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Status, Distribution, Diet, and Growth of Burbot in Lake Roosevelt, Washington

Abstract

The status of burbot populations in Washington State is largely unknown and little biological information has been collected regarding them. This paper is an assimilation of distribution, catch, diet, and growth data for burbot collected via gill nets and electrofishing in Lake Roosevelt, Washington. Burbot distribution was not homogenous throughout Lake Roosevelt. Catch rates were higher in tributaries compared to offshore zones and were low from 1988-1994 (<0.01 fish/hr), peaked in 1995 and 1996 (0.18 fish/hr), and leveled off (0.04 fish/hr) between 1999 and 2001. Highest densities were in the Hawk Creek and San Poil River sections. Catch rates may have been higher in tributaries because of burbot seeking thermal refugia or food in the vicinity. Burbot diets were dominated by isopods (71%) in the offshore zones, whereas burbot sampled in the nearshore zones contained fish (28%), insects (46%), and crayfish (12%) in the spring and mostly fish in the summer (62%) and fall (78%). Burbot averaged six years in age, ranging between three and ten years old. Generally, relative weights were below the 75th percentile national average and condition factors were poor; however, relative weight and condition factors were stable from year to year indicating that conditions were not deteriorating in the reservoir. It is possible that the impact of reservoir operations on spawning and rearing habitats and low invertebrate and forage fish productivity, have led to the slow growth and condition of burbot in Lake Roosevelt.

Introduction

The burbot (*Lota lota)* is the sole freshwater fish of the family Gadidae (Cod) and generally inhabits large lakes, reservoirs and large river systems. Burbot are found throughout North America, from Alaska to Washington, eastward to Connecticut and north to Labrador, Canada (Wydoski and Whitney 2003). Populations are depressed across their North American distribution including Alaska (Lafferty et al. 1992, Bernard et al. 1993, Quinn 2000), Wyoming (Krueger and Hubert 1997), Iowa, where they are threatened (Endangered and threatened Plant and Animal Species, Iowa Administrative Code 57- Chapter 77), Nebraska and Idaho, where they are under consideration as a state listed endangered species (Hesse 1993; Paragamian et al. 2000), and in the Kootenay system of British Columbia where they are red listed (Spence 2000, Taylor and McPhail 2000).

Of the 11 known burbot populations in Washington, one is considered critical (Banks Lake), one is healthy (Lake Roosevelt), and the status of the remaining 9 is unknown (Bonar et al. 1997, 2002). Banks Lake supported a strong burbot fishery during the mid 1950-60s, but after impoundment the fishery collapsed in the early 1970's (Duff 1973) and has not rebounded (Polacek et al. 2002, 2003). Patterns of decline in abundance, following a short peak after dam construction, have been reported by other investigators (Lafferty et al. 1992, Bernard et al. 1993, Hesse 1993, Krueger and Hubert 1997, McPhail 1997, Paragamian et al. 2000). Lake Roosevelt supports a minor burbot fishery, and the status of this population is a concern.

Reasons for burbot population declines include overexploitation and interspecific interactions (Carl 1992, Lafferty et al. 1992, Bernard et al. 1993, Bonar et al. 1997, Krueger and Hubert 1997, McPhail 1997). Dam construction has impacted populations by altering flow regimes that impact spawning success (Hesse 1993, Paragamian 2000), increasing sediment deposition, water temperatures and water level fluctuations (Bergersen et al. 1993, Kruger and Hubert 1997), and reducing productivity in reservoirs (Paragamian et al. 1999).

Until recently, burbot fisheries in western North America were largely unregulated (McPhail 1997) and few states had collected biological

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information (Quinn 2000). Prior to 1969, burbot were not managed in Washington State. Since then, burbot have been listed as a game fish, but no harvest limits were imposed until 1998 (Bonar et al. 1997). Little data exists to evaluate the past and current status and population trends of this species in Washington. Stock assessments with biological data are needed since burbot are an important sport fish in several Washington waters (Bonar et al. 2000), and there has been an increase in popularity of burbot among anglers (Lafferty et al. 1992, Bernard et al. 1993, McPhail 1997).

Currently, the Lake Roosevelt Fishery Evaluation Program (LRFEP) evaluates the fishery on Lake Roosevelt. The LRFEP is a cooperative effort between the Spokane Tribe of Indians (STOI), the Colville Confederated Tribes (CCT), the Washington Department of Fish and Wildlife (WDFW), and Eastern Washington University (EWU). One of the objectives of the LRFEP is monitoring the status and trend of all fishes inhabiting the reservoir. The purpose of this paper was to determine the status, distribution, diet, and growth of burbot in Lake Roosevelt, combining data collected by the LRFEP from 1988 to 2002.

