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AGE, GROWTH, AND TIMING OF SPAWNING OF AN ENDANGERED MINNOW, THE OREGON CHUB (*OREGONICHTHYS CRAMERI*), IN THE WILLAMETTE BASIN, OREGON

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ABSTRACT—The Oregon chub *Oregonichthys crameri* is an endangered floodplain minnow endemic to the Willamette River drainage in western Oregon. We determined age and growth of Oregon chub at 3 locations and the timing of spawning at 2 locations. We found that Oregon chub live much longer than previously thought (up to 9 y) and that most of the fish older than 5 y were females. We found strong relationships between somatic growth and otolith (lapillus) growth within populations and considerable variation among populations. Mature fish were primarily ≥2 y old, and all fish >40 mm long had gonads that were developing or mature. Oregon chub spawned from mid-May through early August with peak activity in July. Juveniles that hatched prior to mid-June were not found in October, suggesting reduced survival of early hatched fish.

Key words: Oregon chub, *Oregonichthys crameri*, age, growth, timing of spawning, otolith analyses, Willamette River, Oregon

Oregon chub *Oregonichthys crameri* are small floodplain minnows endemic to the Willamette River of western Oregon. This species was formerly distributed throughout the Willamette Valley (Snyder 1908) in off-channel habitats such as beaver ponds, oxbows, sloughs, backwater pools, and flooded marshes (Markle and others 1991). In the last century, these habitats disappeared rapidly because of changes in seasonal flows resulting from the construction of dams throughout the basin, channelization, revetments, diking, drainage of wetlands, and agricultural practices. The reduction of suitable habitat and the restricted distribution of the Oregon chub resulted in a determination of "endangered" status under the federal endangered species act in 1993 (Markle and Pearsons 1990; USFWS 1993).

Recent recovery efforts include monitoring and protecting naturally occurring Oregon chub populations and their habitats, reintroducing Oregon chub within their historic range, monitoring reintroduced Oregon chub populations, and monitoring the effects of land use activities on Oregon chub populations and their habitat (USFWS 1998; Scheerer 2002).

We conducted this study to determine age and growth of adult Oregon chub, timing of spawning, and growth rates of juveniles, data which are essential for developing scientifically defensible management and restoration plans for Oregon chub. These data are useful in assessing the impacts and/or risks of environmental or anthropomorphic disturbances on individual populations, which differ if a species is short-lived versus long-lived. Knowledge of the timing of spawning and the temperatures when spawning occurs will aid in the protection of this species by avoiding handling or harassment during key periods and in determining the suitability of potential introduction sites. Understanding patterns of growth and the relationships between pond temperatures and growth may explain differences in population abundance among sites and aid in evaluating potential reintroduction sites.

STUDY AREA AND METHODS

This study was conducted at 3 sites located near Lookout Point Reservoir in the Middle

Fork Willamette River subbasin: East Fork Minnow Creek Pond, Hospital Pond, and Shady Dell Pond. All 3 locations have supported stable and abundant Oregon chub populations (>2500 fish) for the past 5 y (Scheerer and others 2002). The major differences among the 3 sites are water temperature regimes and changes in pond areas during the spring and summer months. Hospital Pond is a cold, spring-fed pond that is typically connected to the reservoir by a culvert between mid-May and early-July of each year. The pond was created approximately 50 y ago when Lookout Point Dam was being constructed. An access road on the north side of the reservoir created the pond by partially blocking a small tributary. Pond temperatures remain relatively constant and cold (9 to 11°C) during most of the year and increase to 15 to 16°C for a short period (6 to 8 wk) when the reservoir is full. Pond surface area increases from about 1800 m^2 to about 4400 m^2 when the reservoir is full and a vegetated terrace is flooded. Shady Dell Pond and East Fork Minnow Creek Ponds are isolated from the reservoir throughout the year. Shady Dell Pond was a former side channel that was isolated by the construction of a state highway on the south side of Lookout Point Reservoir. East Fork Minnow Creek Pond is a large beaver pond that has been in existence for over 20 years. The surface areas of these ponds are greatest during the winter and spring (about 4300 m^2 and 9500 m^2, respectively) and lowest in the summer and early fall (about 1500 m^2 and 7125 m^2, respectively). Pond temperatures begin warming in May and exceed 16°C throughout the summer, which is the temperature threshold at which spawning has been observed in the field and in the laboratory (Scheerer and McDonald 2000).

Adult Oregon chub (5 per month per site) were collected for aging using a dipnet, minnow trap, or seine. Monthly collections allowed us to determine the timing of annulus formation using marginal increment analysis (Bagenal and Tesch 1978). Fish were sacrificed and stored in 95% ethanol. Fish were collected December 1996 through November 1998 from East Fork Minnow Creek Pond (n = 120) and Shady Dell Pond (n = 120) and from March 1998 through February 1999 from Hospital Pond (n = 60). Samples were not randomly collected. Fish were collected to include the range of sizes present in the pond at the time of collection; hence, larger fish were collected disproportionately to their abundance. All Oregon chub in this study were collected under endangered species permit TE-818627 issued by the US Fish and Wildlife Service.

Total fish length was measured to the nearest 0.5 mm. The right lapillus was removed from each fish using a fine tip probe under a dissecting scope. Aging of fish collected in 1998 from East Fork Minnow Creek Pond was done using the left lapillus. These were the 1st fish processed, and initial otolith preparation using the right lapillus yielded unsatisfactory results. Each lapillus that was removed was soaked in a 10% bleach solution for several minutes to remove tissue, rinsed with water, rinsed a 2nd time with 95% ethanol, and allowed to air dry (Secor and others 1992). Cleaned lapilli were weighed (±0.0001 mg) using an electrobalance. Lapilli from adult fish were embedded into molds (plugs) of epoxide resin (Secor and others 1992), which were then mounted on glass slides for thin sectioning using a low speed diamond blade saw. Two transverse cuts were made into the plug to produce a thin section (0.5mm) that included the core. Thin sections were mounted on glass slides in thermoplastic glue and polished using a 0.05-μ to 5.0-μ alumina suspension and 1500 grit wet-dry sandpaper.

