.

Estimated ages of 261 individuals (16-79 cm TL) ranged from 1 year to 10 years. However, only one fish was 10 years old (79 cm) and all the other fish in the sample were less than 9 years old. This included ages of 3–8 years old for females and 2–7 years old for males. A relatively high variability in length-at-age data was found (Table 1). Analysis of growth curve was carried out for the pooled sexes, taking into account the protandrous hermaphroditic characteristics of this species. Calculated VB growth parameters are
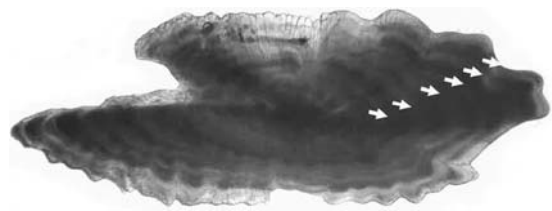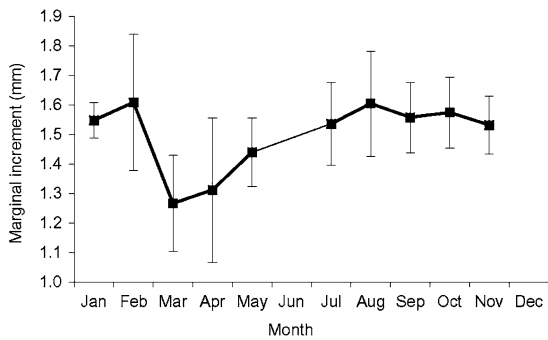


**Fig. 2** Length–frequency distribution of *Eleginops maclovinus* for male and female, caught on the central-southern Chilean coast ($n = 312$). Fish of 79 cm TL is not shown



**Fig. 3** Photomicrograph of entire otolith of 6-year-old (52 cm TL) *Eleginops maclovinus* female, viewed with transmitted light. Growth rings are indicated by arrows

**Fig. 4** Average monthly marginal increment (■ mean ± standard error) of *Eleginops maclovinus* otoliths, captured on the central-southern Chilean coast. Note that no samples were obtained in June and December

presented in Table 2 and a comparison of VB growth curve with previous studies on *E. maclovinus* is shown in Fig. 5.

### Sex change

The sex was relatively easy to determine by macroscopic examination of the gonads, especially in larger individuals. However, gonads from small juveniles (<18 cm TL) were indistinguishable, whereas intermediate gonads were not recorded. Of all the specimens that were sexed, males ranged from 19 cm to 45 cm (or 2–7 years old), whereas females ranged from 28 cm to 58 cm TL (or 3–8 years old). The $L_{50}$ and $A_{50}$ occurred at 35.7 cm TL (CI: 29.3–39.0 cm) and 4.5 years (CI: 4.0–6.2 years) respectively (Fig. 6).

### Diet and feeding strategy

A total of 70 specimens were examined; 36 males (19–45 cm TL) and 34 females (30–57 cm TL). All the fish that were analysed had stomach contents. A total of 27 prey items were identified (Table 3). The most important prey groups were crustaceans, followed by seaweed, mollusks, detritus, polychaete worms and fish. Crustaceans were represented primarily by amphipods and decapods. Overall, the most important prey item was *Emerita analoga* (46.8% IRI), followed by *Corophidae* unid. (17.9% IRI) and *Hemigrapsus crenulatus* (12.3% IRI) (Table 3). These species were probably more available or abundant to *E. maclovinus* in the sampled area, indicating a

generalised opportunist feeding strategy for this species. It was not possible to determine whether seaweed constituted a specific prey or whether it was only ingested during foraging.

The loglinear analysis of the occurrences of the 10 most important prey species (IRI > 1%, Table 3) showed significant differences in the occurrence of consumed prey ($G = 21.58$, d.f. = 9, $P = 0.010$). The most frequent prey were *H. crenulatus* and *E. analoga* followed by Corophidae. Also, a significant interaction was observed between prey type and habitat type ($G = 17.04$, d.f. = 9, $P = 0.045$). The presence of *H. crenulatus* in the diet was associated with the estuary, while *E. analoga* and *Ulva lactuca* were associated with the marine habitat. Strong interaction between the sex and age class was also found ($G = 18.54$, d.f. = 1, $P = 0.001$). Smaller fish (1 to 4 years old) were male and larger fish (5–8 years old) were female. Therefore, the best model that fitted data was considering the interactions between prey items × habitat and sex × age ($G = 44.21$, d.f. = 57, $P = 0.89$).

