

Geographic variation in age, growth and size structure of *Percilia irwini* from south-central Chile

J. R. AEDO*†, M. C. BELK* AND E. M. HABIT‡

*Department of Biology, Brigham Young University, 401 WIDB, Provo, UT 84602, U.S.A. and ‡Aquatic Unit System, Environmental Science Centre Eula-Chile, University of Concepción, Concepción, Chile

(Received 8 January 2008, Accepted 3 October 2008)

Percilia irwini from the Andalién and Biobío River basins of south-central Chile exhibited a mean age of 1.4 years with a maximum age of 4 years. Size at age differed among river zones and males were 10% larger than females at all ages. Compared to other locations, populations of *P. irwini* inhabiting areas subject to industrial and domestic effluents exhibited smaller size structure.

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Key words: Andalién River; Biobío River; Chile; endangered species; *Percilia irwini*; sexual size dimorphism.

Percilia irwini Eigenmann is a small percoid (maximum total length, L_T , of 96 mm; Habit & Belk, 2007), endemic to only two basins in south-central Chile (Andalién and Biobío river basins) (Campos *et al.*, 1993; Dyer, 2000). It is classified as an endangered species because of its narrow distribution and degradation of habitat in the lower zones of the rivers it inhabits (Campos *et al.*, 1998; Parra *et al.*, 2004). Some populations of *P. irwini* have declined recently due to anthropogenic actions, and the species has disappeared from some locations (Habit *et al.*, 2006, 2007a). Information about variation within and among populations is important to assess threats and determine effective conservation and management actions (Ruckelshaus *et al.*, 2002). Although some of the basic biology of *P. irwini* has been documented (Habit & Belk, 2007), little is known about growth or variation in body size within and among populations in this species. Growth and resultant body size, however, are sensitive indicators of environmental quality. Without a clear understanding of variation in growth and body size, it is difficult to effectively conserve or manage populations. This paper describes patterns of age, growth and size structure in *P. irwini* among six sub-basins in the Andalién and Biobío river drainages.

†Author to whom correspondence should be addressed. Tel.: +1 801 422 8615; fax +1 801 422 0090; email: jraedo@gmail.com

These data provide important baseline information for conservation of this endemic and narrowly distributed species.

Individuals for this study were collected from the Andalién, Nonguén and Queule Rivers of the Andalién drainage, and the Biobío, Laja and Rucúe Rivers of the Biobío drainage (specific locations and maps can be found in Habit *et al.*, 2006, 2007*a, b*). In these systems, the rivers exhibit three physical zones (Welcomme, 1985; Maddock, 1999): (1) rhithron or headwaters characterized by colder water temperature, high current velocity and substratum of boulders; (2) transition between rhithron and potamon and (3) potamon or lower elevation areas, characterized by fine substratum, low velocity and higher water temperature. Within zones as defined in this study, temperature, water velocity and substratum are fairly uniform. In the Andalién drainage, *P. irwini* was not found in the rhithral zone but was collected from both the transitional and the potamal habitats in the Andalién and Nonguén rivers and from the potamal zone of the Queule River for a total of five collection locations. In the Biobío drainage, *P. irwini* was found in all three zones of the Biobío River, but only in the rhithral and transitional zones of the Laja River, and in the completely rhithral Rucúe River for a total of six additional collection locations. In the Andalién drainage, potamal sampling locations were found in urban or partially urbanized areas, and the transitional locations were in more rural areas. In the Biobío drainage, potamal and transitional sampling locations were found in areas affected by domestic and industrial effluents, and rhithral locations were characterized as rural with little or no pollution (Habit *et al.*, 2006).

At each sampling location in the Andalién drainage, *P. irwini* was collected by electrofishing from a 100 m segment. Samples were collected twice during high flow (July and August 2003) and three times during low flow (November 2003, March 2004 and May 2004). To obtain an accurate representation of size and corresponding age structure in each drainage, information was recorded from all individuals collected. Biobío drainage samples were collected in the same manner as described above for the Andalién drainage. The Biobío River was sampled during high flow (September 2003) and low flow (March 2004). Laja and Rucúe River samples were collected during January 2004. Most individuals collected from the Biobío drainage were measured for L_T and then returned to the river. Thus, only samples from the Andalién drainage were available for age and size-at-age analyses. Data from the Biobío drainage were used only for comparison of population size structure.

Captured fish were preserved in 95% ethanol. In the laboratory, L_T (to the nearest mm) was measured for all individuals. Sex and reproductive maturity were determined by inspection of the gonads. Ages of fish were determined by counting presumptive annuli on sagittal otoliths. To determine size-at-age increments, presumptive annuli were measured from digital images of the otolith for up to four annuli along the longest axis of the otolith. Size at age was backcalculated from otolith measurement using a modified Fraser–Lee method (Campana, 1990). Ages were estimated for 117 individuals. Eighty-four of the 117 were ≥ 1 year old and were used for analysis of annual growth.

Marginal increment analysis was used to validate presumptive annuli as true annuli. The marginal increment was compared from individuals collected at different times of year. March and April samples were combined and July

and August samples were combined because of low sample sizes. The expected pattern is that a marginal increment near zero would occur only once per year.