Adult lapillus sections were aged using transmitted light at 25× under a compound microscope. The 1st prominent opaque band encircling the core was designated as the 1st annulus. Distances between the otolith core and outer edge of each annulus and between the core and the outer edge of the otolith were measured under transmitted light at 100× using digital imaging software. The distance between the last annulus and the leading edge of the otolith was used for marginal increment analysis to determine the timing of annulus formation (Bagenal and Tesch 1978). Mean marginal increments were plotted for fish collected each month for each age class. Fish from all sample locations were pooled for these analyses. The time of annulus formation was assigned to the month when the mean marginal increment was at a minimum (Bagenal and Tesch 1978).

Lapilli from adult fish were read independently 2 times by the same reader, about 5 months apart, to estimate precision. If the 1st and 2nd age disagreed, then a 3rd count was made. Fish were assigned the age that agreed with either of the previous 2 counts. Individuals that had 3 different counts were excluded from analysis. The percent disagreement, or percent of the fish where count 1 differed from count 2, was calculated to describe reader precision.

The relationship between total length and otolith (lapillus) radius was described using linear regression. For each population, the back-calculated length-at-age was determined using a body proportional method (Francis 1990). The equation was:

$$\text{total fish length at age} = (\text{otolith radius} \times \text{slope} + \text{y-intercept}) \times \text{CR}$$

where CR was the ratio of observed length to predicted length (Francis 1990). The slopes and intercepts of linear regressions of length on age were compared among locations and between years within locations using analysis of covariance (ANCOVA).

The relationship between total length and $\log_{10}$ otolith weight was described using linear regression. Comparisons among locations were made using ANCOVA.

Von Bertalanffy growth parameters were estimated from lengths back-calculated to the most recent annulus. To avoid violating statistical independence, length was not back-calculated beyond the most recent annulus (Vaughan and Burton 1994). These parameters were fitted and statistically compared using a randomization method (Helser 1996).

The sex of each adult chub was determined by dissection and visual examination of the gonads. Oregon chub were classified as breeding (containing developed or maturing gonads) or non-breeding. Breeding adult chub had swollen gonads that completely filled their body cavities. Non-breeding fish had reduced and translucent gonads. The presence and prominence of breeding tubercles on male Oregon chub was also noted.

Hatch date analysis was conducted on juvenile Oregon chub to determine approximate spawning times and differential brood survival. We conducted a larval marking experiment in 1997 in East Fork Minnow Creek Pond and determined that the rate of lapillus increment deposition was 1.01 increment per day (r^2 = 0.997; Scheerer and Apke 1998). Juvenile Oregon chub were collected from East Fork Minnow Creek Pond in October 1997 (n = 50), July 1998 (n = 50), and October 1998 (n = 43) and from Hospital Pond in July 1998 (n = 50) and October 1998 (n = 50). All samples were placed immediately in 95% ethanol and taken to the laboratory for processing. Right lapilli were removed using a fine tip probe under a dissecting scope and mounted dorsoventrally on glass slides with thermoplastic glue. Lapilli were polished in the sagittal plane to the core, flipped, and polished again until a thin section containing the core remained. Lapilli were polished using 1500 grit wet-dry sandpaper and a 0.05-μ to 5.0-μ alumina suspension. The standard length ($\pm$0.01 mm) of each juvenile was measured.

Lapilli from juvenile chub were aged under transmitted light at 1000$\times$ using digital imaging software. Each light and dark band combination was counted as a daily growth increment (DGI). Immersion oil was used to enhance the resolution of the bands. Increments that disappeared when adjusting the fine focus were considered sub-daily increments and were not counted (Campana and Neilson 1985). Counts of DGI were made from the core to the edge of the otolith along the anterior-posterior growth axis. The distances between DGI were recorded as the distance between the middle of 1 dark band to the next. Juvenile hatch dates were determined by subtracting the age in days from the date of capture. Approximate spawning dates were assumed to be 7 to 10 d prior to hatching, based on incubation data from a similar co-occurring cyprinid, the redside shiner *Richardsonius balteatus* (Weisel and Newman 1951). This incubation period is consistent with field observations at Shady Dell Pond (Markle and others 1991). Hatch date distributions were compared using chi-square tests, where each category represented a 7-d period.

We examined both mean length-at-age and mean incremental growth over time to determine when juvenile chub growth was maximized in relation to their age, the time of year, and pond temperatures. Average daily growth rates (mm/d) were estimated by dividing the length at capture by age in days. Comparisons between locations were made using t-tests. Growth rates were determined using a linear regression of length on age, and comparisons between locations were made using ANCOVA.

Lapilli from juvenile fish were read independently 2 times, approximately 1 month apart. If the 1st and 2nd age differed by 4 d for July samples or 7 d for October samples, then a 3rd count was made. The final age assigned was the age from the previous 2 counts that was closest to the 3rd count. Precision was estimated by comparing the slopes of regressions of length on age using ANCOVA and by comparing hatch date distributions from the 2 independent aging sessions using chi-square tests.

Pond water temperatures were recorded at 5-h intervals throughout the study at East Fork Minnow Creek, Hospital, and Shady Dell Ponds using Hobo® temperature loggers to determine the effects of temperature on growth rates and on the initiation and duration of spawning activity.

RESULTS

Adult Aging

Oregon chub lapilli revealed patterns of consistent and interpretable growth. The core area was generally dark in color and was encompassed by a prominent broad opaque band. The outer edge of this opaque band was interpreted as the 1st annulus. Successive annuli (opaque bands) were thinner and more narrowly spaced. This pattern was consistent on most of the lapilli regardless of population. One opaque and translucent zone together represents 1 full year.

Because we did not have known-age fish to validate the ages of Oregon chub, we acknowledge that annuli are putative and some ages may be underestimates. We found, using marginal increment analysis (MIA), that the distance between the annulus and the otolith margin was smallest in June and July for 1- to 3-y-old fish (Fig. 1). Small sample sizes for fish ≥4 y old precluded interpretation using MIA. The distance between the annulus and the otolith margin increased from August until December, then leveled off through May. Our MIA suggests that annuli (opaque bands) were deposited on chub lapilli in June to July.

