GENETIC CHARACTERISTICS OF BURBOT

IN THE KOOTENAI RIVER DRAINAGE

OF MONTANA, IDAHO AND BRITISH COLUMBIA

Madison S. Powell
Hagerman Fish Culture Experiment Station
University of Idaho
3059F National Fish Hatchery Road
Hagerman, ID 83332
Phone: (208)837-9096, Fax: (208)837-6047, e-mail: fishdna@micron.net

Vaughn L. Paragamian
Idaho Department of Fish and Game
2750 Kathleen Ave.
Coeur d' Alene, ID 83814

Joyce C. Faler
Aquaculture Research Institute
University of Idaho
Moscow, ID 83844-2260

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Methods

Burbot, *Lota lota* collected from four locations in the Kootenai River, British Columbia, Canada/Idaho, USA and Montana, USA were examined for differences in mitochondrial DNA (mtDNA) haplotype diversity. Three separate mitochondrial gene regions, NADH dehydrogenase 1, NADH dehydrogenase 2 and NADH dehydrogenase 5/6, were amplified using the polymerase chain reaction. The amplified mtDNA was screened for restriction fragment length polymorphisms (RFLPs). Simple haplotypes from digests of single gene regions were combined for all three regions into composite haplotypes. Nucleotide substitution estimates per site were calculated via the Nei (1987) method using REAP 4.0 (McElroy et al. 1991) and was then used to generate a matrix comparing distance values between all pairs of identified

composite haplotypes. The program KITSCH contained in PHYLIP 3.5 (Felsenstein 1993) was used to generate a distance dendrogram using the least squares method of Fitch and Margoliash (1967). The extent of geographic heterogeneity within identified composite haplotypes was assessed using MONTE a Monte Carlo simulation (Rolf and Bentzen 1989) within the REAP 4.0 program package.

Results

Differences in mtDNA RFLP frequencies correspond to east west geographic areas of the Kootenai River Basin with Kootenai Falls, Montana representing an apparent geographic barrier. A total of 11 composite haplotypes were observed overall with only 1 detected in all four locations (Table 1). Designated Bur-01, this composite haplotype was predominant among burbot from two sample locations below Kootenai Falls (N=93). However, Bur-01 was low in frequency among samples of burbot from above Kootenai Falls (N=57). An inverse relationship was observed with Bur-02 the second most prevalent composite haplotype. Bur-02 decreased significantly in frequency among burbot below Kootenai Falls but was most common in burbot from the two sample locations above the falls. These significant frequency differences, along with the detection of several closely related, minor haplotypes observed only above or below the falls suggest divergent populations. This supports existing life history information and implies burbot recovery within the Kootenai River may benefit from management actions addressing two populations rather than one.

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Table 1. Frequencies of composite haplotypes among burbot sampled from four locations in the Kootenai River Basin.

	Above Kootenai Falls		Below Kootenai Falls	
Composite Haplotype	Lake Koocanusa	Kootenai R. Montana	Kootenai R. Idaho	Kootenay Lake
Bur-01	0.243	0.300	0.638	0.846
Bur-02	0.649	0.550	0.100	0
Bur-03	0	0	0.013	0
Bur-04	0	0	0.225	0
Bur-05	0	0	0.013	0
Bur-06	0.027	0.100	0	0
Bur-07	0.027	0	0	0
Bur-08	0	0	0.013	0
Bur-09	0.027	0.050	0	0
Bur-10	0.027	0	0	0
Bur-11	0	0	0	0.154

OCCURRENCE OF BURBOT (*LOTA LOTA*) LARVAE

IN RELATION TO PH

Lauri Urho
Finnish Game and Fisheries Research Institute.
P.O.Box 6. FIN-00721 Helsinki, Finland

Jyrki Lappalainen
Department of Limnology and Environmental Protection,
Box 27, FIN-00014
University of Helsinki, Finland.
E-mail: Jyrki.T.Lappalainen@Helsinki.Fi

Jakob Kjellman
Department of Limnology and Environmental Protection,
Box 27, FIN-00014
University of Helsinki, Finland

Richard Hudd
Finnish Game and Fisheries Research Institute.
Merenkurkku Fisheries Research Station,
Korsholmanpuistikko 16, FIN-65100 Vaasa, Finland

Introduction

Burbot occurs frequently in both freshwaters and in the brackish Baltic Sea. It is still the fourth common species in Finnish lakes after perch, pike and roach, although it has recently disappeared from several lakes due to eutrophication (Tammi et al., 1997). Another environmental change, acidification, has affected the Finnish fish fauna, but little is known on its effects on the occurrence of burbot (Rask et al., 1995). Spatially the effects of acidification are restricted to small lakes in the southern Finland and to episodically acidified waters in the coastal areas of the Blatic Sea, the Kyrönjoki estuary as an example (Kjellman and Hudd, 1998). The estimated loss of the burbot catch in the Kyrönjoki estuary was 2.4 to 7.4 million FIM in 1979-1988 (Kjellman et al., 1994).

The main objectives here was to study the effects of acidification on the occurrence of burbot larvae. The presence of burbot larvae was studied in lakes ranging from 4.3 to 7.8 in pH, and in relation to distance from the outlet of the River Kyrönjoki, known for its acid waters at spring.

Materials and Methods

The presence of burbot larvae was studied in 31 lakes (61°N, 24°E; 60°N, 26°E) and in the Kyrönjoki estuary (63.2°N, 21.5°E). The samplings were performed with a white-plate method (Urho, unpubl.) or with an ordinary 1.5 l scoop during April and May when the larvae are found in the shallow littoral areas. The occurrence of larvae in lakes was studied with a logistic regression model (SYSTAT, 1992):

(1) $\text{Occurrence} = \exp(\alpha + \beta * \text{pH} + \gamma * \text{pH}^2)/[1 + \exp(\alpha + \beta * \text{pH} + \gamma * \text{pH}^2)]$

(2) $\text{Loss} = -2 * [\text{Occurrence} * \log(\text{Occurence}_{est}) + (1 - \text{Occurrence}) * \log(1 - \text{Occurence}_{est})]$

The statistical significance of the model (1) was based on a deviance reduction obtained with the loss function (2). The fitting was performed in a stepwise manner: first the intercept (α), then the linear (β*pH) and finally the quadratic pH (γ*pH^2) effects were added to function (1). The statistical significance of the pH effects was based on the difference between the deviance reductions (function 2) in the intercept and linear pH, and the linear pH and quadratic pH. The model fit (1) was also estimated posterior with a K-statistic (Titus et al., 1984) More thorough description of the these methods are found from Minns and Moore (1995).

The occurrence of burbot larvae in the Kyrönjoki estuary was studied in two years in relation to distance from the river outlet with the CATMOD procedure of SAS (1989). The level of acidification was estimated as a number of days with pH <5.5 in the river during May. The number of such days was 31 and 0, in 1982 and 1989, respectively.

Results

The logistic regression model showed that the occurrence of burbot larvae depends on pH in lakes (Figure 1). Significant deviance reduction was obtained with the quadratic inclusion of pH to model (χ^2=21.35, p<0.001, df=1). The 50% threshold values for the presence-absence for the presence-absence pattern were 5.6 and 7.1, respectively, for pH. The model predicted the occurrence of burbot larvae correctly in 26 lakes, and only 5 were misclassified. The analysis with the posterior K testing showed that the obtained significant deviance reduction was not by change alone (Z=3.62, p<0.001).

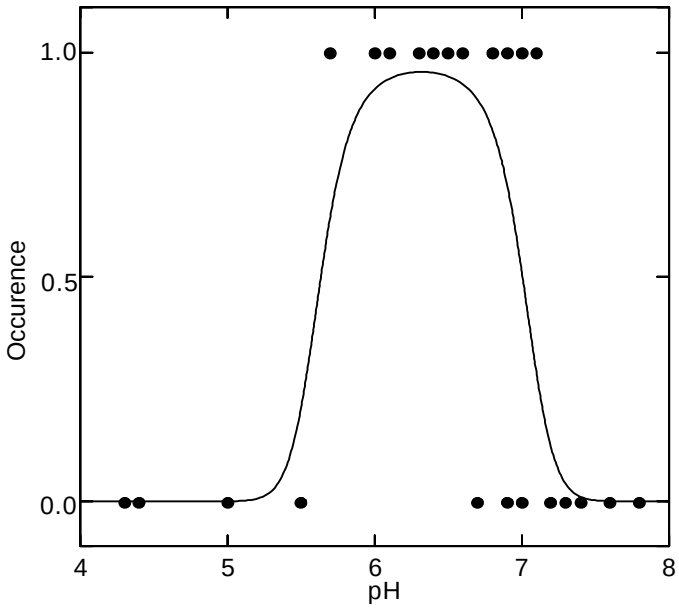


Figure 1. Occurrence of burbot larvae in relation to pH in 31 lakes in southern Finland.

The effects of distance and year on the occurrence of burbot larvae in the Kyrönjoki estuary were first studied including all the stations sampled. The results showed that the decrease in the occurrence of larvae was significant in relation to distance from the river mouth (Figure 2). The interaction term (distance*year) was insignificant and therefore excluded from the model. This model showed that both of the two main effects were significant (distance: χ^2=6.66, p<0.01; year: χ^2=6.85, p<0.01) and the likelihood ratio was insignificant, indicating a good fit of the model (χ^2=50.23, p=ns, DF=56). However, the year effect was not significant when only the stations sampled in both years were included.

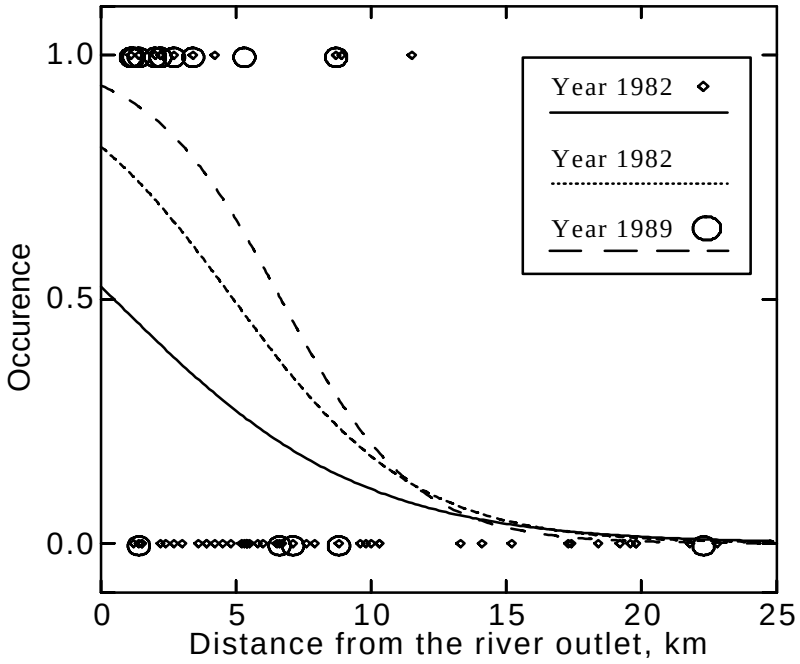


Figure 2. Occurrence of burbot larvae in relation to distance in two years studied. Solid line is for stations sampled in 1982, broken line for stations sampled in 1989, and dotted line for those stations in 1982, which were also sampled in 1989.

Conclusions

Our results suggest an optimum pH range from 5.6 to 7.1 for the occurrence of burbot. Furthermore the occurrence was restricted by low and high pH in the studied lakes. In the Kyrönjoki estuary the prevalence of larvae sharply diminished within the distance of 5 to 10 km from the river outlet. The extent of reproduction area was almost equal in the two years studied, even though larvae were found more frequently in the year with a lower level of acidification. Being a common but sensitive species, burbot seems to be a useful indicator for environmental changes. Furthermore it can be sampled with simple methods during the larva period.

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GASTRIC EVACUATION RATE OF BURBOT

FED SINGLE-FISH MEALS

AT DIFFERENT TEMPERATURES

J.-P.J. PÄÄKKÖNEN
Department of Biology and Environmental Science,
University of Jyväskylä, P.O. Box 35, FIN-40351, Finland
tel. +358 14 602324 fax. + 358 14 602321 email: jaripaa@dodo.jyu.fi

T. J. MARJOMÄKI
Department of Biology and Environmental science,
University of Jyväskylä
email: tmarjoma@cc.jyu.fi

EXTENDED ABSTRACT ONLY DO NOT CITE

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Introduction

In this paper we estimate experimentally the effect of temperature, prey species and meal size on the gastric evacuation rate of adult burbot and compare the results to the data available from other species of northern hemosphere fishes. The validity of food consumption estimates for burbot are also discussed.

Materials and Methods

The gastric evacuation rates of burbot, *Lota lota* (L.), fed a single meal of vendace, *Coregonus albula* (L.), were measured in the laboratory at five temperatures (1.3, 2.6, 4.8, 9.4 and 12.6 ^{o}C). The mean length of the fish was 320 mm (s.d. = 28 mm, n = 73) and mean weight 176 g (s.d. = 47 g, n = 73). Burbot were fed with a single meal consisting of either one small (mean wet weight = 4.05 g, mean dry weight = 1.00 g, n = 35) or one large (mean wet weight = 8.00 g, mean dry weight = 1.78 g, n = 38) whole vendace. The effect of meal size was investigated over the whole range of experimental temperatures.

The effect of food species on the rate of evacuation was examined at 2.6°C. Burbot were fed with a single meal of small or large perch (*Perca fluviatilis* L.), smelt (*Osmerus eperlanus* (L.)) or vendace.

Results and Conclusions

A variety of models have been suggested to describe gastric evacuation in fish (Bromley, 1994). For burbot, no single model provided the best fit of the data over all test temperatures, but square root and exponential model provided the highest adjusted R^2 values. Variation in the adjusted R^2 values were, however, higher in square root model compared to the exponential model, indicating that the exponential model best describes evacuation rates in burbot feeding on vendace.

Gastric evacuation rate increased exponentially with increasing temperature (Fig 1), but the results suggest that gastric evacuation rates of burbot at low temperatures are lower than those of other freshwater fish species (He & Wurtsbaugh 1993, and references therein).

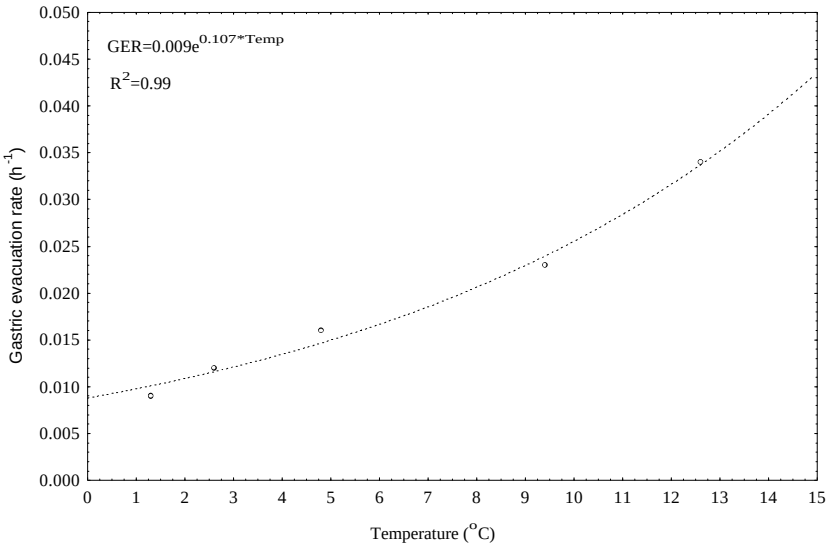


Figure 1. The relationship between gastric evacuation rate (GER, h^{-1}) of meal in burbot and water temperature (°C).

Estimated time (h) required for half of the meal to be evacuated from the stomach of burbot fed single meal of vendace (constant burbot and meal size) decreased with increasing temperature (Table 1).

Table 1. Estimated time (h) required for different proportions of a meal to be evacuated from the stomach of burbot fed a single meal of vendace (constant burbot and meal size).

Temperature	Proportion of meal evacuated			
(^{o}C)	5%	25%	50%	75%
1.3	11.9	32.4	78.1	156.2
2.6	8.9	24.3	58.6	117.1
4.8	6.5	17.7	42.6	85.1
9.4	4.5	12.3	29.7	59.4
12.6	3.0	8.2	19.9	39.9

Van´t Hoff´s Q_{10} value for burbot was 2.97 in temperature range from 1.3 ^{o}C to 12.6 ^{o}C. Gastric evacuation rates in burbot at low temperatures are, however, closest to rates in other gadoid fish. The most important factors affecting gastric evacuation rate were temperature and the ratio of meal weight to burbot weight.

Since different food items vary in their energy and nurtient content, they should be evacuated at different rates from the stomach. There was, howeverm no significant difference in gastric evacuation rate between three different prey species: vendace, perch, and smelt. These results suggest that gastric evacuation rates obtained with burbot feeding on vendace can also be used for burbot feeding on smelt or perch.

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CHARACTERISTICS OF A TRIBUTARY-SPAWNING POPULATION OF BURBOT FROM COLUMBIA LAKE, BRITISH COLUMBIA

Steven K.A. Arndt,
Columbia Basin Fish and Wildlife Compensation Program,
103-333 Victoria St., Nelson, B.C., Canada V1L 4K3
ph. (250) 352-6874 fax (250) 352-6178
email steve.arndt@BCHydro.bc.ca

Joyce Hutchinson
Headwater Resources, Box 455, Invermere, B.C. V0A 1K0
ph. (250) 345-6695 fax (250) 345-6652

EXTENDED ABSTRACT ONLY DO NOT CITE

Introduction

Columbia Lake in western Canada is a shallow, eutrophic lake (2,574 ha) supporting a population of burbot (*Lota lota*) which spawns in a small spring-fed tributary. Objectives of this study were to:

(1) quantify the number and size of spawners, sex ratios, percentage of repeat spawners, length of time spent on the spawning sites, and spawning weight loss;

(2) examine timing of the spawning run in relation to photoperiod, temperature, and moon phase; and

(3) determine whether spawners originate from Columbia Lake or other lakes downstream in the catchment.

Methods

Fish were captured on the way to spawning sites at a fence located in the tributary between the lake and the main area of spring outflows in 1996 (24 Jan.-16 Feb.), 1997 (20 Jan.-26 Mar.), and 1998 (20 Jan.-26 Feb.). The fence included both upstream and downstream traps. Length and weight measurements were recorded for each fish on upstream and downstream capture. Fish were sexed if milt or eggs were expressed with light pressure near the vent, or else classified as unknown sex. Spaghetti tags were applied to all fish in 1996, and passive integrated transponder (PIT) tags in 1997 and 1998. Twenty-six spent fish were implanted with radio tags in March 1997 and monitored from aircraft once per month to the next spawning season.

Results

The number of burbot captured at the fence ranged from 745 to 1,487 (Table 1). The 1996 capture total is an underestimate of all spawners because some fish burrowed under the fence prior to 6 February. This was rectified, but an unknown number of fish which evaded upstream capture were still upstream of the fence when it was removed. The number of fish captured in 1998 was substantially lower than previous years, however, there was evidence of spawning activity downstream of the fence in that year, and the actual number of tributary spawners may have been similar. The average size of the spawners increased from 1996 to 1998 (Table 1), and length-frequency graphs (not shown) suggest that this was due to the influence of one strong year class increasing in length. Males made up over half of the spawners in all years, and females less than 10 percent (Table 1). Fish of unknown sex are believed to be mostly female based on similarities in length, condition factor, and residence time above the fence, although some fish of unknown sex in 1996 were sexed as males in 1997. Eight percent of the 1997 fish were repeat spawners based on spaghetti tags applied in 1996 (Table 1). In 1998, 38 percent had PIT tags from 1997, and 2.8 percent had spaghetti tags from 1996 (Table 1). Half of the 1996 fish returning in the 1998 run were not captured in 1997, indicating that some fish may spawn in alternate years.

Males usually stayed in the spawning area for ≥5 days. About half of the females stayed for <5 days, with the remainder staying for longer periods. In all years, there were some fish which were still upstream of the fence when it was removed in late February or March. Average weight loss after spawning was 17

percent for males, 18 percent for females and 20 percent for fish of unknown sex.

Table 1. Summary of information for 3 years of burbot trapping on an un-named tributary of Columbia Lake, British Columbia, Canada.

	1996	**1997**	**1998**
Total Fish Captured	1,365	1,487	745
Mean±SE Length (mm)	454±1.7	479±1.2	500±2.0
% Female	9.4	6.6	5.9
% Male	61.1	53.9	63.9
% Unknown Sex	29.5	39.5	30.2
% which spawned in 1996	100	8.0 [a]	2.8 [a]
% which spawned in 1997	--	100	37.6 [b]

[a] based on fish marked with spaghetti tags
[b] based on fish marked with PIT tags

The timing of the upstream run was remarkably similar in all three years, suggesting that photoperiod is the most important cue for this population. The first day with more than 10 upstream fish was 29 January in 1996 and 1998, and 28 January in 1997 (Figure 1). The peak day was 3 February for 1997, 2 February for 1998 (Figure 1), and prior to 6 February in 1996 (Figure 1; taking into account that at least 536 fish evaded upstream capture prior to fence repair on 6 February). Upstream movements coincided with increasing temperature trends in 1996 and 1997, but in 1998, daily average temperatures were > 5 ^{o}C throughout the monitored period. This suggests that increasing temperature is not an important spawning cue, however, the warmer temperatures in 1998 may have been a factor influencing a greater number of fish to spawn in the lower tributary (below the fence), away from the major sources of groundwater. Moon phase at the beginning and peak of migration varied.

The radio telemetry study showed that this spawning population comes from Columbia Lake. Some fish were not located for 2 to 4 months during the summer, but this is believed to be caused by poor transmission when fish were in the deepest parts of the lake. No fish were recorded in flights downstream of Columbia Lake.

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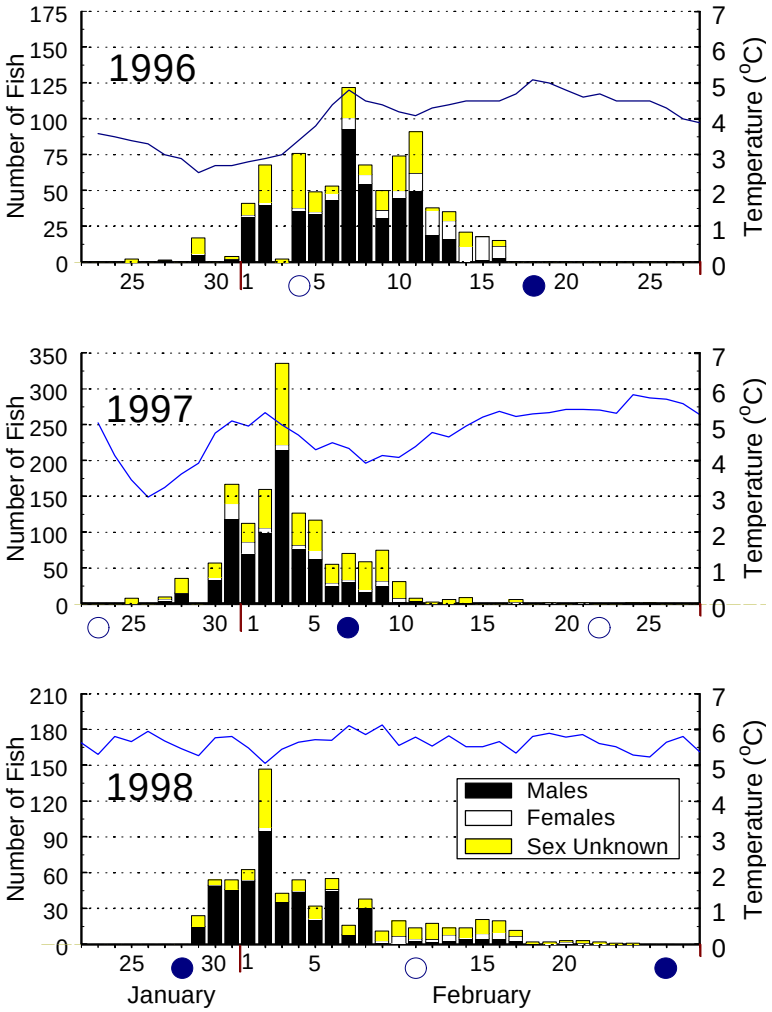


Figure 1. Number of burbot moving upstream by date and sex, for three years of fence operation on an un-named tributary of Columbia Lake, British Columbia. Line indicates water temperature at the fence. Circles indicate moon phase. Note that in 1996 at least 536 fish went under the fence prior to 6 February.

BURBOT – LARVAL EVIDENCE FOR MORE THAN ONE NORTH AMERICAN SPECIES?[1]

Darrel E. Snyder
Larval Fish Laboratory
Department of Fishery and Wildlife Biology
Colorado State University
Fort Collins, Colorado 80523-1474
Phone: (970) 491-5295; Fax: (970) 491-5091
E-mail: DESnyder@CNR.ColoState.edu

Abstract

Historically, the burbot of North America had been described as more than one species, but by the latter part of the 19th century all, including the Eurasian burbot, were generally recognized as one circumpolar holarctic species. During the last few decades, the burbot has been considered by some authorities to exist as three subspecies: *Lota lota lota* in Eurasia, *L. l. leptura* in eastern Siberia and northwestern North America, and *L. l. lacustris* (= *maculosa*) in central and northeastern North America. However, the more recent literature suggests that recognition of these subspecies may be unwarranted. Most systematic work to date has been restricted to adult forms, but we have dramatic evidence based on burbot larvae that, with further study, might lead to the recognition of more than one species, or subspecies, but not corresponding to the aforementioned subspecific designations. There appear to be two distinct larval forms. One is well pigmented with melanophores even as a late embryo and appears to be common to both Europe and North America. The other is without any melanophore pigmentation during the protolarval phase, except for the eyes and dorsal surface of the air bladder, and appears to be restricted to the lower Great Lakes and their tributaries.

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Introduction

Lota lota, commonly known as the burbot, ling, lush, lake lawyer, metling, dogfish, eelpout, mother-of-eels, etc., is the only freshwater member of Gadidae, the cod family (Figure 1). It is a circumpolar holarctic species typically inhabiting the depths of lakes and cooler rivers and streams. In North America it is found as far south as the Missouri and Ohio River systems. The species can be characterized as a relatively large, negatively phototropic, piscivorus carnivore. It is valued by many, when caught during the winter or in cold waters, for its firm, white, delicately flavored flesh (similar to lobster when boiled), and for the exceptionally rich Vitamin A and D content of its liver oil. (Baxter and Simon 1970, Clay 1975, Eddy and Underhill 1974, Hubbs and Lagler 1958, Lindsey 1956, Lo-Chai 1969, McPhail and Lindsey 1970, Moore 1917, Pflieger 1975, and Scott and Crossman 1973).