### Discussion

### Age and growth

In general, *E. maclovinus* otoliths exhibited complex patterns of growth ring deposition, which made them difficult to read, as was also noted by Veas (1998) and Brickle et al. (2005b). For instance, the otolith's nucleus generally showed many fine aggregated rings, which were considered false rings. This is probably due to large fluctuations in temperature and salinity in creeks and inlets (Brickle et al. 2005b) or possibly due to rapid growth during the early years of life (Nikolskii 1969). Nevertheless, age estimates were precise enough, as shown by the relatively low IAPE values (9.4%). Variability was in part due to age estimates of older fish as the growth rings became progressively more closely spaced in these fish. Nevertheless, MIA identified a consistent seasonal minimum from late summer to early autumn (March–April). Afterwards, marginal increment increased slightly during the autumn–winter months, and then reached a peak in mid-summer. Therefore, the trends exhibited

**Table 1** Basic statistics observed for total length (TL, cm) at growth ring number for *Eleginops maclovinus*, from central-southern Chile. S.D. = standard deviation, $n$ = number of fishes

|  | Age (years) | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10 |
| Mean TL cm | 16.8 | 20.1 | 29.8 | 35.3 | 38.6 | 43.9 | 46.5 | 57.0 | 79.0 |
| S.D. | 0.96 | 3.48 | 4.89 | 5.44 | 5.65 | 6.77 | 6.4 | - | - |
| $n$ | 4 | 35 | 52 | 26 | 48 | 44 | 11 | 1 | 1 |

Note that no samples were obtained in 9 age-groups

**Table 2** Comparison of von Bertalanffy growth parameter estimates for *Eleginops maclovinus* in the southeast Pacific (central-southern Chilean coast) and in the Southwest Atlantic (Falkland Islands and Deseado River)

| Parameter | Pacific Ocean (Present study) | Pacific Ocean (Veas 1998) | Atlantic Ocean (Brickle et al. 2005b) | Atlantic Ocean (Gosztonyi 1974)* |
| --- | --- | --- | --- | --- |
| $L_\infty$ (cm TL) | 105.4 | 49.93 | 124.4 | 121.0 |
| $K$ (per year) | 0.08 | 0.40 | 0.136 | 0.14 |
| $t_0$ (years) | –1.03 | –0.31 | –0.01 | 0.16 |
| $n$ | 261 | 126 | 1403 | 191 |
| $L_{max}$ (cm TL) | 79 | 60 | ~90 | 78 |
| $A_{max}$ (year) | 10 | 6 | 11 | 8 |

$L_\infty$ = asymptotic mean length, $K$ = growth constant, and $t_0$ = age at zero length, $n$ = sample size, $L_{max}$ = maximum length observed, $A_{max}$ = maximum age observed

*Von Bertalanffy growth parameter refitted by back-calculating fish lengths at previous ages from the largest *E. maclovinus* observed

by the marginal increments showed that a growth ring is formed annually in *E. maclovinus* otoliths.

Veas (1998) studied *E. maclovinus* specimens from the Bio-Bio river (38°S) on the Pacific coast
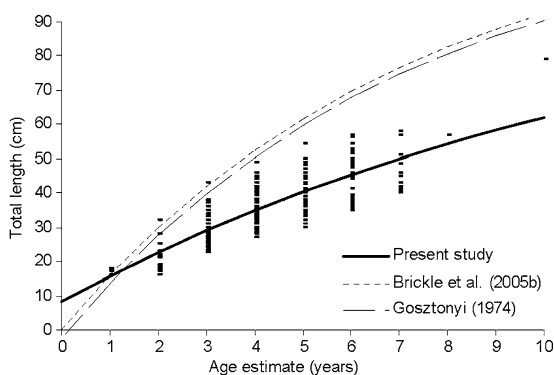