Age distributions were similar at all 3 locations with the majority of the fish aged ≤3 y (mean 91%; range 88 to 97%; Table 1). The number of larger fish collected and aged was disproportionate to their abundance; hence, the proportions of fish ≤3 y old in the populations were even higher than the proportions in our samples. Female fish comprised the majority of the fish >3 y old at all locations (mean 81%; range 79 to 100%).

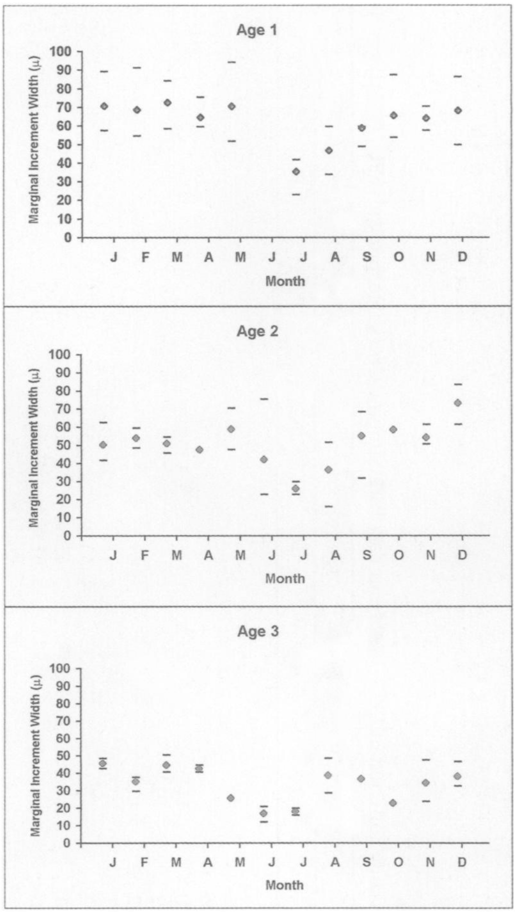

FIGURE 1. Marginal increment width versus month of capture for age 1, age 2, and age 3 Oregon chub. Points represent the mean distance between the last annulus and the edge of the otolith. Horizontal bars represent 95% confidence intervals for the means.

There were strong relationships between somatic growth (total fish length) and otolith growth (lapillus weight) at each location. An exponential equation best described the relationships at East Fork Minnow Creek Pond and Hospital Pond, while a power equation best described the relationship at Shady Dell Pond:

TABLE 1. Mean back-calculated lengths-at-age (mm) for Oregon chub collected in 1997–1999 from East Fork Minnow Creek, Hospital, and Shady Dell Ponds.

Age	*n*	Size range (mm)	Mean size (mm)	Age (y) 1	2	3	4	5	6	7	8	9
East Fork Minnow Creek Pond												
1	25	27–45	37.4	32.1								
2	21	36–53	43.9	33.3	39.6							
3	17	44–54	47.8	34.1	40.0	44.9						
4	5	49–53	51.0	34.4	40.2	45.1	46.7					
5	4	50–52	50.8	33.6	39.2	43.3	46.6	49.1				
6	2	48–54	51.0	33.6	40.1	42.5	45.1	47.5	49.3			
7	1	60–60	60.0	36.7	43.2	47.3	50.5	53.3	55.4	57.5		
8	1	52–52	52.0	30.6	37.1	41.4	43.7	45.8	47.8	49.4	50.8	
9	1	63–63	63.0	32.8	39.9	44.8	48.9	51.9	54.4	56.7	58.8	61.1
Hospital Pond												
1	12	46–56	50.8	43.9								
2	5	52–62	58.6	44.8	53.1							
3	13	58–70	64.4	46.2	54.3	60.9						
4	0											
5	2	69–74	71.5	44.5	51.5	59.0	64.1	68.4				
Shady Dell Pond												
1	30	31–43	36.6	29.6								
2	23	36–54	45.4	31.7	39.8							
3	10	50–57	52.8	31.3	40.7	48.0						
4	4	53–58	55.5	29.9	38.6	46.1	51.8					
5	4	55–66	59.8	31.0	38.8	46.0	51.9	56.4				
6	0											
7	2	62–66	64.0	29.4	37.0	44.8	50.5	55.3	59.0	62.1		
8	1	75–75	75.0	31.5	39.3	47.2	54.2	59.0	63.6	67.6	71.7	

East Fork Minnow Creek Pond:

$$LW = 0.0047e^{0.0874TL}, \quad r^2 = 0.97, \quad n = 64$$

Hospital Pond:

$$LW = 0.0074e^{0.0666TL}, \quad r^2 = 0.98, \quad n = 56$$

Shady Dell Pond:

$$LW = 0.000005 \times TL^{2.807}, \quad r^2 = 0.97, \quad n = 115$$

where LW = lapillus weight (mg) and TL = total fish length (mm). The Oregon chub collected for aging ranged from 19 to 75 mm (TL) and their lapilli ranged in weight from 0.0222 to 1.0376 mg. The lapilli from Hospital Pond chub were typically the lightest at any given length, whereas those from East Fork Minnow Creek Pond chub were the heaviest. This is consistent with similar studies showing that faster growing fish typically have lighter otoliths for a given length (Reznick and others 1989; Secor and others 1992). The slopes of the $\log_{10}$ transformed fish length:lapillus weight relationships were significantly different among locations (East Fork Minnow Creek Pond vs. Hospital Pond: $F = 8.71$, df = 118, $P < 0.001$; East Fork Minnow Creek Pond vs. Shady Dell Pond: $F = 5.49$, df = 175, $P < 0.001$; Shady Dell Pond vs. Hospital Pond: $F = 2.81$, df = 167, $P < 0.05$).

