

Reproductive timing in three southern Appalachian stream fishes

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Abstract – We quantified the reproductive biology of mottled sculpin (*Cottus bairdi*), rosieside dace (*Clinostomus funduloides*) and longnose dace (*Rhinichthys cataractae*) in Coweeta Creek, North Carolina, USA, a fifth-order stream. These species are abundant in coldwater streams throughout the southern Appalachian mountains, the southernmost limit of their range. We collected fishes from Coweeta Creek every second month (between July 1984 and January 1986) and quantified the seasonal reproductive cycles of females, using both histological techniques and the relative gonadal index (RGI). Both techniques indicated that 1) *C. bairdi* reproduced between March and May, 2) *Cl. funduloides* spawned between May and August and 3) *R. cataractae* were reproductively active between June and July. These conclusions were supported by the following: 1) the presence of reproductive coloration, 2) gravid females, 3) courtship displays, 4) the presence of nest-guarding *C. bairdi* males and 5) the timing of young-of-the-year recruitment. The reproductive characteristics of these 3 species were correlated with different environmental variables. The mean monthly RGI values for both *C. bairdi* and *R. cataractae* were inversely correlated with both maximum and minimum daily water temperatures. The mean RGI values for *C. bairdi* also were negatively correlated with photoperiod, whereas the values for *R. cataractae* and *Cl. funduloides* were positively correlated with the change in daily photoperiod.

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Un resumen en español se incluye detrás del texto principal de este artículo.

Introduction

Coldwater streams (those whose temperatures seldom reach 18°C) are common lotic habitats in the temperate zones. Despite the prevalence of these systems, little is known about the demography and reproductive biology of their non-game fishes. This article examines the reproductive biology of 3 abundant stream fishes found throughout the southern Appalachian mountains: mottled sculpin (*Cottus bairdi* Girard 1850), rosieside dace (*Clinostomus funduloides* Girard 1856), and longnose dace (*Rhinichthys cataractae* Valenciennes 1842). In our study site, Coweeta Creek, North Carolina, USA, *C. bairdi* and *R. cataractae* are the two most abundant members of the benthic guild, whereas *Cl. funduloides* numerically dominates the water-column guild (Grossman & Freeman 1987; Freeman et al. 1988).

Both *C. bairdi* and *R. cataractae* are widely distributed throughout North America (Lee et al. 1980), and some information is available regarding

their reproductive biology. In more northern regions, female *C. bairdi* generally are either gravid or spawn between February and June (Hahn 1927; Simon & Brown 1943; Bailey 1952; Savage 1963; Ludwig & Norden 1969; Downhower & Brown 1979). Data from northern populations of *R. cataractae* in Manitoba indicate that female longnose dace ripen between May and June (Bartnik 1970; Gibbons & Gee 1972). There is a paucity of data on the ecology of *Cl. funduloides*; however, Davis (1972) observed spent females in May and June.

Despite the presence of information on *C. bairdi*, *Cl. funduloides* and *R. cataractae*, little is known of the biology of these species in the southernmost part of their range (the southern Appalachians). Consequently, we examined seasonal ovarian cycling in these 3 species using histological techniques and the relative gonadal index (RGI) (Erickson, Hightower & Grossman 1985a). The resulting data were augmented with visual observations of reproductive activity (such as gravid females and nest-guarding) and young-of-the-year recruitment from

by correlating temperatures in this site with another site about 1000 m upstream. The correlation coefficients for these data sets were 0.93 (daily maximum) and 0.94 (daily minimum). We approximated day length (the time between sunrise and sunset) measurements at Coweeta (35° 02' N lat) by using those from 35° 0' N lat. The change in day length was obtained by subtracting the day length one week after the first day of a sampling period from the day length one week before the first day of the period. Because temperature and photoperiod data are unlikely to be independent (Fig. 1A), we subjected all environmental variables to correlation analysis using Spearman's r . This analysis indicated that minimum and maximum daily water temperatures were correlated ($r=0.99$, $P<0.0005$). In addition, both minimum and maximum daily water temperatures were correlated with photoperiod ($r=0.92$, $P<0.0001$, and $r=0.88$, $P<0.0002$ respectively), but neither was significantly correlated with the change in photoperiod. These analyses indicate that correlation analyses involving the reproductive parameters, water temperature and photoperiod were not independent.