**Fig. 5** Comparison of von Bertalanffy growth curves for *Eleginops maclovinus* from the central-southern Chilean coast (present study; ——, combined sexes), from the Falkland Islands (Brickle et al. 2005b; - - - -, combined sexes) and from the Deseado River (Gosztonyi 1974; ——, re-estimated from largest specimen observed). Calculated parameters are given in Table 2

with sizes ranging from 20 cm to 53 cm TL, and this author determined that these fish belonged to the 1 and 6-year-old age-group. Gosztonyi (1974), however, reported a maximum scale-based age and maximum length observed ($L_{max}$) for this species of 8 years and 80 cm TL in the Deseado River (47°S) on the Argentina coast. Recently, Brickle et al. (2005b) reported a maximum age of 11 years and ca. 90 cm TL for *E. maclovinus* captured from around the East Falkland Islands (51°S) in the Atlantic ocean. In this study, the most common age-groups ranged from 2 years to 7 years old. However, we also recorded a 10-year old individual measuring 79 cm TL (gutted weight of 5600 g), caught in San Juan Creek on 26 November 2003. Thus, this species seem to be relatively long-lived.

Our estimates of $L_\infty$ exceed the largest specimens in our field collections. *E. maclovinus* larger that 60 cm TL were uncommon, thus scarcity of large individuals was most likely responsible for the over estimation of $L_\infty$. Similar results were obtained by Brickle et al. (2005b) in the Falk-
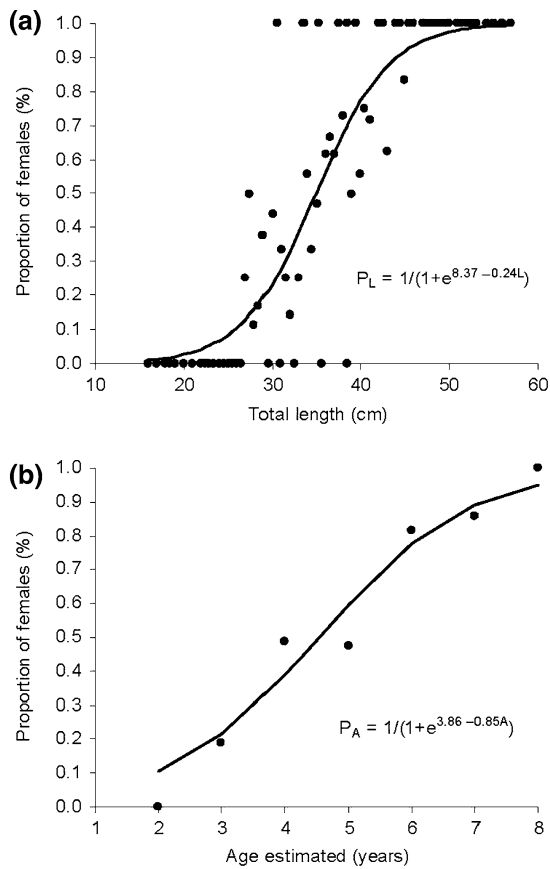
**Fig. 6** Percentage sex change at size (**a**) and age (**b**) for protandrous hermaphroditic *Eleginops maclovinus* from the central-southern Chilean coast

lands Islands, where $L_\infty$ exceeded observed sizes. Gosztonyi ([1974](#)) also estimated an $L_\infty$ (ca. 120 cm TL) fairly similar to the Falklands, applying Walford's method to the largest *E. maclovinus* observed. On the other hand, Veas ([1998](#)) did not include larger individuals, which led to the smaller $L_\infty$ and higher $K$ values than in those previous studies. Nevertheless, based on observed data, we found that specimens of *E. maclovinus* from the Falklands reach larger sizes than specimens from central-southern Chile and this pattern was reflected in growth curves. For instance, *E. maclovinus* in the Falklands reached a larger $L_\infty$ (124 cm vs. 105 cm) and have a higher $K$ (0.136 vs. 0.08) than was estimated for the present study (Fig. [5](#)). In addition, the growth pattern during the first 6 years of life (on average 6 cm per year) seems be slower in central-southern Chile. For instance, Brickle et al. ([2005b](#))

found that *E. maclovinus* grew on average 10.2 cm per year for the first 6 years. A similar result was found by Gosztonyi ([1974](#)), who stated that during the first seven years, *E. maclovinus* show a constant growth rate, with a yearly length increase of ca. 11 cm.