Adult Growth Rates

We found strong relationships between otolith radius (OR) and total length (TL). The following linear regressions were used to back-calculate length-at-age:

East Fork Minnow Creek Pond:

$$TL = 0.089 \times OR + 24.1, \quad r^2 = 0.78, \quad n = 77$$

Hospital Pond:

$$TL = 0.115 \times OR + 30.2, \quad r^2 = 0.88, \quad n = 32$$

Shady Dell Pond:

$$TL = 0.122 \times OR + 18.1, \quad r^2 = 0.90, \quad n = 74$$

Fish (ages 1 to 5 y) from Hospital Pond were significantly larger at a given age than fish collected from East Fork Minnow Creek Pond ($F = 10.13$, df = 100, $P < 0.001$ [slopes]; $F = 36.91$, df = 101, $P < 0.001$[intercepts]) and Shady Dell Pond ($F = 144.59$, df = 99, $P < 0.001$ [slopes]; $F = 18.25$, df = 100, $P < 0.001$ [intercepts]). There were no differences in mean length-at-age for fish from East Fork Minnow Creek vs. Shady Dell Pond ($F = 1.00$, df = 139, $P > 0.05$ [slopes]; $F = 0.01$, df = 140, $P > 0.05$ [intercepts]). There was good separation in the range of back-calculated lengths between sequential age categories at Hospital Pond (Table 1). At East Fork Minnow Creek and Shady Dell Ponds, there was considerable overlap in the range of back-calculated lengths between sequential age categories (Table 1). The larger sizes of fish in Hospital Pond cannot be explained by differences in pond temperatures during the summer; the pond temperatures for June to September were considerably cooler at Hospital Pond than at East Fork Minnow Creek Pond and Shady Dell Pond (Fig. 2). Back-calculated lengths-at-age showed that 45 to 59% of the maximum observed length occurred by the end of age 1 y.

Von Bertalanffy parameters were calculated to describe adult Oregon chub growth (Table 2). Male and female chub growth rates were significantly different at East Fork Minnow Creek Pond ($P < 0.001$). Females grew slower than males, but had a larger asymptotic length. The larger size predicted by the von Bertalanffy model was observed in the lengths of the fish aged 7 to 9 y (55 to 63 mm), all of which were females. There were no differences in growth rates between males and females at Shady Dell Pond ($P > 0.770$). No comparisons were made at Hospital Pond due to the small number of males ($n = 8$) in the sample. We pooled the sexes at East Fork Minnow Creek Pond to obtain a general population growth model and to increase sample sizes for comparisons with the other 2 populations. The asymptotic length of East Fork Minnow Creek Pond fish was 56 mm. This was about 25% less than the asymptotic lengths of 77 mm and 73 mm at Hospital Pond and Shady Dell Pond, respectively. Randomization tests showed significant differences ($P < 0.001$) in the population-specific von Bertalanffy growth models.

Adult Sex Ratios and Size and Age at Maturation

The proportion of males to females in the Oregon chub populations was 1:1.34 at East

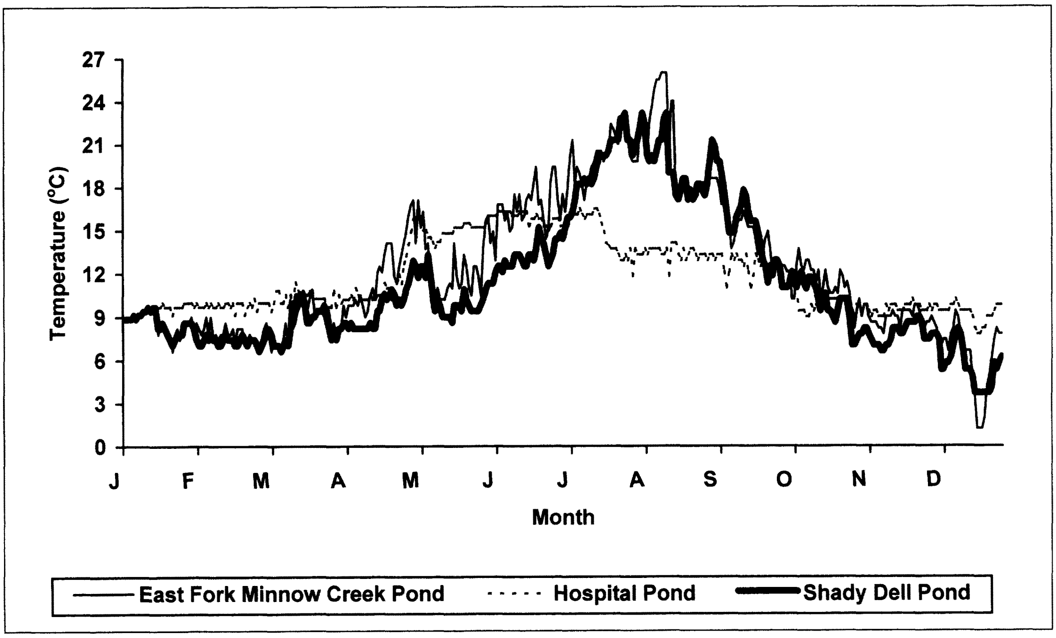

FIGURE 2. Temperatures recorded in East Fork Minnow Creek, Hospital, and Shady Dell Ponds in 1998.

Fork Minnow Creek Pond (n = 115), 1:1.32 at Hospital Pond (n = 58), and 1.24:1 at Shady Dell Pond (n = 114). The male to female ratios were not significantly different from 1:1 (Shady Dell Pond: $\chi^2 = 1.26$, df = 1; East Fork Minnow Creek Pond: $\chi^2 = 1.10$, df = 1; Hospital Pond: $\chi^2 = 2.51$, df = 1; and 3 areas combined: $\chi^2 = 7.37$, df = 3).

Developing or mature individuals were noted primarily between May and July, with a very small number of developing females observed in April. Breeding tubercles were prominent on the pectoral fins and opercles of males during this same time period. We found that all chub >40 mm were developing or mature and that mature fish were primarily age ≥2 y, with the few exceptions being larger age-1 fish from Hospital Pond. The sizes of the mature age-1 fish from Hospital Pond were within the range of the sizes of the mature age-2 fish from East Fork Minnow Creek and Shady Dell Ponds, suggesting that maturity was size- rather than age-dependent.