We attempted to verify ovarian cycling data by comparing it with estimates of young-of-the-year recruitment obtained from quantitative electrofishing population estimates made in a nearby (about 400 m downstream) permanent site, site 2 of Freeman et al. (1988). This site also was chosen because it appeared to be more favorable to recruitment (Freeman et al. 1988). In addition, we recorded observations of gravid females, reproductive coloration, reproductive behavior, and nest-guarding during both population sampling (1984–1990) and underwater observations of microhabitat use (1983–1990) in nearby sites. For greater details about the methods used for these aspects of the study, see Freeman et al. (1988) and Grossman & Freeman (1987). The criteria used to assess reproductive coloration, courtship behavior and nest-guarding are described below.

Reproductive coloration was defined as changes from typical coloration patterns to those associated with reproductive behavior. Reproductive coloration in male *C. bairdi* included a darkening of body pigmentation until a generally uniform dark grey or greenish-grey color was achieved. Reproductively active males also possessed an orange stripe on the dorsal edge of the first dorsal fin. Visibly gravid female *C. bairdi* did not exhibit any striking changes in body pigmentation. Male *Cl. funduloides* displayed heightened reddish coloration on the body and breeding tubercles on the head and the lateral stripe became more diffuse and assumed a bright crimson hue. Aside from a general heightening of reddish body pigment, fe-

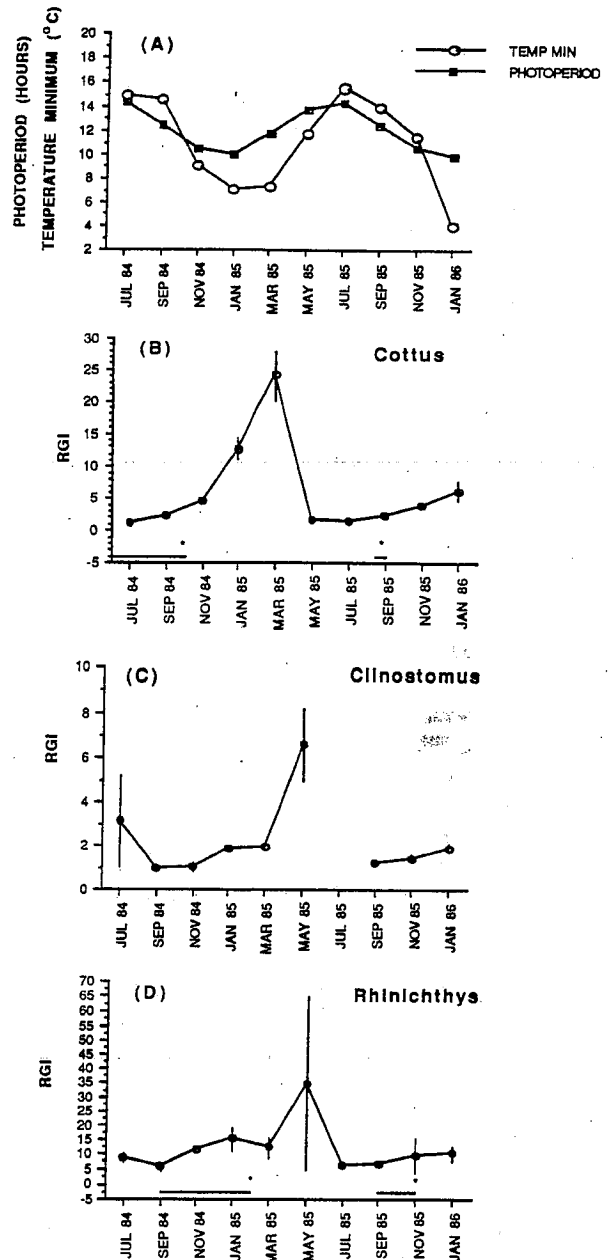


Fig. 1. Daily minimum water temperatures, photoperiod (A), and mean RGI (\pm SE) values for *C. bairdi* (B), *Cl. funduloides* (C) and *R. cataractae* (D). The horizontal bar represents the period of recruitment based on bi-monthly electrofishing samples and the asterisk denotes peak recruitment.

male *Cl. funduloides* did not exhibit readily noticeable changes in coloration. Male *R. cataractae* assumed pinkish hues around the base of the fins and the head. The reproductive coloration for all 3 species was similar to that described by other authors (Lee et al. 1980).

