American Fisheries Society Symposium 59:79–89, 2008

Zooplankton Communities and Burbot Relative Abundance of Some Oligotrophic Lakes of Idaho, USA and British Columbia, Canada

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Abstract.—We examined the relative abundance of zooplankton populations and burbot *Lota lota* in six oligotrophic lakes and one river in British Columbia, Canada and the Kootenai River, Idaho, USA. Burbot were primarily sampled November through March, whereas zooplankton were sampled in May to coincide with larval burbot early growth. The highest zooplankton densities in the 2003 and 2004 sampling were in the Columbia, Moyie, and Trout lakes, while Columbia, Kootenay, and Moyie lakes were the highest in biomass. In the 2-year sample period, the highest densities of zooplankton identified in these lakes ranged from 68 to 400/L and biomass ranged from 154 to 1,350/μg/L × 10^3. Taxonomic breakdown of zooplankton taxa shows that the majority of biomass of Crustacia species sampled was from the subclass Copepoda. When Cladoceran species were present in the sample, however, they made up the majority of the sample in both density and biomass. In all the water bodies sampled, rotifers made up the majority of the proportion of total density (60–92% of the total sample). Most water bodies exhibited rotifer: crustacean densities of approximately 1:1–2:1; the Kootenai River had rotifer:crustacean densities of 12:1 for both years sampled. During the sample period (1993–2005), burbot were captured in each of the water bodies with known or sampled burbot populations. The highest catch per unit effort (CPUE) recorded was found in the Goat River with as high as 12.3 fish/net d. The Kootenai River had the lowest CPUE of burbot at 0.006 fish/net d. We conclude that trends in zooplankton percent composition may exist in these lakes and suggest that managers of burbot culture closely examine these proportions when choosing a location for extensive rearing in order to maximize survival of larvae through critical early life stages.

Introduction

Oligotrophic lakes are usually low in fish species diversity (Gierlowski-Kordesch and Park 2004), and as with many species found in these conditions, burbot *Lota lota* may share or compete with other pelagic species for their early food (Werner and Hall 1979). The availability of food may be a limiting factor for growth and survival of larval burbot if nutrient reductions decrease primary

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production as it did in the Kootenai River and Kootenay Lake (Northcote 1973; Daley et al. 1981; Woods 1982). Burbot populations in the Kootenai River of Idaho, USA and British Columbia, Canada and Kootenay Lake of British Columbia collapsed in the early 1970s primarily after the construction and operation of Libby Dam, Montana, USA by the U.S. Army Corps of Engineers (Paragamian et al. 2000). While the regulation of the river from the dam not only changed the seasonal discharge and temperature of the Kootenai River, the reservoir, formed as a result of the dam (Lake Koocanusa), became a nutrient sink reducing primary production and nutrient spiraling (Woods 1982; Snyder and Minshall 1996). The loss of primary production was cited as one plausible factor contributing to the decline of burbot in the Kootenai River of Idaho and British Columbia (Paragamian et al. 2000; Ahrens and Korman 2002). A cooperative investigation is underway to improve the primary productivity of the Kootenai River in Idaho by restoring nutrients during July through September (Holderman and Hardy 2004).

Furthermore, a comprehensive Kootenai River and Kootenay Lake burbot conservation strategy calls for several measures to rehabilitate the river and lake populations of burbot (KVRI Burbot Committee 2005). The main measures recommend discharge and temperature changes at Libby Dam while a third supports nutrient restoration in both the river and lake. A fourth measure includes a conservation hatchery program (Ireland et al. 2002; KVRI Burbot Committee 2005) to rear burbot for release to prevent extinction. However, hatchery production of burbot is still in the experimental phase (Taylor and McPhail 2000 and Jensen et al. 2008; Vught et al. 2008; both this volume). One measure that should be investigated in the interim of culture research improvements is extensive rearing: the release of embryos or larvae into nursery lakes (KVRI Burbot Committee 2005; Vught et al. 2008) with adequate food supplies for later stocking in the Kootenai River. However, the suitability for a natural lake/pond for extensive rearing is limited because little information is available on what may be an adequate food supply both in quantity and size for successful rearing of larval burbot.