Juvenile Age and Growth

Juvenile age and growth analyses were conducted using lapilli from 184 Oregon chub from East Fork Minnow Creek Pond and Hospital Pond that ranged in size from 6.0 mm to 22.0 mm. In general, incremental rings (increments) on juvenile chub lapilli were more difficult to interpret than those on the adult lapilli.

TABLE 2. Von Bertalanffy growth parameters for Oregon chub from East Fork Minnow Creek, Shady Dell, and Hospital Ponds. Standard errors are in parentheses. Von Bertalanffy growth equation: $L_t = L_\infty(1 - e^{-K(t-t_o)})$.

Parameter	E. Fork Minnow Creek Pond	Shady Dell Pond	Hospital Pond	All
n	77	74	32	183
K	0.386	0.256	0.247	0.409
	(0.059)	(0.039)	(0.126)	(0.081)
L_∞	45	73	77	62
	(2.1)	(4.1)	(7.8)	(3.1)
t_o	−1.02	1.02	−1.42	−0.81
	(0.02)	(0.20)	(0.54)	(0.27)

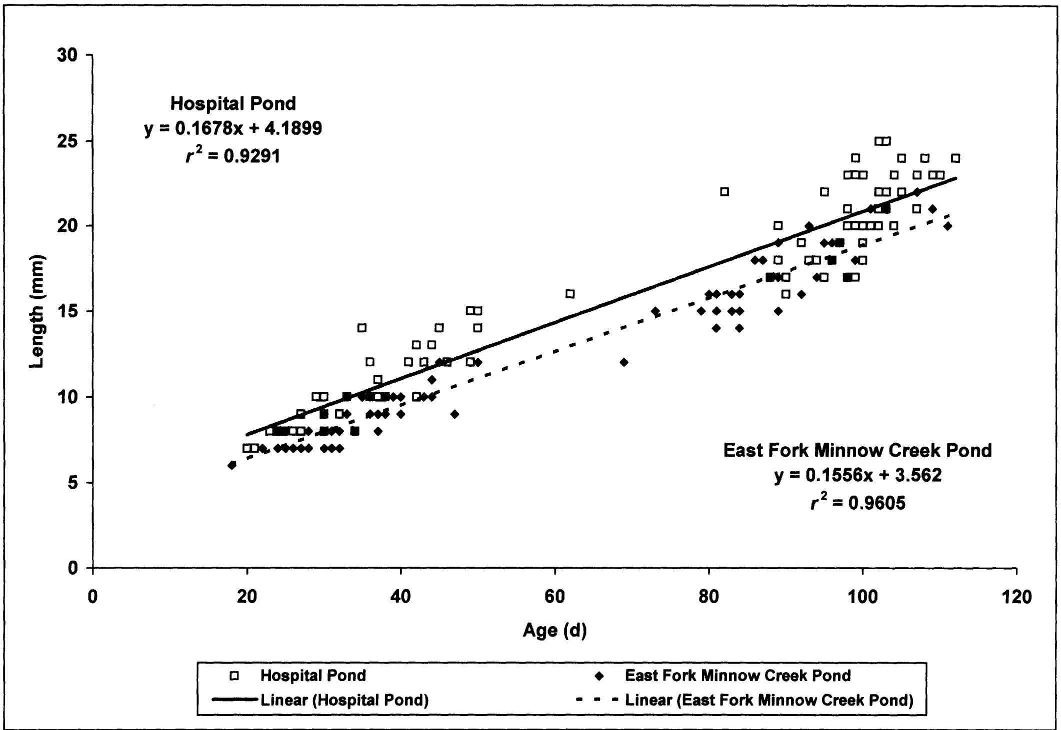

FIGURE 3. Length-at-age for juvenile chub at East Fork Minnow Creek and Hospital Ponds in 1998.

The 1st increment was readily identifiable on most lapilli. Subsequent increments 2 to 20 were more difficult to interpret. This zone (increments 2 to 20) was characterized by many sub-daily rings or checks. Increments in the next zone (increments >20) were very clear and easy to read. The edges of the lapilli from larger juveniles were also difficult to interpret, due to narrow spacing between increments.

There was a strong relationship between juvenile length and age at both locations (Fig. 3). Juveniles from Hospital Pond were larger at a given age than similarly aged juveniles from East Fork Minnow Creek Pond ($F = 5.34$, df = 172, P < 0.001 [slopes]; $F = 44.50$, df = 173, P < 0.001 [intercepts]).

The mean daily growth rates for juvenile chub <55 d old (collected in July) were greater than the growth rates for fish >54 d old (collected in October) at both locations (Fig. 4). The growth rate for chub collected in July in East Fork Minnow Creek Pond (0.26 mm/d, range 0.22 to 0.34 mm/d) was significantly higher than the rate for chub collected in October (0.19 mm/d, range 0.17 to 0.23 mm/d; $t = -15.1$, df = 68, $P < 0.001$). The growth rate for chub collected in July in Hospital Pond (0.30 mm/d, range 0.24 to 0.40 mm/d) was significantly higher than the rate for chub collected in October (0.21 mm/d, range 0.18 to 0.25 mm/d; $t = -14.8$, df = 56, $P < 0.001$). This trend likely applies only to growth measured in terms of length. Daily weight gain was not measured, but was likely greater in the older chub.

Juvenile Oregon chub from Hospital Pond grew faster than chub from East Fork Minnow Creek Pond. The growth rate for chub collected in July from Hospital Pond (0.30 mm/d, range 0.24 to 0.40 mm/d) was significantly higher than the rate for chub collected in July from East Fork Minnow Creek Pond (0.26 mm/d, range 0.22 to 0.34 mm/d; $t = 4.95$, df = 93, $P < 0.001$). Similarly, the growth rate for chub collected in October from Hospital Pond (0.21 mm/d, range 0.18 to 0.25 mm/d) was significantly higher than the rate for chub collected in October from East Fork Minnow Creek Pond (0.19 mm/d, range 0.17 to 0.23 mm/d; $t = 3.65$, df = 87, $P < 0.001$).