Study Area

Lake Roosevelt is a Columbia River reservoir created in 1941 by the construction of Grand Coulee Dam (GCD) at river kilometer 960 (Figure 1). The reservoir covers approximately 33,000 ha at a full pool elevation of 393 m above mean sea level and is managed as a National Recreation Area by the National Park Service. The reservoir extends 241 km upstream from GCD to the Canadian border, is generally 1-3 km wide, and has a maximum depth of 122 m. The dam was built for hydropower generation, flood control and water storage for irrigation in the Columbia Basin Reclamation Project. Grand Coulee Dam also provides downstream flow augmentation for anadromous fish and created a reservoir that provides recreational and fisheries opportunities. The annual hydrologic regime commonly includes spring drawdowns of 12-20 m with a maximum operational limit of 25 m. Water retention times are short (12-80 days) and the zooplankton community is more typical of a large river than a lake or reservoir (Black et al. 2003).

After inundation, the Lake Roosevelt fish community structure consisted primarily of Northern pikeminnow (*Ptychocheilus oregonensis*). Gill net surveys in 1948 indicated 65% of the total sample (Gangmark and Fulton 1949) and 54% in 1976 (Stober et al. 1977) were northern pikeminnow. Catch decreased to 15% from 1980-1983 (Beckman et al. 1985), and to less than 5% in the late 1990's (Cichosz et al. 1997, 1999). Burbot were rarely reported in historical surveys, but now comprise 5-15% of species in gill net surveys (Cichosz et al. 1997, 1999; Baldwin et al. 1999; Lee et al. 2003). Currently, the fish community in Lake Roosevelt is dominated by largescale suckers (*Catostomus macrocheilus*), lake whitefish (*Coregonus clupeaformis*), and walleye (*Sander vitreus)* (Cichosz et al. 1997, 1999; Lee et al. 2003).

Methods

Field Sampling

In 1996 the STOI established ten permanent sampling stations located throughout the reservoir: Evans, Kettle Falls, Gifford, Hunters, Porcupine Bay, Little Falls, Seven Bays, Keller, San Poil River, and Spring Canyon (Peone et al. 1990; Cichosz et al. 1997) (Figure 1). Each station had multiple sampling sites representing several habitats including embayments, stream inlets and offshore sites. Stations were sampled seasonally during a 3-week period in May, July and October from 1988 to present using boat electrofishing and nearshore and offshore gill netting surveys. Horizontal and vertical gill nets were generally set in both the nearshore and offshore zones of each station. Four gill nets were set at each station and included 2-3 horizontals and 1-2 vertical gill nets dependent on station morphology. Horizontal gill nets (61 m in length and 3.7 m deep) were set on the lake bottom. Each horizontal net consisted of four 15.2 m panels (bar mesh sizes 1.3 cm, 2.5 cm, 3.8 cm and 5.1 cm). Two of the horizontal gill nets had mesh sizes ranging from 5.1 to 10.2 cm, but were only used during June through August 1999. Gill nets were set in the afternoon (1400-1800 hrs.) and pulled the next morning (0800-1200 hrs.) (Cichosz et al. 1997; Cichosz et al. 1999).

The WDFW sampled the offshore zone during May, August and October in three sections of the lake, from Grand Coulee Dam to Whitestone Rock, from Lincoln to Hunters, and from Gifford to Kettle Falls from 1998 through 2002. Horizontal gill nets were set in the offshore zones and included