Larval burbot spend the first few weeks of their early life history in the limnetic zone of lakes. After endogenous feeding (4.4–5.5 mm), burbot in lakes may migrate to the surface, become pelagic, and shift to exogenous feeding (Fischer 1999). The larvae may remain in the limnetic zone for 16–27 d (Ghan and Sprules 1993), feeding on phytoplankton and zooplankton (McPhail and Paragamian 2000). During this same time, larval mortality rates are high and densities may shift from as high as 15/m^2 to less than 1/m^2 within a month (Ghan and Sprules 1993; Fischer 1999). The ability of fish larvae to grow and survive through their early life history (ELH) stages ultimately plays a role in recruitment and year-class formation (Houde 1987). Starvation (Hjort 1914; May 1974) and predation (Bailey and Houde 1989; Batty 1989; Blaxter and Fuiman 1990) during ELH stages of multiple fish species have been hypothesized as being the primary factors involved in regulating survival. However, to our knowledge, ELH food habits of burbot in conjunction with food abundance during the published investigations have not been reported.

The objectives of this current investigation were to (1) provide baseline information on zooplankton abundance in lakes within the region that have self-sustained burbot populations during ELH, (2) examine some differences in zooplankton density and biomass in lake and riverine systems within the region, (3) collect catch per unit effort (CPUE) of burbot to validate their presence, (4) provide pertinent literature review and discussion of burbot and other related larval fish early life history stages, and (5) present further recommendations that may aid in burbot rehabilitation in the Kootenai system. This information may be important to managers of other burbot populations since many populations are threatened or have been extirpated (Maitland and Lyle 1990, 1996; Keith and Allardi 1996; Argent et al. 2000; Arndt and Hutchinson 2000; Dillen et al. 2008, this volume).

Study Area

Zooplankton sampling took place in the Kootenai River, Idaho and British Columbia; the Kootenay Lake (South Arm), British Columbia; and the Goat River (tributary to the Kootenay River of British Columbia) in the upper Columbia River basin (Figure 1). Burbot are at the northern edge of the continental United States but near the southern edge of their circumpolar distribution (McPhail and Lindsey 1970). Moyie and Trout lakes and Duncan Reservoir in the Kootenai basin, and Upper Arrow Lakes Reservoir and Columbia Lake in the upper Columbia River drainage, were also sampled (Figure 1).

The Kootenai River, Idaho and British Columbia; Goat River; Duncan Reservoir; and Trout lakes were also sampled for burbot. Duncan Reservoir, formed behind Duncan Dam, flows into the Duncan River, which eventually discharges into the north arm of the Kootenay Lake approximately 7 km downstream from Libby Dam (Figure 1). The outflow from Trout Lake forms the Lardeau River, which flows approximately 50 km before discharging into the Duncan River near its point of entry into Kootenay Lake. These two locations were selected for sampling because they are near Kootenay Lake and continue to support healthy populations of burbot.

FIGURE 1. Map of Kootenay and Upper Columbia River drainages and the eight water bodies sampled during 2003 and 2004.

Methods

Burbot Sampling

Burbot were sampled in lakes and rivers within the region to validate their presence. Burbot were captured using cod traps (Spence 2000) in Upper Arrow Lakes Reservoir, Duncan Reservoir, and Trout Lake. Cod traps were baited with kokanee *Oncorhynchus nerka* spawner carcasses placed in bait bags constructed of marquisette net. Bait bags were placed near the center of the traps under the inner aperture of the trap throat. Trap depths were determined by means of a recreational grade depth sounder (Lowrance Model LMS-350a). Traps were left to fish for 4–49 h before retrieval, but were most commonly set for periods of either 24 or 48 h. Trapping was conducted on Duncan Reservoir and Trout Lake between October 23 and November 15, 2001 and between October 14 and 24, 2002 (Baxter et al. 2002). In Upper Arrow Lakes Reservoir, sampling was conducted from October 1 to October 31, 2002. Catch per unit effort was calculated as catch per 24-h cod trap set.

Adult burbot in the Kootenai and Goat rivers were sampled using baited hoop nets primarily during the winter season to coincide with seasonal migrations. Hoop nets had a maximum diameter of 0.61 m (see Bernard et al. 1991 for a description of the nets and the method of deployment). Although sampling dates varied annually, sampling seasons generally began in November and continued through March. Catch per unit of effort was measured by a 24-h set period for each net, which equaled one unit of effort. Nets were deployed in deep areas (usually the thalweg) of the Kootenai River between river kilometer (rkm) 123 (south arm of Kootenay Lake) and rkm 244.6 (Ambush Rock). However, effort was concentrated at the mouth of Boundary Creek near Porthill, Idaho (rkm 170), Nick's Island (rkm 145), British Columbia, and the Goat River, near Creston (rkm 152) and Ambush Rock (rkm 244.6).