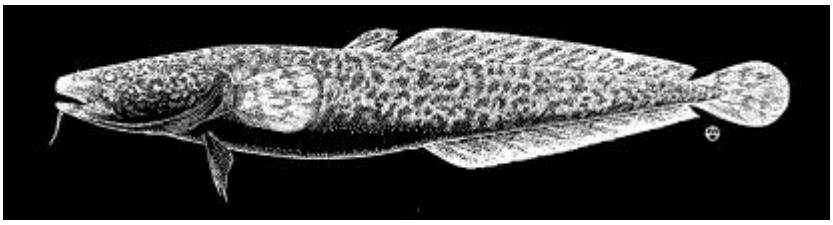


Figure 1. *Lota lota* adult, male, 510 mm TL, from Lake Opeonge, Ontario. Reproduced with permission from Scott and Crossman (1973, page 164).

Burbot are most frequently reported to spawn at twilight or during the night from January to mid-April in the shallows of lakes, usually under ice, and to a lesser extent in streams. They are also suspected to spawn in the depths of lakes. The fish have been observed to spawn as individual pairs but more frequently in large, relatively dense, spawning aggregations, and occasionally in a very compact "withering ball" of about a dozen fish. During the spawning season large females may, based on fecundity studies, scatter more than a million eggs over gravel or sand substrates. The eggs are semibuoyant, clear with a large oil globule, and when water hardened, typically measure 0.9 to 1.3 mm in diameter with a reported range of 0.8 to 1.9 mm or greater. Incubation requires about four to six weeks at 6 to 2 °C. (Bailey 1972, Baxter and Simon 1970, Bjorn 1939, Breder and Rosen 1966, Cahn 1936, Fabricius 1954, Hewson

1955, Lo-Chai 1969, McCrimmon 1959, McPhail and Lindsey 1970, Miller 1970, Prince and Halkett 1906, and Scott and Crossman 1973).

The young hatch as protolarvae (Snyder 1976) at about 3 to 4 mm total length (TL) and transform to the mesolarval phase at about 8 to 9 mm TL. Protolarvae and early mesolarvae are most readily identified by a large myomere count of about 55 to 65, 14 to 21 of which are preanal, and a ventral finfold that continues unbroken below the vent region (Figures 2, 3, and 5). The earlier stages typically carry a large oil globule with the yolk, while later stages exhibit pelvic buds below or anterior to the pectoral fins and a bulky coil in the gut. Later mesolarvae, metalarvae and juveniles can be easily distinguished by a single medium chin barbel, a short first dorsal fin, long second dorsal and anal fins (over 60 rays each) which extend onto the caudal peduncle, and a proterocercal (diphycercal) caudal fin (Figure 4).

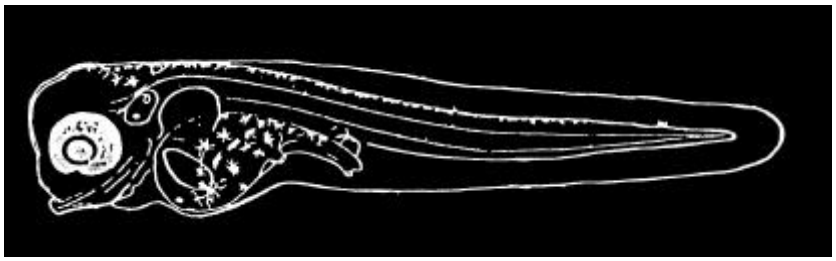


Figure 2. *Lota lota* protolarva, 5 mm TL from Europe. Reproduced from Ehrenbaum (1909, Figure 98, page 274).

Historically, the burbot has been described as more than one species. LeSueur in 1817 described what he believed to be two species of burbot from the Connecticut River in Massachusetts. These were similar to but considered distinct from the European species. Additional descriptions and species designations followed but in 1862 Gunther concluded that all, including Old and New World forms, were indeed but one universal species. Thereafter it was generally accepted that only one species inhabited North America. But, since the American burbot differs in vertebra counts and predorsal lengths, not all ichthyologists agreed that the burbot should be considered one holarctic species. This difference of opinion was sustained well into the 20th century (Fish 1930). In 1941, Hubbs and Schultz, though recognizing one species, described and designated three subspecies: *Lota lota lota* of Eurasia, *L. l. leptura* of

northwestern North America and eastern Siberia, and *L. l. maculosa* (*L. l. lacustris,* Speirs 1952) of central and eastern North America. Lo-Chai (1969) agreed with the designations.

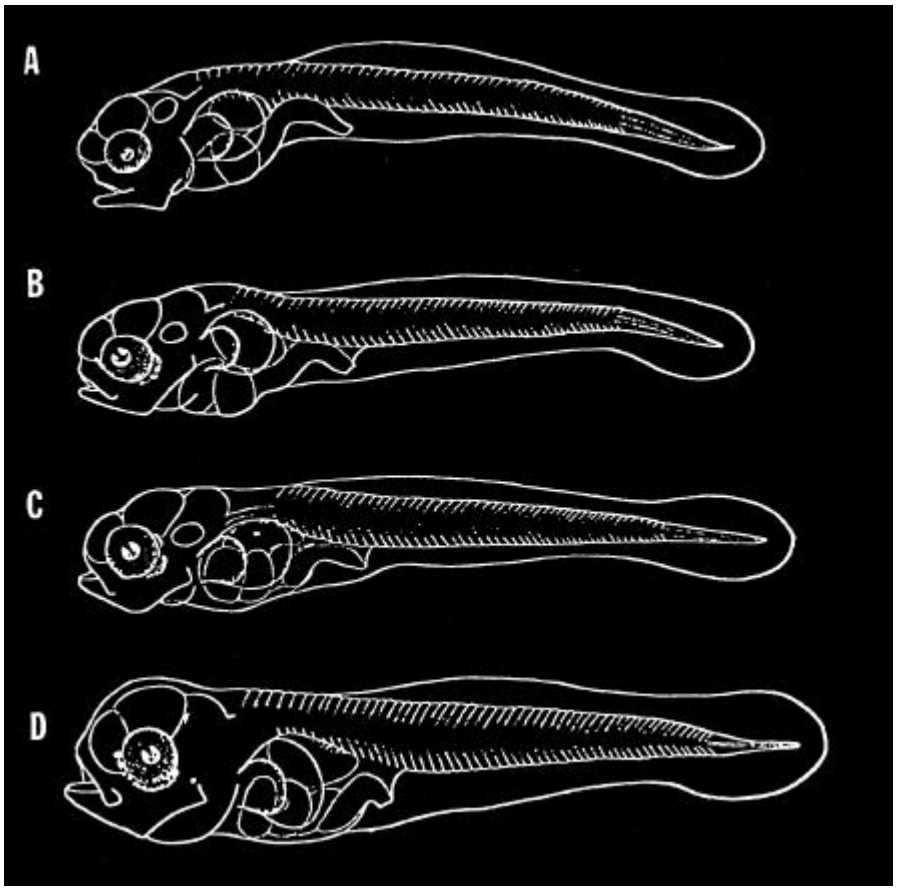


Figure 3. *Lota lota* protolarvae, 3.5 (A), 4.5 (B), 6.0 (C) and 6.8 mm TL (D) from Lake Erie. Reproduced from Fish 1932, Figures 138-141, pages 393 and 394.

Differentiation was based on the shape of the caudal peduncle, predorsal length, and various meristic values. However since these characters appear to be clinal with relatively broad areas of intergradation, Berg (1949) and Pivnicka (1970)

considered *L. l. leptura* as a form of *L. l. lota* and Lindsey (1956), Lawler (1963), McPhail and Lindsey (1970), and Scott and Crossman (1973) considered recognition of any subspecies unwarranted without more intensive taxonomic study.

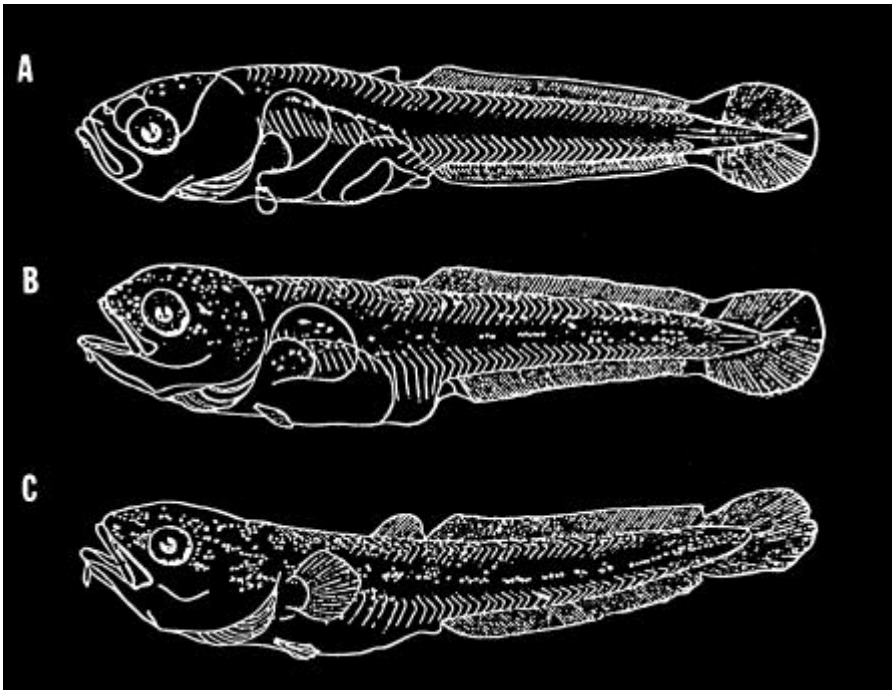


Figure 4. Lota lota mesolarvae, 10.9 (A) and 14 mm TL (B), and metalarva (?), 19 mm TL (C) from Lake Erie. Reproduced from Fish 1932, Figures 142-144, pages 395-396.

Larval Evidence

Most systematic work to date has been restricted to the adult forms. But we have dramatic evidence based on burbot eggs and larvae that, with further study, might lead again to the recognition of more than one species, or at least subspecies, but not corresponding to the aforementioned subspecific

designations. Fish (1930) recognized and pointed out the potential significance of this larval evidence, but the evidence seems to have been ignored. She found that the melanophore pigmentation of eggs and larvae of European burbot, as described by Sundevall (1855) and Ehrenbaum (1909), differed markedly from that of the American form. The late embryos and recently hatched protolarvae of the European burbot were described and illustrated as having considerable pigmentation along the dorsal surface of the head and body, over the dorsal surface of the gut, and on the lateral and ventral surfaces in the stomach or yolk region (Figure 2). Subsequent descriptions and illustrations of European protolarvae and mesolarvae by Nordqvist (1915) and Kasansky (1928) were similar but included additional pigmentation along the mid-ventral surface posterior to the vent. In contrast to the European larvae, Fish (1929, 1930 and 1932) found burbot protolarvae from Lake Erie to be totally without melanophore pigmentation except in the eyes and, in later protolarvae, over the air bladder (Figure 3). The only additional melanophores on a 10.9-mm-TL mesolarvae were found on top of the head, followed by barely discernable subsurface pigmentation over the anterior portion of the notochord, and possibly continuing for its entire length (Figure 4). Melanophore pigmentation was considerable over the dorsal and lateral surfaces of 14 and 19-mm-TL specimens, but Fish neither described nor illustrated pigmentation on the ventro-lateral and ventral surfaces. The ventral surface of a 30.5-mm TL specimen remained "unmarked except for a double series of about 20 chromatophores along the base of the anal fin ." Fish apparently assumed that the numerous Lake Erie specimens she examined were representative of the early developmental stages of all American burbot. This is not the case.

Other biologists working with larvae of American burbot have either ignored pigmentation or failed to note it in published form. Faber (1967 and 1970) and Clady (1976) published on the distribution of burbot larvae in Wisconsin Lakes, Lake Huron, and Oneida Lake, respectively, but neither described the larvae nor mentioned pigmentation. Miller (1970) noted that burbot larvae he collected in Wyoming were comparable to those described by Fish from Lake Erie, but in a personal communication to me, he related that he failed to mention pigmentation and that melanophore distribution was similar to that illustrated in Figure 5. Grant Hagen included several photographs of burbot eggs and larvae taken in 1952 in an unpublished report to the Wyoming Game and Fish Commission entitled "Ling hatching experiment, Cokeville." All were pigmented in a manner similar to that illustrated in Figure 5.

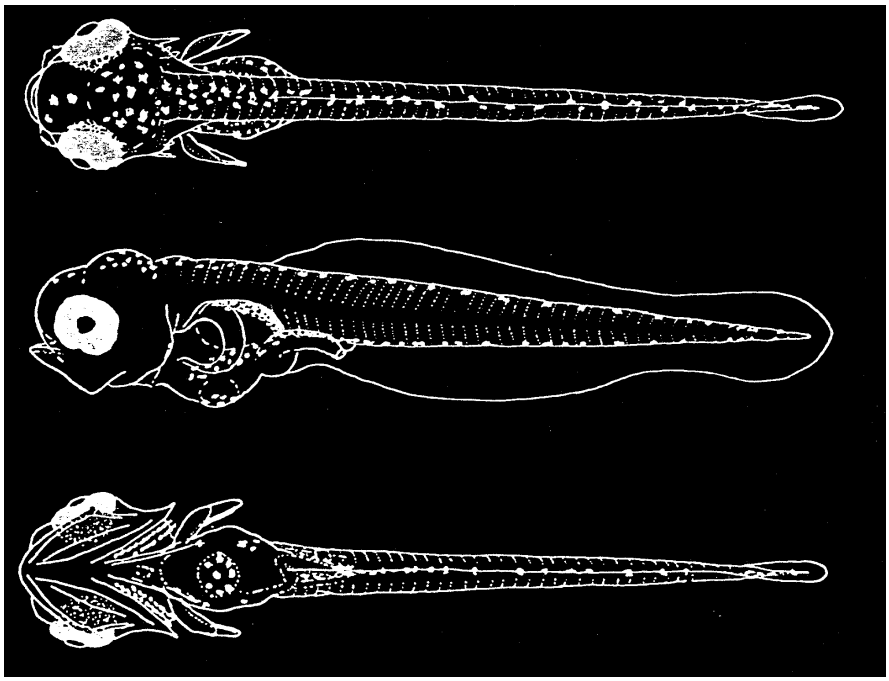


Figure 5. *Lota lota* protolarva, 4.7 TL from Mississippi River, Minnesota. Drawing by author, reporduced from Snyder 1979, Figure 5, page 213.

During the mid-1970s, I have had an opportunity to examine cultured burbot embryos and protolarvae from Wyoming and collected protolarvae and mesolarvae from the Missouri River in North Dakota, Mississippi River in Minnesota, Chippewa River in Wisconsin, Genessee River and Oneida Lake in New York, and Lakes Superior, Michigan, Erie, and Ontario. Of these, only a protolarvae from the Genessee River, a tributary of Lake Ontario, was of the unpigmented form described by Fish. All others were pigmented with most approximating the form of the upper Mississippi River protolarvae illustrated in Figure 5 and described for the European burbot by Nordqvist (1915) and Kasansky (1928). Some exhibited reduced pigmentation on the ventral surface posterior to the vent, approaching the condition described and illustrated by Ehrenbaum (1909) (Figure 2). Pigmentation on recently collected specimens

from Lake Erie was generally reduced to a state somewhat intermediate to the typical pigmented and unpigmented forms.

Conclusions

It appears that there are at least two distinct larval forms of burbot. One form is well pigmented, even as a late embryo, and appears to be common in Europe and North America (I have not yet seen larvae or descriptions of burbot from northwestern North America or the Soviet Union). The other form remains essentially unpigmented until well into the mesolarval phase and has been observed thus far only from Lake Erie (Fish 1929, 1930, and 1932) and, more recently (1970s), the Genessee River (tributary to Lake Ontario). Specimens examined from Lake Erie in the 1970s were somewhat intermediate.

Do the two extreme forms represent distinct species or subspecies? Are the recently collected "intermediate" specimens from Lake Erie a variation of the unpigmented form described for the Lake Erie burbot by Fish (1930)? Or do they represent hybridization between the two forms and (or) the near loss of the unpigmented form? Is the unpigmented form, apparently common throughout Lake Erie in the 1920s, approaching extinction due to man's activities, as was the case for the blue pike *Stizostedion vitreum glaucum*?

Or do we simply have one species which exhibits unprecedented variation in embryonic and larval pigmentation? The larvae of the burbot's many marine relatives are often distinguished by relatively subtle differences in pigmentation (Hardy 1978).

To answer the above questions, and others, it will be necessary to examine many more larvae from throughout North America, Europe, and northern Asia, to study in detail other larval characters, and to try to correlate differences in the larvae with differences in the adults. Emphasis on the systematics of the burbot should focus immediately on both the adults and larvae in the Great Lakes region of North America. If there are two distinct genetic forms and one is restricted to the lower Great Lakes, we may lose the latter form, represented by unpigmented larvae, before we know it exists.

Acknowledgments

I thank Ken Mueller, Northern States Power; Don Miller and Chuck Viox, Wyoming Fish and Game; Kathleen Hadley, BioSystems Research; John Dorr, Great Lakes Research Institute; Lee Fuiman, Cornell University (now University of Texas), ; Vince Kranz, NUS Corporation; Steve Dennis, Stearns-Roger; Ross Rasmussen, Texas Instruments; George Kandler, Swanson Environmental; and Tony Pekovitch and Daniel Patulski, Hazleton Environmental Sciences, for the loan or donation of study specimens or comments on the pigmentation of specimens they have encountered. I also thank Robert Behnke, Clarence Carlson, Edmund Wick and Maryann Snyder, all of Colorado State University, for critically reviewing the original manuscript.

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Addendum–I am maintaining a file of descriptive "notes" on burbot larvae from all locations. Individuals who have collected or reared burbot larvae and wish to contribute their observations should make photocopies of the form on the next page and supply as much of the requested information as conveniently possible. I am also interested in acquiring preserved series of reared specimens.

Larval Fish Laboratory
Colorado State University
Ft. Collins, Colorado 80523

Lota lota, Burbot
Contributed notes on
early developmental stages

Please print clearly and use a separate photocopy of this form for each developmental phase (Snyder 1976) and/or general location.

Specimen Data

Developmental Phase:_____
Number:_____ Size Range:_____mm TL

If time permits, any of the following information for one or more specimens would be appreciated.

Lengths (mm)

Total	___	___	___
Standard	___	___	___
Snout (Sn)* to Eye*	___	___	___
Sn* to Pectoral bud or fin*	___	___	___
Sn* to Pelvic bud or fin*	___	___	___
Sn* to Dorsal finfold*	___	___	___
Sn* to Dorsal fin*	___	___	___
Sn* to Preanal finfold*	___	___	___
Sn* to Air bladder*	___	___	___
Sn* to Vent'	___	___	___
Eye	___	___	___
Yolk	___	___	___
Oil Globule	___	___	___
Pectoral bud or fin	___	___	___
Pelvic bud or fin	___	___	___

Body Depths (mm)

Posterior margin of eye"	___	___	___
Posterior margin of vent"	___	___	___

Myomeres

Preanal (as per Siefert '69)	___	___	___
Postanal	___	___	___

*origin or anterior margin.
'posterior margin.
"just posterior to, excluding finfold or fin.

(Place any additional notes on reverse side.)

Illust. typical pigmentation by completing the generalized drawings regardless of developmental stage. Atypical pigmentation should be illustrated on separate forms.

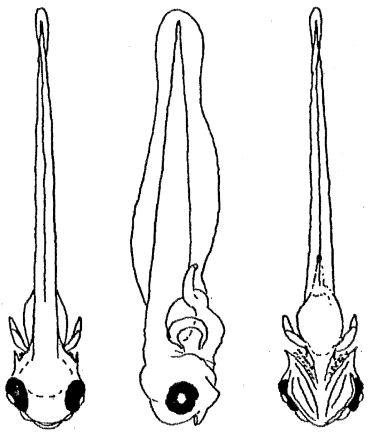
Collection Data

State:_____ County:_____
Body of water:_____

Specific location:_____

Distribution within study area:_____

Dates:_____
Water temperatures:_____



Contributor (Name, affiliation, address and phone):_____

Specimens available for study via loan (___) or donation (___).
Mail form(s) to above address c/o Darrel E. Snyder. Sources of data or specimens used for publication will be duly acknowledged.

LARVAL BOTTLENECKS

IN OLIGOTROPHIC FISH COMMUNITIES

Leon M. Carl
Ontario Ministry of Natural Resources
Trent University
1600 West Bank Drive P.O. Box 4840
Peterborough, Ontario K9J 8N8
Phone (705) 755 2268 Fax (705) 755 2276
e-mail: carll@gov.on.ca

Abstract

The objective of the study was to examine the effect of two planktivores, lake herring (*Coregonus artedi)* and lake whitefish (*C. clupeaformis),* on the population structure of four benthic fish species having pelagic larvae. Data on burbot (*Lota lota),* longnose sucker (*Catostomus catostomus*) and white sucker (*C. comersonii*) were examined in relation to the presence/absence of these coregonines. The effect of lake herring on lake whitefish was also examined because lake whitefish adopt a benthic niche in the presence of lake herring. Subyearling burbot were absent or rare in juvenile habitat in the lakes where lake herring were present, and common in the lakes where lake herring were absent. The population data for burbot and lake whitefish indicate both species are scarce and grow to a large size in the presence of lake herring compared to with lakes without lake herring. The longnose sucker predominated in gill net catches in the lakes without lake herring or lake whitefish, was scarce in the lakes with lake whitefish and absent in lakes with lake herring. White suckers were lower in abundance in the presence of lake herring. In one of the study lakes, analysis of data collected before and after lake herring were introduced indicated that the abundance of longnose sucker declined following the lake herring introduction. In the same lake, larval fish were common in the lake herring diet. These results suggest that the burbot, lake whitefish, longnose and white suckers experience a larval bottleneck in inland lakes caused by lake herring predation. Lake whitefish, as a planktivore, differentially impact longnose suckers over white suckers but did not appear to effect burbot with it's smaller larvae.

Introduction

Planktivorous fish can impact other fish species with pelagic larvae through predation and/or competition (Nilsson and Pejler 1973, Svardson 1976, and Werner and Hall 1979). Lake herring (*Coregonis artedi*) and the lake whitefish (*C. clupeaformis*) may be termed planktivores because they may feed on zooplankton in pelagic habitat depending on whether competing species are present (Langeland et al 1991, Carl in prep.).

Four benthic fish species of interest have pelagic larvae. Burbot (*Lota lota*) spawn in February with eggs hatching in the spring. The larvae move into the water column at a size of 4 - 6 mm until mid summer when the fish move inshore at a size of 20 - 25 mm (Carl 1992, Ryder and Pesendorfer 1992). Longnose suckers (*Catostomus catostomus*) and white suckers (*C. comersonii)* spawn in streams during the spring. The larvae move into the lake approximately one month after spawning when longnose sucker larvae are 10- 12 mm long and white sucker larvae are 12 - 17 mm long (Scott and Crossman 1973). The fourth species, lake whitefish, shifts to a benthic niche in the presence of lake herring (Carl in prep.). Whitefish spawning takes place near the time of ice formation and larvae are pelagic in the spring at a hatching size of 12- 14mm.

The objectives of the study were to determine if lake herring and lake whitefish have an effect on other fish species with pelagic larvae and to examine whether the mechanism is predation or competition.

Methods

A total of 13 lakes (Table 1) in the Algonquin highlands region of southern Ontario were chosen based on similar size, fish community, water chemistry, productivity, high water clarity and low angling effort.

Several methods were employed to examine the impact of lake herring and whitefish on the other species. Gillnet (1.5 to 3.5" stretched mesh) records were examined from 8 lakes, 3 without whitefish or herring, three with both species and two with whitefish only (Table 2). The number of adult white and longnose suckers was recorded and reported here as the ratio of the two species to avoid differences due to varied effort and gear and, in the case of old records, incomplete information. White sucker gillnet catch data from a standardized survey on 2 lakes

(1 with lake whitefish and one with lake whitefish and herring) from 3 years were examined.

Table 1. Combined survey design from electrofishing and netting data.

	No Herring	Herring
No Whitefish	5 lakes	-
Whitefish	3 lakes	5 lakes

Table 2. The number of white and longnose suckers captured in gillnets, and the ratio of white to longnose suckers.

Lake	White Suckers(WS)	Longnose Suckers(LNS)	Ratio of WS/ LNS
No herring or whitefish			
Cache	16	92	0.17
Happy Isle	23	40	0.57
Louisa	74	331	0.22
Mean			0.32
Whitefish only			
Aylen	63	4	15.7
Opeongo (1936-50)	244	21	11.6
Mean			13.6
Herring and whitefish			
Booth	13	0	-
Opeongo (1968-92)	10193	9	1132.6
Smoke	19	0	-
Mean			>1000

I used shoreline electrofishing (Smith Root electrofisher, 5 KW generator) in July and August on 10 lakes to enumerate subyearling (YOY) burbot after they had moved inshore (Table 1, both planktivores were absent in three of the lakes). In addition, adult burbot and lake whitefish trapnet and gillnet data from another standardized study (Carl in preparation) were examined in reference to the presence/absence of lake herring.

To compare relative abundance of larval fish in Lake Opeongo (whitefish and herring) and Aylen Lake (whitefish, a larval trawl (0.5 m diameter, 3:1 filtering

ratio, 500 um mesh) was towed(1m/s, 5 minute duration) nearshore in May and June.

To test the hypothesis that adult lake herring prey on larval fish, floating gillnets (3/4, 1 and 1.5" stretched mesh in three 50' panels) were set in Lake Opeongo after sunset for 10 - 20 minutes in areas of larval fish concentrations, (as determined by the larval tows), to capture planktivorous fish. The stomachs of all fish captured were fixed in 10% formalin immediately after capture to slow digestion of stomach contents.

Larval fish were identified with a key for the Great Lakes (Auer 1982) and drawings of larval fish from Lake Opeongo (D. O. Evans, personal communication). After all larval fish had been removed, stomach contents were subsampled, counted, weighed and identified to the lowest identifiable taxa (Usinger 1956; e.g. species where possible for fish, order for some aquatic insects).

Results

In lakes without lake herring or whitefish, longnose suckers predominate (Table 2). Where whitefish are present, longnose suckers are scarce averaging only 1 caught for 13 white suckers. If both lake herring and whitefish are present longnose suckers are so rare as to be thought extinct unless an intensive netting effort is undertaken (e.g. one captured compared to 1000 white suckers). In Lake Opeongo gillnet records were available from six different years. In the 1940's lake herring were successfully introduced and by the mid 1950's were well established in the lake. The longnose suckers were scarce in Opeongo through 1950 after which they were extremely rare (Table 3). There were 3.8 white suckers taken per gillnet night in Smoke Lake (lake herring and whitefish) and 10.5 in Aylen Lake (lake whitefish only) in a standard survey.

Table 3. The number of white and longnose suckers captured in gillnets from 1936 to 1950 and with trapnets in 1991 and 1992 from Lake Opeongo.

Year	White	Longnose
1936	132	8
1939	80	10
1950	32	3
1968	102	0
1991	1496	3
1992	8595	6

The catch per unit effort (CUE; #/km of shoreline) of subyearling burbot was similar (~ 100 per kilometre) in lakes with lake whitefish and in lakes with neither coregonine (Table 4). In lakes with lake herring and whitefish present, subyearling burbot were uniformly very scarce at less than one per kilometre of shoreline.

