Changes in Population Indices of a Diminishing Burbot Population in the Kootenai River, Idaho, USA and British Columbia, Canada

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ABSTRACT

We quantified changes that occurred in proportional stock density (PSD), relative stock density (RSD), relative weight (W_r), and catch per unit effort (CPUE) of a diminishing burbot (*Lota lota*) population in the Kootenai River, Idaho, USA and British Columbia, Canada. Sampling with hoop nets took place periodically over 46 years. After completion of the Libby Dam in Montana in 1973, the burbot population declined. The mean length of burbot increased from 459 mm total length (TL) in 1957-1958 to 615 mm TL in 2002-2004. PSD did not increase appreciably, rising only from 92 in 1957-1958 to 98 by 2002-2004; but, RSD (preferred) increased from 17 in the early samples to 86 by the last sampling interval, which suggested recruitment failures. All other RSD values increased although not incrementally, which also suggested recruitment failures. As the burbot population declined, W_r increased from 75 to 98 from the early 1980s to early 2000s, suggesting that Wr may have a length bias in burbot. We found RSD was more useful when combined with CPUE, which also decreased from 1993 through 2004. Together these indices provide good indication of burbot population change. Hoop nets are the most important sampling gear for burbot but are length selective; thus, PSD (quality) alone will not detect recruitment issues. Managers and researchers of other burbot populations should design sampling programs that consider the value in measuring RSD and CPUE when hoop nets are used.

INTRODUCTION

In Idaho (ID), the burbot (*Lota lota*) is endemic only to the Kootenai River (spelled Kootenay for Canadian waters) (Simpson and Wallace 1982). Burbot in the Kootenai River, ID, USA and Kootenay Lake, British Columbia (BC), Canada were once very abundant and may have provided one of the most robust fisheries in North America (Paragamian and Hoyle 2005). However, the burbot in the Kootenai River is now expected to reach extirpation within the next 10 years unless effective remedial measures are taken (Paragamian et al. 2008); this estimate came about through the analyses of 12 years of capture-recapture data (1993-2004).

Burbot has been the subject of periodic study by the Idaho Department of Fish and Game beginning in winter 1957-1958 (Paul Jeppson, Panhandle Region Archives, IDFG) and continuing in 1979-1982 (Partridge 1983) and 1993-2004 (Paragamian et al. 2008). Between the 1957-1958 sampling and the 1979 collections, the Libby Dam was completed on the Kootenai River near Jennings, Montana. After the dam became operational in 1973, the burbot fishery in Idaho rapidly declined and was closed in 1992 (Paragamian et al. 2000). Concomitant with the collapse in Idaho was the collapse of the burbot fishery in Kootenay Lake, BC (Andrusak 1976, Andrusak and Crowley 1978, Paragamian et al. 2000, Redfish Consulting 1998). In addition to the Libby Dam, other ecosystem changes occurred such as dyking, disconnection from the floodplain, poor forest practices, and mining; and, the Libby Dam has created a nutrient sink by impounding Lake Koocanusa (Paragamian et al. 2000, Anders et al. 2002).

Our objective was to examine population indices that would identify changes in burbot stock structure that had occurred in the Kootenai River. We examined the proportional stock density (PSD), relative stock density (RSD), and relative weight (*Wr*) of burbot in the Kootenai River, ID and BC, as it transitioned from a robust fishery in the 1960s through 2004 when it approached extirpation, and evaluated previously published catch per unit effort (CPUE) data as an index for population assessment.

METHODS AND MATERIALS

Study area

The Kootenai River is one of the largest tributaries to the Columbia River (Bonde and Bush 1975). Originating in Kootenay National Park, BC, the river discharges south into Montana, where Libby Dam impounds water into Canada and forms Lake Koocanusa. From Libby Dam, the river discharges west and then northwest into Idaho and then north into BC and Kootenay Lake. The river eventually joins the Columbia River near Castlegar, BC. The burbot is found throughout the river and lake; our study area was from about Kootenay Lake, BC to Bonners Ferry, ID.

Burbot sampling

There were three principal study intervals, with most collections of burbot taking place from October through April of each interval. All study periods used hoop nets to capture burbot, and only data from hoop net-captured burbot were used in our PSD, RSD, and *Wr* analyses. In the first interval, Jeppson (pers. comm., IDFG, retired) sampled burbot from early November 1957 through January of 1958 and July 1958. Hoop net size was 91-cm diameter, about 3.66-m length, and 25-cm bar web. Nets were set at the mouth of Boundary Creek at the ID/BC border and Deep Creek. Only burbot total lengths (TL) were measured. In the second interval, Partridge (1983) collected burbot from December 1979 through July 1982, using hoop nets with a maximum diameter of 91 cm, 3.66-m length, and 25-cm bar web. He fished Boundary Creek and Deep Creek and the Kootenai River in the vicinity of Copeland, ID. Captures of burbot from early March 1993 through March 2004 were with baited hoop nets. The 91-cm diameter by 3.66-m long nets were used briefly from 1993 through 1995 but were replaced with smaller diameter hoops of 61-cm because there is no difference in burbot vulnerability and the smaller diameter hoops were lighter and easier to handle (Bernard et al. 1991). Nets were deployed in deep areas of the Kootenai River between Ambush Rock near Bonners Ferry, ID, and Nicks Island, BC. Burbot were also sampled at three tributaries – Deep Creek and Boundary Creek, ID, and the Goat River, BC.