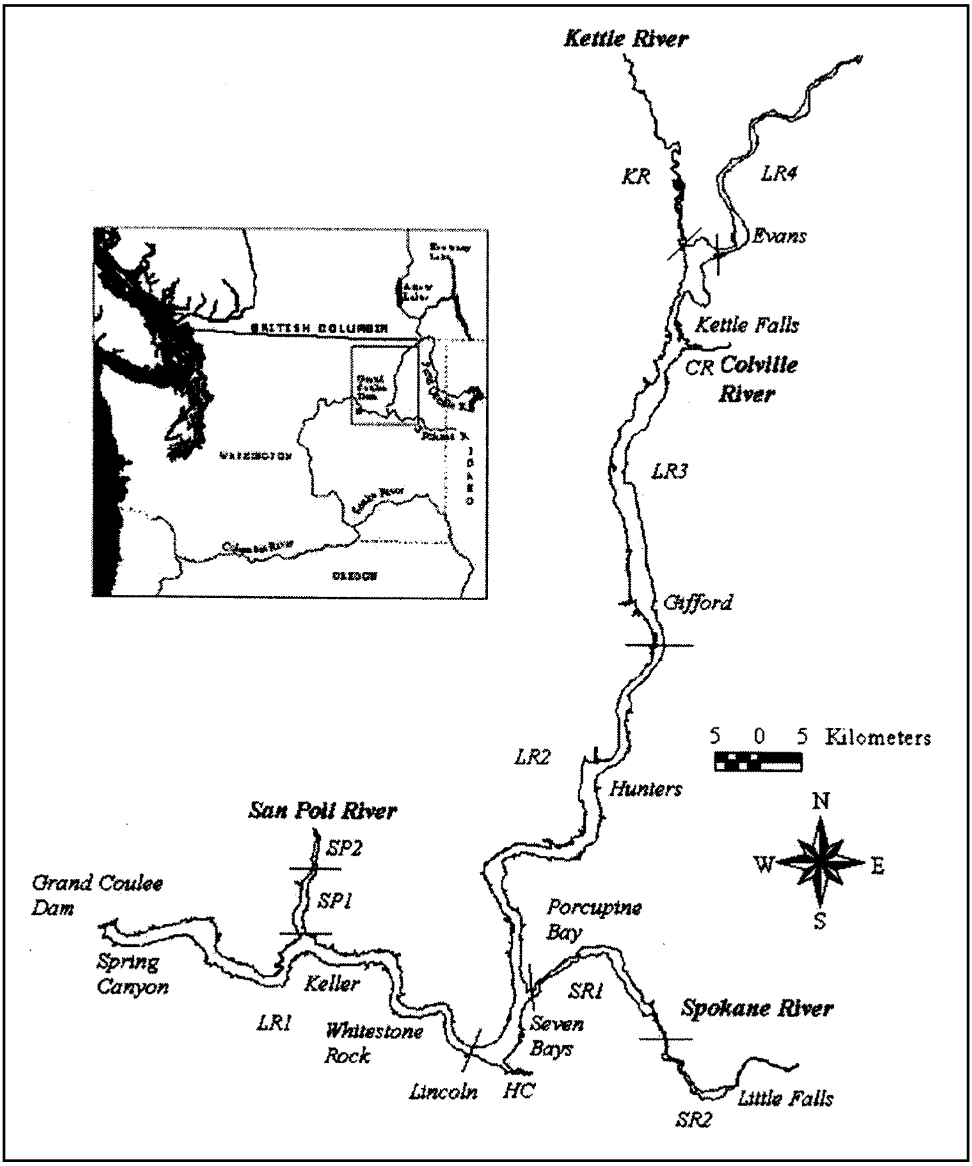

Figure 1. The eleven sections used to evaluate burbot distribution on Lake Roosevelt, Washington. LR1-4 = main lake, SP = San Poil River, HC = Hawk Creek, SR = Spokane River, CR = Colville River and KR = Kettle River. See Table 1 for section descriptions. The inset shows the location of the study area in Washington State.

floating, midwater, and bottom nets with 6 m long by 2.6 m deep panels (mesh sizes from 25 to 102 mm in 13 mm increments). Vertical gill nets were 2.6 m wide and 26.2 m deep, and consisted of one mesh size throughout (25, 38, 51, 64, 76, 89, or 102 mm stretch).

EWU seasonal boat electrofishing data collected annually from 1997-2001 on randomly selected embayments, stream inlets and shorelines were combined and used for analysis.

All agencies measured (mm, total length), weighed (g), and recorded species-specific information. Stomach and otoliths were dissected from burbot that were captured in gill nets. Most electrofished burbot were released; however, some were sacrificed for stomach contents.

TABLE 1. Beginning coordinates, distance and description of each section selected for burbot distribution analysis for Lake Roosevelt, Washington. LR1-4 = main lake, SP = San Poil River, HC = Hawk Creek, SR = Spokane River, CR = Colville River and KR = Kettle River.

Section	Beginning UTM Coordinate	Approximate Section Distance (km)	Section Description
LR1	11 0352208E, 5313100N	56.4	Lentic-like
LR2	11 0394231E, 5298719N	56.7	Lower lentic/lotic transition
LR3	11 0415455E, 5346610N	49.9	Upper lentic/lotic transition
LR4	11 0421715E, 5391208N	43.0	Lotic
SP1	11 0374391E, 5311935N	5.0	Embayment
SP2	11 0375734E, 5320004N	8.5	Lotic
HC	11 0397389E, 5297468N	4.4	Lotic Embayment
SR1	11 0400475E, 5305301N	23.8	Lotic Embayment
SR2	11 0416108E, 5300594N	22.7	Lotic
CR	11 0418576E, 5380422N	2.1	Lotic, lotic embayment
KR	11 0418124E, 5391961N	12.9	Lotic, lotic embayment

Status and Distribution

The status of the burbot population in Lake Roosevelt was analyzed by establishing a 13-year trend using mean catch rates from October surveys. Gill net catch rate data from 1988-1996 were taken from numbers reported in Bonar et al. (1997), and gill net and electrofishing data collected by the LRFEP from 1997-2001 were summarized. We only used data collected by electrofishing and gill netting from 1997 through 2001 because each station was sampled consistently each year. We only used fall gill netting data for annual catch rate comparisons to avoid variability due to spring drawdowns, summer temperature, and water retention time differences. Gill net catch rates from 1998-2001 were converted from fish/gill net night to fish per hour by dividing by 17 (the average number of hours of an overnight gill net set).

To determine distribution, we calculated the mean catch rates each season (spring, summer, and fall) for boat electrofishing and sinking horizontal gill nets in 11 sections of the reservoir. The mainstem (LR) (4 sections), Spokane River (SR)(2 sections), and San Poil River (SP)(2 sections) were divided into sections based on reservoir hydrology, bathymetry and limnology. The Colville River (CR), Hawk Creek (HC), and Kettle River (KR) were one section each and were shorter based on limitations of the sampling gear to reach farther into these main tributaries (Figure 1, Table 1). Mean annual catch rates were calculated across the three seasons plus or minus one standard error.