A mixed model ANOVA was used to analyse differences in size among ages, sexes, zones and rivers (Littell *et al.*, 1996). Size-at-age data were used as repeated measures for each individual as the response variable and zone, river, age and sex as main effects in the model. A zone by age interaction was included to assess the possibility of a different growth pattern among zones. Differences in mean L_T as a measure of population size structure among zones within the Andalién and Biobío drainages, among rivers within drainages, and between the Andalién and the Biobío drainages were determined using a one-way ANOVA (Keller, 2001). To assess whether size distributions were influenced by temperature or elevation, two separate regression analyses were performed. Mean annual water temperature and elevation for each zone were used as independent variables and mean L_T of *P. irwini* for each zone was used as the dependent variable.

Marginal increment analysis was consistent with formation of one band per year in the spring (November; Fig. 1). Opaque bands are hereafter referred to as annuli. Maximum age observed was 4 years. Mean age of all samples from the Andalién drainage combined was 1.4 years and modal age was 2 years. The combined sample was composed of 25.9% age 0+ year individuals, 27.6% age 1 year individuals, 29.3% age 2 year individuals, 11.2% age 3 year individuals and 6.0% age 4 year individuals. Reproductive maturity was first observed in individuals 1 year of age.

The L_T in *P. irwini* was significantly affected by age, sex and the interaction of zone by age (mixed model ANOVA, $P < 0.01$ for all). The mean L_T at age increased with age (Table I). In general, males were *c.* 6 mm larger than females, representing a 10% difference in L_T at age between sexes. Individuals from the transitional zone were *c.* 4 mm shorter at age 1 year compared to individuals from the potamal zone; however, at ages 2 and 3 years, individuals from the transitional zone were *c.* 4 mm longer than those from the potamal zone. There were no significant differences in size at age among rivers (mixed model ANOVA, d.f. = 2,78, $P > 0.05$) or zones (mixed model ANOVA, d.f. = 1,67, $P > 0.05$).

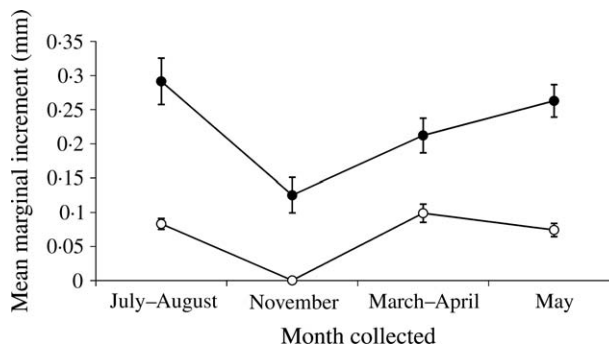


FIG. 1. Plot of mean \pm S.E. marginal increment width for age 1 (●) and age 2+ (○) year *Percilia irwini* and month of the year when fish were collected.

TABLE I. Backcalculated mean \pm s.e. total lengths (L_T) of *Percilia irwini* from the Andalién River basin

L_T (mm)				
Age (years)	1	2	3	4
1	41.0 \pm 0.9			
2	39.7 \pm 0.9	54.4 \pm 1.1		
3	42.4 \pm 1.4	57.5 \pm 1.6	64.5 \pm 1.7	
4	38.8 \pm 3.4	54.3 \pm 3.8	61.4 \pm 4.0	65.2 \pm 4.2
Means	40.5 \pm 0.6	55.1 \pm 0.9	63.4 \pm 1.8	65.2 \pm 4.2

Size structure of *P. irwini* differed among drainages, between rivers within drainages and among zones within rivers (Fig. 2). Overall, mean L_T in the Andalién drainage was *c.* 3 mm larger than mean L_T in the Biobío drainage (ANOVA, d.f. = 1,1054, $P < 0.01$). In the Andalién drainage, the mean L_T of the Queule River population was greater than those of the Nonguén and Andalién rivers (ANOVA, d.f. = 2,38, $P < 0.01$). In the Biobío drainage,