We defined courtship behavior as interactions between 2 or more specimens (at least one of which was in breeding coloration) that appeared to be related to attraction rather than aggression. Repro-

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Table 1. Observations of gravid females, breeding coloration, courtship behavior, and nest-guarding activity, made during microhabitat use and population estimation studies

Season (range of observation dates)	Species	Days of observation	No reproductive activity	Gravid females	Male breeding coloration	Courtship behavior	Males guarding nests (#)	Technique: microhabitat (M) electrofishing (E)
Spring 1983 (15 March–6 May)	<i>C. bairdi</i>	5	23 March, 6, 11 April		15 March		6 May (2)	M
	<i>Cl. funduloides</i>		All dates			M		
	<i>R. cataractae</i>		All dates			M		
Summer 1983 (5 July–19 August)	<i>C. bairdi</i>	6	All dates					M
	<i>Cl. funduloides</i>		5, 19 July, 10, 18 Aug.		11 July, 9 August	11 July, 9 August		M
	<i>R. cataractae</i>		5, 19 July, 10, 18 August		11 July, 9 August	11 July		M
Spring 1984 (22 March–24 April)	<i>C. bairdi</i>	8	22, 23 March, 5, 11, 17, 24 April	27 March, 1 April				M
	<i>Cl. funduloides</i>		All dates				M	
	<i>R. cataractae</i>		All dates				M	
Spring 1985 (4–6 May)	<i>C. bairdi</i>	2		4 May			6 May (2)	E
	<i>Cl. funduloides</i>		All dates					E
	<i>R. cataractae</i>		All dates					E
Spring 1986 (8 April–20 May)	<i>C. bairdi</i>	3	9, 20 May	8 April				E
	<i>Cl. funduloides</i>		8 April	9, 20 May				E
	<i>R. cataractae</i>		8 April	9, 20 May				E
Spring 1987 (10 March–22 May)	<i>C. bairdi</i>	4	22 May	10, 30 March 6 April				E
	<i>Cl. funduloides</i>		All dates				E	
	<i>R. cataractae</i>		10, 30 March, 6 April	22 May			E	
Spring 1988 (7 April–27 May)	<i>C. bairdi</i>	5	19, 27 May	7 April	28 April		28 April (1), 9 May (2)	E (7 April) M (rest)
	<i>Cl. funduloides</i>		28 April, 9 May	16, 27 May			E (7 April) M (rest)	
	<i>R. cataractae</i>		7, 28 April, 9, 27 May				E (7 April) M (rest)	
Summer 1988 (5–18 August)	<i>C. bairdi</i>	4	All dates					M
	<i>Cl. funduloides</i>		All dates					M
	<i>R. cataractae</i>		8, 10, 16 August			5 August		M
Spring 1989 (15 May)	<i>C. bairdi</i>	1	15 May					E
	<i>Cl. funduloides</i>			15 May				E
	<i>R. cataractae</i>			15 May				E
Spring 1990 (26 April–11 May)	<i>C. bairdi</i>	4	1, 11 May				26, 27 April	M
	<i>Cl. funduloides</i>		26 (2), 27 (2) April, 1 May	11 May	11 May			M
	<i>R. cataractae</i>		All dates					M

Seasons during which reproductive activity was not observed

Season (range of observation dates)	Technique – microhabitat (M)	Days of observation
Autumn 1983 (9 October–9 November) (M)		5
Summer 1984 (16 July–18 August) (M)		4
Autumn 1984 (26 September–1 November) (M)		6
Summer 1986 (20 August–15 September) (M)		4
Autumn 1986 (9–19 November) (M)		3
Summer 1989 (8–13 August) (M)		3
Autumn 1989 (13–19 October) (M)		4
Summer 1990 (4–19 August) (M)		3
Autumn 1990 (16 October–11 November) (M)		4