Table 4. Number, distance electrofished and catch per unit effort (CUE; #/km) for subyearling burbot.

Lake	Number	Distance (km)	CUE
No herring or whitefish			
Little Crooked	73	0.30	243.3
Big Porcupine	0	1.30	0
Butt	0	0.18	0
Mean			81.9
Whitefish only			
Aylen	182	3.40	53.5
LaMuir	85	0.48	177.1
Mean			115.3
Herring and whitefish			
Bark	1	5.50	0.2
Booth	0	0.24	0
Opeongo	1	4.02	0.2
Smoke	6	6.00	1.0
White Partridge	1	1.50	0.7
Mean			0.4

The CUE of larval burbot in Aylen was greater , although not significantly different, than the CUE in Opeongo on three of four dates sampled (Figure 1). The overall number of larval burbot in each 5 minute tow was not significantly different (P=0.05) in Aylen and Opeongo (Table 5). Larval lake whitefish, white suckers and yellow perch (*Perca flavescens*) were lower in number in Opeongo compared to Aylen (P=0.05). In both lakes the actual densities may be higher than reported because of net avoidance by the larger larvae. The mean size of burbot taken in the larval tows increased from 4 mm on May 14th to over 8 mm on June 6th and was larger in Aylen Lake compared to Lake Opeongo. The growth rate of larval burbot was similar in both lakes (Figure 2).

Figure 1. Plot of mean larval burbot catch per 5 minute tow over time.

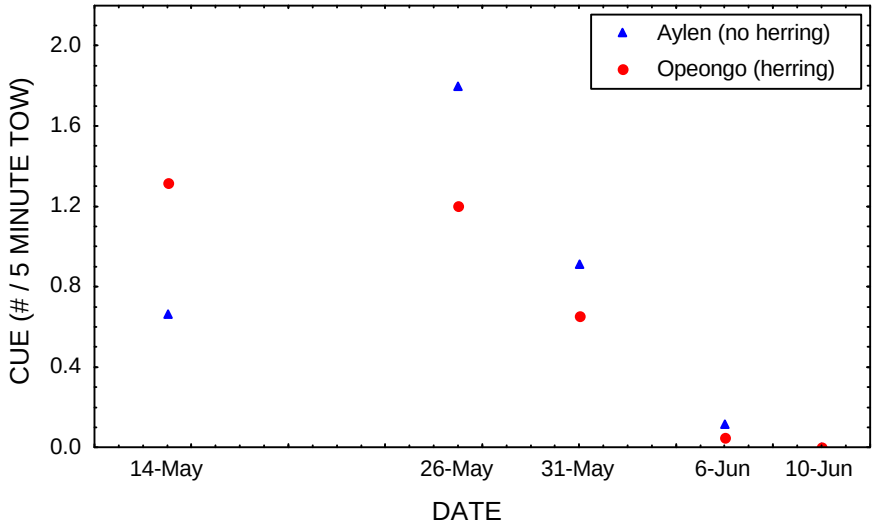


Table 5. The number of larval fish captured in tows on lakes Aylen and Opeongo during May and early June, 1995.

Species	Aylen #/5min	Opeongo #/5min	Larvae/ L.herring stomach	Larval Length (mm)
Burbot	0.6	0.9	0.01	5.7
Lake herring	-	2.9	0.03	14.5
Lake whitefish	0.5	0.01	0.02	13.7
White sucker	1.9	0.2	0.30	14.1
Yellow perch	5.8	1.8	0.05	13.2

A total of 712 lake herring and 6 lake chub (*Couesius plumbeus*) were taken from 156 short set gillnet sets. Six percent of the lake herring had larvae in their stomachs, with an average of 11 per stomach. Lake herring with and without larvae were of comparable length (156 Vs 150 mm, respectively). Fish made up 0.1% of the lake herring diet by number and 3.2% by weight (Table 6). White suckers were

the most common larval fish found in the stomach of lake herring while burbot were the least common larvae and the smallest larvae found in the lake herring stomachs (Table 5). Bosminidae followed by Daphnidae were the predominant food items in lake herring diet.

Table 6. Food items in lake herring diet and % of total stomach item count (Lake Opeongo).

Item	# / stomach	% of total count
Bosminidae	564.9	57.1
Daphnidae	185.2	18.7
Cyclopoida	123.4	12.5
Unk Crust.	53.8	5.4
Calanoida	44.1	4.5
Other Crust.	15.1	1.5
Diptera	1.7	0.2
Fish	0.7	0.1

The mean total length of adult burbot was significantly smaller in lakes with whitefish or no coregonines compared to lakes with herring and whitefish (ANOVA, $P < 0.05$; Table 7). The CUE of adult burbot did not differ across the three lake types ($P= 0.05$). Lake whitefish CUE was significantly greater while mean size was smaller in lakes without herring compared to lakes with herring ($P = 0.05$; Table 7).

Table 7. Adult burbot and lake whitefish population CUE and mean length for lakes with no lake herring or whitefish (2 lakes), lakes with only lake whitefish present (3 lakes) and lakes with lake herring and whitefish present (5 lakes).

	No Coregonine	Whitefish	Whitefish and Herring
<u>Burbot</u>			
CUE (trapnet)	0.9	1.2	0.7
Length (mm)	229	245	375
<u>Lake Whitefish</u>			
CUE (gillnet)	-	20.5	2.1
Length (mm)	-	168	300

Discussion

In these simple communities, where planktivores are absent, competition between sucker species may be an important factor with longnose suckers being dominant. In the presence of planktivores the white sucker benefits due to it's larger larvae. If we hypothesize a size threshold is available above and below which planktivores rarely prey on larval fish, then it is likely that white sucker larvae reach the upper refuge more often than longnose suckers because of their larger initial size. The reduction in white sucker population in the presence of lake herring indirectly supports this hypothesis in that lake herring do impact white suckers but less so than longnose suckers. Burbot with their smaller larvae may be below the preferred prey size initially. However, they must pass through the size bottleneck before moving inshore and are therefore severely impacted. It also appears that other factors besides predation strongly influence burbot recruitment since two of three lakes without any coregonines had few juvenile burbot while both lakes had reasonable numbers of adults (Carl in preparation; Table 4).

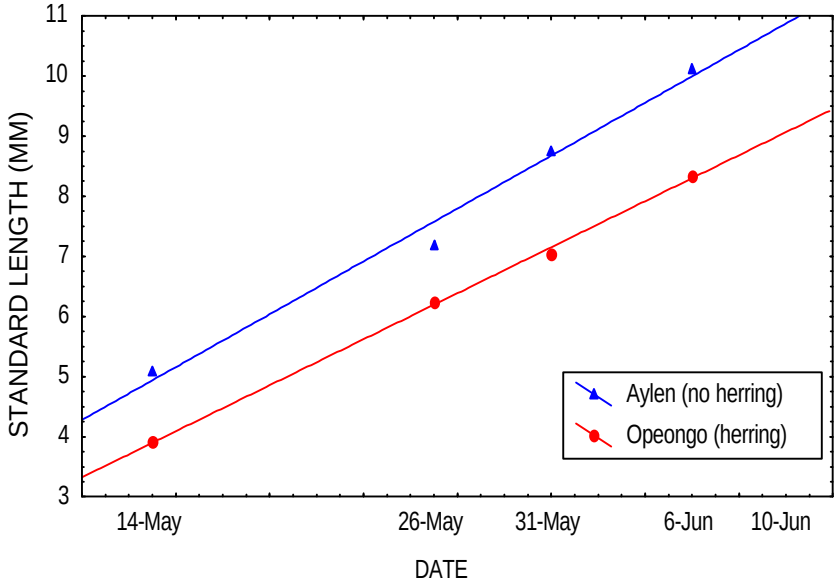
Anecdotal information from long-time anglers on Lake Opeongo indicate the burbot population declined in number after the establishment of lake herring. Carl (1992) first described a larval bottleneck when he estimated 75 to 150 million eggs were deposited by burbot but only one subyearling was captured in 2 years of shoreline electrofishing. The comparative lake electrofishing confirmed that burbot juveniles are extremely rare where lake herring are present.

While lake whitefish do not appear to impact burbot abundance, longnose suckers were less abundant in whitefish lakes (Table 2 & 4). It may be that lake whitefish rarely prey on larval fishes and the decline in longnose suckers is a competitive interaction among lake whitefish, longnose and white suckers. This interaction is possible since longnose suckers and lake whitefish inhabit deeper areas of lakes than white suckers and their food habits may overlap.

The trawling data suggest that, for fish species with a pelagic larvae stage, densities are lower in lakes with lake herring than in lakes where they are absent. Competition may not be a factor in the reduced numbers of larvae found in herring lakes. Although larval burbot in Aylen were larger on a given date compared to Opeongo (perhaps due to earlier hatching), the growth rate of burbot were similar in both lakes (Figure 2). If competition between lake herring and burbot larvae was important, then burbot larvae should grow more slowly in Opeongo where lake

herring are present than in Aylen where lake herring are absent. The similar growth rates and the burbot larvae found in the lake herring diet indicate predation is the primary cause of the bottleneck for burbot and most likely for the other three species as well.

Figure 2. Mean larval burbot standard length versus time for Lakes Opeongo and Aylen.



Lake herring comprised over 99% of the catch in floating gillnets set in areas with significant numbers of larval fish in Lake Opeongo. Yet only 6% of the adult lake herring had fish larvae in their stomachs. Larval fish dissolve quickly in the gut (Crowder 1980) and are therefore difficult to verify in diet analyses yet they were found in lake herring stomachs. Fish larvae appear to make up a small and perhaps not important part of the herring diet. However, herring are abundant in these lakes and appear to severely impact species with a pelagic larval stage.

The comparative trawling and lake herring diet data suggest that lake herring reduced white sucker recruitment. It is likely that the population would adjust to poor recruitment by delayed spawning (Nikolski 1969) so that the population has a

reproductive reserve available to counteract year class failures. The reduction in burbot and lake whitefish recruitment lead to similar adjustments by these species (Table 5). Both are large-bodied and low in number (the total burbot population is reduced in size compared to lakes without herring when adult trapnet and juvenile electrofishing data are combined) where lake herring has reduced recruitment. Therefore lake herring can impact all three species at the population level as well. Where lake herring are present, fish larvae are less abundant and adults are large in size when compared to lakes without lake herring. Lake herring can influence fish community composition by preying on the larvae of such species as longnose and white suckers, burbot and lake whitefish. Thus it appears that the lake herring plays a fundamental role in structuring these populations.

Acknowledgements

I thank Tony Gentile and students at Harkness Lab who worked on the project.

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OXYGEN CONSUMPTION OF BURBOT (*LOTA LOTA*)

FED DIFFERENT RATIONS

OF VENDACE (*COREGONUS ALBULA*)

J.-P. J. PÄÄKKÖNEN
Department of Biological and Environmental Science.
University of Jyväskylä, P.O. Box 35,
FIN-40351 Jyväskylä, Finland,
e-mail: jaripaa@dodo.jyu.fi.

T. LYYTIKÄINEN
Department of Biological and Environmental Science.
University of Jyväskylä

Introduction

Burbot (*Lota lota* (L.)) is a freshwater gadoid fish with a northern circumpolar distribution in rivers, lakes and brackish waters. It is exposed to low temperatures for 6 to 8 months annually. The aim of the current study was to determine the oxygen consumption of burbot at low temperatures and answer to the following questions:

1) What was the minimum metabolic rate at 2.1°C?

2) What was the average metabolic rate?

3) How did feed ration influence metabolic rate?

4) How did acute stress influence metabolic rate and what was the duration of recovery?

Materials and Methods

The oxygen consumption was measured in 20 square plastic tanks (volume 17.1 litres) at 2.1 °C. One burbot was placed in each tank. Tank was covered with a plastic sheet and an iron net to prevent oxygen from the air to dissolve in the water. Water inflow to test tanks was 1.6 l min^{-1}. Once a day water inflow was turned off and tanks were as closed respirometers. After two hours oxygen concentration within tanks was measured by oxygen meter and values were calibrated with Winkler samples. Burbot (average weight 225 g, s.d.= 27 g) were offered a meal of vendace (*Coregonus albula* L., average weight = 2.9 g, s.d. = 0.26 g) 6 or 8 day after the experiment started. The amount of food fed varied from 2.93 to 17.8 g (12.7 kJ-77.4 kJ; meal weight to burbot weight ratio from 0.014 to 0.085). The oxygen consumption was measured for 13-15 consecutive days after feeding.

Results and Discussion

Minimum metabolic rate was estimated as the average of minimum oxygen consumptions of individuals (N =20). Minimum metabolic rate of burbot (20.7 mg kg^{-1} h^{-1}) was near to standard metabolic rate observed in cod *Gadus morhua* and walleye pollock *Theragra chalcogramma* (Soofiani & Priede, 1985, Smith et al., 1988). Burbot was estimated to use for maintenace on average about 6.8 kJ kg^{-1} per day which correspondes to a vendace meal of 1.56 g. Average metabolic rate during experiment was 39.9 mg kg^{-1} h^{-1} and it was almost twice the minimum one. Average metabolic rate was related to minimum metabolic rate on present study similarly as maintenance ratio is usually related to routine metabolic rate (maintenance ratio = 1.9 times routine metabolic rate) (Hepher, 1988).

Multiple regression model was used to estimate the effect of meal ratio (FI, meal weight/body weight) on the oxygen consumption (M, mg kg^{-1} h^{-1}) of 4 days following the feeding (± SE):

$$M = 99.9\ (\pm 35.0)FI + 0.7\ (\pm 0.17)M_{pre} + 14.2\ (\pm 5.63),$$

where M_{pre} = Mean oxygen consumption of an individual during 4 days preceding the feeding, $R^2 = 0.55$, $N = 20$, $P<0.001$.

An estimate of SDA for 4 days after a meal was derived from the model and it was 3.0 % of the energy concentration of the meal. This is only 25-50% of the usual proportion of consumed energy used in SDA (Cho & Kaushik, 1990) and may be a result of that SDA was estimated only for 4 days.

Acute stress is observed earlier to stimulate oxygen consumption (Morgan & Iwama, 1996) and this appeared to be the case also in burbot at 2.1°C. Oxygen consumption was high after the transfer and declined later; the minimum was reached in four days (Fig.1) but the long term mean was reached after two days. Duration of recovery after acute stress was similar to the recovery period of rainbow trout after thermal change (Evans, 1990).

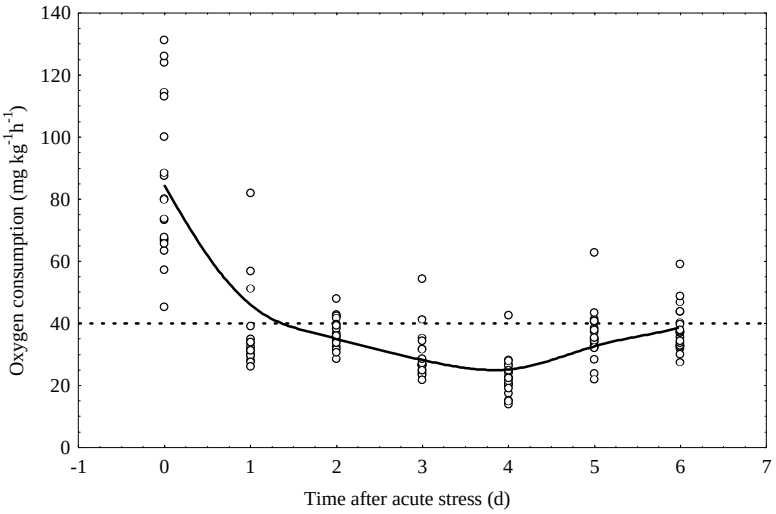


Figure 1. The recovery of oxygen consumption of burbot (*Lota lota*) from acute stress at 2.1 °C. Individuals are indicated as dots, solid line is the distance weighted least square fit for the data and broken line indicates the long term mean of oxygen consumption during experiment.

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BAD MATCHING BETWEEN HATCHING AND ACIDIFICATION;

A PITFALL FOR THE COASTAL BURBOT , *LOTA LOTA* L.,

OF THE RIVER KYRÖNJOKI

Richard Hudd
Finnish Game and Fisheries Research Institute,
Merenkurkku Fisheries Research Station,
Korsholmanpuistikko 16, FIN-65100 Vaasa, Finland
phone +358205751671 / Fax +358205751679 /
e-mail Richard.Hudd@RKTL.Fi

Jakob Kjellman
University of Helsinki,
Dept. Limnology and Environmental Protection, P.O.Box 27,
F1N-00014, University of Helsinki, Finland

Introduction

Burbot, *Lota lota*, is considered a fresh water fish, even if it is abundant in the coastal waters of the Baltic Sea. In the Gulf of Bothnia burbot spawns in estuaries and rivers (Eriksson & Müller 1982). Therefore, acidification of rivers has been suggested to be the main reason behind declining catches in the Gulf of Bothnia (Hildén *et al*. 1982).

Materials and Methods

Burbot were collected during spawning, which according to local fishermen takes place 20-28 February. For calculation of hatching, we assumed, that spawning took place 25 February and an incubation of 117-131 degree-days after spawning (Müller 1960). The size of annual catch samples, 1985-1997, varied between 84 and 500 individuals, measured for total length (mm) and weight (g). Ageing was done from otoliths. Yearclass strengths were calculated using the relative yearclass strength method (Böhling *et al*. 1991).

Temperature and pH were measured 2-3 times per week in the river. Data, from days of no measurements, was interpolated by linear filling. The relationship between acidification and yearclass strength was calculated optimising the correlation between a pH-index and the yearclass strength. The pH-index was calculated as number of days below a pH value during a
limited period. The maximum correlation between the index and yearclass strength was sought by varying the pH-threshold value and the period.

Results

In the River Kyrönjoki the most acid period took place, within 30 days after late April. The mean hatching date was calculated to 10 May. At the threshold value, pH 5.2 on 7 May and 24 days thereafter, the correlation between yearclass strength and pH index was the strongest (r_p=-0.73). With a range of 30 days, the correlation was less than -0.6 from 27 April to 17 May at pH values 5.0-5.5. The calculated mean hatching date, 10 May, coincided with this period.

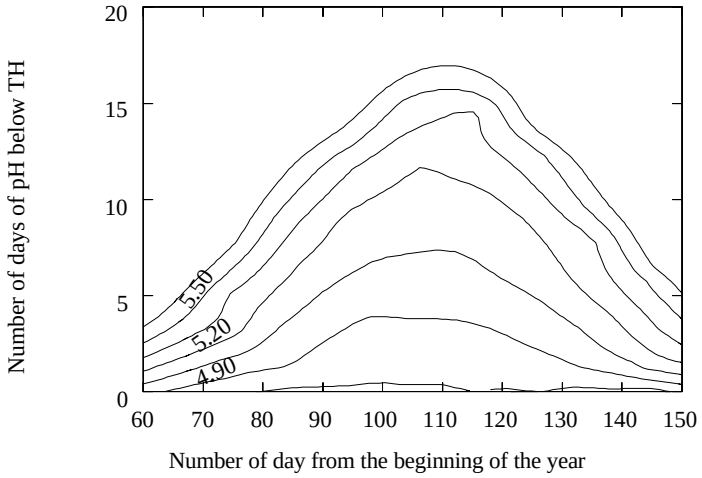


Figure 1. The number of days, when pH has been below a threshold value during a 30 day period. The first day of the period is indicated on the x-axis.

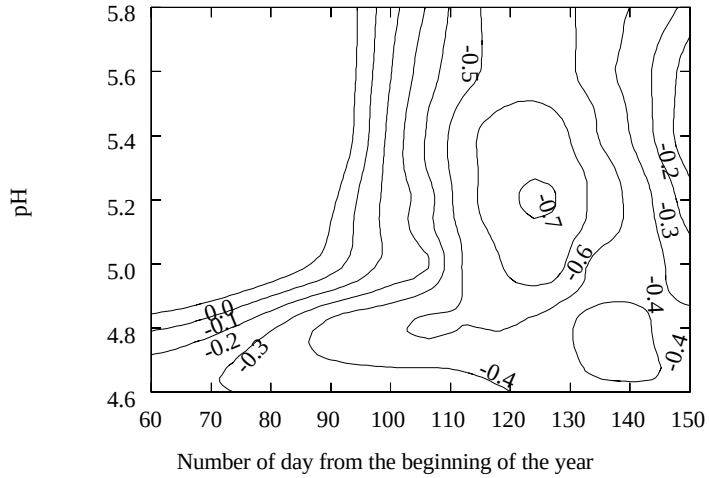


Figure 2. The effect of level and timing of low pH on yearclass strength. Contour plot of correlations (r_p) between the pH-index and yearclass strength 1983-1992.

Discussion

The correlations, between the pH-index and yearclass strength, indicate that, the formation of burbot yearclass strength is sensitive to acidification in the River Kyrönjoki. Two factors contribute to the high sensitivity. Larvae are sensitive to low pH, and the pelagic biology of the newly hatched larvae (Urho *et al*. 1990). Due spawning in estuaries and to the pelagic behaviour, the larvae are exposed to acid outflows of rivers.

The pelagic period of the larvae is considered to be short, but in the Kyrönjoki estuary, pelagic larvae have been observed for nearly one month (Hudd *et al*. 1983). Occurrence of newly hatched larvae during one month, supports the possibility of some larvae to survive, as the pH eventually rises even in acid years.

During the incubation time, acid river water flows above the more saline bottom water. As the semiboyant burbot roe lays close to the bottom, they are not in contact with the river water. This could explain the lesser importance of acid periods before hatching.

The strongest correlation between the pH-index and yearclass strength was found at pH 5.2. However, pH was measured in the river, whereas the larvae occur in the estuary, where the pH is higher. We also got high negative correlations, with pH ranging from pH 5.0-5.5. We conclude that, rather than the precise level of acidification, the bad timing between hatching and acid out flow, forms a pitfall for the coastal burbot of the River Kyrönjoki.

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ECOLOGY OF BURBOT IN WESTERN LAKE SUPERIOR

Stephen T. Schram
Wisconsin Department of Natural Resources
141 South 3rd Street, Box 589
Bayfield, Wisconsin 54814
Phone (715) 779-4030 Fax (715) 779-4025
schras@dnr.state.wi.us

Theodore N. Halpern
Minnesota Department of Natural Resources
5351 North Shore Drive
Duluth, Minnesota 55804
Phone (218) 723-4785 Fax (218) 725-7738
lake.superior@dnr.state.mn.us

Timothy B. Johnson
Ontario Ministry of Natural Resources
R.R. #2, 320 Milo Road
Wheatley, Ontario N0P 2P0
Phone (519) 825-4684 Fax (519) 825-3163
johnsot@gov.on.ca

Abstract

We examined characteristics of the burbot *Lota lota* population in three ecoregions of western Lake Superior during 1976-1997. Relative abundance decreased within the Apostle Islands region and remained stable along the Wisconsin shore and the Minnesota shore between 1992 to 1997. Over 6,000 burbot were collected with a variety of gears to depths of 100 m, although abundance was highest in waters less than 50 m. Burbot ranged in size from 127-833 mm and in age from 3 to 17 years, with a modal age of 10 years for each sex. Total annual mortality was estimated at 43%. Fishing mortality was minimal based on angler caught tag recaptures and observed bycatch in the commercial fishery. Sea lamprey marking was observed on less than 0.1% of the sample suggesting most mortality resulted from other natural causes. All burbot were sexually mature when they reached 533 mm, with first maturity observed at 409 mm for males and 485 mm for females. Burbot were

piscivorous for all sizes sampled. Overall diet composition (by mass) was represented by unidentified coregonines, *Coregonus sp.* (21%), lake herring *C. artedi* (19%), chubs *C. hoyi* and *C. kiyi* (14%), and rainbow smelt *Osmerus mordax* (13%). We estimated the burbot population size in western Lake Superior between 1976 and 1997 at 164,131 to 1,798,941 age 1+ fish. This population consumed between 48 and 528 tonnes (0.26 to 2.14 kg/ha) of prey. Given the current burbot population size in western Lake Superior, this species is unlikely to control production of prey fish or invertebrate taxa.

Introduction

Burbot, *Lota lota,* are piscivorous fish native to Lake Superior. They share similar habitat and food resources with other predators including the lake trout, *Salvelinus namaycush*. Like the lake trout, they declined in abundance due to sea lamprey, *Petromyzon marinus*, predation (Smith 1968, Lawrie and Rahrer 1973, Smith and Tibbles 1980), and have subsequently increased in abundance following sea lamprey control.

Recent bioenergetics analyses have noted a predator-prey imbalance in the fish community of western Lake Superior (Negus 1992, 1995; Ebener 1995). These results have raised concerns regarding the impact of current predator stocking programs on lake trout rehabilitation. Unfortunately, these studies only modelled salmonid populations. Attempts to balance predator demand with prey production must include the predatory demand of all major predators, including burbot. However, little information is available on the ecological role of burbot in Lake Superior because they have little commercial or recreational value.

Our objective was to describe the biology and population characteristics of burbot in western Lake Superior to better understand their role in the fish community. We combined this information with a bioenergetics model for burbot (Rudstam et al. 1995) to estimate the predatory impact of burbot on the Lake Superior fish community. Through an improved understanding of burbot ecology and a more complete description of predator-prey relationships in western Lake Superior, we hope to enhance the assessment, analysis and forecasting capabilities of management agencies.

Study Area

Burbot were studied in three adjacent ecoregions in western Lake Superior, comprising all waters of Minnesota and Wisconsin (Figure 1). The Minnesota region (656,145 ha) extends 332 km from Duluth, Minnesota to the Canadian border. The entire shoreline is steep and rocky, with depths up to 213 m. The Wisconsin region (80,745 ha), extends 85 km from Superior, Wisconsin to the western Apostle Islands. This shoreline is a mixture of red clay, sand and sandstone, which produce turbid water in nearshore areas. The bottom slopes gradually to 150 m. The Apostle Islands region (447,337 ha) is characterized by 22 islands and the adjacent mainland, with a shoreline characterized by red clay, sand, sandstone and boulders. In this region, water depths rarely exceed 65 m. The exception is a trench near the eastern edge of the Islands, where the bottom drops to 140 m.

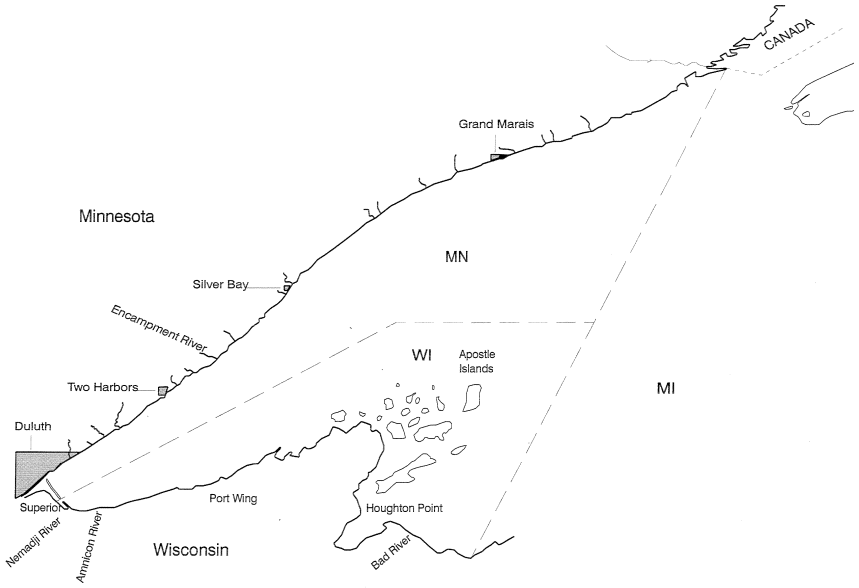


Figure 1. Location of sampling areas in western Lake Superior

Methods

Burbot were sampled in western Lake Superior from 1976 through 1997 by the Wisconsin Department of Natural Resources (WDNR) and from 1992 through 1997 by the Minnesota Department of Natural Resources (MDNR).