The data available to analyze catch rates, distribution, growth, and diets varied by year (Table 2). A single factor analysis of variance (ANOVA) test was used to test for a statistical difference ($P \leq 0.05$) among annual fall catch rates, catch rates among sections, and among annual relative weights.

TABLE 2. The years in which data was used to calculate the status, distribution, diet, age and growth, relative weight and condition factor for burbot in Lake Roosevelt, Washington.

Parameter	Source Agency	Years of data used for analysis
Status	STOI[a], WDFW	1988-1996
	EWU, STOI	1998-2001
Distribution	WDFW, STOI	1997-2001
Diet	WDFW, STOI	1998-2001
Age and Growth	WDFW	1999-2001
Relative Weight	WDFW, EWU, STOI	1997-2002
Condition Factor	WDFW, EWU, STOI	1997-2002

[a] Reported in Bonar et al. 1997

Diet

Stomach contents were examined under a dissecting microscope in the laboratory and prey were sorted by taxon to the nearest order for invertebrates, and family, genus or species for fish. Fish prey was identified using diagnostic bone keys (Hansel et al. 1988) and voucher specimens taken from Lake Roosevelt. The blotted-dry wet weight for each prey category of individual predators was recorded to the nearest 0.01 g (Baldwin et al. 2000). Prey dry weights were converted to wet weights when needed (Hanson et al 1997).

Diets for all years were combined and stratified by season, and analyzed by wet weight proportions (Bowen 1983). Since the majority of burbot used in the diet analysis were > 400 mm (age-4), the diet composition represented adult burbot in Lake Roosevelt.

Age, Growth, and Condition

Fish ages were determined by examining otoliths at the WDFW aging laboratory in Olympia for burbot captured between 1999 and 2001. Three laboratory personnel independently examined and aged specimens by counting the annuli under a dissecting microscope at 8-16x. In instances where age determinations differed between readers, the otoliths were re-examined and a consensus was reached, or if necessary, decided by a "majority rule." Whole otoliths were read for ages 1-5, but older fish otoliths were sectioned transversely through the core and burned with an alcohol flame (Chilton et al. 1982).

Relative weights were calculated using the coefficients for burbot in Fisher et al. (1996).

$$\log_{10} W_s = -4.868 + 2.898 \log_{10} TL$$

where, W_s = standard weight (g) and

TL = the total length (mm).

Mean seasonal relative weights were calculated by length group (Murphy et al. 1991) from 1997 through 2002. Length groups included stock to quality (200-379 mm), quality to preferred (380-529 mm), preferred to memorable (530-669 mm), memorable to trophy (670-819 mm), and trophy (>820 mm) (Fischer et al. 1996). Mean annual condition factors (k) were calculated as,

$$\frac{W}{TL^3} \times 10^4$$

where, W = weight (g) and

TL = the total length (mm).

Results

Status and Distribution

From 1997 through 2001, 1,387 burbot were collected with sizes ranging from 95-770 mm, with a mean total length of 490 mm (± 68 SD) (Figure 2).

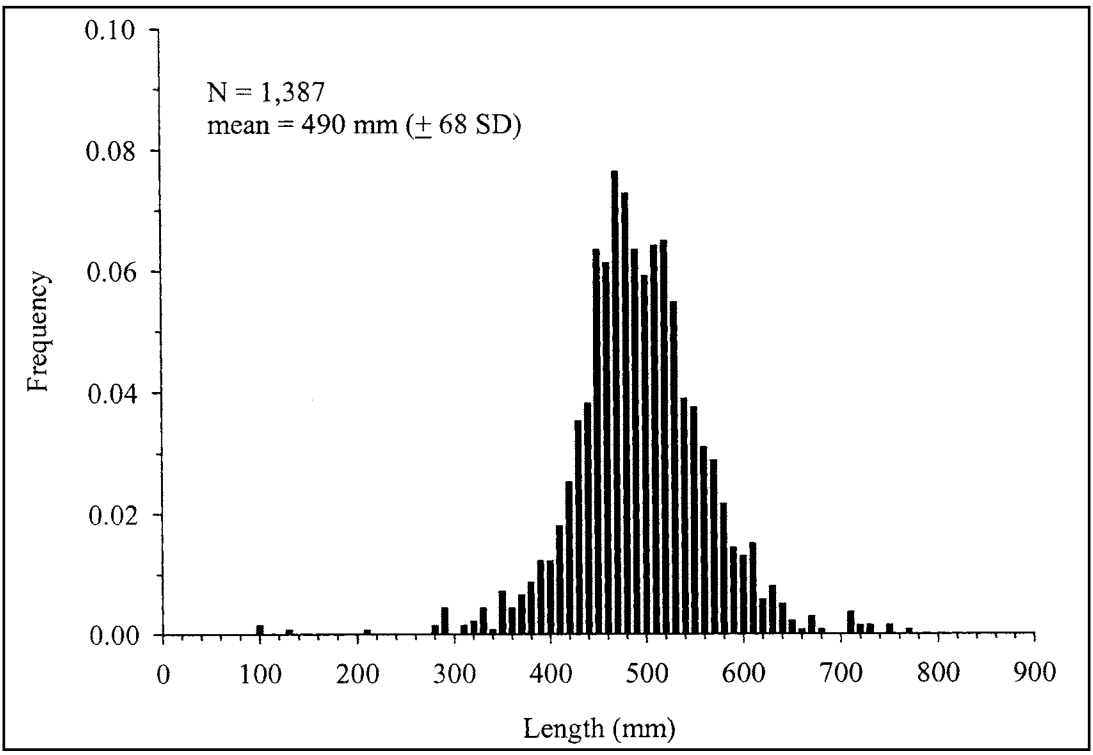

Figure 2. The length frequency of burbot captured in Lake Roosevelt, Washington, between 1996 and 2002. Gear types included gill nets, electrofishing boats, and a midwater trawl.