Zooplankton Sampling

Microinvertebrates (zooplankton) were sampled in 2003 and 2004 in six Canadian lakes in British Columbia (Duncan Reservoir, Upper Arrow Lakes Reservoir, Columbia, Kootenay, Moyie, and Trout lakes) as well as the Goat River, British Columbia and the Kootenai River in northern Idaho. Upper Arrow Lakes Reservoir was only sampled in 2004. Sampling of the identified water bodies took place on May 12, 2003 and May 8, 2004. Zooplankton were sampled in early May to coincide with the time when larval burbot would be first feeding (Ghan and Sprules 1993). Three whole water and three vertical tow samples were taken at three locations (distributed evenly across the water body) to obtain a representative sample. Sampling locations were marked with global positioning system and resampled the subsequent year. For whole water samples, zooplankton were collected by filtering 10 L of water through a 1-L straining cup lined with a 63-µm mesh filter material. These samples were taken approximately 0.3 m from the surface, which assumes that crustaceans and rotifers were mixed evenly in river systems (Hynes 1970). Vertical tows were performed by using a 118-µm mesh tow net. The net was dropped to specific depths and pulled immediately to avoid any horizontal flow influence. The volume of water filtered was determined by calculating the volume of a cylinder. Preservation and identification was performed identical to surface collections. Contents were then rinsed into 60-mL NALGENE® bottles and preserved with 0.05–0.1 mL of Lugol's iodine solution per 1-mL sample volume. Analysis of the zooplankton was performed by Aquatic Taxonomy Specialists Malinta, Ohio. Detailed laboratory analysis methods are described in Hardy (2003).

Results

Burbot

During the sample period (1993–2005), burbot were captured in each of the water bodies with known or sampled burbot populations. Catch rates varied between water bodies, with the majority of the catch occurring during fall sampling periods. Average catch rates for Moyie, Columbia, and Trout lakes; Duncan Reservoir; Upper Arrow Lakes Reservoir; and the Goat and Kootenai rivers during the sample periods were 2.1 SE ± 0.1; 0.22 SE ± 0.1; 0.96 SE ± 0.0; 0.43 SE ± 0.15; 8.45 SE ± 1.2; 12.3 SE ± 0.0, and 0.02 SE ± 0.0 fish/net d, respectively. With the exception of the Goat River, the highest CPUE recorded was consistently found in Upper Arrow Lakes Reservoir in 2003, 2004, and 2005, with as high as 10.1 fish/net d. The water body with the lowest catch rates was the Kootenai River with as few as 0.006 fish per net d. Additional study during this sample period describe burbot captured in Kootenay Lake (Paragamian et al. 2008, this volume).

Zooplankton

The highest zooplankton densities in the May 2003 and 2004 sampling were in Columbia, Moyie, and Trout lakes, while Columbia, Kootenay, and Moyie lakes were the highest in biomass (Tables 1 and 2). Although the same water bodies showed similar density and biomass of zooplankton between the 2 years sampled, the 2004 samples showed a significant increase in both density and biomass. In the 2-year sample period, the highest densities of zooplankton identified in these lakes ranged from 68 to 400/L and biomass ranged from 154 to 1,350/μg × 10^3.

Taxonomic breakdown of zooplankton species shows that the majority of Crustacia species sampled were from the subclass Copepoda, while only a small percent of the total were from *Cladocera* (Tables 1 and 2). The highest percent of *Cladocera* were located in the Goat and Kootenai rivers and Columbia Lake in 2003. On the contrary, Cladocerans made up less than 3% of the Crustacia species sampled in 2004. When Cladoceran species were present in the sample, they made up the majority of the sample in both density and biomass. The two most frequent species

TABLE 1. Zooplankton (*Crustacea* and *Rotifera*) density estimates taken from water bodies in the Pacific Northwest (Idaho and British Columbia, Canada) in 2003 and 2004. *N*/L represents number of zooplankton per liter.