In Wisconsin, burbot were sampled at 27 stations with graded mesh gill nets during July and August. Mesh size varied from 75 mm to 178 mm stretch measure in 12.7 mm intervals. Nets were set for 24 hours at depths from 12 to 92 m. In most years, burbot caught in gill nets were counted and released. In 1996 and 1997, burbot were frozen for subsequent examination of length, weight, sex, age and diet. Ages were determined by examining whole otoliths under a binocular microscope (Bailey 1972, Muth and Smith 1974). Stomach contents were identified to species, where possible, and enumerated and weighed to determine percent occurrence and percent by weight for each item.

Between 1979 and 1982, additional burbot were captured along the Wisconsin shore from April through October using a 1.8 m trap net in depths of 3.6 to 9.0 m. Burbot captured in the trap net were measured for lengths and weighed as conditions permitted. Burbot caught in the trap net between 1979 and 1981 were tagged with spaghetti tags (Floy FD67c). Burbot captured in 1982 were sacrificed for age determination. Additional fish were sampled during 1996 and 1997 from the sport and commercial fisheries.

In Minnesota, burbot were sampled in July and August from 1992-1997 at 13 stations. Graded mesh gill nets were set for 48 hr at depths from 33 to 122 m. Mesh sizes varied from 25mm to 63.5 mm. All fish captured were measured, and in 1996 and 1997 fish were also weighed. Diet items were enumerated in 1996 and 1997, and weights of diet items were taken in 1997.

Relative abundance (CPUE) of burbot within each ecoregion was used to describe spatial distribution. Mortality estimates were calculated from the catch curve (Ricker 1975) of fish captured in the trap net, and from tag recoveries. Fishing mortality occurring as bycatch in commercial gill nets was based on onboard observations. Estimates of mortality in the recreational fishery were derived from creel surveys in Wisconsin and Minnesota, and returns of tagged fish from 1981-1990. Patterns of distribution were determined from tag recoveries, and more generally from the number and location of fish captured during routine fishing operations.

To better understand the ecological role of burbot in western Lake Superior, we combined the bioenergetics parameter set developed for burbot (Rudstam et al. 1995) with the computer software developed by Hanson et al. (1997) to explore patterns of consumption of prey by burbot stocks. We estimated burbot stock size from the ratio of burbot:lake trout caught in the Wisconsin graded mesh nets set in July and August of each year. Lake trout stocks are managed in Lake Superior using population models developed for discrete management units. An age-based lake trout population model is available for the Apostle Islands ecoregion (WI-2) but not for the Wisconsin shoreline (WI-1) or the southwestern region of the Minnesota shoreline (MN-1). We estimated the number of lake trout one year and older in WI-1 using the quota allocation factor (16.1% - 17.3% of WI-2) and the WI-2 population size. We assumed the burbot stock size in Minnesota was the same as that in WI-1. Using a 5-year moving mean of the species ratio, we estimated the number of burbot age one year and older from these lake trout population estimates for each management unit.

Mortality and weight-at-age were generated from fish collected in this study. We ran the bioenergetics model for a hypothetical burbot population of 100,000 individuals described by the above age structure, and scaled the consumption by the estimated population size in that year.
We used water temperature data collected in the Apostle Islands in 1996 and 1997 to describe the thermal distribution of burbot in western Lake Superior. We assumed that burbot would occupy the warmest water available up to the physiological optimum of 12 C for juvenile burbot (age 1-3) and 10 C for adult burbot (Rudstam et al. 1995).

Burbot energy density was assumed to be constant at 5125 J/g wet mass for all sizes of burbot (Johnson et al. unpubl.). Energy density of prey varied seasonally (Vondracek et al. 1996) with the exception of *Mysis* and sculpins, which had constant energy densities of 3537 and 5588J/g, respectively (Cummins and Wuycheck 1971, Rottiers and Tucker 1995).

Results

Abundance

From 1976 to 1997, relative abundance of juvenile burbot (<400 mm) decreased from a high of 52.3 fish/1000m in 1979 to 1.3 fish/1000m in 1997 in the Apostle

Islands region but juvenile abundance remained relatively stable along the Wisconsin shore (Figure 2). Along most of the Minnesota shore, juvenile relative abundance ranged from 19.4 fish/1000m to 55.2 fish/1000m between 1992 and 1997, with no noticeable trend. However, in the area near the Minnesota-Ontario border, juvenile burbot abundance decreased. The relative abundance of adults decreased in the Apostle Islands from 3.5 fish/1000m in 1978 to 0.2 fish/1000m in 1994 but only slightly along the Wisconsin shore. Relative abundance of adult burbot was not measured in Minnesota waters. Juvenile and adult burbot were collected at depths up to 100 m, but were most abundant in waters less than 50 m.

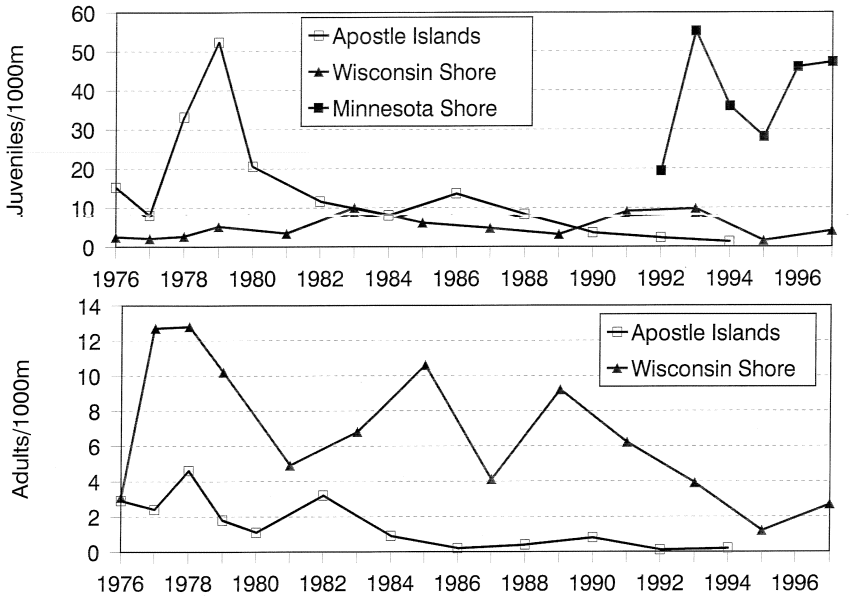


Figure 2. Relative abundance of juvenile (top) and adult (bottom) burbot from western Lake Superior, 1976-1997.

Mortality

Total annual mortality for burbot collected in the trap net along the Wisconsin shore during the period 1979-1982 was 43%. Although we were unable to separate fishing and natural mortality, it is likely that most of the mortality can

be attributed to natural causes. Since 1970, an active commercial fishery in the Apostle Islands has traditionally discarded burbot. Over the past 8 years onboard observations of commercial gill netting operations suggest that bycatch of burbot is currently negligible. From 1981 to 1990, Wisconsin anglers harvested only 43 (3.9%) of the 1,112 fish tagged between 1979 and 1981. Most of this harvest occurred during the spawning season on the Nemadji and Amnicon Rivers and during a sport ice fishery at Superior, WI. From 1992 to 1997, estimates of burbot harvested in the Apostle Islands creel ranged from 37 to 286 fish, with a mean of 114 burbot per year. Minnesota does not estimate the number of burbot caught in the creel, as the numbers are too small to provide reliable estimates. Between 1992 to 1997, only six harvested burbot were observed by creel clerks.

Age and Growth

Age of burbot collected ranged from two to 17 years, with a median age of 10 for both sexes. Burbot ranged in length from 127 mm to 833 mm. The median length was 498 mm. Since there were no differences in the length-weight relationship for burbot collected in 1979-82 and for burbot collected in 1996-97 (ANCOVA F=0.16, p=0.69) data were combined. The following equation, based on a sample of 1900 fish, describes the relationship:

$$W(g) = 0.000002084\ L(mm)^{3.208} \qquad r^2 = 0.95$$

Growth coefficients (± standard errors) fitted to a Von Bertalanffy growth model include:

	n	L-inf or W-inf	K	t_0
length	852	674.1±15.7	0.192±0.017	0.337±0.283
weight	667	2245.1±182.6	0.054±0.0009	3.321±0.228

Maturity and Spawning Areas

Information on maturity was derived from a sample of 146 fish collected during the spawning season from the Nemadji and Amnicon Rivers. Length at first maturity was 409 mm for males and 485 mm for females, and all burbot were sexually mature when they reached 533 mm.

Only two spawning areas were located, the Nemadji and Amnicon Rivers on the Wisconsin shoreline. Burbot are thought to spawn in the Bad River, WI., but we did not sample there. Post-spawn burbot are routinely taken by anglers in March near Houghton Point, WI, but no spawning areas were identified. Juveniles have been collected in tributary streams along the Minnesota shore (Charles Krueger Cornell University, pers. comm. 1983), but no known spawning populations exist.

Seasonal Movements

Burbot began concentrating in the extreme western end of Lake Superior in late fall, prior to making spawning runs up the Nemadji and Amnicon Rivers (Schram 1983). Upstream migration continued until spawning occurred in late December and early January. By the third week in January most fish had spawned and started moving downstream. Following this descent, adult burbot remained concentrated in nearshore regions until early July.

Adults remained just offshore of the mouths of the Nemadji and Amnicon Rivers during May and June. Beginning in mid-May and continuing until early July, they moved eastward along the shore. Fish were observed to have traveled up to 50 km, from the Nemadji River, where they were tagged, to Port Wing, WI, where they were captured.

Diet

Diet was analyzed on 916 burbot by season, depth and fish size. Overall, frequency of occurrence consisted of unidentified fish (28%), rainbow smelt *Osmerus mordax* (10%), *Mysis relicta* (10%), lake herring *Coregonus artedi* (9%), and unidentified coregonines *Coregonus sp.* (9%). By mass, diets were dominated by unidentified coregonines (21%), lake herring (19%), chubs *C. hoyi* and *C. kiyi* (14%), and rainbow smelt (13%). Frequency of occurrence of smelt decreased with increasing depth, while *Mysis* occurrence increased. By mass, smelt proportion was highest at depths <20 m, while lake herring and chubs dominated diets between 20 and 60 m. Incidence of *Mysis* increased in the summer and autumn, although fish continued to dominate the diet throughout the year.

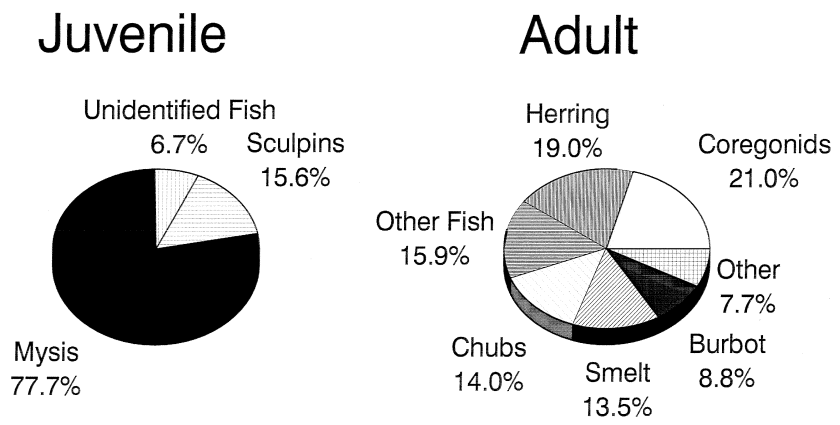


Figure 3. Diets (% mass) of juvenile (<399 mm) and adult (> 400 mm) butrbot from western Lake Superior, 1996-1997

Juvenile burbot (<400 mm) ate more *Mysis* (78% by mass) and sculpins *Cottus cognatus* and *Myoxocephalus thompsoni*, (16% by mass) while larger burbot were exclusively piscivorous (>95% incidence of fish) (Figure 3). Cannibalism was highest for larger burbot (15% by mass), nearshore (18%) and during the summer (30%), although other burbot never averaged more than 8% of the mass. Total ration was highest during the summer (11.9 $g \cdot fish^{-1}$) and lowest in the spring (5.9 $g \cdot fish^{-1}$).

Bioenergetics

We estimated the burbot population size in western Lake Superior between 1976 and 1997 at 164,131 to 1,798,941 fish age one year and older. During this time period, the population consumed between 48 and 528 tonnes (0.26 to 2.14 kg/ha) of prey. Estimated predation on *Mysis* represented 46% of the total, with herring (13%), chubs (10%) and smelt (4%) representing lesser fractions. Juvenile burbot were responsible for over 75% of the predation, with age 2 fish comprising the largest fraction.

Discussion

The abundance of burbot in western Lake Superior prior to the sea lamprey invasion is unknown. Following control of sea lamprey in 1952, burbot abundance is thought to have been high because of the lack of predators (sea lamprey, lake trout and siscowet lake trout *Salvelinus namaycush siscowet*) and low fishing mortality. Since 1970, burbot abundance has decreased dramatically in the Apostle Islands area while remaining fairly constant along the Wisconsin shore. This change in burbot abundance may be a consequence of changes in the fish community caused by increased predation and/or competition from recovered lean and siscowet lake trout stocks. Carl (1992) found no measurable impact on burbot from an increased lake trout population in Lake Opeongo, Ontario. He suggested the burbot population may be controlled at the larval stage by competition with, or predation by, planktivorous lake herring. Lake herring are abundant in western Lake Superior and could contribute to burbot mortality. However, burbot abundance has not declined along the Wisconsin or Minnesota shores where lake herring are more abundant. Burbot larvae in these areas may find refuge in the rivers where they are spawned, whereas burbot in the Apostle Islands region are likely shoal spawned and could be susceptible to predation by lake herring.

The low mortality rate we observed (43%) reflects a population that is not commercially exploited and only lightly exploited by sport anglers. We estimated similar mortality rates for burbot populations in Lake Superior (Bailey 1972) and Lake Erie (Clemens 1951b). Muth and Smith (1974) reported a total annual mortality rate of 64% for an exploited population of burbot in Lake of the Woods. Historically, natural mortality probably fluctuated with sea lamprey abundance, however sea lamprey marks were observed on less than 0.1% of the sample from 1979-1982 and no marks were observed between 1996-97.

Burbot in western Lake Superior live longer and grow slower than has been reported for other populations in the Great Lakes basin (Scott and Crossman 1973). The cold water temperature and lower productivity no doubt contribute to this slower rate of growth.

The piscivorous nature of burbot in western Lake Superior is characteristic of other populations (Van Oosten and Deason 1938, Bailey 1972, Fratt 1991). However, the present burbot population demonstrated a much stronger affinity for coregonines than reported elsewhere, including Bailey's (1972) assessment in

the Apostle Islands region of Lake Superior in the late 1960s. During the late 1960s, coregonine stocks, principally lake herring, were severely depressed in Lake Superior (Anderson and Smith 1971) which may have contributed to the different diet composition between studies. Nevertheless, we feel much of the difference between studies results from differences in the size of burbot sampled. The median size of burbot in Bailey's (1972) study was only 400 mm, and the diet was more characteristic of juvenile burbot collected in the present study (predominance of sculpins and invertebrates). Clemens (1951a) documented a progressive shift from invertebrates to fish with increasing size of burbot in Lake Erie, similar to what we observed in Lake Superior.

The western Lake Superior burbot population consumed considerably less prey (0.3-2.1 kg/ha) than burbot in Green Bay (15.8 kg/ha; Rudstam et al. 1995) and other predators in western Lake Superior (5.2 to 22.4 kg/ha; Negus 1995, Ebener 1996). Much of this difference is attributable to the smaller population size of burbot in western Lake Superior. Our areal population estimates for adult burbot averaged only 1.6% of the Green Bay stock, with associated reductions in prey consumed. Conversion efficiencies were comparable for both stocks, although slightly less in Lake Superior owing to the slower growth rates. Nearly half of the prey consumed by the western Lake Superior burbot population was *Mysis*. However, this consumption was considerably less than that consumed by forage fish in western Lake Superior during the same period (6-44 kg/ha; Johnson et al.1998)

Given the current burbot population size in western Lake Superior, this species is unlikely to control production of prey fish or invertebrate taxa. However, if burbot stocks increase to levels seen in the late 1970s, burbot could cause a significant predatory mortality to *Mysis* and prey resources.

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FEEDING OF BURBOT (*LOTA LOTA* (L.))

AT DIFFERENT TEMPERATURES

J.-P. J. PÄÄKKÖNEN
Department of Biology and Environmental Science,
University of Jyväskylä
P.O.Box 35,FIN-40351 Jyväskylä, Finland
Tel.: +358 14 602324; fax: +358 14 602321;
email: jaripaa@dodo.jyu.fi

T. J. MARJOMÄKI
Department of Biology and Environmental Science,
University of Jyväskylä
email: tmarjoma@cc.jyu.fi

Introduction

Accurate estimates of feeding rates of burbot are lacking and, therefore, the role of burbot as a piscivore in lakes is unclear (Edsall et al 1993; Carl 1995; Rudstam et al. 1995).

The aim of this work is to estimate, at different temperatures, maximum food intake of burbot, day-to-day variation, daily feeding probabilities and the amount of food left in the stomach at the moment of return of appetite.

Materials and Methods

Feeding experiments were done at four temperatures 2.4, 5.1, 10.8, and 23.4°C(S.D. ± 0.49^{o}C). Random samples of 66 burbot were used, with a mean weight of 296 g (S.D. ± 48 g; n = 66) and a mean length of 324 mm (S.D. ± 0.22 mm; n = 66). The duration of the experiment was 14 to 21 days at different temperatures.

Each burbot was places in a circular cage. For each feeding, the burbot were fed a meal consisting of 10 vendace (Coregonus albula (L.)). After 10 minutes, the food remaining in the cage was removed and the number of eaten meal items

was recorded. The weight of consumed food was estimated by multiplying the number of vendace eaten by an average weight of vendace in the batch (mean = 3.02 g, s.d. = 0.11 g)

Mean daily food intake (MDI, g/d) values were calculated for each fish (g/d). The weight of food was also related to burbot weight (RDI, % of burbot weight). Three kinds of probabilities of feeding were modelled for burbot: the probability of feeding on any day t ($P[(feed)_t]$) and the conditional probabilities of feeding on day t given feeding on day t-1 $P[(feed)_t \mid (feed)_{t-1}]$ or not feeding $P[(feed)_t \mid (not\ feed)_{t-1}]$.

For each temperature, day-to-day variation (DV) of the daily food intake (DI, g) was calculated for successive feeding days d and d+1

$$DV = \frac{\left|DI_{d+1} - DI_d\right|}{DI_d} * 100$$

An exponential model including the effect of meal weight in relation to burbot weight and the effect of temperature on gastric evacuation (Pääkkönen & Marjomäki 1997) was fitted to feeding data of each burbot to estimate the amount of food remaining in the burbot stomach at the feeding moment (% ob burbot weight) at different temperatures.

Results and Discussion

Both mean and relative daily food intake (MDI and RDI) increased at temperature range from 2.4 to 10.8 °C, being highest at 10.8 °C, and decreasing to lower level at 23.4 °C (Table I). Both MDI ($F_{3,59}$=3.691, p=0.017) and RDI (F3,59=4.990, p=0.004) varied significantly between temperatures, RDI at 10.8 °C differing from all other temperatures and MDI in 2.4 °C differing from that in 10.8 °C (Tukey honest significant difference test). Nor MDI neither RDI did correlate (Spearman R) with burbot weight.

Table 1. Mean daily food intake values (g/d, % BW) of burbot (*Lota lota* (L.)) at different temperatures fed vendace (*Coregonus albula* (L.)). (n = number of fed burbot in experiment).

	Food intake		
T (°C)	MDI (s.e)	RDI	n
2.4	2.31 (0.31)	1.06 (0.14)	18
5.1	3.42 (0.74)	1.37 (0.22)	15
10.8	4.83 (0.76)	2.42 (0.35)	16
23.4	2.58 (0.53)	1.56 (0.34)	14

The daily probability for feeding varied from 0.442 to 0.498. Thus, burbot feed once in every two or three days.

Both intra- and inter-individual variation in food intake were detected. Usually a day of heavy feeding was followed by days of no feeding or feeding of low amounts. There was no significant difference in DV between temperatures (Kruskal-Wallis $H_{3,50}$ =1.026, p=0.795). The mean DV in all temperatures was 65.4% (s.d=58.9). Inter-individual variation of feeding was great in all temperatures. The number of non-feeding fish were highest at the 23.4 °C.

The amount of food left in the stomach at the moment of the return of appetite predicted by evacuation model varied at different temperatures being 2.8% , 2.6%, 3.5% and 0.5% of body weight at 2.4 °C, 5.1°C, 10.8 °C and 23.4 °C, respectively.

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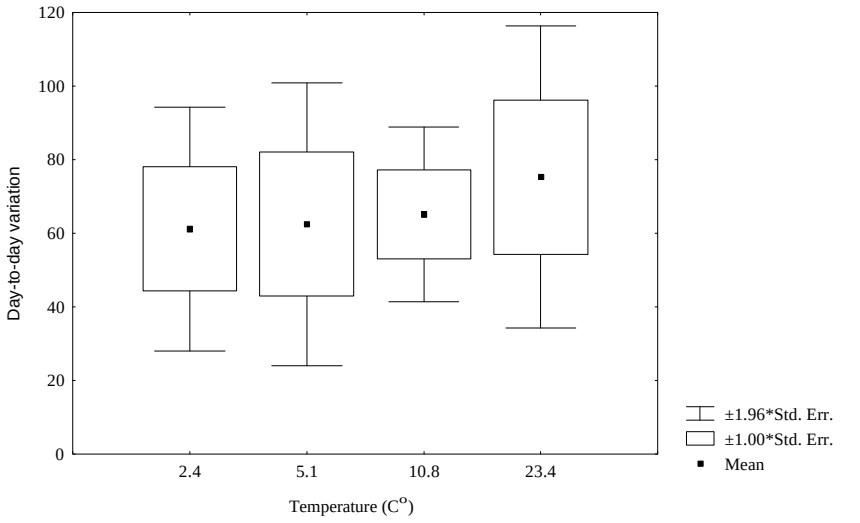


Fig. 1. Day-to-day variation (DV) of daily food intake of burbot in different temperatures. There was no significant difference in DTDV between temperatures.

SONIC TRACKING OF BURBOT

IN LAKE OPEONGO, ONTARIO

Leon M. Carl
Ontario Ministry of Natural Resources
Trent University
1600 West Bank Drive
P.O. Box 4840
Peterborough, Ontario K9J 8N8
(705) 755 2268 Phone
(705) 755 2276 Fax
carll@gov.on.ca

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The diel movements of seven adult burbot (*Lota lota)*, 55-67 cm in total length, were monitored with sonic tags in Lake Opeongo during 1989 and 1991 to determine patterns of activity and habitat use. A Friedman two-way nonparametric analysis of variance was used to test three hypotheses:

(1) Swimming speed was different among seasons and fish;

(2) depth of occurrence was different among seasons and fish;

(3) speed was different between fish and between the years 1989 and 1991.

Burbot were inactive during daylight hours, began moving near dusk and moved throughout each night until dawn. In the summer, burbot moved more slowly and occupied deeper water than in the spring. Swimming speed then appeared to increase in the fall (Table 1). Burbot occupied the same local areas within seasons and between years. Burbot were sometimes active in 20°C water for extended periods at night but moved to cooler water during the day. The fidelity to activity sites, the zig-zag patterns (Figure 1) and abrupt changes in swimming speed suggest that burbot use an area-restricted searching pattern. In this search pattern, predators concentrate activity near where they have captured prey

(Tinbergen et al. 1967; Smith 1974; Krebs 1978). None of the adult burbot were located in water less than 2 m deep where juveniles are found. In Lake Opeongo there seemed to be a discrete shift in habitat or ontogenetic niche from inshore areas for juvenile burbot to offshore benthic areas for adults. Several authors have shown a similar shift in other animals (Keast 1977; Polis 1984; Werner and Gilliam 1984).

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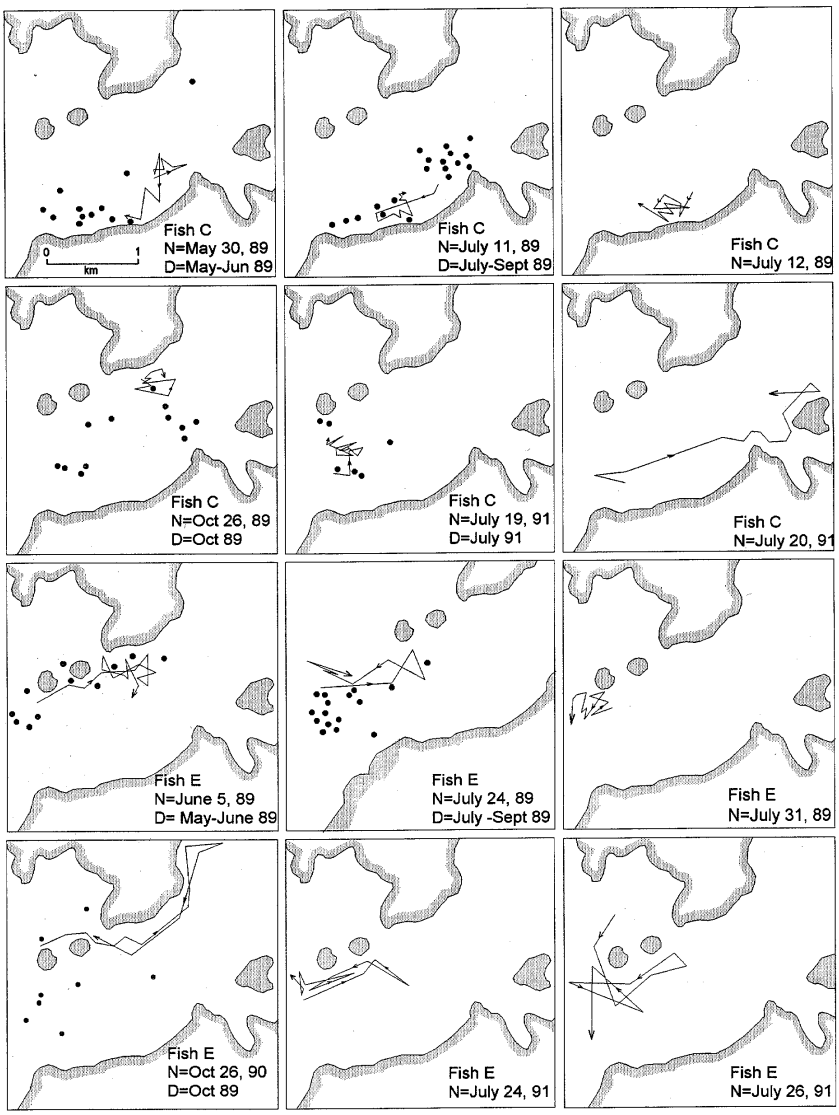


Figure 1: Night Tracks (N, lines) and Daytime Locations (D, dots) of Burbot C & E in 1989 & 1990.