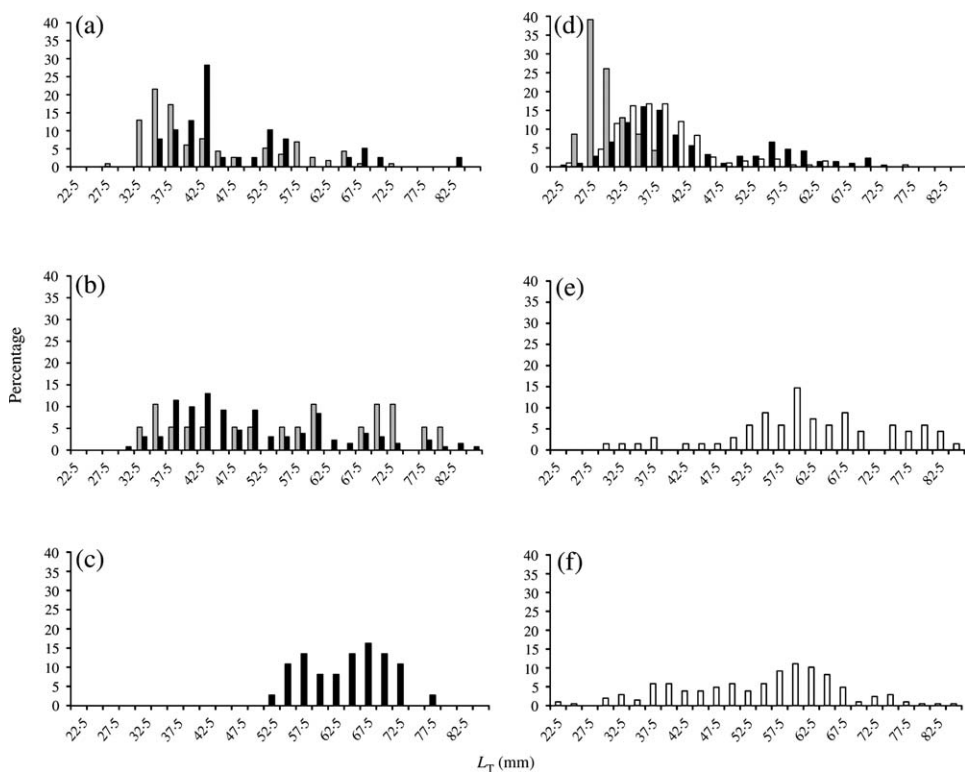


FIG. 2. Total length (L_T) distribution of *Percilia irwini* in the Andalién and Biobío drainages by river: (a) Andalién, (b) Nonguén (c) Queule, (d) Biobío, (e) Laja and (f) Rucúe Rivers and zones represented include: rhithron (□), transition (■) and potamon (■).

the mean L_T of Rucúe and Laja populations was greater than the Biobío River population (ANOVA, d.f. = 2,722, $P < 0.01$). Mean L_T in the Biobío River was smaller in the transitional zone compared to either the rhithral or the potamal zones (ANOVA, d.f. = 2,447, $P < 0.01$). In the Andalién River, however, size structure was not different between the transitional and the potamal zones (ANOVA, d.f. = 1,153, $P > 0.05$). Mean annual water temperature and elevation were not significantly correlated with mean L_T of *P. irwini* ($n = 11$, both $P > 0.05$).

Patterns of age, growth and size structure are consistent with patterns observed in other species of small-bodied freshwater fishes (Fernandez-Delgado, 1989; Mills *et al.*, 2004). Patterns of growth among zones and between sexes, however, revealed surprising variability for this monomorphic species. Variation in growth of Andalién basin populations is not a function of temperature or elevation but appears to be a complex response between age and river zone. This may indicate ontogenetic variation in resource use and differential resource availability among river zones. Variation in size at age among sexes was previously unknown for *P. irwini*. Sexual size dimorphism independent of variation in colour or form occurs in other species (Hart, 1979; Morison *et al.*, 1998), and such variation can evolve for several reasons including parental care by males (Bisazza & Marconato, 1988; Wiegmann & Baylis, 1995), competition among males for females (Parker, 1992; Pyron, 1996) or resource competition (Oddie 2000). It is not clear which of these mechanisms may be operating in *P. irwini*.

The differences observed in mean L_T between the Andalién and the Biobío drainages are potential indicators of health of the aquatic ecosystem. Growth rate, in particular, is a sensitive and integrative indicator of life history and environmental quality. Poor habitat quality and low resource availability are manifest as reductions in growth rate (Quist & Guy, 2001; Arendt & Reznick, 2005). In addition, increased adult mortality rate leads to decreased growth rates and increased allocation to reproduction as an adaptive life-history response in some small-bodied fishes (Reznick *et al.*, 1990). As a consequence of low growth rates and differential allocation, population size structure skewed towards small body size is a typical indicator of poor or degraded systems (Abrams *et al.*, 1996). This pattern is consistent with the population size structure of *P. irwini* and the relatively poor environmental conditions observed in the transitional zone of the Biobío River (Orrego *et al.*, 2005; Habit *et al.*, 2006). Similar patterns of reduced body size associated with impaired water quality, including those identified in pulp-mill effluents have been noted for several species including *Salmo trutta* L. (Vuorinen & Vuorinen, 1987) and *Micropterus salmoides* (Lacepède) (Sepúlveda *et al.*, 2003). In contrast, the differences in growth rate observed among rivers in the Andalién drainage are relatively small and do not result in reduced size structure of the population. Populations in the Andalién drainage and in the Laja and Rucúe Rivers of the Biobío drainage exhibit a diverse population size structure that is indicative of a healthy environment. Growth patterns and size structure observed in these populations can serve as a baseline expectation for future conservation and management purposes.

We are grateful to P. Victoriano and W. San Martín for their support in the field. Fish collections were made according permits of the Chilean Fisheries Agency (Subsecretaría de Pesca de Chile) for the Andalién River (Res. Ex. N 1176/6 June 2003), Biobío River (Res.Ex. N 2196/9 September 2003) and Laja River (Res.Ex. 130/9 January 2003). Funding was provided under projects 204.310.041-1.0 and 205.310.042-ISP Dirección de Investigación, Universidad de Concepción.

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