We examined the mean otolith increment

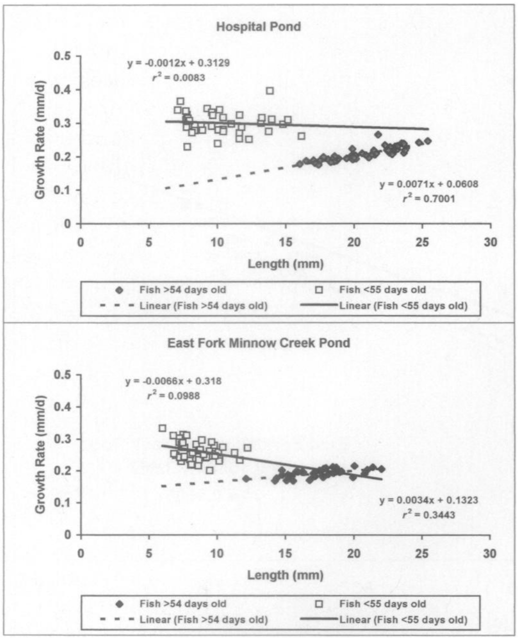

FIGURE 4. Growth rates for juvenile Oregon chub from Hospital and East Fork Minnow Creek Pond in the summer 1998 (<55 d old) and fall 1998 (>54 d old).

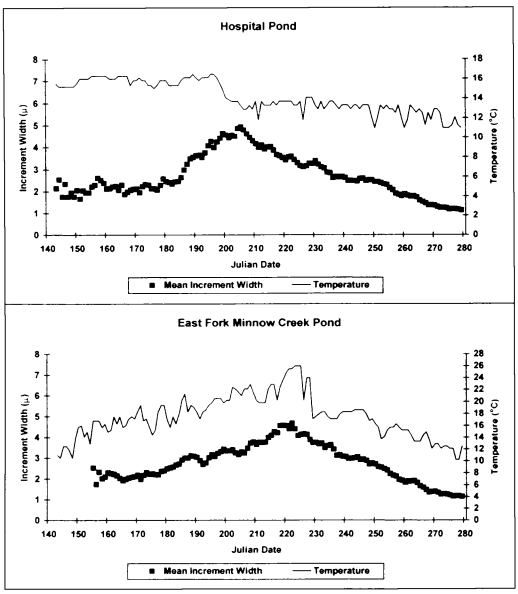

FIGURE 5. Mean otolith increment widths of juvenile Oregon chub and maximum daily pond temperatures from East Fork Minnow Creek and Hospital Ponds in 1998.

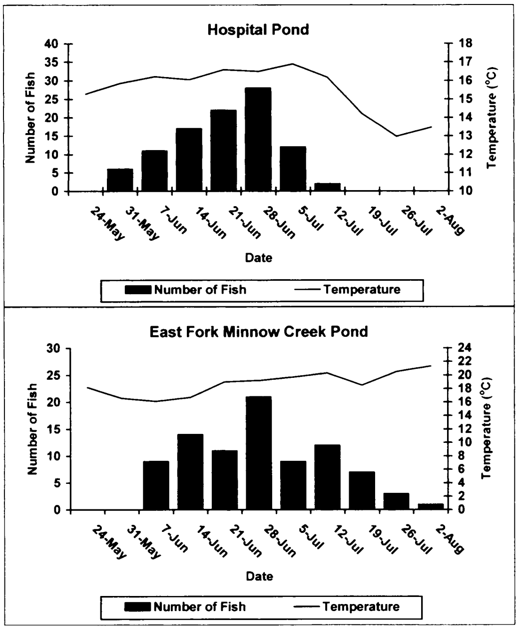

FIGURE 6. Average weekly temperatures and hatch-date distributions for Oregon chub at Hospital and East Fork Minnow Creek Ponds in 1998.

width vs. date and found that the peak increment width, or peak fish growth, was similar for juveniles from East Fork Minnow Creek Pond and Hospital Pond. However, the peak at Hospital Pond was approximately 2 wk earlier (Fig. 5). The growth rates closely paralleled changes in pond temperature at East Fork Minnow Creek Pond but not at Hospital Pond. The reduction in temperature at Hospital Pond, which happened when the pond was isolated from reservoir, occurred approximately 10 d prior to the reduction in growth rate for fish at that location. This may indicate that juvenile ages were overestimated at Hospital Pond, however it seems unlikely because otolith microstructure and the ease of aging was similar for juveniles from Hospital Pond and Minnow Pond.

Hatch Date Distributions

Hatch date analyses showed that successful spawning of Oregon chub occurs over a broad period from late-spring into the summer. The distribution of hatch dates in East Fork Minnow Creek Pond ranged from 8 June through 3 August 1998 (57 d) when pond temperatures ranged from 17 to 23°C (Fig. 6). In Hospital

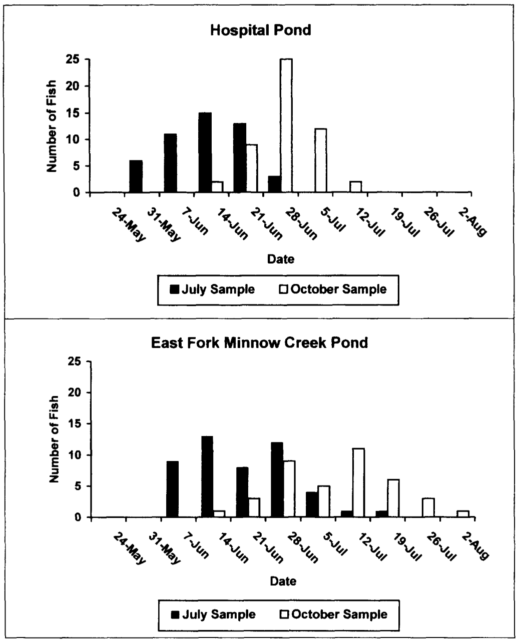

FIGURE 7. Hatch-date distributions for Oregon chub from Hospital and East Fork Minnow Creek Ponds collected in July and October 1998.