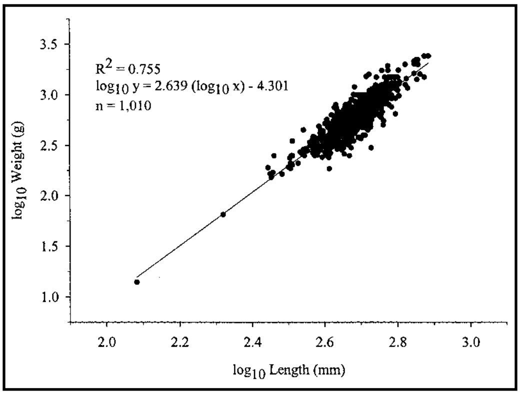

Figure 3. Log_{10} transformed length weight relationship for burbot in Lake Roosevelt, Washington, between 1997 and 2002.

Lengths and weights from 1,010 burbot were $\log_{10}$ transformed to produce a linear length/weight relationship equation of $\log_{10} y = 2.639 (\log_{10} x) - 4.301$ where x = length (mm) and y = weight (g) (Figure 3). Average annual catch rates for burbot were 0.38 (± 0.08 SE) fish per hour for electrofishing and 0.69 (± 0.12 SE) fish per net night for sinking gill nets. Burbot were most commonly captured in sinking horizontal gill nets, and 40% of the offshore burbot catch came from nets suspended 5-10 m off the bottom.

Burbot distribution was not homogenous throughout Lake Roosevelt when sampled by electrofishing ($P < 0.01$; F = 7.49; df = 10) or gill netting ($P < 0.01$; F = 11.03; df = 8). Catch rates (fish/hour) for electrofished burbot were the highest in the Hawk Creek Arm (HC) (2.05 ± 0.58 SE), the Colville River (CR) (1.12 ± 0.43 SE) and section LR2 (1.01 ± 0.21) (Figure 4). Catch rates (fish/gill net night) for gill netted burbot were highest in the San Poil River Arm 2 section (SP2) (2.75 ± 0.71 SE), HC (1.96 ± 0.51 SE), and the Colville River Arm (CR) (1.65 ± 0.44 SE) (Figure 5). Seasonal catch rates did not differ significantly for either boat electrofishing ($P > 0.05$; F = 2.38; df = 2) or sinking gill nets ($P > 0.05$; F = 1.94; df = 2); however, mean catch rates for both gear types were highest in the fall (Figures 4, 5).

Burbot gill net catch rates showed a trend with three distinct periods in the time series. Catch rates were generally low (< 0.01 fish/hour) from 1988 to 1994, increased substantially starting in 1995, peaked at 0.18 fish/hour in 1996, then leveled off, averaging 0.04 fish/hour between 1999 and 2001 (Figure 6).

Diet

Stomach contents of 208 burbot (122 nearshore and 74 offshore) were analyzed for prey composition, with 79% of the stomachs containing prey. Fish analyzed for diet contents ranged from 121 to 610 mm (mean = 487 mm), with no significant difference in total length between fish captured in the nearshore and offshore zones ($P > 0.05$; z = -1.19; df = 206). Diet analysis indicated that

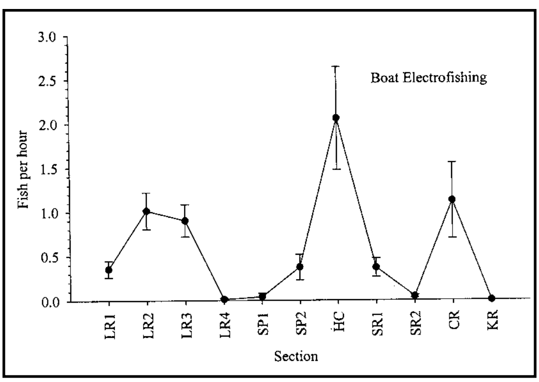

Figure 4. Average annual catch rate (± 1 SE) by boat electrofishing for burbot in Lake Roosevelt, Washington between 1997-2001. Each section represents the mainstem (LR), San Poil River Arm (SP), Hawk Creek (HC), Spokane River Arm (SR), Colville River (CR) and Kettle River (KR).