Table 1: Movement of Burbot at Night, by Season in the Opeongo, 1989 & 1991.

Fish	Number of times Tracked	Total Number of fixes	Speed (m/min.)	Night depth (m) Mean	Range	Bottom Water temp. (C)
			Spring 1989			
B	2	32	7.4	10	3-25	9.7
C	2	24	6	5	2-14	10.7
D	4	59	5.7	8	3-13	9
E	1	16	9.1			
F	2	58	6.3	11	2-38	10.3
Mean			6.9	8	2-38	9.9
			SUMMER 1989			
A	2	51	1.9	16	6-26	
C	4	55	3.2	11	4-38	12.7
D	3	66	2.3	16	4-30	8.3
E	4	62	7.4	11	4-20	11.4
F	2	39	3.1	12	3-22	10.3
G	4	80	2.9	11		
Mean			3.5	13	3-38	10.4
			FALL 1989			
C	1	25	4.9	23	20-33	
D	1	27	6.4	7	3-11	
E	2	37	12.3	11	4-21	
Mean			7.9	14	3-33	
			Summer 1991			
C	3	51	6.8	13	9-19	
D	3	42	3.8	16	10-26	
Mean			5.3	14	9-26	

THE STATUS OF RECREATIONAL FISHERIES FOR BURBOT IN THE UNITED STATES

Steve Quinn
In-Fisherman, Inc.
Two In-Fisherman Dr.
Brainerd, MN 56401
218/829-1648
218/829-2371 (fax)
scottl@in-fisherman.com

Abstract

Although the burbot *Lota lota* has a large geographical distribution across the northern tier of the United States from Maine to Alaska and is common throughout much of Canada excluding Nova Scotia and the Atlantic islands, the species has received relatively little attention from recreational anglers. In the United States, burbot have achieved a peak of popularity in Alaska. There, angling pressure for burbot increased rapidly in the late 1970s. Regulations have been tightened, including harvest bans on some lakes. Several lake populations have revived while others remain overharvested. Other western burbot populations and associated fisheries have suffered from water level manipulations. Around the Great Lakes, burbot are primarily caught incidentally by ice anglers. In Minnesota, Wisconsin, and New Hampshire, burbot don't rank high in species preference but fishing derbies have attracted large participation over the last two decades.

Although the visibility and prestige of burbot has risen somewhat in the upper Midwest and Canada, many anglers have yet to appreciate the fighting qualities and culinary value of this species. In most states, no regulations restrict harvest, and ice anglers frequently discard fish on the ice. Anglers who target burbot have developed specialized gear and use tactics that shift according to season and characteristics of the body of water. State records for burbot range from 5 pounds (Vermont) to 24-3/4 pounds (Alaska). Possibilities for promotion of burbot fisheries exist in many areas. With increasing fishing pressure on burbot, more regulations will be required to prevent overharvest. Regulations may also increase angler esteem of burbot.

Introduction

The burbot *Lota lota* has several biological characteristics generally considered attractive in a gamefish. First, it has a native range that spans from the Atlantic to the Pacific coast of North America and extends into Asia. This distribution potentially allows formation of a large base of angler support and a network of communications among anglers, fishery managers, and the fishing tackle industry that spurs further growth of a fishery. Second, burbot are large predatory fish, characteristics that find favor among anglers. They readily take baits presented in appropriate habitat. The all-tackle record burbot, recorded by the International Game Fish Association is a 24-pound 12-ounce fish taken from Lake Louise in Alaska in 1976. In many areas, burbot commonly grow over 10 pounds. Eight states have burbot records over 15 pounds (Table 1). Third, burbot are now recognized as a fine food fish in much of their range. As a member of the codfish family, their flesh has many of the culinary elements that make other gadids so popular as food. Some special preparation is needed to preserve burbot by freezing, however (Gunderson 1986). Oil made from the liver of burbot has the health attributes of widely acclaimed cod liver oil, including high concentrations of vitamins A and D (Scott and Crossman 1973, Bell 1987). Early in the 20th century, the United States Bureau of Fisheries (predecessor to the U. S. Fish and Wildlife Service) promoted the use of burbot as food, distributing educational materials on economic aspects of a burbot fishery and recipes (Becker 1983). Similar efforts were undertaken in Canada (MacKay 1963).

Despite these attractive characteristics as a sportfish, burbot haven't historically achieved as high a level of popularity with recreational anglers as other similar-size predatory species. Part of the disdain by anglers may stem from the burbot's unusual, snakelike appearance and tendency to curl around an arm trying to hold it (Chen 1969, Gunderson 1986, Bell 1987, Muth and Smith 1974). Early reports of its unpalatability (DeKay 1842) may have biased the opinions of anglers and discouraged development of commercial fisheries for burbot (Scott and Crossman 1973, Wisconsin Department of Natural Resources 1976). Although fisheries at Lake of the Woods have recorded annual harvests over half a million pounds from the 1940s through the 1960s (Muth and Smith 1974), most burbot were used as food for mink. Bailey (1972) noted that although burbot rank among the most nutritious of freshwater fishes, catches by commercial fishermen in Lake Superior often were discarded because of the lack of a profitable market.

Table 1. State records for burbot.

State	Weight	Angler	Water	Year
Alaska	24 lbs. 12 oz.	George Howard	Lake Louise	1976
Idaho	14 lbs.	P. A. Dayton	Kootenai River	1954
Indiana	7 lbs. 11 oz.	Larry Malicki	Lake Michigan	1990
Maine	18 lbs. 8 oz.	Annette Dumond	Eagle Lake	1986
Michigan	18 lbs. 4 oz.	Tom Courtemanche	Munuscong Bay	1980
Minnesota	18 lbs. 5 oz.	Robert Wilmes	Lake of the Woods	1988
Montana	17.04 lbs.	Jeff Iwen	Missouri River	1989
Nebraska	6 lbs. 5 oz.	Richard Smith	Gavins Point Dam	1994
New Hampshire	11 lbs. 2 oz.	John MacKenna	Sunapee Lake	1984
New York	16 lbs. 2 oz.	Terrence Colwell	Black River Bay	1991
North Dakota	18 lbs. 4 oz	Orland Kruckenberg	Knife River	1984
Ohio	9 lbs. 12 oz.	Thomas Franjesn	Lake Erie	1994
South Dakota	12 lbs. 3 oz.	Norman Sheldon	Lake Sharpe	1974
Vermont	5 lbs.	John Hawthorn	Lake Memphramagog	1979
Washington	17.01 lbs.	Patrick Bloomer	Palmer Lake	1993

Anglers also have considered burbot a competitor with more favored species (Tomelleri and Eberle 1990), especially lake trout. This potential competition with or predation on lake trout has spurred biological investigations (Stauffer and Wagner 1979, Edsall et al. 1993). State agencies also have contributed to the low regard of burbot by labeling it a ‘trash’ fish or ‘rough’ fish, or not regulating harvest with bag or length limits (only four states with burbot populations regulate its harvest). In Lake Winnebago, Wisconsin, the Department of Natural Resources has engaged in burbot removal as a lake management strategy (Weber 1976).

Burbot are a coldwater species, with the southern extent of their range being the Missouri River in northern Missouri and Nebraska (Lee and Gilbert 1980). In northern lakes of the Upper Midwest, they rarely are caught once water temperatures exceed 50°F. Anglers who catch burbot incidentally may be puzzled by the unusual catch. Yet in localized regions from Maine to Alaska, substantial recreational fisheries exist, and a summary of the status of fisheries in each state follows. Within much of its range, recent reports indicate that angling interest in burbot has grown in the last decade or so, with accompanying increases in harvest. Some management agencies have seen the need to tighten regulations to prevent overharvest of this species. Recent emphasis on ecosystem-based management has focused more attention on this large and sometimes abundant member of the fish community. The lack of historical fisheries information on burbot and the paucity of biological studies of burbot have spurred investigations in some areas. The trend toward multispecies angling has increased angler interest in burbot, particularly in areas where catch rates and size structure of populations of northern pike *Esox lucius*, walleye *Stizostedion vitreum*, or trout Salmonidae have declined. In other regions, declining burbot populations have led to closure of fisheries, and research efforts are underway to assess habitat needs and to monitor remaining populations. Seven states that administer angler award programs offer awards for burbot.

Little information on catch and harvest of burbot is available in most states because of their low priority to management agencies. Aside from Alaska, few agency reports have been published on recreational fisheries for burbot. Although some creel surveys collect data on harvested burbot, no further analysis is done in most cases. Collection and assimilation of such raw data is beyond the scope of this paper.

Alaska:
Burbot are widespread in the lake and river systems of Alaska, but the species did not generate much interest from recreational anglers until the 1970s, when people moved to Alaska in connection with the building of the Alaska Pipeline (Matt Evenson, Alaska Dept. Fish and Game, personal communication). No bag limits, possession limits, gear restrictions, or other harvest regulations covered burbot until 1979. During the early 1980s, some burbot populations in the two main areas of recreational fishing intensity, the Tanana River basin and the Upper Copper/Upper Susitna River Management Area (known as the UCUSMA or Glennallen area), declined. A tagging study of 15 lakes in the Glennallen area (surface area ranging from 321 to 16,108 acres) found exploitation heavy in 7, moderate in 3, and light in 5 lakes (Bernard et al. 1993. A 15-fish daily limit

was enacted prior to the 1979 winter fishery in the UCUSMA (Szari 1996). The largest fishery of the UCUSMA has occurred in the Lake Louise complex. Most angling takes place from November to April (Szari 1996).

Harvest in the Tanana River drainage peaked in 1984 at 5,556 fish, with a mean harvest from 1977 through 1992 of 3,640 fish per year. (Arvey et al. 1995). In the Glennallen area, harvest peaked in 1985 at 22,015 fish (Szari 1996), and the peak Alaskan statewide harvest occurred that year. To prevent further declines in burbot populations of the Tanana River drainage, the Alaska Department of Fish and Game implemented emergency regulations in 1987 that prohibited use of set lines from May 15 to October 15, and reduced the bag and possession limits in all lakes of the Tanana drainage to 5 fish. Set lines were banned from 4 lakes and 2-fish bag limits were enacted there as well in 1987. Present regulations ban set lines in the UCUSMA, except for flowing waters of the Copper River. On flowing waters of the Tanana River drainage, set lines may be used and a 15-fish daily bag limit was retained and remains in effect into 1998. In Alaska, the number of hooks that may be used is the same as the daily bag limit in the water fished. As a result of these regulations, 59% of the 1996 Alaskan catch of burbot (6,359 fish)were released (Alaska Dept. Fish and Game, unpublished data). The catch was roughly split between the Tanana River drainage and the south-central region, primarily around Glennallen. The Department of Fish and Game gives angler awards for burbot over 8 pounds.

Idaho:

In northern Idaho, burbot once provided an important winter fishery, as the fish migrated from the lower Kootanai River and Kootenay Lake. After construction of the Libby Dam, the fishery gradually declined and finally was closed in the early 1990s (Paragamian 1995). All burbot caught must be immediately released without removing them from the water. This decline was thought to be due to change in the hydrograph and temperature regime of the Kootenai River. Burbot in that river may be physically unable to migrate upstream against the artificially increased current velocities. Reproduction of burbot in Idaho is virtually nonexistent but some recruits may enter the state from a spawning population in the Goat River, British Columbia (Paragamian 1995). Burbot may be recommended for Idaho's endangered species list (Vaughn Paragamian, Idaho Fish and Game Dept., personal communication).

Illinois:
Although burbot occur in the Illinois waters of Lake Michigan and have been found in the Mississippi River and its major tributaries, little or no directed fishing occurs for them (Smith 1979). No regulations restrict harvest.

Iowa:
Burbot inhabit the Mississippi and Missouri rivers but are rare catches and little or no directed fishing occurs (Harlan et al. 1987).

Maine:
Moosehead Lake, an oligotrophic lake covering 74,890 acres, has a long-standing and popular fishery for burbot (called cusk in Maine) that occurs during winter nights. Incidental catches also occur during the day. An annual creel assessment has been done since 1967, but it only included burbot since 1985. Annual harvest has ranged from 2,200 to 7,100 fish and 2,100 to 11,100 pounds, peaking in 1985. A decline in fishing pressure for burbot is associated with problems affecting the salmonid fishery and is not related to burbot abundance. The mean size of harvested burbot has ranged from 14 to 27 ounces, with a 13-year average of 21 ounces. Fish up to 10 pounds are occasionally taken, however (Scott Roy, Maine Dept. of Inland Fisheries and Wildlife, unpublished data). No regulations restrict harvest.

Michigan:
Although burbot are common in the Michigan waters of Lake Michigan and migrate up tributaries, very little angling is directed toward them. A limited winter fishery occurs in Lake Michigan and a few inland lakes. The species is eligible for Michigan's Master Angler program (minimum size 5 pounds or 22 inches) but few entries are received. No regulations restrict harvest.

Minnesota:
Burbot (called eelpout in the state) are widespread in larger, deeper inland lakes in Minnesota and commonly occur in Lake Superior and occasionally in the Mississippi River. Over the last decade, they have gained popularity with recreational anglers. The high profile International Eelpout Festival in Walker, an annual event for the last 18 years, has promoted eelpout fishing. As many as 10,000 anglers have participated in the weekend-long derby, with additional spectators and visitors. Yet throughout the state, most burbot are caught incidentally during the winter ice fisheries for walleye and northern pike. On Mille Lacs, a large winter fishery primarily targeting walleye, an average of 28,000 burbot were harvested, with a peak of 86,000 fish during the winter of

1980-1981 (Rick Bruesewitz, Minnesota Dept. Nat. Res., personal communication). Lake of the Woods contains a large population of burbot, though there are indications that numbers have declined. A small commercial fishery exists, with fish used as food at a fox ranch or live hauled to pay-fishing ponds in the midwest, primarily Ohio and Indiana (Tom Heinrich, Minnesota Dept. Natural Resources, personal communication; John Heinen, commercial fisherman, personal communication). At this lake and others, substantial waste occurs as anglers leave burbot on the ice. No regulations restrict harvest.

Missouri:
Burbot occasionally are caught in the Missouri and Mississippi rivers, but catches are so unusual as to be considered a curiosity (Pflieger 1975). No regulations restrict harvest.

Montana:
Burbot are common throughout the Missouri River system in Montana and also occur in the upper Yellowstone River system. Long established and popular recreational fisheries occur at Canyon Ferry Reservoir on the Missouri River and Clark Canyon Reservoir on the Beaverhead River . In Canyon Ferry, burbot fishing has gained popularity over the last 5 years. The burbot population seems to be growing, increasing their incidental catch by winter anglers targeting yellow perch *Perca flavescens* and trout. Anglers also fish flowing rivers. People who catch burbot tend to eat or release them, avoiding the regrettable waste that occurs in some regions (Bruce Rich, Montana Dept. Fish, Wildlife, and Parks, personal communication). The daily bag limit is five burbot.

Nebraska:
Although burbot inhabit the Missouri River and Lower Platte River, there is no directed fishery for them. The species is eligible for the state's Master Angler program (minimum size 1 pound or 16 inches) but only a handful of awards are given for incidentally caught fish (Daryl Bauer, Nebraska Game and Parks Commission, personal communication). No regulations restrict harvest.

New Hampshire:
Burbot, called 'cusk' here, are common in many of the state's larger lakes and have traditionally been popular with ice anglers. Popular fisheries include lakes Winnipesaukee and Sunapee. A derby on Lake Winnipesaukee offers prizes for the largest burbot, often in the 7- to 9-pound range (Don Miller, New Hampshire Fish and Game Dept., personal communication). To encourage burbot fishing, the Fish and Game Department allows use of 6 'cusk lines' in addition to lines

set for trout or other species. Cusk lines must be rigged in a prescribed manner that selects burbot and must be checked once during each 24-hour period.

New York:
Burbot occur sporadically in the Allegheny and Susquehanna river drainages, and in the New York waters of Lakes Erie and Lake Ontario, as well as in tributaries of the St. Lawrence River (Smith 1985). They also occur in the Finger Lakes, Lake Oneida, and Lake Champlain. While directed hook-and-line fisheries apparently don't exist, special regulations allow blind snatching of burbot during winter in a tributary of Lake Champlain, and burbot may be speared there through spring and summer. No regulations restrict harvest.

North Dakota:
The Missouri River system contains burbot, and some recreational fishing occurs in the Garrison Dam tailrace and in the confluence of the Yellowstone and Missouri rivers. Anglers target postspawn 'ling,' as they're known, that move into tributary streams before walleyes enter the streams (Dave Willis, South Dakota State Univ., personal communication). The population in the Missouri River has apparently declined as fish became less abundant and smaller through the 1970s and 1980s (Al Sapa, U. S. Fish and Wildlife Service, Bismarck, North Dakota, personal communication). No regulations restrict harvest.

Ohio:
Burbot now are common in Lake Erie but have failed to inspire a recreational fishery. The commercial fishery was closed from 1971 to 1994 but has grown slightly in recent years, to about 1,700 pounds in 1997. No regulations restrict harvest.

Oregon:
The Columbia River seems to represent the southern extent of the burbot's West Coast distribution, and burbot are rare catches. No regulations restrict harvest.

South Dakota:
Burbot inhabit the upper Missouri River and its impoundments, with large populations in lakes Sharpe and Oahe. Very little directed fishing occurs for them, however. No regulations restrict harvest.

Vermont:
Burbot inhabit several of the state's larger, deeper lakes but there is virtually no directed fishing for them. Anglers often leave them on the ice. Burbot, called 'cusk or ling,' reportedly approach 10 pounds in Lake Champlain but run smaller in other lakes. Small specimens (6 to 8 inches) also occur in tannic, high-gradient streams of the boreal forest (Len Gerardi, Vermont Dept. Fish and Wildlife, personal communication). No regulations restrict harvest.

Washington:
Eleven lakes and reservoirs in the north-central portion of Washington contain burbot, generally large, deep, oligotrophic waters. In several waters, set-line fisheries have been rather popular and anglers also jig for burbot. Since 1971, only one set line has been allowed on four lakes, but with an unlimited number of hooks. Regulations have varied in other waters. In experimental fishing with set lines, overnight sets caught 0.24 fish per hook (Bonar et al. 1997). Overexploitation may have contributed to the collapse of the Banks Lake burbot population, but effects of harvest on other lakes is unknown. At other lakes, however, burbot numbers are increasing (Bonar et al. 1997). Burbot are the least popular game fish in Washington according to angler surveys (Mongillo and Hahn 1988; Washington Department of Fish and Wildlife 1996). The percentage of anglers fishing for burbot increased, however, from 1.4% in 1986 to 4.1% in 1995. In response to increased angler interest, a 5-fish daily bag limit was enacted in 1998. The maximum number of hooks on a set line has also been reduced to 10.

Wisconsin:
Burbot are abundant in the Wisconsin waters of Lake Michigan and Lake Superior, where limited winter fishing occurs. The Washington Island (Door County) Lion's Club Fishing Derby, an annual event for over 15 years, awards prizes for trout, perch, and pike, but the biggest prizes are for 'lawyer,' as burbot are locally known. Fish from 10 to 12 pounds are frequent catches. In Lake Winnebago, the state's largest lake, burbot are widely scattered and abundant, and a commercial fishery existed there. During the 1960s and 1970s, the Department of Natural Resources removed burbot with fyke nets during winter as part of a fish-control program (Weber 1976). No regulations restrict harvest. Becker (1983) concludes, "in Wisconsin, except for a small market that has developed in some eastern counties, it is a despised fish species."

Canada:
A summary of the status of recreational burbot fisheries in Canada or in Eurasia is beyond the scope of this report. Scott and Crossman (1973) describe the low regard that burbot were held throughout the provinces, both among commercial and recreational fishers. Documentation of fishing effort and harvest seem sparse. Smedley (1998) describes efforts of the Ontario Department of Game and Fisheries from the 1920s through the 1950s to remove burbot to improve lakes, and reports removals up to 25 tons annually. The huge number of cold, deep lakes throughout Canada suggests that burbot populations may be far larger than those in the United States. In his popular article, Smedley (1998) promoted fishing for 'ling' in Ontario and recommended techniques and locations.

Recreational Fishing Tactics and Equipment

In New England, the upper Midwest, and in western lakes and reservoirs, nearly all angling for burbot occurs through the ice. Open-water fisheries occur in the Missouri River and Yellowstone River, and in the Tanana and Copper river systems in Alaska. In ice-covered lakes, anglers target prespawn burbot as they gather to feed prior to the mid-winter spawn. Burbot feed on benthic prey (Becker 1983) and successful ice fishermen place baits on or slightly above the bottom. During winter, anglers targeting burbot have found that offshore bars and underwater humps that cover an acre or more and are located near deep water (40 to 60 feet or more) attract large numbers of burbot. Except at spawning time, burbot tend to roam about unpredictably, generally remaining near the bottom (Bernard et al. 1993).

Where set lines have been legal, fishers place lines with a series of hooks along the bottom, weighted with heavy lead sinkers. Barrel swivels are used to prevent line twist. Where burbot concentrate, fishing individual lines on a rod and reel can be productive. Anglers have begun using portable sonar units to find likely spots to target burbot, just as they do when searching for perch, walleyes, or other species. In the regions of burbot abundance, ice thickness can approach 36 inches or even more by burbot spawning time. Gas-powered augers are essential, and anglers have devised many other items of fishing equipment. Extreme weather conditions also must be expected.

In New England, some anglers use cusk lines, such as prescribed in the New Hampshire regulations, with a sinker set on the bottom and a hook baited with cut fish. Midwestern anglers generally select short (24- to 40-inch) ice fishing

rods and match them with mid-size spinning reels or small baitcasting reels. Monofilament lines from 8- to 10-pound test are favored as they prevent break-offs by large burbot and do not deter bites. Phosphorescent lead-head jigs, jigging spoons, or other lures dressed with pieces of a phosphorescent plastic grub seem to attract burbot at night. Anglers use photographic flash units or lanterns to activate the glowing paint. Burbot can be caught during winter days, and by anglers fishing deeper flats, sometimes as deep as 60 feet. Jigging spoons tipped with a minnow head seem to attract fish by flash and vibration and the fish flesh may offer olfactory cues. Ice fishermen also set tip-ups with live, cut, or dead bait set just above the bottom. Tip-ups, sometimes called 'traps,' consist of a spool of line held below the surface on a square plastic or wooden stake supported by a pair of cross pieces that cover the ice hole. Bites are signaled when a flag is sprung as line is pulled from the spool. A float line involves setting a float so a weighted bait is held inches from the bottom. The float positions the bait and signals bites. Phosphorescent paints on jigs or hooks also are used on tip-ups by some anglers.

In shallower mesotrophic lakes, burbot are active as soon as ice forms in early December, and anglers targeting perch, walleyes, and northern pike frequently catch them in water from 10 to 30 feet deep. Burbot in these situations may be caught during the day, though the bite intensifies toward dusk and after dark. To fish water in the 30-foot range, anglers selects leadhead jigs from 1/4 to 1/2 ounce or spoons from 3/8 to 5/8 ounce, tipping them with a live shiner Cyprinidae, a shiner head, or a piece of cut fish.

In the Tanana and other Alaskan rivers, anglers target burbot in deep channels, fishing on the bottom with set lines. Some anglers use fishing rods to cast weighted baits into deep holes, much the way anglers fish for catfish Ictaluridae in more southern rivers. In the Tanana River, Evenson and Hansen (1991) reported that 78% of burbot harvest came by open water fishing. Ninety percent of anglers fished with 10 set line hooks or fewer per day. In tailraces, anglers target burbot in deep holes away from the strongest current. Leadhead jigs weighing 1/4 to 3/4 ounce carry a live minnow or piece of cut fish into the depths. In some tailraces, shore fishing for burbot is possible.

Management Implications

Clearly, the burbot makes a fine sportfish because of its broad distribution, large size, tenacious battling behavior, and fine flavor. In waters from Maine to

Alaska, anglers have long appreciated these qualities, and harvest has been limited through various regulations. From coast to coast, more anglers are targeting burbot after discovering its qualities through incidental catches, word of mouth, or by reading publications on the subject. Although some agencies have promoted fisheries for burbot, more efforts should be made by Information and Education offices, field biologists, and agency marketing personnel. Simultaneously, regulations to restrict harvest would be beneficial, to prevent overharvest before population assessments can be made. Also, restrictions on the taking of a fish species seem to create value in the minds of anglers, while unrestricted fish may be viewed as worthless. More biological investigations will be needed to study habitat requirements, basic biology and effects of harvest on populations.

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BURBOT MANAGEMENT: POPULATION CONDITION AND SIZE STRUCTURE ASSESSMENT TOOLS AND THEIR APPLICATION

Shannon J. Fisher
Department of Wildlife and Fisheries Sciences
South Dakota State University
Brookings, SD 57007
(605) 688-6121
email: i2sp@sdsumus.sdstate.edu

Introduction

Declining burbot (*Lota lota*) abundance in some populations has prompted a need for more intensive management. To assess population status and the effects of management actions, additional evaluation tools were needed, including quantifiable and easily communicated measures of condition and population size structure.

Methods

Wege and Anderson (1978) first proposed the use of relative weight (*Wr*) as an index to evaluate fish condition. *Wr* is given by the equation:

$$Wr = (W/Ws)*100,$$

where W is the individual weight and *Ws* is a length-specific standard weight for the species. The form of the *Ws* equation is:

$$\log_{10}Ws = a' + b * \log_{10}L,$$

where *a'* is the y-intercept, *b* is the slope of the $\log_{10}$ (weight)-$\log_{10}$(length) regression equation and, *L* is the total length. *Wr* has been used to evaluate condition of many species and has advantages over Fulton-type indices (e.g., *K*),

including the absence of length-related bias and communication ease because a *Wr* value of 100 represents the 75th percentile level for all fishes (Anderson and Neumann 1996).

Length-frequency histograms allow an initial assessment of population size structure and speculation concerning recruitment, growth, and mortality; however, communicating and quantifying length-frequency data can be difficult. Proportional Stock Density (PSD) and Relative Stock Density (RSD) can provide numerical descriptors of population size structure (Gabelhouse 1984). PSD is calculated as:

$$\text{PSD} = \frac{\text{number of fish} \geq \text{minimum quality length}}{\text{number of fish} \geq \text{minimum stock length}} * 100.$$

Values of PSD range from 0 to 100, should be rounded to the nearest whole number, and are unitless. Anderson and Weithman (1978) defined stock (S) and quality (Q) lengths as percentages of world-record length and Gabelhouse (1984) further described length categories for preferred (P), memorable (M), and trophy (T) lengths. The length categories of S, Q, P, M, and T for all fishes are 20-26, 36-41, 45-55. 59-64, and 74-80% of world-record lengths, respectively. RSD is the proportion of fish in any designated length group in a sample and is calculated as

$$\text{RSD} = \frac{\text{number of fish} \geq \text{specified length}}{\text{number of fish} \geq \text{minimum stock length}} * 100.$$

RSD values are reported in the same manner as PSD.