Table 4. Percentage of *R. cataractae* in each histological stage, July 1984 to January 1986

Year	1984			1985			1986			
	July	September	November	January	March	May	July	September	November	January
Mean SL (mm)	72.3 (66-79) ^a	65.2 (43-81)	75.8 (39-89)	70.0 (39-105)	83.5 (75-92)	55.0 (31-82)	58.5 (40-77)	74.0 (56-99)	65.0 (50-82)	62.0 (52-77)
Class	Histological stage:									
Immature	1	20	17	29		33	50	14	33	
Early developing	2	60	83	71		33		86	67	75
Developing	3				50					
Late developing	4				50	33				
Ripe	5									
Spent	6	100	20				50			
Number examined	4	5	12	7	2	3	2	7	3	4

^a Numbers in parentheses represent the range of fish standard length (SL)

during late fall and winter, when both photoperiod and temperature were at their lowest. Gonadal recrudescence appeared to occur very rapidly in *Cl. funduloides* and was significantly correlated only with the change in photoperiod.

The adaptive significance of correlations with environmental data and the differential timing of reproduction for the two dace versus the sculpin is unclear. Although there may be a selective advantage for *C. bairdi* to reproduce in the spring, with summer being more favorable for the 2 cyprinids, the timing of reproduction also possibly represents a phylogenetic constraint for these species (Heins & Baker 1992). For example, the majority of North American freshwater cottids reproduce in the spring (Lee et al. 1980), whereas many, if not most, cyprinids reproduce in the summer (Lee et al. 1980). Given the wide distribution of these families and the diversity of habitats they occupy (such as lakes, streams and rivers), it seems unlikely that selective pressures would be sufficiently similar to produce comparable reproductive seasons for so many species in such different habitats. Although this possibility can not be disregarded, it appears more likely that phylogenetic constraints play a more important role in determining the timing of reproduction for these species than microevolutionary adaptation.

A number of other investigators have reported on reproductive activity in *C. bairdi*. Most researchers have documented spawning for this species during spring, primarily during April and May (Hahn 1927; Savage 1963; Ludwig & Norden 1969; Downhower & Brown 1979), although Simon & Brown (1943) and Zarbock (1952) listed the spawning period as late February to May. These populations inhabited sites in Maryland, Michigan, New York, Ohio, Ontario, Utah, Washington, Wisconsin and Wyoming. It is noteworthy that several western studies (Wyoming (Simon & Brown 1943) and Utah (Zarbock

1952)) observed early spawning of *C. bairdi*, although a Montana population apparently spawned during June of both 1950 and 1951 (Bailey 1952). Spawning temperatures for Coweeta Creek *C. bairdi* (daily minimums of 9-11.8°C) were similar to those reported for both Montana (Bailey 1952) and Wisconsin populations of this species (Ludwig & Norden 1969). In addition, the minimum length at maturity for females in Coweeta Creek was 41 mm, a length similar to the 45 mm length reported for Michigan *C. bairdi* by Hahn (1927). Bailey (1952), however, observed that female sculpin in Montana reached sexual maturity at a minimum length of between 55 and 59 mm.

Cl. funduloides in Coweeta Creek probably spawned between May and July, although we observed courtship behavior as late as 9 August. Davis (1972) recorded spawning of this species between the first week in May and the end of June in a Maryland stream, a finding concordant with that of Breder (1920). Breder (1920) also observed sexually mature female *Cl. funduloides* at a length of 42 mm, whereas the smallest mature female noted by Davis (1972) was 53 mm total length (TL). The smallest reproductively active specimen captured during our study was 51 mm.

Observations indicated that *R. cataractae* were reproductively active in Coweeta Creek during late spring and summer, a finding supported by both histological and RGI data. Both Bartnik (1970) and Gibbons & Gee (1972) noted ripe or spawning *R. cataractae* in Manitoba in May and June. A population of *R. cataractae* in New York, however, spawned in July (Becker 1983), and specimens from a Pennsylvania stream contained ripe eggs and thickened testes on 12 September (Reed 1959). We also found a spent female in our September 1984 collection. The smallest reproductively active *R. cataractae* in our collections was 62 mm, a size