Pond the hatch date distribution extended from 31 May through 12 July 1998 (43 d), when pond temperatures ranged from 15 to 17°C. The 1998 hatch date distributions at Hospital Pond and East Fork Minnow Creek Pond were significantly different ($\chi^2 = 25.43$, df = 6, $P < 0.001$). Not surprisingly, there were significant differences between 1998 hatch date distributions for fish collected in the summer (July) vs. those collected in the fall (October), at both East Fork Minnow Creek Pond ($\chi^2 = 34.4$, df = 4, $P < 0.001$) and Hospital Pond ($\chi^2 = 58.9$, df = 4, $P < 0.001$). At both locations no fish hatched prior to 14 June were present in the October samples (Fig. 7), suggesting limited survival of these earliest hatched fish.

Aging Precision Estimates

Multiple aging of individual fish is commonly used in aging studies to measure precision. We found the aging of adult chub lapilli to be highly repeatable. Overall, there was 93% agreement (range 92 to 96%) between the initial and the repeat counts. No discrepancies were more than ±1 year, and all were resolved after a 3rd reading.

The aging precision for lapilli from juvenile chub was examined by comparing hatch date distributions from the initial aging and the repeat aging. No significant differences were found at East Fork Minnow Creek Pond ($\chi^2 = 9.08$, df = 7, $P > 0.10$) or Hospital Pond ($\chi^2 = 8.44$, df = 6, $P > 0.10$). In addition, the regression coefficients were compared from the length-at-age relationships. At East Fork Minnow Creek Pond, the 2 counts resulted in significantly different slopes ($F = 2.95$, df = 170, $P < 0.005$) and intercepts ($F = 5.96$, df = 171, $P < 0.001$). However, the length-at-age relationship from resolved ages showed no significant differences between the slopes ($F = 0.204$, df = 170, $P > 0.20$) or intercepts ($F = 1.61$, df = 171, $P > 0.10$) when compared to the length-at-age relationship from the 1st count. At Hospital Pond, the 2 counts resulted in similar slopes ($F = 1.25$, df = 172, $P > 0.20$) and different intercepts ($F = 2.10$, df = 173, $P < 0.05$). Again, the resulting length-at-age relationship, using resolved ages, showed no significant differences between the slopes ($F = 0.31$, df = 172, $P > 0.5$) or intercepts ($F = 0.29$, df = 173, $P > 0.5$) when compared to the relationship from the 1st count.

DISCUSSION

Adult Oregon chub were previously thought to be a relatively short-lived minnow. Pearsons (1989) separated chub into 3 presumed year classes (0 to 1 y, 1 to 2 y, and 2 to 3 y) based on length frequencies. We found that Oregon chub live much longer than previously expected. Using otolith aging, we found Oregon chub males up to 7 y old and females up to 9 y old. The proportion of fish older than ≥3 y was low in all populations (<10%). Underestimation of age is not uncommon in western minnows. Validated ages in blue chub (*G. coerulea*), Sacramento pikeminnow (*Ptychocheilus grandis*), Colorado pikeminnow (*P. lucius*), tui chub (*G. bicolor*), and leatherside chub (*G. copei*) were several times older than previously thought (Scoppettone 1988; Johnson and others 1995). Longevity in fishes is a mechanism that can buffer populations from year-class failures due to unfavorable environmental conditions that might otherwise doom short-lived species.

We found, using marginal increment analysis, that chub annuli were deposited on lapilli in June to July. We can use this knowledge to differentiate year-classes in Oregon chub populations. For example, age-2 fish collected in the spring are from the same year class as age-2 fish collected the previous fall, but are from a different year-class than age-2 fish collected in the summer and fall of the same year. These data can be used to track the abundance of individual year-classes, to predict or assess changes in population abundance from year to year, and to infer relationships between these changes and changes in physical habitat and environmental variables.

We found that all chub >40 mm were developing or mature, that mature fish were primarily ≥2 y old, and that maturity appears to be size- rather than age-dependent. This is consistent with data for other small western minnows, which have been found to spawn in their 2nd year of life or older (Weisel and Newman 1951; Johnson and others 1995). We can use this information, in combination with our annual population abundance estimates and age composition data, to estimate the abundance of the spawning population at each location, and possibly to develop stock-recruitment models.

We found substantial differences in age, growth, and timing of spawning among populations of Oregon chub. Both juvenile and adult Oregon chub at Hospital Pond had higher growth rates than chub at East Fork Minnow Creek Pond and relationships between fish length and otolith radius indicated that larval chub at Hospital Pond were significantly larger at hatch than larval chub at East Fork Minnow Creek Pond. Density-dependent factors do not appear to explain these results. Hospital Pond had a higher density of adult fish of all species combined in 1998 (0.94 fish/m^2), except during the brief period when the reservoir is full, than East Fork Minnow Creek Pond (0.69 fish/m^2; Scheerer and McDonald 2000). Pond temperatures were also consistently cooler at Hospital Pond during the spring and summer than at East Fork Minnow Creek Pond. These differences are of particular interest because gene flow among populations of Oregon chub is very low or nonexistent (Scheerer 2002). Consequently, these findings suggest a need for genetic studies into the heritable variation of different population traits. If these traits have a genetic basis, they are extremely important both as a fundamental precept of recovery planning and as parameters to be considered when planning future reintroductions into new habitats.

Hatch-date analysis is a powerful tool for determining the approximate spawning distribution and relative brood survival for a population of fish (Campana and Neilson 1985). We found, using hatch-date analysis, that Oregon chub spawned from mid-May through early August with peak activity in July at temperatures >15°C. Spawning activity has been observed in the field and in the laboratory during this same time period (Scheerer and McDonald 2000). This knowledge allows us to minimize handling or harassing chub during spawning and to avoid scheduling activities at or near chub habitats during and immediately prior to the spawning season. This knowledge may also be useful for determining those factors that affect the timing and success of spawning and in determining whether potential reintroduction sites have suitable temperatures for spawning of Oregon chub.