Results and Discussion

To utilize *Wr*, PSD, and RSD as assessment tools for burbot, a *Ws* equation and length categories had to be established. Weight-length data were compiled for 10,293 burbot from 79 North American populations (Fisher et al. 1996) and a 75th-percentile *Ws* equation using the regression-line-percentile technique (Murphy et al. 1990) was developed. The proposed equation is

$$\log_{10} Ws = -4.868 + 2.898 \log_{10} L,$$

where *Ws* is the standard weight in grams and *L* is the total length in millimeters. The equation is valid for burbot ≥20 cm; the variance of weight measurements on burbot <20 cm is too great to allow reliable calculation of *Wr*. Based on the length of the longest burbot in the data set (104.3 cm), the following minimum standardized length categories were proposed: 20, 38, 53, 67, and 82 cm for S, Q, P, M, and T lengths. Fisher et al. (1996) reported mean *Wr* by length category for 79 burbot populations from throughout the species range in North America.

Mean *Wr* values were assessed by water body type. Water body types were categorized into rivers, lakes <19,000 km^2, lakes ≥ 19,000 km^2, and reservoirs. Burbot populations from rivers and reservoirs had lower mean *Wr* values than lake populations (Fig. 1). Discussions with local biologists, however, did not indicate that the lower riverine *Wr* values were due to health or food resource problems. Therefore, a preliminary *Wr* objective range for burbot in lakes might be 100±5, whereas a range of 80±5 may be more applicable to rivers and reservoirs.

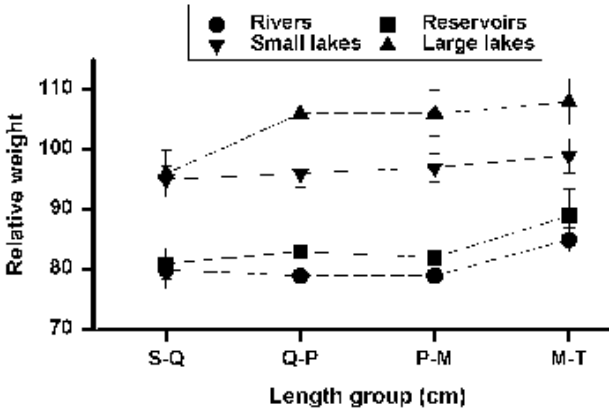


Fig. 1. Means of population relative weights (*Wr*) for stock- to quality-length (S-Q), quality- to preferred-length (Q-P), preferred- to memorable-length (P-M), and memorable- to trophy-length (M-T) categories for burbot populations collected from rivers, reservoirs, large lakes (≥ 19,000 km^2),

and small lakes (< 19,000 km^2). Vertical bars represent one standard error.

Mean PSD, RSD-P, RSD-M, and RSD-T values were also assessed by water body type (Fig. 2). Lake populations had lower stock density index values than reservoirs and rivers, indicating that burbot populations in rivers and reservoirs often include a higher proportion of larger individuals. In fact, some river and reservoir populations had RSD-T values as high as 33, suggesting that 1/3 of the population was composed of old fish ≥ 82 cm. When stock density index values for a population are high (e.g., >70), recruitment may be low or inconsistent. Recruitment problems are sometimes indicated by the absence of small fish that results in high stock density index values. High index values can occur in consistently recruiting populations if adult mortality rates are low and growth rates are high. Consideration must also be given to the time of year and gear type used during sample procurement (Pope and Willis 1996).

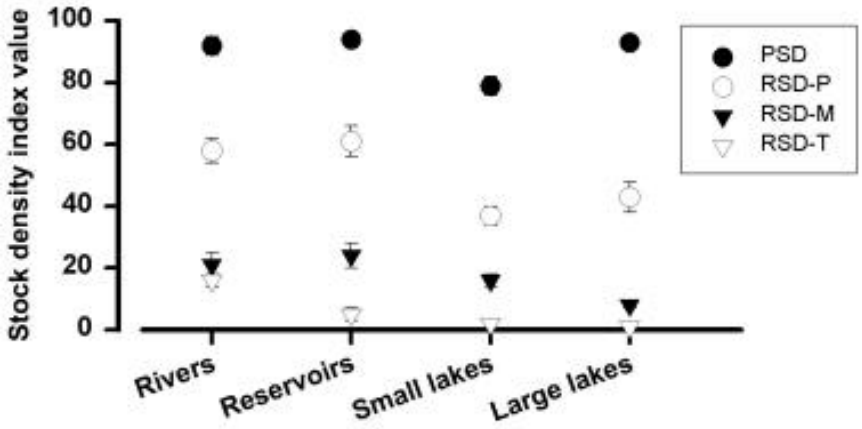


Fig. 2. Mean values for proportional stock density (PSD = percentage of 38-cm and longer burbot that also exceed 20 cm) and relative stock density of preferred- (P), memorable- (M), and trophy- (T) length burbot (RSD-P = percentage of 53-cm and longer burbot that also exceed 20 cm; RSD-M = percentage of 67-cm and longer burbot that also exceed 20 cm; RSD-T = percentage of 82-cm and longer burbot that also exceed 20 cm) for population samples collected from rivers, reservoirs, large lakes (≥ 19,000 km^2), and small lakes (< 19,000 km^2). Vertical bars represent one standard error.

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THERMAL ACCLIMATION CAPACITY

OF THE BURBOT (*LOTA LOTA* L.)

FROM MONTENEGRO

M. Nikcevic,
Center for Multidisciplinary Studies, University of Belgrade, Belgrade, Yugoslavia
29 Novembra 142, 11000, Belgrade, Yugoslavia
fax: +38111 761433; e-mail nikcevic@afrodita.rcub.bg.ac.yu
Hegedish, B. Mickovic, and R K. Andjus,
Center for Multidisciplinary Studies, University of Belgrade, Belgrade, Yugoslavia

Abstract.

According to the capacity for acclimating its routine oxygen uptake to temperature, the adult burbot (*Lota lota* L.) occupies an intermediary position between cold-water trouts, and the more thermophylic cyprinids. Its thermal acclimation is preponderantly of a translational type. In their natural habitat, burbot juveniles actively feed in summer, when feeding of adults is said to be strongly inhibited. *

Introduction

The burbot (*Lota lota* L.) inhabits both the lowland and the highland waters of the Danube basin throughout Serbia and Montenegro. Catches by local fishermen are of negligible economic interest, and restricted to the winter season (December to March), when burbots actively feed. It is known, namely, that feeding, spawning, and embryonic development occur in this species within a narrow temperature interval below 10°C (Tyulpanov, 1967; Volodin, 1960). At summer temperatures, feeding is practically arrested and the fish may even enter a state of summer torpor (Tyulpanov, 1967). Isolated digestive enzymes are

* Some of these data have been briefly reported previously in Yugoslav journals (Nikcevic et al., 1995).

active at temperatures approaching zero, but become inefficient (particularly the proteases) around 20°C (Gomazkov, 1959).

The present report is a brief account of our field studies of the thermal environment of juvenile and adult burbots, and of our attempts to define, by means of experiments with captive fishes, burbot's capacity for thermal acclimation.

Materials and Methods

During summer months (end of May and July), burbot fry (31-87 *mm*, 0.25-5.4 *g*) were electrofished in the coastal region (up to 1 *m* deep) of Lake Plavsko (Montenegro), and adult burbots (27.5-33.5 *cm*) in the nearby river Vruja, a tributary of Lake Plavsko. Captured fry (54 specimens) were immediately fixed for subsequent stomach content analyses, while live adults were transported to our Belgrade laboratory, where they were maintained, during three months prior to the acclimation experiments, in a closed aquaculture system with recirculating refrigerated water (5-9°C). They were fed once weekly with minced hake flesh *ad libitum*.

When acclimating the adults to different temperatures, a daily change of 1°C was applied following the procedure of Beamish (1964). The chosen acclimation level was maintained for additional 30 days before measuring the metabolic rate. Three burbots of similar size were kept per tank, in a series of thermostatically controlled, individually filtered and aerated 50-liter tanks. During the acclimation experiments the fish were deprived of feeding, and maintained in a constant, 12-hr light, 12-hr dark, photic environment.

In acute experiments, group oxygen uptake was measured in groups of three burbots, enclosed in 8-liter respiration chambers supplied with magnetic water stirrers. The temperature in the chamber was increased in a stepwise manner (from 3.5 to 25°C in 7 steps), starting with the lowest temperature in the series. The concentration of dissolved oxygen was recorded continuously by means of an oximeter probe (WTW OXI 96A, EOT 196 electrode). Rates of O_2 uptake, recorded under conditions of routine metabolism, were computed from the linear slope of the concentration of oxygen decreasing over 20 to 40-minute stop-flow, stop-aeration periods.

The classical procedure of Beamish (1964) was applied for converting metabolic rates recorded in fish of different size to the metabolism of 100 *g* individuals. In a series of control experiments, O_2 uptake was measured individually in seven burbots ranging in body mass from 50 to 250 *g* and acclimated to an intermediate temperature of 12°C. The results of these O_2 uptake measurements, performed at the temperature of acclimation (12°C), provided a linear slope in a double logarithmic plot. The value of this slope, defining the dependence of O_2 uptake per fish on body weight, was subsequently used in acclimation experiments for converting metabolic rates recorded in burbots of different size to rates per 100 *g* individuals.

Results and Discussion

Summer feeding activity of the fry.

At the site where juveniles were caught, the temperature of the shallow water differed substantially in May and July: 8.2 and 18.6°C, respectively. The concentration, however, of dissolved oxygen did not differ substantially (10 and 10.8 mgO_2/l). The results of stomach content analyses (10 taxa of prey organisms identified in July, with Ephemerotera prevailing; empty stomachs only in 12% of individuals) indicated that the fry actively feed in summer, at a time when feeding activity of adults is said to be strongly depressed or even arrested. The percentage of empty stomachs was even lower in July than in May. The results, therefore, indicate that the summer inhibition of feeding activity is not operational in burbot fry, at least under the conditions of the habitats presently explored.

Temperature acclimation of adults.

Regardless of acclimation temperature (3.5, 8.3, 15.5, 20.5 and 24° *C*), Arrhenius plots of oxygen uptake as a function of acute temperature (3.5 to 25° C), provided continuous straight regression lines throughout the range of temperatures explored. As shown by the example in Fig.1 (inset), the results are suggestive of a preponderantly translational type of acclimation. $Q_{10(10\text{-}20°C)}$ figures amounted to 2.43 and 2.61 after acclimation to 3.5 and 20.5° C, respectively. Only at acclimation temperatures above 25° C, Q_{10} became substantially reduced. Such a decrease of Q_{10} was reported in other fish species as well, although the range of temperatures within which it occurred varied

(above 30° C in the carp, according to Beamish, 1964). Data displayed in the main panel of Fig.1 compare our burbot data with those concerning fish species commonly used in aquaculture, published by other authors (Beamish, 1964, for *Salvelinus fontinalis* and *Cyprinus carpio*; Florke et al., 1959, for *Salmo gairdneri* according to Beamish, 1964). Our data strongly indicate that the burbot occupies an intermediary position between typically cold-water trout species, and the more thermophylic cyprinids (the carp).

Acknowledgments

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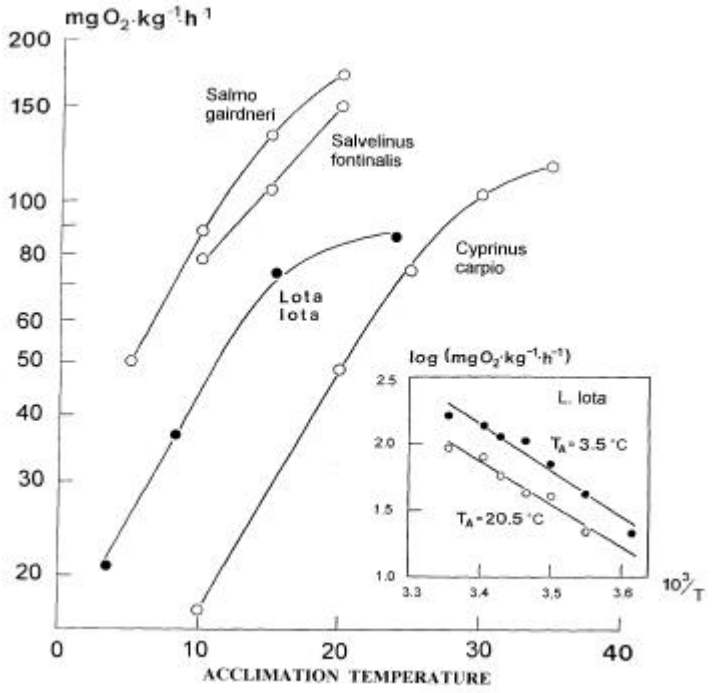


Figure. 1. - Main panel: oxygen consumption of the burbot as a function of acclimation temperature (experimental temperatures equal to acclimation temperatures). Inset: Arrhenius plots of oxygen uptake after acclimation to 3.5 and 20.5° C (closed and open symbols, respectively).

COLLAPSE OF BURBOT FISHERIES

IN KOOTENAY LAKE BRITISH COLUMBIA

AND THE KOOTENAI RIVER, IDAHO

Vaughn L. Paragamian
Idaho Department of Fish and Game
2750 Kathleen Avenue
Coeur d'Alene, Idaho 83815
(208) 769-1414 (208) 769-1418
vparagam@idfg.state.id.us

Jay Hammond
British Columbia Ministry of Environment Lands and Parks
401-333 Victoria Street
Nelson, British Columbia V1L 4K3
(250) 354-6343 (250) 354-6332
jhammond@nelson.env.gov.bc.ca

Harvey Andrusak
Redfish Consulting Ltd.
1514 Atholone
Victoria, British Columbia V8P 2T1
(250) 477-7410 (250) 477-7412
harvey andrusak@bc.sympatico.ca

Abstract

The burbot *Lota lota* is common in the upstream reaches of the Columbia River Basin in the northwestern U.S. and Canada. In Idaho burbot are endemic only to the Kootenai River while they also occur in this same river system in British Columbia as well as Kootenay Lake. The Kootenai River and Kootenay Lake once provided popular sport and commercial fisheries for burbot.

However, soon after the formation of Lake Koocanusa and start of operation at Libby Dam, in 1972, the respective burbot fisheries in the Kootenai River, Idaho, and Kootenay Lake, B.C., collapsed. Our objective was to examine

archived data for the Kootenay Lake and Kootenai River burbot fisheries and document their collapse. The environmental degradation of the Kootenai River and its effects on Kootenay Lake are well documented. Some of these effects are believed to have had a direct impact on the burbot populations in the two respective fisheries. The most serious impact is thought to be Libby Dam, constructed by the US Army Corps of Engineers on the Kootenai River at Libby, Montana, for hydropower and flood control management. Shortly after the dam became operational the fishery in Kootenay Lake rapidly diminished from an annual harvest of over 26,000 burbot in 1969 to none in 1987. Angling regulations for burbot fishing in both bodies of water became more restrictive but the fisheries did not recover; eventually both fisheries were closed. The main reasons for the loss of both fisheries are believed to be high winter flows during the traditional spawning period for burbot and loss of nutrients to the impoundment created by Libby Dam. We propose several directions for research to help recover both fisheries.

Introduction

The burbot *Lota lota* is common in the upstream reaches of the Columbia River Basin in the northwestern U.S. and in Canada. It is also relatively abundant in the other drainages of western Canada (McPhail and Lindsay 1970). In many locals of northwestern U.S. and western Canada it is called 'ling' and is a popular sport and food fish. In Idaho burbot are endemic only to the Kootenai River (Simpson and Wallace 1982). They are also endemic to this same river system in British Columbia (B.C.) and Kootenay Lakea which is in the basin (Figure 1).

The Kootenai River and Kootenay Lake once provided popular sport and commercial fisheries for burbot. However, soon after formation of Lake Koocanusa and start of operations at Libby Dam, Montana, both fisheries collapsed. Our objectives were to examine archived data for these fisheries and document the chronology of the collapse, review harvest and creel data for Kootenai River, review agency catch records for Kootenay Lake and Kootenai River, interview anglers to help document the antidotal change in the fisheries, review the literature for plausible reasons for their demise, and to plan reasonable research and management measures that may lead to recovery.

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a Kootenai is spelled Kootenay in Canada.

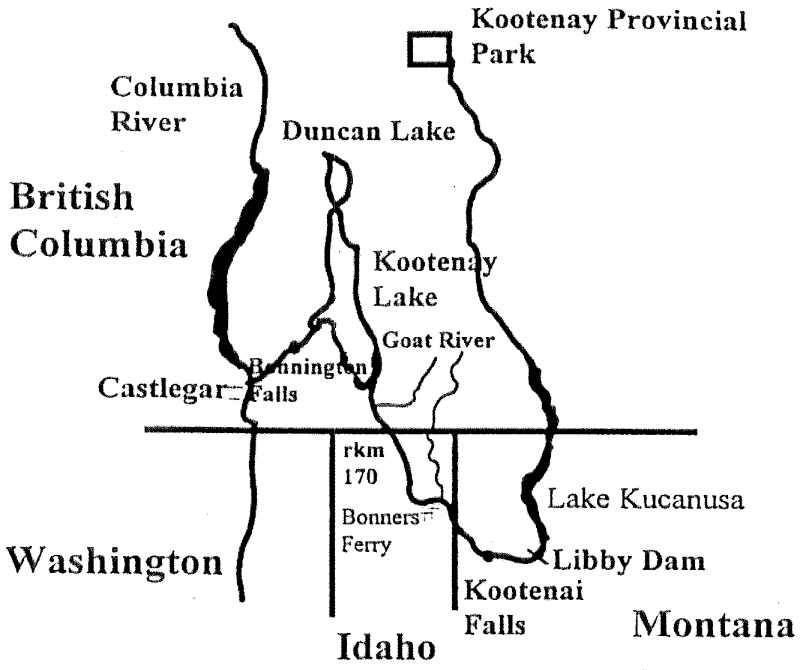


Figure 1. Location of the Kootenai River, Kootenay Lake, Libby Dam and other major points in British Columbia, Idaho and Montana.

Kootenai Basin

The Kootenai River is part of the upper Columbia River drainage, is the second largest tributary to the Columbia River, originates in Kootenay National Park, B.C., and has a drainage of 49,987 km^2 (Bonde and Bush 1975) (Figure 1). From Kootenay Provincial Park the river flows south through B.C. and into Montana, at Libby it is impounded forming Lake Koocanusa. From Libby Dam, the river turns west, then travels northwest into Idaho, then north into B.C. and Kootenay Lake. The river drains Kootenay Lake through the West Arm, and joins with the Columbia River near Castlegar, B.C.

The geological history of the Kootenai River system can be traced back to the Wisconsin Glacier and glacial Lake Kootenay (Alden 1953). Colonization of

the river with a variety of fish species is thought to have occurred during this period (Northcote 1973). Many changes have occurred since then including channelization, dyking, eutrophication, nutrient reduction, and dam construction and operation.

Historic Status of Burbot

Kootenai River, Idaho

The earliest records of burbot sampling in the Kootenai River, Idaho were taken from the Idaho Department of Fish and Game (IDFG) Panhandle Region archives. They indicated Department personnel caught 199 burbot in a 2-year period of winter sampling, 1957 and 1958. The
length-frequency distribution demonstrated an abundance of young fish (350 to 500 mm) total length and a good representation of older fish. The burbot fishery in Idaho, was primarily in the winter. The combined average annual catch by the sport and commercial fisheries in Idaho during the 1960's was thought to have been over 23,000 kgs (Ned Horner, IDFG Regional Fish Manager, personal communication). Soon after completion of Libby Dam, a substantial reduction in the abundance of burbot was noted. Partridge (1983) captured a total of 108 burbot using three different gear types from 1979 through 1982. He found fewer fish than the archival records, and in 1979 caught only 8 fish (or one burbot/16 net days) "with a similar amount of effort" that was used to catch burbot in 1957 and 1958. Although all age groups vulnerable to sampling gear appeared in Partridge's catch, he believed the abundance was substantially less compared to the late 1950's.

The Kootenai River Fisheries Investigation was initiated in 1993 and was designed to address burbot abundance, distribution, size, reproductive success, movement, and to identify factors limiting burbot in the Kootenai River (Paragamian 1993). A total of only 17 burbot were caught in 1993 (CPUE one burbot/33 net days) and 8 in 1994 (CPUE of one burbot/111 net days). However, numerous age groups of fish were apparent in the net catch indicating burbot were spawning somewhere. One burbot was sampled between Bonners Ferry and the Montana border and there was no evidence of reproduction in Idaho. Sampling for burbot during the winter of 1993 through 1994 at the mouths of Idaho tributaries was carried out in anticipation of intercepting a spawning run of fish from Kootenay Lake or lower river; no burbot were caught.

Anglers were interviewed and asked about their fishing experiences, and we reviewed IDFG archives. Anecdotal information indicated an excellent winter fishery was present from the 1950s through the early 1970's. Anglers reported catching many burbot through the ice on set lines. Warmer water temperatures because of the outflow from Libby Dam eliminated the winter ice fishing. Spearing of burbot on spawning runs in tributaries like Snow, Caribou, and Deep Creeks accounted for many fish, and there was no departmental limit to the harvest of burbot. Some anglers reported filling gunny sacks with fish. It was believed that many of these burbot were from Kootenay Lake, B.C. (Partridge 1983). Burbot regulations in Idaho were very liberal until 1983 when a two-fish limit was adopted. This was followed in 1992 by a ban on all burbot harvest . The burbot harvest from 1979 through 1982 was estimated at less than 250 fish/year. Burbot were nonexistent, even as a non-target species, in a creel survey that extended from spring 1993 through spring of 1994 (Paragamian 1993; Paragamian 1994).

Kootenay Lake, B.C.

We examined archived information from of the B. C. Ministry of Environment fisheries office in Nelson, for the same time period as the change in the fishery in Idaho. The burbot fishery in Kootenay Lake was primarily a late spring-early summer fishery. Management of burbot in Kootenay Lake was also liberal, with a limit of 15 fish/day into the mid 1960's, although in 1967, the limit was lowered to 12/day (Sinclair and Crowley 1969). Burbot were concentrated in the Balfour area of the West Arm of Kootenay Lake, and were very vulnerable to angling. The concentration of burbot on the locally know “ling beds” perhaps was likely due either to the abundance of Mysid shrimp used as food and/or spawning habitat (Andrusak and Crowley 1978). Over 26,000 burbot were caught in 1969 and about 20,000 in 1971 (Figure 2). The angling catch rate of burbot averaged about 1 fish/h during this period (Figure 2). Harvest of burbot declined substantially in the following years, and the limit was reduced to 10/day in 1975 (Andrusak 1976). The need for more intensive management was apparent (Andrusak and Crowley 1976) and a potential production and harvest study was undertaken. The findings of the study indicated an optimum sustainable yield of about 12,000 burbot at 14,560 rod hours would sustain the fishery (Martin 1976). The limit of burbot was reduced to 5 fish/day in 1976 although no improvement in the burbot population was observed. The harvest of burbot continued to decline through the 1970's, although angling catch success remained at about 0.7 fish/h (Figure 2). The burbot fishery collapsed, and as of 1987 no fish have been recorded in the fishery at Balfour; the lake was

closed to burbot fishing in 1997. No burbot were caught during two weeks of sampling in the West Arm in 1994 (Paragamian 1994).

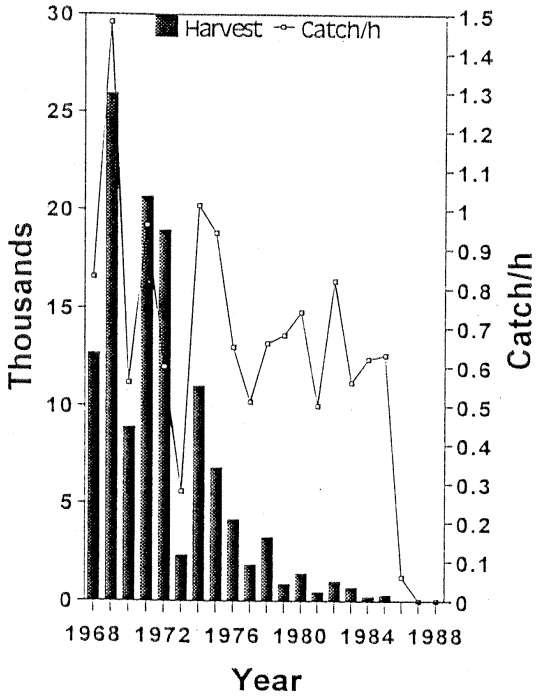


Figure 2. Sportfishing harvest and catch success (fish/h) of burbot from the West Arm of Kootenay Lake, B.C.

Without any knowledge of environmental stresses to the burbot fishery, the assumption could be made that over-exploitation led to the demise of the population. During the same time interval of the collapse as the burbot fishery other fish populations declined, e.g. kokanee *Oncorhynchus nerka*, white sturgeon *Acipenser transmontanus*, and to a lesser extent rainbow trout *O.mykiss*.

Cooperative sampling by U.S. and Canadian researchers in the Kootenai River in B.C. and Idaho, from 1994 through 1996 (Paragamian 1995; Paragamian and Whitman 1996), indicated the density of burbot in the Kootenai River diminishes rapidly upstream of the Goat River, B.C. Only one burbot was

caught from late November 1995 through April 1996 in Kootenai River, Idaho. Hoop nets fished from rkm 145 to 170 during the winter of 1994-1995 yielded only two fish upstream of the Goat River while 31 additional burbot were caught in the Goat River and downstream during that same period.

Potential Reasons for the Burbot Collapse

Exploitation

Over-exploitation of the burbot in Kootenay Lake and the Kootenai River was a concern for fish managers when it became evident the fisheries were at risk of failing. Measures were taken to reduce exploitation by reduction in creel limits and fishery closures but none of these measures restored the fisheries. In contrast to the Kootenai River burbot population may be the burbot fishery in Lake Michigan. The burbot fishery there was on the brink of extirpation because of predation by the invading sea lamprey *Petromyzon marinus* (Smith 1968; Wells and McLain 1973). After development of a selective toxicant for sea lamprey and control of this exotic, the burbot population rebounded without stocking, and their commercial landings increased almost five-fold (Fratt 1991). During the time when burbot populations were depressed there were no reported changes in the environment. Thus, the resiliency of the burbot in Lake Michigan enabled this stock to rebound when habitat was unaltered, whereas the burbot populations in the ecologically disturbed Kootenay Lake and Kootenai River systems have not improved despite fishing closures.

Burbot stocks in Alaska have been shown to be vulnerable to over-exploitation (Vincent-Lang 1993; Mills 1994). However, after restrictive angling regulations and closures were applied to these fisheries the burbot populations in at least some lakes responded with improved age structures and densities (Taube and Bernard 1995). The burbot fishery in Columbia Lake also declined because of over-exploitation but recovered after angling restrictions were applied (Bill Westover, B.C. Ministry of Environment, personal communication).