Sex change

Previous studies have investigated variations in size at sex change of *E. maclovinus* by using the range or the size of the second smallest sex individual as the "size at sex change" (Calvo et al. [1992](#); Panoso [1996](#); Oyarzún [1998](#)). Therefore, no estimates of age at sex change have been examined. In this study, transition from male to female of *E. maclovinus* was estimated with binomial data criteria as a function of length or age. This method provided a more statistically rigorous and quantitatively consistent estimation of the population's average size at sex change (Allsop and West [2003](#)). Nevertheless, histological analysis was not performed, which would have enabled the detection of transitional individuals (Calvo et al. [1992](#)) whose presence strongly supports sex change occurrence (Shapiro [1987](#)). Although differences in male and female length–frequency distribution and the absence of small or young females is a weak indicator of protandrous hermaphroditism, this was described by Panoso ([1996](#)) and Oyarzún ([1998](#)) on the central-southern Chilean coast. In addition, Brickle et al. ([2005a](#)) recently found that hermaphroditism in *E. maclovinus* is not solely a localized phenomenon in continental populations.

The $L_{50}$ estimated in this study was consistent with studies by Panoso ([1996](#)) and Oyarzún ([1998](#)). In particular, Panoso ([1996](#)) and Oyarzún ([1998](#)) estimated sex change at a range of 36–40 cm TL. In the current study, 50% of the males in the population had transformed into females at a size of ~36 cm TL and at the age of ~5 years. Similarly, Oyarzún ([1998](#)) found that fish under 36 cm TL were males, and no males were observed above 50 cm TL. On the other hand, Calvo et al. ([1992](#)), studying *E. maclovinus* caught in the Beagle Channel (Argentina), recorded that the proportion of males to females was similar at a range of 41–45 cm TL. In the Falkland Islands,

**Table 3** Diet composition of *Eleginops maclovinus* in southern Chile, expressed as a percentage of number (%N), weight (%W), frequency of occurrence (%FO), and index of relative importance (%IRI, as a percentage of the total IRI)

| Item | %N | %W | %FO | %IRI |
|---|---|---|---|---|
| Phylum Annelid | | | | |
| Class: Polychaete | | | | |
| *Polychaete* (undet.) | 0.12 | 0.04 | 6.15 | 0.03 |
| Phylum Arthropod | | | | |
| Class: Crustacean | | | | |
| Order: Amphipod | | | | |
| *Corophidae* (undet.) | 24.54 | 1.58 | 26.15 | 17.95 |
| *Gamaridae* (undet.) | 15.86 | 1.03 | 10.77 | 4.78 |
| Order: Cirripede | | | | |
| *Austramegabalanus psitacus* | 0.03 | 2.29 | 6.15 | 0.38 |
| Order: Decapod | | | | |
| *Acanthocyclus albatrossis* | 0.62 | 4.22 | 15.38 | 1.96 |
| *Cancer cetosus* | 0.77 | 6.15 | 12.31 | 2.24 |
| *Cancer edwarsii* | 0.27 | 2.01 | 7.69 | 0.46 |
| *Emerita analoga* | 13.87 | 44.06 | 30.77 | 46.85 |
| *Eurypodius latreillei* | 0.03 | 0.11 | 1.54 | 0.01 |
| *Hemigrapsus crenulatus* | 2.55 | 10.65 | 35.38 | 12.27 |
| *Petrolisthes* sp. | 0.06 | 1.03 | 1.54 | 0.04 |
| *Pinixia* sp. | 0.92 | 0.34 | 1.54 | 0.05 |
| *Taliepus dentatus* | 0.06 | 0.14 | 1.54 | 0.01 |
| Order: Isopod | | | | |
| *Exosphaeroma* sp. | 2.16 | 0.17 | 10.77 | 0.66 |
| *Isocladus* sp. | 30.53 | 4.16 | 6.15 | 5.61 |
| Order: Mysidacea | | | | |
| *Micidacea* (undet.) | 6.08 | 0.47 | 6.15 | 1.06 |
| Undetermined Crustaceans | 0.03 | 0.31 | 1.54 | 0.01 |
| Class: Insect | | | | |
| *Chironomido* (undet.) | 0.30 | 0.03 | 4.62 | 0.04 |
| Phylum: Chordate | | | | |
| Class: Teleostomi | | | | |
| Osteichthyes (undet.) | 0.03 | 0.67 | 1.54 | 0.03 |
| Order: Perciformes | | | | |
| *Miyxodes sp.* | 0.03 | 0.89 | 1.54 | 0.04 |
| Phylum: Mollusk | | | | |
| Class: Pelecypod | | | | |
| *Mytilus chilensis* | 0.09 | 0.01 | 3.08 | 0.01 |
| Clam (undet.) | 0.33 | 0.01 | 10.77 | 0.10 |
| Phylum: Chlorophyta | | | | |
| Order: Ulvales | | | | |
| *Ulva lactuca* | 0.24 | 8.55 | 13.85 | 3.20 |
| Seaweed 1 (undet.) | 0.12 | 1.03 | 6.15 | 0.19 |
| Seaweed 2 (undet.) | 0.15 | 7.04 | 7.69 | 1.45 |
| Seaweed 3 (undet.) | 0.09 | 0.67 | 4.62 | 0.09 |
| Detritus | 0.15 | 2.32 | 7.69 | 0.50 |