We found that the hatch-date distribution at Hospital Pond was truncated in the summer, compared to East Fork Minnow Creek Pond, and coincided with the drop in pond temperatures that occurred when the pond was isolated from the reservoir and the shallow vegetated terrace in the pond was dewatered. The result is that eggs spawned on vegetation on the dewatered terrace desiccate and die when the pond level drops. Chub larvae may also have reduced survival at the lower pond temperatures that occur when the pond becomes isolated from the reservoir. Humpback chub (*Gila cypha*) eggs incubated at low water temperatures (12 to 13°C) showed only 12% and 15% survival to the egg and swim-up fry stages, respectively, compared to 62% and 91% survival at temperatures of 16 to 17°C (Hamman 1982). These findings have implications regarding reservoir operation and potential habitat modifications, such as the installation of a standpipe or water control structure to maintain water levels, to extend the suitable spawning period at this site.

In summary, the information we gathered in this study enhances our ability to recover this species. The ability to make management decisions is enhanced with knowledge of the age and growth of Oregon chub, size and age at maturity, the timing and duration of spawning activity, and the relationship between pond temperatures and timing of spawning.

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LITERATURE CITED

BAGENAL TB, TESCH FW. 1978. Age and growth. In: Bagenal TB, editor. Methods for assessment of fish production in fresh waters. 3rd ed. Oxford, England: Blackwell Scientific Publications. p 101–136.

CAMPANA SD, NEILSON JD. 1985. Microstructure of fish otoliths. Canadian Journal of Fisheries and Aquatic Sciences 42:1014–1032.

FRANCIS RI. 1990. Back-calculation of fish length: a critical review. Journal of Fish Biology 36:883–902.

HAMMAN RL. 1982. Spawning and culture of humpback chub. Progressive Fish-Culturist 44:213–216.

HELSER TE. 1996. Growth of silver hake within the U.S. continental shelf ecosystem of the northwest Atlantic Ocean. Journal of Fish Biology 48:1059–1073.

JOHNSON JB, BELK MC, SHIOZAWA DK. 1995. Age, growth, and reproduction of leatherside chub (*Gila copei*). Great Basin Naturalist 55:183–187.

*MARKLE DF, PEARSONS TN. 1990. Petition to list the Oregon chub, *Oregonichthys crameri,* as an endangered species. Corvallis, OR: Oregon State University. Available from: Department of Fisheries and Wildlife, Oregon State University, Nash Hall, Corvallis, OR 97331-3803.

MARKLE, DF, PEARSONS TN, BILLS DT. 1991. Natural history of *Oregonichthys* (Pisces: Cyprinidae), with a description of a new species from the Umpqua River of Oregon. Copeia 2:277–293.

PEARSONS TN. 1989. Ecology and decline of a rare western minnow: the Oregon chub (*Oregonichthys crameri*) [thesis]. Corvallis, OR: Oregon State University. 89 p.

REZNICK D, LINDBECK E, BRYGA H. 1989. Slower growth results in larger otoliths: an experimental test with guppies (*Poecilia reticulata*). Canadian Journal of Fisheries and Aquatic Sciences 46:108–112.

SCHEERER PD. 2002. Implications of floodplain isolation and connectivity on the conservation of an endangered minnow, Oregon chub *Oregonichthys crameri,* in the Willamette River, Oregon. Transactions of the American Fisheries Society 131: 1070–1080.

*SCHEERER PD, APKE GD. 1998. Oregon chub research: Santiam and Middle Fork Willamette River drainages. Portland, OR: U. S. Army Corps of Engineers. Contract E96970022. 53 p. Available from: Oregon Department of Fish and Wildlife, 28655 Highway 34, Corvallis, OR 97333.

*SCHEERER PD, KAVANAGH PS, JONES KK. 2002. Oregon chub investigations. Portland, OR: U. S. Fish and Wildlife Service. Contract EF-01. 73 p. Available from: Oregon Department of Fish and Wildlife, 28655 Highway 34, Corvallis, OR 97333.

*SCHEERER PD, MCDONALD PJ. 2000. Oregon chub research (2000): Santiam and Middle Fork Willamette River drainages. Portland, OR: U. S. Army Corps of Engineers. Contract W66QKZ93345985. 85+ p. Available from: Oregon Department of Fish and Wildlife, 28655 Highway 34, Corvallis, OR 97333.

SCOPPETTONE GG. 1988. Growth and longevity of the Cui-ui and longevity of other catostomids and cyprinids in western North America. Transactions of the American Fisheries Society 117:301–307.

SECOR DH, DEAN JM, LABAN EH. 1992. Otolith removal and preparation for microstructural examination. In: Stevenson DK, Campana SE, editors. Otolith microstructure examination and analysis. Ottawa, ON: Canadian Special Publication of Fisheries and Aquatic Sciences 117. p 19–57.

SNYDER JO. 1908. The fishes of the coastal streams of Oregon and northern California. Bulletin of the U. S. Bureau of Fisheries 27:153–189.

[USFWS] UNITED STATES FISH AND WILDLIFE SERVICE. 1993. Endangered and threatened wildlife and plants; determination of endangered status for the Oregon chub. Washington, DC: USDI Fish and Wildlife Service. Federal Register 58: 53800–53804.

[USFWS] UNITED STATES FISH AND WILDLIFE SERVICE. 1998. Oregon chub (*Oregonichthys crameri*) Recovery plan. Portland, OR: USDI Fish and Wildlife Service. 69+ p.

VAUGHAN DS, BURTON ML. 1994. Estimation of von Bertalanffy growth parameters in the presence of size-selective mortality: a simulated example with red grouper. Transactions of the American Fisheries Society 123:1–8.

WEISEL GF, NEWMAN HW. 1951. Breeding habits, development and early life history of *Richardsonius balteatus,* a northwestern minnow. Copeia 3:187–194.

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