Environmental Degradation

The history of environmental degradation to the Kootenai River and its ecosystem is well documented (Northcote 1973, Cloern 1976, Daley et al. 1981, Partridge 1983; Anonymous 1996). Logging and mining in the drainage have

always been an environmental concern, particularly with the release of heavy metals and their subsequent toxicity (Partridge 1983). The natural conditions of the Kootenai River no longer exist. Logging and mining operations as early as the 1880's caused tributary discharge to flash and physically changed the streams and caused siltation (Northcote 1973). Additional disturbances came to the drainage in 1892 with attempts to dike the lower reach of the river and claim land for agricultural uses (Northcote 1973). Mining added to the deterioration of the water quality in the tributaries and river, and from 1953 through the 1970's, operation of a fertilizer plant on the St. Mary River greatly increased nutrient loading (Northcote 1973). Most of these physical changes, however, came about many years before Libby Dam thus it is unlikely they could be responsible for such a dramatic decline in the burbot fishery.

Reduced Productivity

Artificial eutrophication because of pollution from a fertilizer plant on a tributary to the Kootenay River in B.C. brought about an elevation in productivity, particularly in Kootenay Lake (Northcote 1973). Pollution abatement in the mid-1970s and the impoundment of water and consequential settling of sediment nutrients behind Libby Dam reduced the nutrient loading to the river (Daley et al. 1981; Snyder and Minshall 1996).

If food is limiting, reduced food abundance could equate to lower survival of young burbot. Larval burbot can be pelagic (Faber 1970) and feed on a variety of micro and macro organisms in the water column including rotifers, copepod nauplii, copepods, and cladocerans (Vachta 1990, Ryder and Pesenderfer 1992; Ghan and Sprules 1993). After Libby Dam was constructed there was a precipitous decline in the catch of burbot from the West Arm. In an effort to estimate how this reduction in productivity may have affected the harvest of burbot, we examined the annual harvest of burbot and ortho-phosphate (ortho-P) levels in the South Arm of Kootenay Lake at spring turn-over (Daley et al. 1981). Ortho-P is a good indicator of potential primary production (Jones and Bachman 1974). Annual harvest of burbot from 1971 through 1982 (Figure 2) was paired with ortho-P levels four years prior, 1967 through 1978, and then evaluated through regression analysis. A four year lag period was used for ortho-P levels because burbot recruited to the fishery at age 4. This would reflect any affect on productivity of age 0 burbot, productivity of their first year of life, and productivity of the remaining stock for that year. The resulting analysis suggested up to 56% of the variation in harvest was due to productivity

of the lake four years prior (P=0.014). Ortho-P plummeted from concentrations of 80 to 90 u/L in the late 1960's to 4 u/L by 1978 (Daley et al. 1981).

Water Management

As productivity was changing because of pollution abatement and impoundment of Lake Koocanusa, the natural Kootenai River was converted to a regulated system. High summer flows through the West Arm disappeared as a consequence of impounding water in Lake Koocanusa, during the prime months for the burbot fishery in the West Arm of Kootenay Lake; this may have affected the burbot fishery. The West Arm fishery was unique in that a shallow shelf at the mouth of the West Arm formed a trap for Mysis shrimp, a food source for burbot. (Martin and Northcote 1991). We also compared the harvest of burbot to the spring discharge out the West Arm for the same years as ortho-P, i. e., 1971 through 1982. The results suggested a significant correlation (P=0.013, r^2= 0.557) between discharge and harvest. Discharge data and ortho-P concentrations were then combined in a multiple regression model (P=0.000. R^2=0.95),1981 through 1987. Stepwise regression analysis indicated ortho-P levels were the best predictor of burbot harvest. Reduced productivity of the lake reduced zooplankton densities (Ashley et al. 1994) and this could have been a more important factor re: the reduced numbers of burbot.

Temperature Changes

Disturbance of the Kootenai River ecosystem was heightened by the construction and operation of Libby Dam and impoundment of Lake Koocanusa. Libby Dam was created under an International Columbia River Treaty between the U.S. and Canada for cooperative water management of the Columbia River Basin (Columbia River Treaty 1964). Construction of the dam began in 1966 by the U.S. Army Corps of Engineers (USACE). Its main purpose is hydropower production, with secondary benefits of flood control and navigation. Impoundment of Lake Koocanusa and regulation of downstream flows began in March of 1972. Temperature also increased by 3^{o}C (Partridge 1983). Under the present operation, the river now remains ice-free during the winter.

We considered the possible consequences of post-dam changes in winter flows and temperature of the Kootenai River downstream of Libby Dam. Burbot are winter spawners and often spawn under the ice in January through March

(Becker 1983). Prior to the dam, the Kootenai River froze frequently during these months. Burbot spawn at about 1.5^{o} C, or near freezing temperatures (Becker 1983; MacKay 1963). Since 1974, the winter river temperatures are now 3-4^{o} C as opposed to the pre-dam years of near 1^{o}C and less. It seems unlikely that temperature in itself could have led to the demise of burbot because some populations are known to spawn at slightly warmer temperatures, although burbot appear to be attracted to colder water (Paragamian 1995). Recent test sampling in the North Arm of Kootenay Lake has revealed burbot spawning at about 4^{o} C. It is not known if these burbot are of the same stock as fish in the South Arm and the river but it is possible that there may be more than one stock of burbot.

Hydropower and Flood Control

After completion of the dam, mean monthly flows downstream during spring were reduced by 50%, and winter flows tripled, changing dramatically (Figure 3). Prior to Libby Dam the natural discharge during January-February slowly increased in June to a peak spring freshet from melting snow in the mountains. At present, average discharge is higher during September to February than before the dam. Winter hydropower and with it power peaking may play a key role in inhibiting populations of fluvial and adfluvial burbot in the Kootenai River from moving to spawning areas and tributaries. Current velocities in the lower Kootenai River are subject to change with daily winter operations at Libby Dam, the factors responsible for the reversed hydrograph, and elevation of Kootenay Lake. Burbot are weak swimmers and have a low endurance for extended periods of increased flow with a critical velocity of 24 cm/s (Jones et al. 1974) (Figure 4). Flows in the Kootenai River at Copeland, Idaho, above 255 m^3/s produced average current velocities higher (>24cm/s) than the critical velocity for burbot (Paragamian 1995). Flow near the Idaho/ B.C. border can often be as high as 510 m^3/s during normal winter operations of Libby Dam.

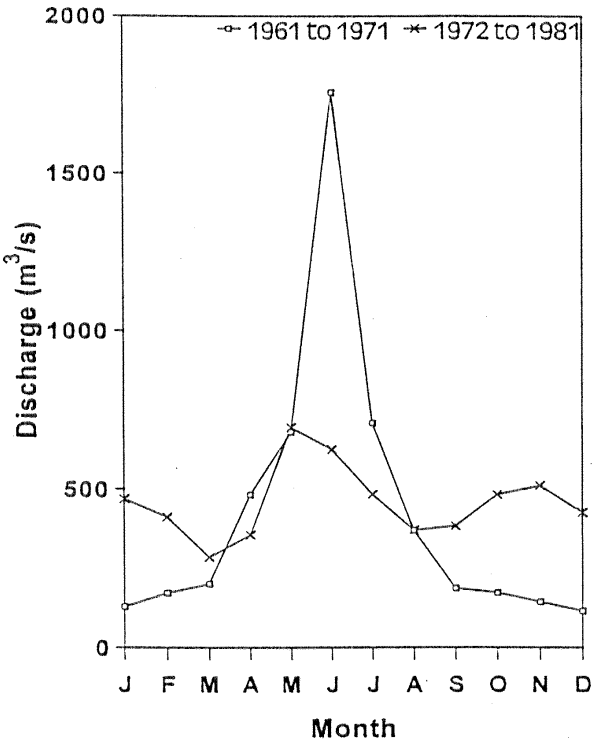


Figure 3. Mean monthly discharge in the Kootenai River at Bonners Ferry, Idaho, from 1961 through 1971 (pre-Libby Dam) and from 1972 through to 1981 (post Libby Dam).

Burbot can move extensive distances during the winter to spawn (McCrimmon 1959, Morrow 1980, Breeser et al. 1988; Evensen 1993). In some systems they move as far as 125 km to spawn (Breeser et al. 1988). The winter months are normally the most environmentally stable times of the year which would allow weak swimmers like burbot the opportunity to travel great distances to spawn. In the Kootenai River traditional spawning tributaries in Idaho are 50 to 120 km from Kootenay Lake. Tagging and telemetry studies in the river have shown that burbot in Idaho move freely between the lake and the river in Idaho, providing flow conditions are low. Paragamian (1995) provided telemetry data

that suggested high flows during the winter inhibits spawning migrations of burbot in the Kootenai River. In addition to these movements Paragamian (1994) captured three female burbot in Idaho that still had eggs well past the traditional spawning season while an unspawned male was also caught (Paragamian and Whitman 1996).

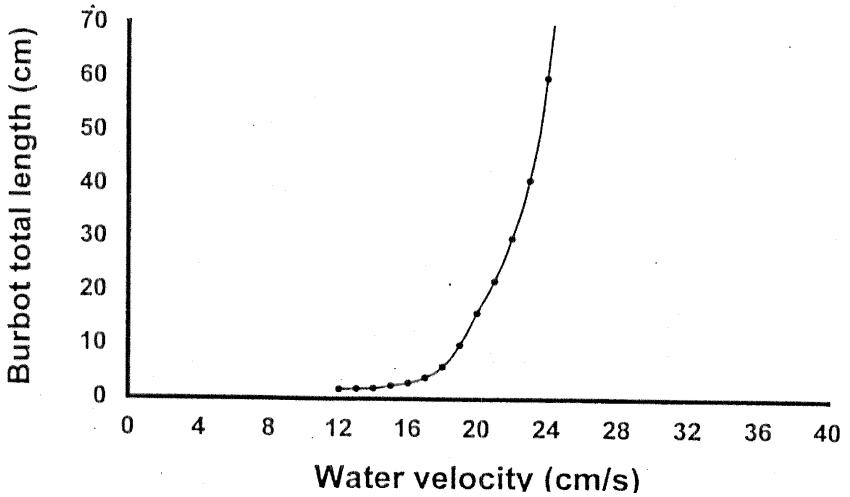


Figure 4. Critical velocities for burbot swimming performance and endurance, data from Jones et al. (1974).

These data and the timing of the collapse with the operation of Libby Dam implicates winter hydropower and flood control operations as important factors that have led to the collapse of the burbot populations. McPhail (1995) stated " although burbot populations often increase after impoundment, the downstream effects of impoundment can be detrimental". Burbot are plentiful in Lake Koocanusa, Montana (Don Skarr, Montana Department of Fish, Wildlife, and Parks, personal communication) and make up a portion of the fish entrained through Libby Dam (Skarr et al. 1996). High flows very well could have, altered their behavior, disrupted the spawning synchrony of burbot [they are considered highly ordered in their spawning (Becker 1983)], it may have effected their physiological fitness, or spawning readiness.

Research Focus

Winter water management and the loss of productivity/nutrients are two critical changes in the Kootenai River ecosystem that appear to be the most likely reasons for the collapse of the burbot fisheries. Data from the literature and our own preliminary study has shown how these changes could seriously impair the life history processes of burbot. Research efforts should direct attention to locating burbot spawning areas in the system, monitoring adults and their responses to changes in flow during the pre-spawn and spawning season, and focusing on environmental factors that may affect early life history. In addition, means of restoring the productivity of the Kootenai River and South Arm of Kootenay Lake should also be explored as an option for restoring burbot.

Burbot in the Kootenai River and Kootenay Lake are transboundary fish. Recent genetic studies have revealed that burbot from the South Arm of Kootenay Lake and from Idaho are of the same stock but differ from fish in Montana (Paragamian et al. In press). It is therefore of paramount importance that researchers and managers in B.C. and Idaho work jointly in their efforts to restore burbot.

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THE EFFECTS OF VARIABLE FLOWS AND TEMPERATURE ON BURBOT SPAWNING MIGRATIONS IN THE KOOTENAI RIVER, IDAHO, USA, AND KOOTENAY LAKE BRITISH COLUMBIA, CANADA, POST LIBBY DAM

Vaughn L. Paragamian
Idaho Department of Fish and Game,
2750 Kathleen Avenue, Coeur d' Alene, Idaho 83814 USA
(208) 769-1414 (208) 769-1418
E-mail: vparagam@idfg.state.id.us

Introduction

The burbot *Lota lota* is a holarctic freshwater member of the family Gadididae (McPhail and Lindsay 1970). It is found throughout Canada, Alaska and the northern tier of states in the US. In Idaho it is endemic only to the Kootenai River (Simpson and Wallace 1970) and is also found in Kootenay Lake and River in British Columbia (B.C.). The burbot once provided important sport and commercial fisheries in the Kootenai basin with an estimated harvest of 26,000 fish from the west arm of Kootenay Lake, B.C., in 1968 (Paragamian et al. 1998) and an estimated annual harvest of over 23,000 kg in the Kootenai River, Idaho (Ned Horner, Idaho Department of Fish and Game Regional Fisheries Manager, personal communication). However, soon after completion of Libby Dam by the US Army Corps of Engineers (USACE), on the Kootenai River in Montana, the two respective fisheries collapsed (Paragamian et al. 1998). Despite increasing restrictions to the angler harvest of burbot neither fishery recovered and each was eventually closed to fishing.

Operation of Libby Dam for hydropower and flood control during the winter reversed the river hydrograph and created warmer winter water temperatures (Partridge 1983 and Paragamian 1993), winter flows are now more erratic and 300% greater than before (Figure 1). In addition, Lake Koocanusa, the

impoundment created by Libby Dam, acts as a nutrient sink and has reduced the productivity of the river downstream (Snyder and Minshall 1996) and that of Kootenay Lake (Northcote 1973).

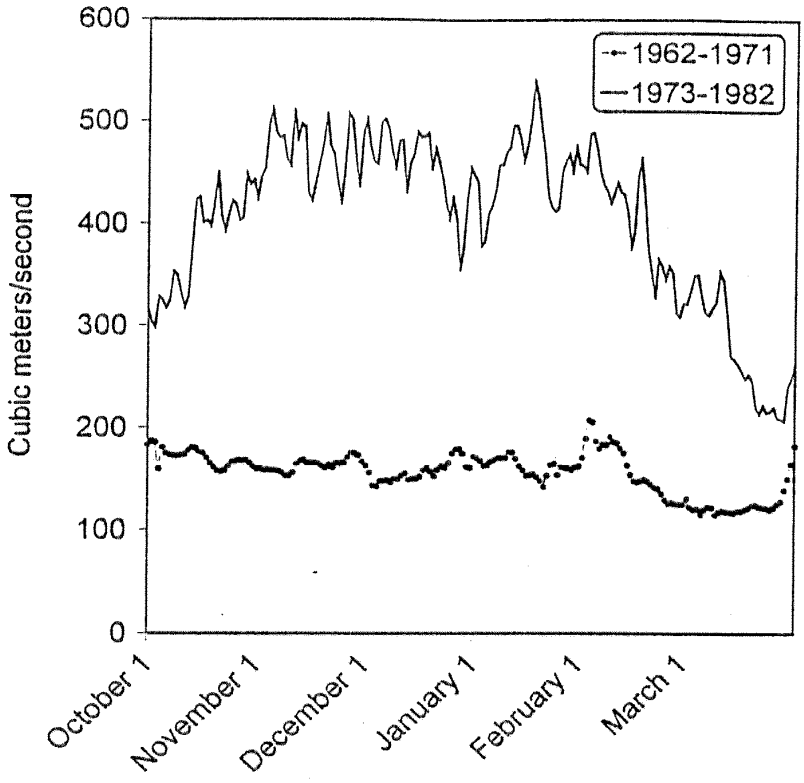


Figure 1. Mean daily discharge rates from October through March for the Kootenai River at Bonners Ferry, Idaho, for pre-Libby Dam (1962-1971) and post-Libby Dam (1973 - 1982).

Burbot are winter spawners and are known to travel over 125 km to spawn (Bresser et al. 1988). In the Kootenai River burbot are thought to have traveled up to 120 km from Kootenay Lake, to spawn in tributaries in Idaho. The winter is the most environmentally stable period of the year and prior to Libby Dam

flows in the Kootenai River were at there lowest seasonal level (Figure 1). Burbot are weak swimmers and have low endurance (Jones et al. 1974), thus it is likely any change in flow could effect spawning migration.

My initial objective was to make general observations of burbot spawning behavior using sonic telemetry (1994 - 1995). Results of the initial objective directed proceeding studies to the examination of the effects of water management on burbot migrations by testing the H_1 hypothesis: high velocities created by winter discharge for power production and flood water evacuation disrupts burbot spawning migration.

I also examined how velocities within the river could vary with changing flows, how velocities between river reaches could differ, and how temperature might effect the distribution of burbot. My goal was to provide information that would be useful to the management and eventual recovery of burbot in Idaho and B.C.

Study Area

The Kootenai River is in the upper Columbia River drainage, it is the second largest tributary in the basin. The river originates in Kootenay National Park, B.C., in the Canadian Rockies and has a drainage of 49,987 km^2 (Bonde and Bush 1975). From the Canadian Rockies the river traverses south into Montana. Near Libby, Montana, the river is impounded forming Lake Koocanusa. From Libby Dam, the river turns west, then northwest into Idaho, then north into British Columbia and Kootenay Lake. Kootenay Lake drains out the West Arm, and eventually the river joins the Columbia River near Castlegar, B.C. My study area was the reach of the Kootenai River from Bonners Ferry, Idaho, to Kootenay Lake, B.C., and the South Arm of Kootenay Lake.

Methods

Sampling adult burbot

Technicians sampled burbot in the Kootenai River in Idaho and B.C., (rkm 120 to 245) in anticipation of intercepting burbot moving from Kootenay Lake and the lower river to their historic spawning areas. Burbot were usually sampled from November through April each year (occasionally earlier or later) with seven to 12 hoop nets of two sizes (Bernard et al. 1991) . Each net was baited with fish before deployment. Nets were checked every 24 to 72 h. Fish

captured in hoop nets were identified, enumerated, measured in total length (TL) and weighed. All burbot were passive integrated transponder (PIT) tagged in the left cheek muscle and released.

Implanting sonic transmitters

Adult burbot selected for telemetry were surgically implanted with either a 420 d, 40 d, or 60 d sonic transmitter (Paragamian 1995). Before surgical implantation burbot were anesthetized in about 25 mg tricanmethanolsulfanate (MS-222)/L or CO_2. The fish were then placed in a cradle (Courtois 1981) and continuously bathed with water and anesthetic. Sonic transmitters were implanted according to the procedures of Hart and Summerfelt (1975), and size of transmitter was apportioned to the size of burbot. Sex of most fish was determined during the surgery. After completion of surgery burbot were allowed a recovery period of 20 min and usually released at the location of capture.

Movements of burbot were studied throughout the year but intensity varied with the season, only the autumn and winter movements are reported in this ms. In general burbot were monitored once a week from April through September, several times a week during October and November, nearly daily from December through February, and daily several days prior to, during, and immediately after a flow test. When burbot were located by telemetry, depth was measured with an echo sounder, and nose velocity was measured within 15 cm of the bottom using a Marsh-McBirney 2,000 electronic current meter. ANOVA was used to statistically test differences in nose velocities during various unrestricted water management and control periods of low flow.

Kootenai River discharge, velocity, and temperature

Daily discharge from Libby Dam and temperature values for the Kootenai River were obtained from USACE and the U.S. Geological Survey (USGS) office in Sandpoint, Idaho. Prior to the onset of burbot sampling, from autumn 1995 through 1997, a conditional agreement was formulated with Bonneville Power Administration (BPA) and USACE to provide experimental minimum flows for burbot prespawn migrations. There were to be three minimum discharge ($113 m^3/s$) periods from Libby Dam of approximately five days duration during November, December, and January for the winters of 1995-1996, 1996-1997, and 1997-1998. It was hypothesized that these minimum flow periods would allow burbot to move upstream by replicating pre-dam winter river flow. In

turn, it was expected that the return of unrestricted water management after each minimum test flow would inhibit upstream movement or even move burbot back downstream.

I used Chi-quare analysis to detect differences in burbot movement during flow tests and unrestricted winter operation of Libby Dam. I evaluated daily movement in three categories; no movement, upstream, and downstream during two treatments ; low flow controls and unrestricted water management. Burbot movement was interpreted as $\geq$.1 km and $\geq$ 1.0 km. Telemetry data sets were combined and analyzed by month; November, December, and January. I also studied the supposition that at low vs high flows from Libby Dam some locations in the Kootenai River may become velocity barriers to burbot. The river was segmented into three reaches based on major hydraulic controls; reach 1 - rkm 120-132 (downstream of the east channel), reach 2 - rkm 133-152 (downstream from the mouth of the Goat River), and reach 3- rkm 153-175 (from the Goat River to five km above the Idaho/BC border to Smith Creek). Two rkm locations within each segment were selected from a table of random numbers where average velocities would be measured. Velocities were measured approximately 15 cm above the river bottom using a Gurley 2030R flow meter suspended by a rope with 0.67-0.84 kg of lead weight attached. On December 21, 1995, (maximum flow from Libby Dam) velocities were measured and repeated on February 16, 1996, at a much lower flow. To test for differences at the two discharge rates I used (ANOVA).

Results

Burbot catch, telemetry, and river temperature and flow

Winter 1994-1995 Technicians caught 33 burbot in the Kootenai River, B.C., from November 1994 through February 1995 and averaged one fish/21.5 net days. TL ranged from 385 to 958 mm (Figure 2) and they weighed from 272 to 4,086 g (mean = 982 g). Fourteen burbot were monitored during this study period. They included two burbot that were previously implanted with sonic transmitters (Paragamian 1994) and 12 implanted and released at capture sites in the B.C. portion of the Kootenai River (Appendix Table A).

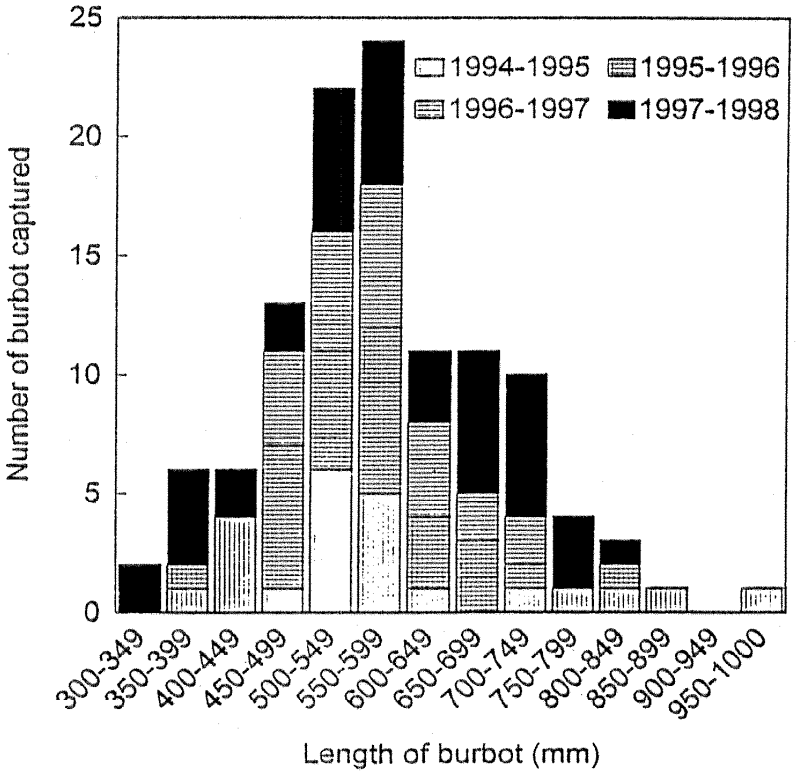


Figure 2. Length frequency distribution of burbot caught in baited hoop nets in the Kootenai and Goat Rivers, 1994 through 1998.

Six burbot were monitored during the pre-spawn period of November 24, 1994 through January 15, 1995. Initially, most burbot remained in deep pools in close proximity to release sites. River discharges at this time from Libby Dam were usually between 383 and 510 m^3/s. Temperature of the Kootenai River was 5^oC. On two occasions discharges from Libby Dam were reduced from about 510 to 113 m^3/s, On December 16, 1994 and January 11, 1995. Temperature of the river remained at 5^oC. On each occasion burbot moved upstream several km when discharge was decreased. But burbot drifted downstream when discharge increased to 510 m^3/s. Burbot returned to the vicinity of their release or were

located further downstream. Burbot 96 had not been located since July 7, 1994, but was relocated in Crawford Bay of Kootenay Lake (rkm 85) on December 13, 1994. It was located at rkm 116 on January 1, 1995, at the mouth of the Kootenai River.

Twelve burbot were monitored between January 15 and February 27, 1995. The most notable burbot movement occurred after January 27 when discharge was again reduced and stabilized at 113 m^3/s. Temperature of the Kootenai River was 4°C to 5°C. Most burbot moved upstream to the confluence with the Goat River where the temperature was 1°C to 2° C. I measured temperature of the Goat and Kootenay Rivers and prepared a temperature profile of the confluence of the rivers (Figure 3). Most burbot staged in the cooler mixing portion of the Kootenai River.

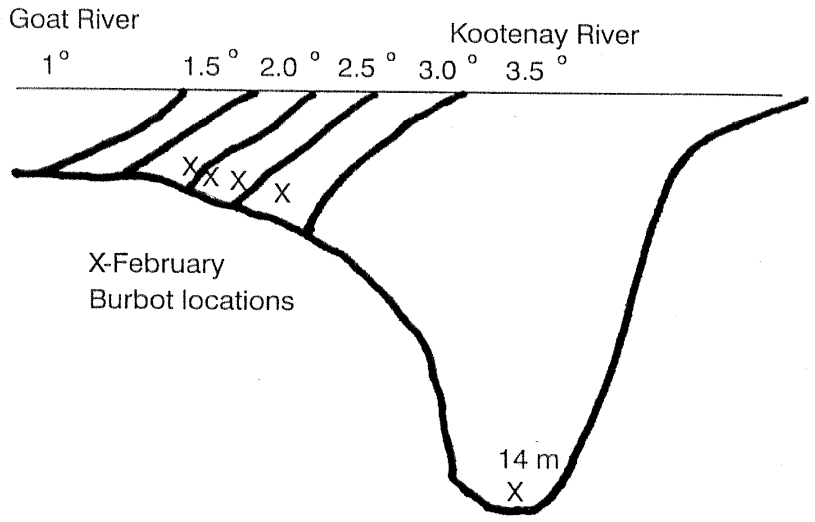


Figure 3. Temperature profile at the confluence of the Goat and Kootenai Rivers, January 27, 1995, and the location of five burbot (x).

The last two burbot to be implanted (446 and 3334) were captured at the confluence of the two rivers. They remained in that reach for several days then bypassed the Goat River in late February when the temperature of the two rivers was the same (5°C). Burbot 446 reached rkm 191.9 (in Idaho) in late May and drifted downstream to rkm 186, while 3334 remained in a deep pool (25 m) at

rkm 190. Burbot 96 moved upstream to rkm 197 then downstream in late March and was later relocated on the east side of Kootenay Lake (rkm 117.9) on June 25, while 446 and 3334 eventually returned to the lake, none of these burbot demonstrated any spawning behavior.