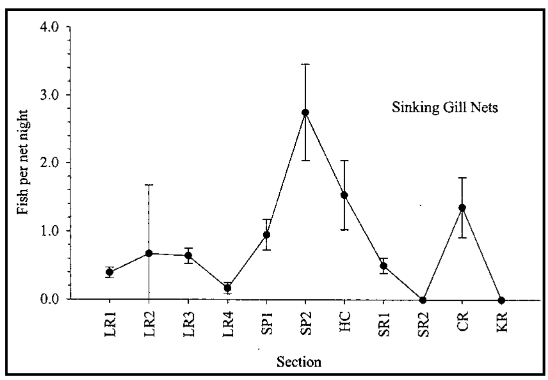

Figure 5. Average annual catch rate by gill netting (± 1 SE) for burbot in Lake Roosevelt, Washington between 1997-2001. Each section represents the mainstem (LR), San Poil River Arm (SP), Hawk Creek (HC), Spokane River Arm (SR), Colville River (CR) and Kettle River (KR).

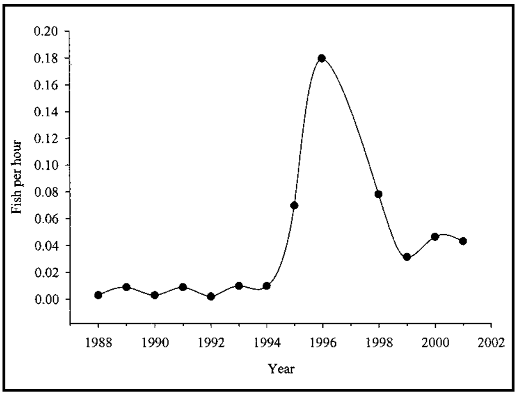

Figure 6. Catch of burbot in horizontal gill nets in Lake Roosevelt, Washington between 1988 and 2001. 1998-2001 gill net catch rates were converted from fish/gill net night to fish per hour by dividing by 17 (the average number of hours of an overnight gill net set).

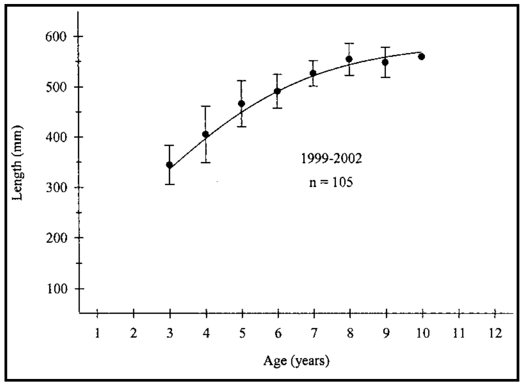

Figure 7. Length-at-age (± 1 SD) for burbot in Lake Roosevelt, Washington. Age was determined by counting the number of annuli on the otolith.

burbot sampled in the nearshore zones consumed fish, insects, and crayfish in the spring, but shifted to primarily fish in the summer and fall (Table 3). By weight, isopods dominated the diet of burbot captured in the offshore zones during all seasons (Table 3). Leeches were present in the diet of offshore burbot, and only one burbot captured neashore contained isopods. Overall, the annual diet of burbot was dominated by the wet weight proportions of fish (38%) and isopods (35%), with insects occurring less frequent (11%).

Age, Growth, and Condition

A total of 105 burbot otoliths, collected between 1999 and 2001, were analyzed for age determination. Burbot ranged from 3 to 10 years old, with considerable overlap in length at age for adjacent year classes. The most common age of fish in the sample was age-6 (27%), followed by age-8 (19%), age-7 (17%), age-4 (12%), age-5 (11%), age-3 (7%), age-9 (6%) and age-10 (1%). On average, burbot grew by 61 mm per year between age three and five, 30 mm per year between age five and eight, and very little thereafter (Figure 7).

Most relative weight values were below the 75th percentile national average, and generally decreased as the fish became larger (Figure 8).

TABLE 3. The mean wet-weight proportion for each prey category found in the diets of adult burbot in Lake Roosevelt, Washington from 1998-2001. The prey composition includes all burbot where diet items were present.

	Prey	(n = 48) Spring	(n = 62) Summer	(n = 43) Fall	(n = 12) Winter	(n = 165) Total
Nearshore	Isopod	0.00	0.02	0.00	---	0.01
	Insect	0.46	0.14	0.06	---	0.02
	Leach	0.00	0.00	0.05	---	0.01
	Crayfish	0.12	0.16	0.11	---	0.14
	Fish	0.28	0.62	0.78	---	0.57
	Other	0.14	0.06	0.01	---	0.07
	Total	1.00	1.00	1.00	---	1.00
Offshore	Isopod	0.75	0.75	0.52	0.93	0.71
	Insect	0.01	0.13	0.00	0.00	0.03
	Leach	0.08	0.11	0.11	0.00	0.08
	Crayfish	0.03	0.00	0.06	0.00	0.03
	Fish	0.12	0.02	0.30	0.06	0.14
	Other	0.00	0.00	0.02	0.01	0.01
	Total	1.00	1.00	1.00	1.00	1.00

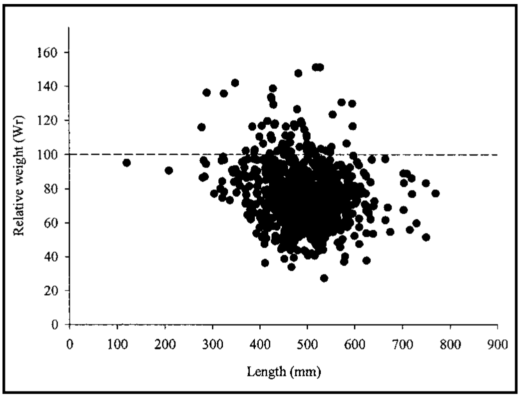

Figure 8. Relative weights (Wr) of burbot in Lake Roosevelt, Washington, 1997-2002, compared to the national average (dashed line).