Brickle et al. (2005a) observed that the proportion of male to female was similar at 53 cm TL.

By comparing geographical areas, these results seem to indicate that there are latitudinal differences in terms of the size at which sex change is reached, with higher sizes at higher latitudes. For instance, for continental southern-central populations (Panoso 1996; Oyarzún 1998, present study), the sex change occurs at ca. 36–40 cm TL, while in the Falklands it occurs at size >50 cm TL. These differences could be explained due to local environmental conditions or by local fishing effort (discussed in the next section). For instance, Brickle et al. (2005a) found that the reproductive timing and habitat of *E. maclovinus* in the Falklands differed from those described for continental South American populations. Spawning in the Falklands takes place in deeper inshore

waters (>40 m) during spring, whereas in continental populations it occurs in estuaries during late autumn (Panoso 1996). Estuaries are highly dynamic systems; hence environmental variations can produce important variability in fish recruitment. Quiñones and Montes (2001) recently found evidence that river runoff and rainfall strongly influenced the survival rate of *E. maclovinus* during the first year of life. Therefore, sex change at a relatively smaller size (or age) could be a reproductive success strategy. It could maximize the time for breeding, favouring large highly fecund or fertile individuals and thus decrease its expected high mortality rate during the early stage of life.

Feeding habits and ecological considerations

In general, although the sample size for feeding analysis was not extensive, it was possible to recognize a spatial pattern of distribution of *E. maclovinus* in relation to prey items consumed. Given that *E. maclovinus* utilizes estuaries as breeding areas (Pequeño 1981; Ruiz 1993), younger fish (or males) were associated with the estuarial prey, preferentially consuming crustaceans such as *H. crenulatus, Corophidae* unid. and *Gamaridae* spp. These results agree with those found by Pavés et al. (2005), whom recorded the presence of corophiid amphipods and *H. crenulatus* in the Valdivia River estuary. Pavés et al. (2005) based on diet analysis also suggested that immature males did not migrate into brackish or marine areas to feed, but rather consumed prey from freshwater. On the other hand, older fishes (or females) were believed to be mainly associated with the sea, given that items such as *E. analoga* are typically associated with the exposed sea (Jaramillo et al. 1996). In fact, Pequeño (1979) found that *E. maclovinus* feeds on *E. analoga* on sandy beaches on the central-southern Chilean coast. However, on the contrary to younger fishes, *E. maclovinus* inhabiting the marine habitat also feed on estuarial prey, possibly due to their ability to move between coastal and estuarine waters (Duarte et al. 1980; Ruiz 1993). It is possible that changes of habitat and the consequent ontogenetic shift in diet could be related to an optimisation of the energy gained

from one or another type of diet (Stephens and Krebs 1986). For instance, Pavés et al. (2005) found a reduced number of species in the fish stomachs in the limnetic habitat (14 items) in opposition to a higher diversity of preys in the estuary and marine habitats (24–35 items in Pequeño 1979, Isla and San Román 1995, present study). Then, these changes (from limnetic/estuary to marine habitat) could be associated with sexual maturation and reproduction of *E. maclovinus*. Therefore, the dietary shift observed could be only part of a behavioural response to the process of maturation, given that these processes are energetically demanding. The results also indicate that *E. maclovinus* is a broad spectrum predator that preys on the most available prey present in estuarine and marine environments, suggesting a generalized and opportunist feeding strategy, supporting previous observations (Guzmán and Campodonico 1973; Pequeño 1979; Pavés et al. 2005).