During the winter of 1994-1995 there were 17 observations when a burbot moved greater than 1 km between telemetry contacts. Five burbot moved down stream when discharge went up, two fish went down when discharge went down, ten moved upstream when discharge went down, and none moved up when discharge went up. The Fisher Exact Test indicated a significant relation existed between burbot movement upstream and flow (P=0.0034).

During the winter of 1995-1996, researchers captured 27 burbot in the Kootenai River, Idaho and the Goat River, B.C., Canada. No burbot were caught in the B.C. reach of the river but 26 were caught at the mouth of the Goat River. Burbot catch from November 1995 through March 1996 averaged one fish/18.2 net-days. Captured burbot ranged from 396 to 830 mm TL (Figure 2) and weighed from 400 to 2,800 g (mean = 1,376 g). One burbot was captured at rkm 170 (the Idaho/Canada border) in mid-March, after the spawning season.

Heavy precipitation from autumn 1995 through winter 1995-1996 prohibited a low flow pre-spawn migration test for burbot. Only burbot with sonic 96 could be monitored during the pre-spawn period. Burbot 96 spent the summer of 1995 in Kootenay Lake. In August of 1995 it reentered the river and moved upstream entering Idaho in early September and was located at (rkm 244). During October 1995 it drifted 2 rkm downstream and was sedentary throughout the spawning and pre-spawning period. No other burbot could be located or captured during the pre-spawn period to monitor movement.

Flow from Libby Dam during the pre-spawn period ranged from 113 - 765 m^3/s from November 1995 through January 1996 but ranged from 162 m^3/s in early October, 1995 to 1,205 m^3/s on December 14, 1996, at the Idaho/B.C. border.
Eight burbot were monitored between February 13 and February 26, 1996 (Appendix Table A), all were tagged in the Goat River. Temperature of the Kootenai River ranged from 2 to 5^oC. Telemetry indicated most burbot were within the confluence of the Goat River with the Kootenai River where the temperature was <1 to 3^oC. None were known to move further up the Goat River during the spawning season. But telemetry upstream beyond the mouth of the Goat River was occasionally limited by ice formations. Approximate nose

velocities were recorded. Velocities ranged from <1 to 40 cm/s with a mean of 15 cm/s.

In the winter of 1996-1997, twenty three burbot were captured in the Kootenai River, Idaho and B.C., only two of which were caught in Idaho. Burbot catch averaged one fish/45.6 net days. Burbot ranged from 450 to 743 mm TL (Figure 2) and weighed from 700 to 2,700 g (mean=1,323 g). Two burbot previously implanted with transmitters were at large during the first pre-spawn minimum flow test, 374 and 357 (Appendix Table A). Burbot 374 progressively moved upstream from about rkm 133 to rkm 144 during October to a pool that was already occupied by 357. Water temperature during this migration was about 10^{o} C. Both burbot remained at about rkm 144 until the first test flow when flows were reduced from about 425 m^3/s on November 13, 1996 to 113 m^3/s on November 15. Within two days of the initiation of the test flow; 374 moved from rkm 142.8 on November 15 to rkm 150.7 on November 22, burbot 357 could not be located. When the unrestricted operation of Libby Dam resumed on November 24 burbot 374 returned to rkm 144.0.

The second pre-spawn flow test started on December 25, 1996 and lasted only three days. Nine burbot had sonic transmitters at the initiation of this test. Six burbot were already in the immediate vicinity of the Goat River. This brief test did not result in any obvious burbot movement.

Eleven burbot were monitored between February 1 and February 26, 1997 (Appendix Table A). A request for a flow test just prior to the spawning period was denied by the USACE. Temperature of the Kootenai River ranged from 0 to 2.5^{o}C. Telemetry indicated burbot had gradually moved upstream during unrestricted winter operation to the mouth of the Goat River where at least four burbot with transmitters moved up the Goat River during the spawning season. Temperature of the Goat River ranged from 0 to 2.5^{o}C during the spawning period. Flow in the Kootenai River from Libby Dam remained high during most of the spawning period but after burbot completed spawning the USACE reduced flows. Discharge during the last week in February was reduced to base flow of 113 m^3/s, and remained low through March 17, 1997.

In the winter of 1997-1998. technicians captured 42 burbot in the Kootenai and Goat Rivers, three fish were caught in Idaho, seven in the Goat River, and the remainder in the Kootenai River in B.C. Burbot ranged from 300 to 810 mm TL (Figure 2) and weighed from 175 to 4,100 g (mean = 1,508 g). The USACE provided three low flow tests during the winter 1997-1998. Technicians

monitored five burbot during November, 1997 (Appendix Table A). Flows prior to the first test from Libby Dam ranged 170 to 510 m^3/s and temperatures from 9 to 12 ^oC. Prior to the flow test, during the last week in November, little movement took place. However, the most notable movement was that of 374 (monitored for the third consecutive season)(Figure 4), this burbot had traveled from rkm 133 during late September to rkm 144.3, remained there until November 20, then traveled to rkm 150.7 when flow was rising from about 270 to 440 m^3/s, stayed two days then returned to rkm 144.3. The first flow test started November 28 and ended December 1, none of the five burbot moved >1km although some short range movement was recorded. The same five burbot were also monitored during the second flow test provided the last week in December. Flows from Libby Dam ranged from 113 to 649 m^3/s, temperatures ranged from 4 ^oC to 9 ^oC while temperature of the Goat River ranged from <1 ^oC to 2.2^oC. The second flow test commenced on December 25 when the USACE reduced flows from 442 to 113 m^3/s. There were 11 occasions during the test when burbot moved 1 km or more, four times upstream and seven downstream. After unrestricted water management operations were resumed there was very little movement of burbot.

Twelve burbot were monitored during the third period of study. Flows from Libby Dam ranged from 113 to 360 m^3/s, temperatures ranged from <1 ^oC to 4^oC. Very little movement occurred during the weeks prior to the third test. The third flow test began January 24 when flow from Libby Dam was reduced from 351 m^3/s to 113 m^3/s. Technicians recorded 15 instances when burbot moved 1 km or more during this test, 11 upstream and four downstream.

Following the third flow test load following was a frequent method of operation for Libby Dam. Flow ranged from 113 to 587 m^3/s on a daily basis. Most burbot appeared to move with changes in flow, moving upstream then downstream etc. For example burbot 374 made three extensive journeys from rkm 144 to 154 back to rkm 144 and then back to 153 (Figure 4). At this same time migrations into the Goat River by spawning burbot occurred (about February 13) when temperature was 3.2 ^{o} C . Five burbot were recorded in the Goat River but at least 6 of the 12 burbot tracked during this last period showed no behavioral traits indicative of spawning but were found to be moving frequently. After spawning all burbot moved downstream, several entered Kootenay Lake.

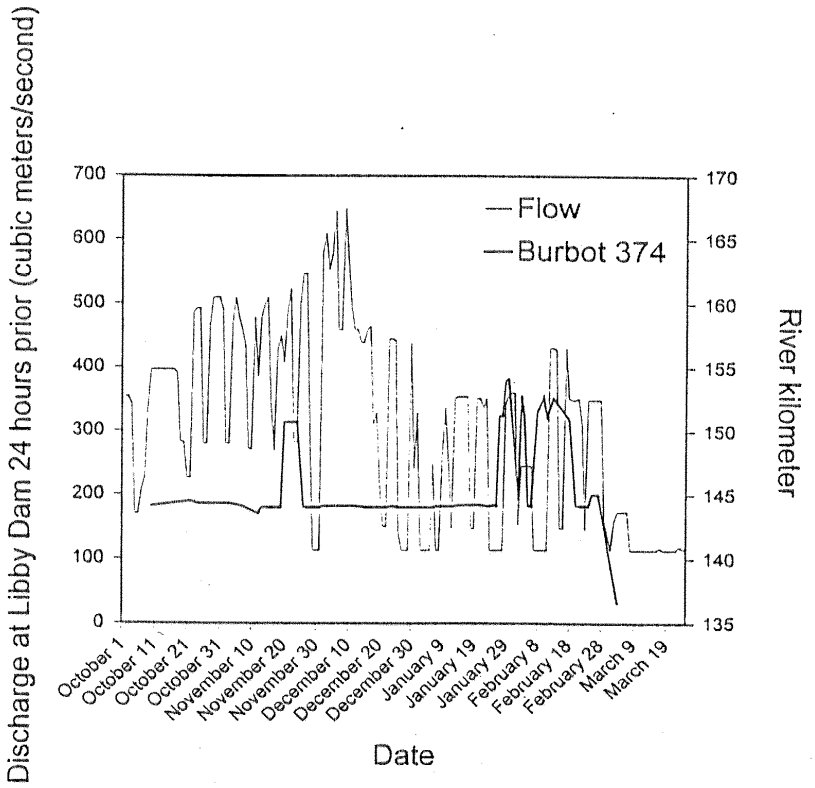


Figure 4. Daily discharge from Libby Dam, October 1, 1997 through March 26, 1998, showing rapid daily increases and decreases in flow (load following) and the movement pattern of burbot 374 and its responses to flow.

Burbot movement upstream during flow tests (control) were nearly twice the frequency than during unrestricted winter water management or 49% and 28%, respectively. Chi square analysis indicated burbot moved with significantly higher frequency during the low flow tests as compared to unrestricted conditions, Pearson Chi-square = 8.913, P = 0.012 . Additional analysis indicated there was no significant difference in the amount of burbot movement between the three test periods; Pearson Chi-square = 9.81 ; P = 0.04. Within the three study periods there was no detectable difference in the direction of

movement for the first two test periods: Pearson Chi-square = 1.51 and P = 0.47 ; Pearson Chi-square = 1.12 and P = 0.57, respectively, but I found movement upstream during the January flow test was significantly higher than the unrestricted period, Pearson Chi-square = 9.05, P = 0.01.

Nose velocities were periodically measured at the locations of 13 burbot during the winter study period of 1997-1998. Velocities measured during unrestricted dam operation average 11.85 cm/s (S.D. = 9.08, N = 40) while those measured during the controlled test period averaged 7.46 cm/s (S.D. = 5.23, N = 59). One-way ANOVA testing indicated nose velocities measured during the controlled low flow period were significantly different than the days of unrestricted dam operation (F with 1, 97 DF; P = 0.01, F = 6.96; test F = 9.28).

Kootenai River Flow and Velocities

The travel time for flow releases to reach (rkm 170), the Idaho/B.C. border, is about 24 h. Velocity in the Kootenai River is reliant on flow from Libby Dam and the elevation of Kootenay Lake, B.C. The lake is at it's lowest elevation during the winter months at about 531.5 m sea level. Flows at the border can sometimes be substantially higher than at Libby Dam ranging from 155 - 1,566 m^3/s depending on water management and daily precipitation.

I obtained discharge and velocity measurements collected at Copeland, Idaho, (rkm 190) to calculate a regression formula for the two variables (John Gralow, USGS, personal communication). An increase in discharge during the winter months creates a direct proportional increase in velocity. I found significant differences in current velocities of the Kootenai River at near maximum discharge (742 m^3/s) and much lower discharge (201 m^3/s) from Libby Dam using ANOVA testing. At near maximum discharge I found significant differences in velocities between sites (P = 0.0009) but at lower discharge they were not significantly different (P = 0.088), further testing also indicated the highest velocities at six randomly selected locations during maximum discharge occurred at rkm 152 (P=0.0015.

Discussion

Flow management at Libby Dam affected burbot spawning migration during winter. Movement of burbot with sonic transmitters was significantly higher (P<0.01) during controlled low flow conditions, which were designed to

replicate pre-dam Kootenai River flow. Flows are now three to four times greater than they were historically, when conditions were relatively stable, and now daily differences in flow can range up to 652 m^3/s. These increased volumes of flow equate to increased velocities.

High fluctuating flows from Libby Dam continuously disrupted burbot migrations upstream. When load following was a common water managment factor most burbot demonstrated repeated sequences of movement upstream, no movement, and/or fall back. I also found burbot nose velocities were significantly higher ($P<0.01$) during unrestricted winter operation of Libby Dam than during controlled low flow periods. The specific affect of this disruption to burbot spawning migration is unknown, but may have reduced spawning fitness, timing of spawning, and reduced stamina. One or all of these possible reasons could have been enough to reduce spawning success and reduce adequate recruitment to sustain the fishery. Jones et al. (1974) found burbot had the lowest swimming stamina of 20 species studied, velocities higher than 25 cm/s were too great for even the largest burbot to maintain a stable position. Malinin (1971) reported burbot moved slowly during their spawning migration, at speeds that did not exceed 10 m/min, and remained in the river thalweg where current velocities were low e.g. 30 - 40 cm/s. Breeser et al. (1988) monitored burbot spawning movement in an unregulated Alaskan river but they did not report long periods of little or no movement nor fall back. Breeser et al. (1988) also reported some burbot in the river system they studied moved into smaller tributaries in late summer after water velocities had dropped.

Movement of burbot was significantly higher ($P<0.01$) during January than other months of study. The motivation to move more during January was probably a result of the proximity to spawning which usually occurred during the first two weeks of February. Breeser et al. (1988) found burbot moved extensive distances but most movement occurred during the spawning season.

Burbot are thought to be highly synchronous in their spawning (Becker 1975). Burbot spawning synchrony may have been disrupted in several ways. I found burbot travel time was slower during flows higher than 113 m^3/s. Telemetry findings during winter 1994-1995 indicated three burbot that migrated to Idaho, from Kootenay Lake and the Kootenai River in B.C., did not arrive until a month or more after the spawning season and when they did arrive water temperatures were warmer than burbot spawn at. These burbot demonstrated no behavior indicative of spawning. Inhibition of spawning movement may also explain why three unspawned females were captured in a preliminary study

(Paragamian 1994). Burbot are known to travel long distances to spawn in some river systems (Breaser et al. 1988). In this study at least one burbot traveled over 120 km during the spawning migration period. Thus, in order for burbot, that are naturally slow moving, to reach spawning tributaries in Idaho it may take nearly a month to travel from Kootenay Lake and any disruption is likely to affect spawn timing.

Warmer winter temperatures in the Kootenai River may not have affected burbot spawning synchronony but it could have masked the location of spawning tributaries. During the winters of 1994-1995 I found burbot were attracted to the colder water of the Goat River compared to the Kootenai River, 1^{o} and $4^{o}C$, respectively. Soon after this observation burbot ascended the Goat River to spawn but when the temperature of the two rivers was similar, several days later, three additional burbot bypassed the Goat River on a suspected spawning journey into Idaho (none of these burbot demonstrated any behavior indicative of spawning). The Goat River is the largest tributary to the Kootenai River between Bonners Ferry and Kootenay Lake. The Goat River also has the largest cold water input. Although, other tributaries were substantially cooler than the Kootenai River their low volume was diluted by the higher flow in the river.

Migrations of burbot may be further complicated by higher velocities at some segments of the Kootenai River. Telemetry studies of 1994-1996 indicated few burbot moved above rkm 152. Velocity measurements during winter 1995-1996 indicated this reach had significantly higher velocities than other randomly selected sites. No doubt there may be other locations in the river that may have significantly high velocities. This fact suggests future management of the river for burbot migrations may also need to take into consideration velocities at specific locations when discharge is reduced.

I recommend that the USACE modify present flood rule curves and return the flow in the Kootenai River, during January and the first two weeks in February, to pre-dam levels of about 113 m^3/s. Burbot would thus be conceded a travel corridor similar to natural conditions and allowed to migrate unimpeded to tributaries in Idaho. However, it will also be necessary to establish spawning runs, to specific tributaries, by transporting adult fish of similar genetic make up/ life history, to various sites, and maintaining them in captivity until they spawn.

The collapse of burbot populations below dams after their construction is a common phenomenon in the northwestern US and in western Canada (McPhail

1996). Information from this study may be useful to recovery efforts of other burbot populations. Since most of the dams constructed in western North America are for flood control and/or hydropower. It seems likely the reasons for the collapse of these fisheries could be similar.

Acknowledgment

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Appendix Table A. Summary of sonic telemetry data and physical characteristics of 11 burbot in the Kootenai River, Idaho, and Kootenay Lake, B.C., Canada, 1994 through 1998.

Sonic code	Date implanted	Total length (mm)	Weight (g)	PIT tag number	Sex	Last date located
96	06/29/94	590	1,135	7F7D0B684C	M	05/12/96
2246	02/01/95	543	1,078	34353643868	F	10/04/95
903[a]	02/13/96	830	2,800	7F7D0A373D	F	02/13/96
365	02/13/96	396	400	7F7D0D6C6C	M	09/16/96
357	02/13/96	457	650	7FD0A2409	M	09/16/96
2237[a]	02/18/96	655	2,250	7F7D0A3852	F	05/29/96
12[a]	02/20/96	560	1,000	7F7D0A407E	M	02/20/96
374	02/20/96	648	2,100	7F7D0D7748	F	04/01/98
455[a]	02/20/96	545	1,300	7F7D0D7D10	F	07/02/96
276[a]	02/20/96	703	3,100	7F7D0A3031	M	05/29/96
258[a]	02/20/96	645	2,050	7F7D0D746F	F	09/05/96
374	02/20/96	590	1135	7F7DOB684C	M	08/28/97
96	11/22/96	626	1450	7F7D430070	M	08/28/97
383	11/22/96	568	1145	7F7D24071E	M	04/15/97
2228	12/04/96	678	1890	7F7D29757B	F	08/05/97
2237	12/04/96	570	1400	7F7DOA417E	F	08/28/97
3334	12/17/96	618	1800	7F7D374E69	F	08/28/97
2632	12/17/96	655	1710	7F7D424726	F	08/28/97
93	12/17/96	494	755	7F7D42472F	F	07/29/97
293	01/14/97	702	2550	7F7DOA246E	F	01/10/97
12	01/19/97	595	1356	7F7D401C23	M	08/19/97
276	1/19/97	570	1430	7F7D31682E	M	05/28/97

[a]Forty day life expectancy sonic tag.

Appendix Table A - continued.

Sonic code	Date implanted	Total length (mm)	Weight (g)	PIT tag number	Sex	Last date located
578	01/14/98	729	2150	7F7DOC124D	-	05/08/98
279	01/28/98	675	1950	7F7D430015	F	04/22/98
269	11/18/97	650	1900	7F7D431B3C	F	02/20/98
592	01/02/98	720	2150	7F7D433107	F	04/22/98
233	01/28/98	653	1900	7F7D41374F	F	04/22/98
3344	10/27/97	688	1850	7F7D403703	M	04/22/98
583	11/19/97	715	2480	7F7D401B28	F	03/04/98*
284	10/27/97	631	1510	7F7D39523A	-	04/22/98
2246	10/27/97	637	1710	7F7D3655561	M	02/26/98
243	01/13/98	747	2750	7F7D321B4E	F	02/12/98
639	12/02/97	700	2250	7F7D381334	F	03/04/98*
596	01/23/98	610	1850	7F7D42473D	-	02/13/98

EFFECTS OF COMPENSATORY GROWTH

ON A BURBOT POPULATION

Jakob Kjellman
Department of Limnology and Environmental Protection,
Box 27, FIN-00014 University of Helsinki, Finland.
phone +358 9 7085465, fax + 358 9 7085257, E-mail:
Jakob.Kjellman@Helsinki.Fi

Richard Hudd
Finnish Game and Fisheries Research Institute.
Merenkurkku Fisheries Research Station,
Korsholmanpuistikko 16, FIN-65100 Vaasa, Finland

Introduction

Growth is generally accepted to be both a density dependent and a density independent process. Thereby, growth often is a function of the relationship between potential food resources and temperature. Growth of cod species has been demonstrated to be dependent on population size as well as temperature (Dorn, 1992, Jørgensen, 1992), Also length-at-age of burbot has been demonstrated to vary between regions in the Gulf of Bothnia (Kjellman et al., 1993)

The acidification of the River Kyrönjoki has reduced the recruitment of burbot during several years of the 20th century. The aim of this study was to show that the level of acidification is inter-related to growth, population size and to the outcome of the fisheries. The basic assumption was that the acidification hampers the recruitment and leads to a smaller population size.

Material and Methods

Burbot were collected in years 1979-1997, and was measured for total length (mm) and weight (g), and aged from otolits. Commercial catches were estimated from official commercial catch statistics, while recreational and subsistence catches were estimated as a constant part (71%) of the commercial catches.

Growth was studied using General Linear Models (GLM) and partial correlation analysis. The population dynamics were estimated using virtual population analysis (VPA). Natural mortality was assumed to be constant 0.2. Yield per recruit estimates were based on the average fishing mortalities and weights-at-age during large and small population sizes.

Results

The mean length-at-age increased as the burbot population crashed in the early 1980s and decreased again as the population was reinforced in the late 1980s (Figure 1). Annual growth could be explained to 82% by including population size to the GLM. Even if the population size influenced the growth the effect of compensatory growth was minor, ~10 %. No relationship between temperature and growth could be found. Growth of young age groups reacted to an increasing population (Figure 1) with a 2 year lag between the adult population size and individual growth (r_p=-0.88, n=10).

Fishing mortalities were affected as the growth changed. Due to the increased growth rates, fishing mortality increased on the younger age-classes. At low population size, the mortality of the age-classes 4-7 rose by 100-20%. At the same time mortality decreased in older age-classes (age $\geq$8).

However, the impact on Y/R was small. Yield per recruit was even higher at low population size due to the compensatory growth, though the population was over fished by 40%. Due to flat Y/R-curves, reducing the over all fishing mortality (Y/R_{max}) would only increase the catches by 3%. A much stronger effect could be induced by increasing the minimum weight of recruitment from 0.5 kg to 1.0 kg. By this alone, the catch per recruit could be enhanced by 20% at low population size, with fast growth rates.

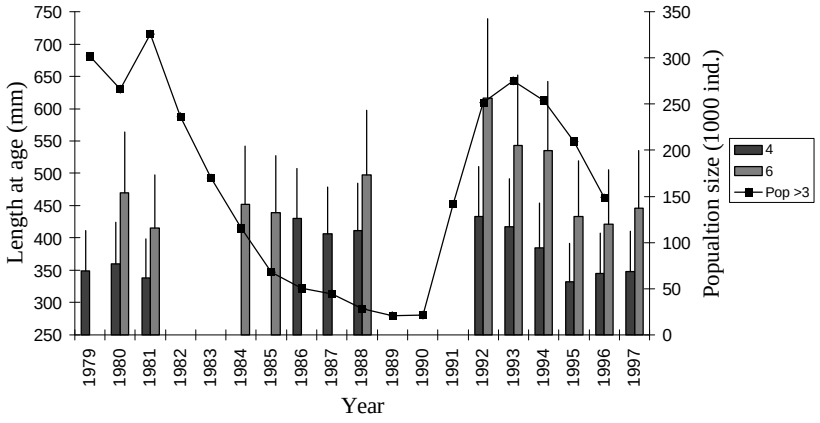


Figure 1. Population size and length-at-age (+ sd) of burbot in studied years (No samples taken 1982-83, 1989-91. Other missing values due to small year-classes).

Independently of any management strategy, the population crash in the 1980s could not have been prevented, as it was caused by the episodic acidification. However, when the outer circumstances for recovery were good in the late 1980s and early 1990s, the population did not recover, to the size before the crash. Excluding recruitment in acid years 1979-1993, a Ricker shaped stock-recruitment relationship was found for the non acid years (Figure 2). Due to the low number of non acid years the results were not conclusive, but indicated that the maximum population size would be around 200 000 $ind_{\geq age\text{-}class\ 4}$, not able to sustain a yield of 40 tonnes annually, as noted before the population crash in the 1980s.

Conclusions

The episodic acidification of the River Kyrönjoki lead to a population crash in the 1980s. Due to this, the individual growth rates increased by 10 % for adults and substantially more for juvenile burbot. The altered growth rates lead to and increased fishing mortality on the younger age-classes, way past the Y/R_{max}, but obtained Y/R remained virtually unchanged, due to the compensatory growth. As the Y/R-curves are flack, an overall reduction of F was not the most efficient

management strategy, but a introduction of minimum size of capture could generate more added value.

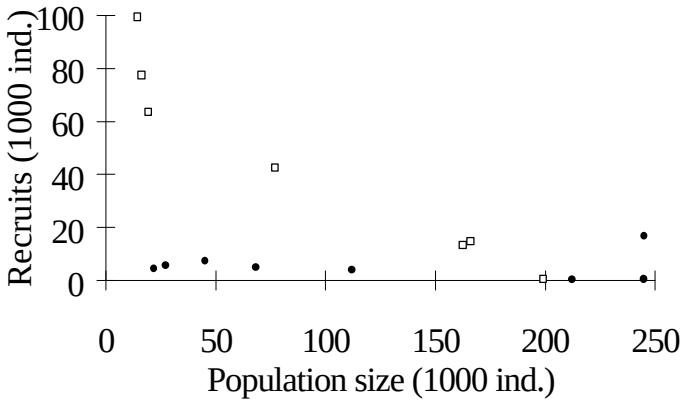


Figure 2. Stock-recruitment relationship of burbot. Recruitment in non acid years is marked with open squares and recruitment in acid years is marked with black dots.

The relatively strong compensatory growth effect, especially on juveniles, indicated that competition was severe on the juvenile stages. This, and the possible presence of a stock-recruitment relationship, lead us to the conclusion, that the estuary has a certain carrying capacity. The loss of reproduction areas, documented as an abounded fishing areas and no recruitment in the river (Hudd et al., 1983, 1986), may have forced the population towards a lower equilibrium size, which could explain the omitted recovery in the 1990s.

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BURBOT SURVIVAL FROM SEA LAMPREY ATTACK

William D. Swink
U.S. Geological Survey, Biological Resources Division,
Great Lakes Science Center, Hammond Bay Biological Station,
Millersburg, Michigan 49759;
517-734-4768; Fax 517-734-4494;
William_Swink@usgs.gov

EXTENDED ABSTRACT ONLY DO NOT CITE

The introduced sea lamprey *Petromyzon marinus* almost eradicated lake trout *Salvelinus namaycush* and burbot *Lota lota* from the Great Lakes by the 1960s. The near elimination of these two native piscivores further altered the Great Lake's fish community, prompting adoption of an extensive sea lamprey control program. Although low-level sea lamprey predation continues to limit lake trout restoration, many burbot populations have recovered soley through natural reproduction. The recovery by burbot suggested they might better resist sea lamprey attack and act as a buffer to aid lake trout restoration.

In laboratory studies, single sea lamprey attacks on burbot caused mortalities of 63% for larger (635-789 mm) and 81% for smaller (500-600 mm) burbot. Similar studies conducted with lake trout resulted in mortalities of 43% for larger (559-799 mm) and 64% for smaller (469-557 mm) fish. Hence, the burbot's unassisted recovery more likely results from their younger age at maturity, higher fecundity, or differences in distribution.

The burbot's more rapid growth to a size (>600 mm) preferred by sea lampreys might still help buffer lake trout from moderate sea lamprey predation. However, any benefits might be offset by increased predation by burbot on smaller lake trout.