	Water bodies							
Year/taxa	Columbia Lake	Duncan Reservoir	Goat River	Kootenay Lake	Kootenai River	Moyie Lake	Trout Lake	Upper Arrow Lakes Reservoir
2003	*N*/L	*N*/L	*N*/L	*N*/L	*N*/L	N/L	*N*/L	*N*/L
Cladocerans	32.0	0.2	2.3	1.0	0.1	0.0	0.2	–
Copepods	49.6	4.7	2.7	29.0	1.2	44.8	13.3	–
Rotifers	136.0	33.0	9.4	16.2	15.2	37.3	54.8	–
2004								
Cladocerans	7.20	0.00	0.00	0.57	0.00	0.47	0.67	0.00
Copepods	88.0	6.6	0.8	50.4	1.4	95.7	66.9	3.1
Rotifers	223.5	15.7	0.6	54.9	16.5	303.9	70.6	21.8

TABLE 2. Zooplankton (*Crustacea* and *Rotifera*) biomass estimates taken from water bodies in the Pacific Northwest (Idaho and British Columbia, Canada) in 2003 and 2004.

	Water bodies							
Year/taxa	Columbia Lake	Duncan Reservoir	Goat River	Kootenay Lake	Kootenai River	Moyie Lake	Trout Lake	Upper Arrow Lakes Reservoir
2003	µg/L (10³)	µg /L (10³)	µg /L (10³)	µg /L (10³)	µg /L (10³)	µg /L (10³)	µg /L (10³)	µg /L (10³)
Cladocerans	1,136.2	5.1	45.1	13.2	–	0.0	10.4	–
Copepods	187.5	21.1	41.4	366.2	–	231.9	77.2	–
Rotifers	26.3	8.7	4.0	4.4	–	21.8	8.9	–
2004								
Cladocerans	308.79	0.00	0.00	3.50	0.00	3.17	6.06	0.00
Copepods	226.7	49.1	6.9	478.0	8.4	342.4	270.3	25.6
Rotifers	68.6	8.2	0.2	19.7	4.6	97.2	148.6	5.6

of Cladocerans identified in samples were *Bosmina longirostris* and *Daphnia thorata*. The five most common *Copepoda* species identified in the 2003 and 2004 samples included *Nauplii*, *Cyclopoid copepodite*, *Calanoid copepodite*, *Diacyclops thomasii*, *Leptodiaptomus ashlandii*. The most common *Rotifera* species identified in these sample years included *Kellicottia longirostrus*, *K. longispina*, *Keratella longispina*, *K. cochlearis*, *Polyarthra major*, *P. remata*, and *Proales* spp. In all the water bodies sampled, rotifers made up the majority of the proportion of total density (60–92% of the total sample). Most water bodies exhibited rotifer:crustacean densities of approximately 1:1 or 2:1; the Kootenai River had rotifer:crustacean densities of 12:1.

Discussion

Total catch per unit effort (CPUE) has been used to compare burbot stock densities (Parker et al. 1988) and is a suitable general population index, but for our purpose, only for validation of the presence of burbot. Also, because we used both cod traps and hoop nets, the comparison between the two gears can only be generalized due to the fact hoop nets are better for rivers while cod traps are more suited for lakes (Spence 2000). The Goat River had the highest CPUE, averaging about 12.3 burbot/net d, which was substantially higher than that of Duncan Reservoir (mean CPUE = 0.43) and Trout (CPUE = 0.96) lakes. The high catch rates in the Goat River were expected since spawning activity during the winter sampling concentrated burbot in a defined location. Burbot CPUE in the Kootenai River was only a small proportion of that in the other bodies of water (mean CPUE = 0.02). For comparison, CPUE of burbot in four Alaskan lakes caught by hoop net ranged from 0.5 to 3.0 CPUE (Parker et al. 1988), while in the Tanana and Chena rivers, CPUE was greater than 1.0 and 0.5, respectively (Evenson 1993). Based on these comparisons, the densities of burbot in exploited Alaskan fisheries appear to be 20 times greater, at a minimum, than the Kootenai River population, about the same for the Duncan Reservoir and Trout lakes, and less abundant than the single sampling season in Upper Arrow Lakes Reservoir.