Management

Recently, Alonzo and Mangel (2004) discussed that the management of sex-changing fish is unique. Fishing pressure can impact these species by decreasing their spawning stock biomass, and the male's sperm production, which could act as a limiting factor to fish population increase. Therefore, hermaphroditic species may respond differently to fishing mortality than typical dioecious (separate-sex) species do, and hermaphroditic species may even be more sensitive to over fishing (Bannerot et al. 1987, Alonzo and Mangel 2004). The effort to sample larger fish (>60 cm TL) in the population was considered intense enough, by sampling different habitats. Therefore it was concluded that larger individuals were uncommon or simply were not present. Total landings of *E. maclovinus* have decreased notably during recent years, declining from 800 t in 1992 to <200 t in 2001–2003 (SERNAPESCA 2002). Fishery-size selection reduces the mean size-at-age (Ricker 1975). In addition, estuarial species such as *E. maclovinus* could also be indirectly affected by anthropogenic activities such as pollutants from industries and coastal development.

# References

Allsop DJ, West SA (2003) Constant relative age and size at sex change for sequentially hermaphroditic fish. J Evol Biol 16:921–929

Alonzo SH, Mangel M (2004) The effects of size selective fisheries on the stocks dynamics of and sperm limitation in sex–changing fish. Fish Bull 102:1–13

Arcos D, Peña H, Nuñez S, Ortiz J, Furet L, Figueroa S, Sepúlveda A, Rebolledo H, Castillo J, Turner A, Gonzales H, Valenzuela G, Menschel E (2002) Determinación de la capacidad de carga de las zonas estuarinas de los ríos Valdivia y Bueno, X Región. INPESCA Inf. Téc. No. 2000–29. p 333

Bannerot SP Jr, Fox WW, Powers JE (1987) Reproductive strategies and the management of snappers and groupers in the Gulf of Mexico and Caribbean. In: Polovina JJ, Ralston S (eds) Tropical snappers and groupers: biology and fisheries management. Westview Press, Boulder, CO, pp 561–603

Beamish RJ, Fournier DA (1981) A method for comparing the precision of a set of age determination. Can J Fish Aquat Sci 38:982–983

Brickle P, Laptikhovsky V, Arkhipkin A (2005a) Reproductive strategy of a primitive temperate notothenioid Eleginops maclovinus. J Fish Biol 66:1044–1059

Brickle P, Arkhipkin AI, Shcherbich ZN (2005b) Age and growth in a temperate euryhaline notothenioid, Eleginops maclovinus from the Falkland Islands. J Mar Biol Assess 85:1217–1221

Calvo J, Morriconi E, Rae G, San Roman N (1992) Evidence of protandry in a Subantartic Notothenoid, Eleginops maclovinus (Valen., Cuv., 1830) from the Beagle Channel (Argentina). J Fish Biol 40:157–164

Cortés E (1997) A critical review of methods of study fish feeding based on analysis of stomach contents: application to elasmobranch fishes. Can J Fish Aquat Sci 54:726–738

Draper NR, Smith H (1981) Applied regression analysis. 2nd edn. John Wiley & Sons, New York, NY

Duarte W, Jara F, Moreno C (1980) Contenido energético de algunos invertebrados bentónicos de la costa de Chile y fluctuación anual en Mytilus chilensis Hupe (1854) B Inst. Ocean São Paulo 29:157–162

Eastman JT (1993) Antarctic fish biology. Evolution in a Unique Environment. Academic Press, New York, p 322

Efron B, Tibshirani RJ (1993) An introduction to the bootstrap. Chapman, Hall, New York, NY, p 436

Gosztonyi A (1974) Edad y crecimiento del ''robalo'' Eleginops maclovinus (Osteichthyes, Nototheniidae) en aguas de la ria Deseado y sus adyacencias. Phycis Sec A 33:1–8

Guzmán L, Campodónico I (1973) Algunos aspectos de la biología de Eleginops maclovinus (Cuv. y Val.) 1830, con especial referencia a su morfometría, caracteres merísticos y alimentación. Ans Inst Pat, Punta Arenas (Chile) 4:1–3