TABLE 4. Mean relative weights (W_r) (± 2 standard errors (SE)) for burbot greater than 200 mm total length from Lake Roosevelt, Washington.

	Mean W_r (SE)		
Length Group	Spring	Summer	Autumn
Stock to Quality (200 to 379 mm)	98 (1.4) n = 2	100 (12.0) n = 13	93 (10.0) n = 25
Quality to Preferred (380 to 529 mm)	82 (4.2) n = 69	80 (2.4) n = 238	71 (1.5) n = 396
Preferred to Memorable (530 to 669 mm)	86 (6.8) n = 27	79 (4.2) n = 68	72 (2.4) n = 133
Memorable to Trophy (670 to 819 mm	58 (10.8) n = 3	77 (0.4) n = 2	71 (10.3) n = 8

TABLE 5. Sample size (n), mean annual relative weights (W_r) and condition factors (k) (± 2 standard errors (SE)) for burbot in Lake Roosevelt, Washington.

Year	n	W_r	SE	k	SE
1997	331	74.8	1.5	0.53	0.01
1998	195	76.4	3.1	0.55	0.02
1999	171	79.5	6.4	0.57	0.18
2000	120	77.4	3.4	0.56	0.01
2001	88	72.4	3.3	0.52	0.02
2002	104	76.2	2.2	0.55	0.02
Totals	1,009	76.1	1.1	0.55	0.01

Relative weights generally decreased with age (total length) (Table 4). Mean annual relative weights were the highest in 1999 (79.5) and lowest in 2001 (72.4), and were not significantly different among years ($P > 0.05$, F = 281, df = 1014). Condition factors (k) were low for all years, with a combined annual average of 0.55 (± 0.01 2 SE). Similar to relative weights, k was not significantly different among years ($P > 0.05$, F = 202, df =742) (Table 5).

Discussion

We acknowledge that electrofishing and gill netting may not be the most efficient or representative methods for capturing burbot and monitoring burbot populations over time; however, they should still provide a relative index of population status if inter-annual methodology is consistent. Low catch rates can result from low abundance of fish, but for burbot, low catch rates may not equate to low abundance when inefficient sample gears are used (Spence 2000). In Lake Winnipeg, burbot were caught as by-catch in commercial gill nets, and certain areas of the lake were avoided by fisherman due to the high catch rates of burbot (Hewson 1955). Others have used gill netting as a standardized method of evaluating annual catch rate trends for walleye populations (Pererra et al. 1993; Tennessee Fishery Assessment Guidelines 1998; Morgan 2000). Annual gill net catch from Lake Roosevelt indicated that the burbot population was increasing between 1988 and 1996 (Bonar et al. 2000) but then declined and stabilized from 1998 to 2001 (Figure 6). The cause of the increase in catch rates between 1995 and 1998 is uncertain; however, its possible that survival increased due to prey fish availability following the increased hatchery releases of kokanee (*Oncorhynchus nerka*) and rainbow trout (*Oncorhynchus mykiss*) in the early 1990's.

The federally funded kokanee and rainbow trout hatcheries on Lake Roosevelt increased the potential forage base starting in 1988, but if gill net catch rates of adult burbot represented survival then we would have expected to see a ramping up effect beginning 3-4 years after implementation of the hatchery programs. Additionally, salmonids are not a consistent component of burbot diets, although they are known to feed on juveniles shortly after release from the hatchery and on adult kokanee returning to tributaries to spawn (Baldwin et al. 2003). It is possible that unusually good spawning conditions existed for two or more consecutive years in the late 1980's and early 1990's. Nothing is known about the quantity and quality of spawning habitat in Lake Roosevelt or how reservoir operations might affect them.

The highest catch rates for gill netting occurred in the San Poil River (SP1 and SP2), Hawk Creek (HC) and Colville River (CR). The highest catch rates for burbot collected with electrofishing occurred in Hawk Creek, the Colville River and sections LR2 and LR3, both containing many creek inlets and embayments. Rawson (1951) found that burbot in Great Slave Lake, Northwest Territories were caught in higher numbers in embayment localities with river inflow. This distribution pattern could be related to thermal refuge and food supply. Each of the aforementioned stations contributes annual or perennial inflow, serving as possible thermal refugia for burbot and other Lake Roosevelt fishes. Vertical temperature profiles in offshore areas during the summer ranged from 15° to 21°C, generally with a gradual stratification and no thermocline (Lee et al. 2003). However, the epilimnion is usually isothermic at 18-19°C down to a depth of 80-100 m from mid August to early October, with temperatures reaching 14-15°C near the bottom (Lee et al. 2003). In Lake Opeongo, Ontario, burbot were active at night in water that was 20°C, but moved to cooler water during the day (Carl 1995). Hackney (1973) indicated that burbot prefer summer water temperatures of 10-12°C, and avoid temperatures above 13°C. Therefore, thermal stress could occur for burbot in Lake Roosevelt, particularly in the upper portions of the reservoir where there is no evidence of deep, cool water refuges.