During this study, we identified densities of zooplankton in burbot waters ranging from 1.3/L in the Goat River, Idaho to 400/L in Moyie Lake, British Columbia. Biomass of these same samples ranged from 0.7/µg × 10^3 in the Kootenai River, Idaho to as high as 1,350/μg × 10^3 in Columbia Lake, British Columbia. Clearly, other stock limiting factors (Paragamian et al. 2000, 2008) keep us from drawing conclusions from zooplankton density in relation to burbot density in these northwest water bodies directly; however, it is intuitive that higher densities of zooplankton during the switch to exogenous feeding may reduce starvation mortality. Direct mortality in fishes due to starvation seems only to be a factor following the transition to exogenous feeding (Folkvord and Hunter 1986). Vught et al. (2008) found 10 rotifers/mL adequate for intensive larviculture of burbot during this critical switch following yolk absorption. Extensive larval rearing in ponds as a means of conservation of burbot stocks has been seen to have some success (Stipek 1992; Kainz and Gollmann 1996; Dillen et al. 2008; Vught et al. 2008). In mesocosm studies, Clemmesen et al. (2003) showed that Atlantic cod *Gadus morhua* larvae, a species related to burbot, survived and grew significantly faster when zooplankton densities averaged 50/L during a March–June experimental study as opposed to 30/L in the same study. It has been hypothesized that larval survival and recruitment is conditioned by the match of larvae with prey fields in time and space, referred to as the match–mismatch hypothesis (Cushing 1972). Therefore, larvae must locate food patches during this critical period before a time of irreversible starvation or point of no return is reached (Miller et al. 1988). Once a larva has successfully initiated feeding, starvation resistance dramatically increases (Blaxter 1969; Hunter 1981).

In addition to density and biomass for extensive pond culture, managers should also consider the type and relative proportions of indigenous zooplankton species as well. In our sampling, we found that on average, most lakes that had good burbot populations also had a proportion of 2:1 rotifer: crustacean densities. Once again, this is not to say there is a direct link between the two, but rather that it at least warrants some consideration. First feeding burbot require food as small as 200–300 μm (Shiri Harzevili et al. 2003). Therefore, a pond low in rotifer density, yet possessing high density and biomass of Cladoceran species for example, may be inadequate in proportion to reduce starvation mortality. In our sampling, this same scenario was exhibited in the south arm of Kootenay Lake where coincidentally burbot populations have collapsed over the past few decades (Paragamian et al. 2000). Imsland et al. (2006) found that Atlantic cod fed strictly rotifers through their ELH had significantly higher incidence of skeletal deformities and lower growth rates, food intake, and feed conversion ratios than those started on enriched rotifers during the first 4 d and then strictly fed crustaceans for the rest of the experiment (4-month rearing period). Vught et al. (2008) showed that at first feeding, rotifers such as *Brachionus calyciflorus* proved adequate for a starter food following yolk absorption, but then needed to be replaced after 7 to 8 d with larger *Artemia* nauplii. Some studies have also indicated that the first food items taken by larval burbot are rotifers (Ghan and Sprules 1993), while others suggest the first foods are phytoplankton and that larvae then switch to copepod nauplii after day 3 of exogenous feeding (Vatcha 1990). Our suggestion for extensive pond rearing is for managers to locate those water bodies that have not only adequate density and biomass of zooplankton, but also maintain an adequate proportion of rotifers:crustaceans (e.g., 2:1), allowing a more linear growth through larval burbot development. Once burbot make the switch to exogenous feeding, they will, as other species, select the largest prey items they can ingest (Ghan and Sprules 1993).

Many other external factors such as trophic cascading (top-down predation) may be responsible for an apparent unequal proportion of small to large zooplankton. This could be the case in Upper Arrow Lakes Reservoir, which sustains a large kokanee fishery following fertilization (Hyatt et al. 2004) and where the proportion of rotifers: zooplankton was approximately 7:1 in density in our study. During our sampling, the Kootenai River exhibited a 12:1 ratio of rotifers: crustacean densities; yet, it is unlikely that trophic cascading was the reason. Historically, the majority of zooplankton production in the lower part of Idaho's Kootenai River took place in extended floodplains and backwater areas that have since been reduced through diking and channelization occurring in the early 1930s through the completion of Libby Dam in the early 1970s (Redwing Naturalists 1996). It is very likely that this type of prey size structure in the Kootenai River leaves little ability for larval burbot to switch to a secondary food source following their first feeding on phytoplankton and rotifers.

Acknowledgments

The authors would like to give special thanks to David Bennett, Ken Caine, and Nathen Jensen for their editorial comments; field technicians Corie Laude, Josh McCormick, and Don Miller; and many other temporary and contract employees for all of their hard work in collecting burbot CPUE. We also extend our thanks to Colin Spence of the British Columbia Ministry of Land, Water, and Air Protection for permitting our sampling of zooplankton in British Columbia water bodies. Funding for this work was provided by the Bonneville Power Administration.

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