Hart TJ (1946) Report on trawling surveys on the Patagonian continental shelf. Discovery Reports 23:223–408

Hayashi J (1976) Studies on the growth of the red tilefish in the East China Sea–I A fundamental consideration for age determination from otoliths. Bull Jpn Soc Sci Fish 42:1237–1242

Hyslop E (1980) Stomach contents analysis: a review of methods and their application. J Fish Biol 17:411–429

Isla M, San Román N (1995) Alimentación de Eleginops maclovinus (Pisces, Nototheniidae) en el Canal Beagle, Argentina. Nat Patagon Ser Cienc Biol 3:107–127

Jaramillo E, Contreras H, Quijon P (1996) Macroinfauna and human disturbance in a sandy beach of south–central Chile. Rev Chil Hist Nat 69:655–663

Lopez RB (1963) Problemas sobre la distribución geográfica de los peces suramericanos. Mus Arg de Cs Nat B Rivadavia Hidrobiología 1:111–135

Nikolskii GV (1969) Theory of fish population dynamics. Oliver and Boyd, Edinburgh, p 323

Oliva J, Carvajal W, Tresierra A (1986) Biología reproductiva e histología de gónadas de peces. Universidad Nacional de Trujillo, Trujillo (Perú), p 93

Oyarzun AP (1998) Ciclo Reproductivo de Eleginops maclovinus (Cuv., Val., 1830) en la Bahía de Corral, Valdivia, Chile. BS Thesis, Universidad Austral de Chile. p 40

Panoso R (1996) Evidencias del hermafroditismo secuencial en el Róbalo Eleginops maclovinus, Valenciennes 1830 (Perciformes– Eleginopsidae). BS Thesis, Universidad de Concepción, Chile. p 22

Pavés H, Pequeño G, Bertrán C, Vargas L (2005) Limnetic feeding in Eleginops maclovinus (Valenciennes, 1830) in the Valdivia River, Chile. INCI, mar 30:120–125

Pequeño G (1979) Antecedentes alimentarios de Eleginops maclovinus (Valenciennes, 1830) (Teleostomi: Nototheniidae), en Mehuín, Chile. Acta Zool Lilloana 35:207–230

Pequeño G (1981) Peces de las riberas estuariales del rió Lingue. Chile Biol Mar Roscoff 22: 141–163

Pequeño G (1989) The geographical distribution and taxonomic arrangement of South American nototheniidae fishes (Osteichthyes, Nothenidae). Bol Soc Biol Concepción, Chile 60:183–200

Pinkas L, Oliphant M, Iverson Y (1971) Food habits of albacore, bluefish tuna and bonito in California waters. Calif Fish Game 152:1–105

Quiñones RA, Montes RM (2001) Relationship between freshwater input to the coastal zone and the historical landings of the benthic/demersal fish *Eleginops maclovinus* in central–south Chile. Fish Oceanogr 10:311–328

Re ME, Beron JC (1999) Relevamiento de la pesca artesanal con red de costa en la Provincia del Chubut. Nat patagon Rep Téc 2:1–67

Ricker WE (1975) Computation and interpretation of biological statistics of fish populations. Fish Res Board Can Bull 191:1–382

Ruiz VH (1993) Ictiofauna del Rio Andalien (Concepción, Chile). Gayana Zool 57:109–278

SERNAPESCA (2002) Anuario Estadístico de Pesca. Ministerio de Economía, Fomento y Reconstrucción, Santiago, Chile

Shapiro D (1987) Differentiation and evolution of sex change in fishes. Bioscience 37:490–497

Stephens DW, Krebs JR (1986) Foraging theory. Princeton University Press, New Jersey, p 247

Veas IR (1998) Tasa de crecimiento en relación al cambio de sexo en el róbalo *Eleginops maclovinus* (Valenciennes, 1830) (Pisces: Eleginopsidae) en la zona de la desembocadura del rió Bio–Bio, Chile. BS Thesis, Universidad de Concepción, Chile. p 54

Vivanco M (1999) Análisis estadístico multivariable. Teoría y práctica. Editorial Universitaria. Santiago de Chile

Von Bertalanffy L (1938) A quantitative theory of organic growth. Human Biol 10:181–213