In the autumn, tributaries serve as spawning or staging areas for kokanee, a prey species for burbot in the reservoir (Baldwin et al. 1999). In some lakes, burbot move into shallow areas in the autumn (Lawler 1963) as part of a pre-spawning feeding migration (McPhail and Paragamian 2000). This was apparent in Lake Roosevelt, as overall catch rates were highest during both gill netting and electrofishing surveys and the highest proportion of fish was found in the diets of burbot during the fall surveys.

We found very few studies that described the depth distribution of burbot captured in offshore areas. In Great Slave Lake, burbot were captured between 2 and 100 m but were most commonly caught between 46 and 75 m. In Lake Opeongo, burbot were sonically tracked in depths ranging from 2 and 38 m, but frequencies at specific depths were not reported (Carl 1995). Larval and juvenile burbot were commonly captured from 5 and 10 m deep in Lake Constance, Germany (Wang and Appenzellar 1998). In Lake Roosevelt, burbot were most commonly captured between 30 and 40 m in sinking horizontal gill nets, consistent with their general benthic orientation. However, 40% of the fish that we captured in offshore horizontal gill nets were suspended 5 to 10 m off the bottom of the reservoir, although the relative catch of suspended fish was biased because suspended fish are probably more active and therefore more vulnerable to capture in a gill net. This still demonstrated that substantial portions of the burbot population were suspended at night. Sonic-tagged burbot in Lake Opeongo, Ontario were found to be the most active from dusk to dawn and inactive during daytime hours (Carl 1995), supporting our gill net catch results.

Although adult burbot are typically described as piscivores, their diet was more diverse in Lake Roosevelt, particularly when captured in deep offshore areas. Generally, Lake Roosevelt burbot preyed upon invertebrates (insects, isopods, leeches and crayfish) and fish (dominated by sculpin (*Cottus* spp.)), with only 38% of the diet comprised of fish. In nearby Banks Lake, Washington, four burbot stomachs contained insects (27%), crayfish (25%), sculpin (23%) and yellow perch (*Perca flavescens*) (25%) (Polacek et al. 2002). Fish prey made up 75% of the diet in Great Slave Lake (Rawson 1951) and by age-4 fish dominated the diet of burbot in upper Yukon and Tanana River drainages, Alaska (Chen 1969). Fish comprised 59% of the adult burbot's diet in Lake Winnipeg (Hewson 1955), 63% in Lake Biel, Switzerland (Guthruf et al. 1990), 98% in Lake Simcoe, Ontario (McCrimmon and Devitt 1954), 100% in MilleLacs Lake, Minnesota (Bonde and Maloney 1960), 100% in fish greater than 250 mm in the White River, Michigan (Beeton 1956) and 97% in Lake Superior (Bailey 1972). In most of these waters insects and crustaceans were generally found in the diet, but were less frequent than fish. The low densities of nearshore habitat in Lake Roosevelt, resulting from drastic water level fluctuations, is likely one factor limiting the abundance of suitable fish prey species for burbot (Black et al. 2003).

Beeton (1956) and Ghan and Sprules (1993) reported that a positive relationship occurred between burbot length and the length of its prey. Chen (1969) attributes this relationship to the decline in small prey types (macro invertebrates and scuplin) in the diets of larger burbot. However, Lake Roosevelt burbot preyed upon small prey regardless of their total length. The growth (length at age) of burbot in Lake Roosevelt was consistent with slow to moderate growing populations in Lake Michigan, Lake Superior, and Lake of the Woods, Ontario (Schram 2000; Katsman and Zale 2000). Likewise, the majority of fish sampled had relative weights below the national 75th percentile. Although the relative weights and condition factors varied somewhat from year to year there was not an inter-annual trend indicating that feeding and growth conditions are deteriorating in the reservoir.

The low to moderate growth and condition of burbot in Lake Roosevelt may just be indicative of the oligotrophic status of the reservoir and the relatively low invertebrate and forage fish productivity of a reservoir with large water level fluctuations and limited complex nearshore habitat (Irwin and Noble 1996; Ney 1996; Black et al. 2003). The differences in diet composition between nearshore and offshore burbot, low relative weights and condition factors, and low catch rates may be indicative of a trophic bottleneck for burbot in the lake. Active management will be necessary if burbot become a species of concern for fisheries managers. The current hydrograph for Lake Roosevelt will likely not change due to water demands for lower Columbia River salmon, however, prey fish habitats could be added to the system in areas of high burbot catch rates. A long-term habitat improvement program, coupled with continued monitoring and evaluation, may have positive impacts on burbot and other resident fishes in Lake Roosevelt.

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