Length frequencies

Length frequencies were pooled into three sampling year class intervals with one exception. Length frequencies from 1957-1958 were the summary of the data for fish that Jeppson (unpublished) captured from November 1957 to January 1958 and July 1958. We also used length frequencies for burbot captured in hoop nets from 1979-1982 (Partridge 1983), 1993-1995, 1996-1998, 1999-2001, and 2002-2004 (Paragamian et al. 2008). We pooled our sample into three-year intervals from 1993 to 2004 to match the three study years of Partridge (1983) and because we needed sample sizes to correspond to Paragamian et al. (2008) so that the samples were large enough to compute density plots. Also, in the later years of sampling, burbot numbers were in rapid decline and captures in single seasons were low. While this violates the strict assumption of independence between years or between 3-yr periods, it had little consequence on the results (Paragamian et al. 2008). Only 30 of the 333 lengths were for recaptures. In the previous study, a regression analysis and analysis of variance (ANOVA) were run using only "newly found" fish, both for the annual and 3-yr periods; the results were very similar to those obtained when the data also included recaptures. In theory, excluding recaptures for the sake of independence may also bias results. Because we were interested in documenting changes in mean body length within the population over time, a sample that included between-year recaptures should be random and representative as long as all fish have the same probability of being captured in a given year (Paragamian et al. 2008). Regardless, results and conclusions are essentially the same with or without recaptures. Burbot were not sacrificed for age analysis of otoliths because the population was in decline.

We used ANOVA and Tukey's studentized test to compare differences between means of total length of burbot for all data sets ($\alpha = 0.05$; SYSTAT version 11, SYSTAT 2004).

Proportional stock densities

PSD is the percentage of the sampled stock that is of quality length or longer. We used values for stock length (S) and quality length (Q) of 200 mm TL and 380 mm TL, respectively, as calculated by Fisher et al. (1996). PSD was further defined in terms of RSD using the preferred (P), memorable (M), and trophy (T) lengths recommended by Gablehouse (1984) and calculated for burbot by Fisher et al. (1996), where P = 530 mm, M = 670 mm, and T = 820 mm TL. We calculated PSDs and traditional RSDs (Willis et al. 1993) for both of the unpublished data sets from 1957-1958 (Jeppson IDFG) as well as for the data from 1979-1982 and 1993-2004 (Partridge 1983, Paragamian and Laude 2008). We calculated 95% confidence intervals for PSDs and RSDs with the method of Gustafson (1988).

Relative weight

We calculated relative weight (W_r; Wege and Anderson 1978) of burbot based on burbot standard weight (W_s; Fisher et al. 1996), where $\log_{10}W_s = -4.868 + 2.898 \log_{10}\text{TL}$. Relative weights were calculated for the 1979-1982 data set and the 1993-2004 data set.

We used ANOVA and Tukey's studentized test to compare differences between means for W_r of burbot for the 1979-1982 and 1993-2004 data sets ($\alpha = 0.05$; SYSTAT version 11, SYSTAT 2004). To determine if pre-spawn and post-spawn burbot weights could be combined, we used a two-tailed t-test to compare the means of W_r for pre-spawn and post-spawn burbot. The mean W_r's for pre-spawn and post-spawn burbot included pooled data from the 1979-1982 and 1993-2004 data sets ($\alpha = 0.05$; SYSTAT version 11, SYSTAT 2004). Fish collected between 1 October and 10 February were considered pre-spawn, and fish collected between 11 February and 30 November were considered post-spawn fish (Paragamian 2000).

Weights and analyses were not separated by season but combined because we found no difference in W_r at the 0.01 level; $p = 0.158$. Pre-spawn burbot had a mean W_r of 92, and post-spawn burbot had a mean W_r of 89.

Catch per unit effort (CPUE)

We used CPUE data in Paragamian et al. (2008), where one unit of effort was a 24-h set, as a reference to population change for comparison to that of PSDs and RSDs.

RESULTS

Lengths of burbot in the samples from 1957 through 2004 increased significantly ($F_{5,478} = 21.49$, $p < 0.001$) from a mean of 459 mm TL in 1957-1958 to 615 mm TL by 2002-2004 (Table 1 and Fig. 1). Mean lengths of burbot in all class intervals from 1979 to 2004 were significantly larger than the mean of the 1957-1958 sample (ANOVA $p < 0.01$). Mean TLs of burbot collected in 1996-1998 and 2002-2004 were longer than the mean TL of those collected in 1993-1995, while the 1996-1998 burbot were longer than those of 1999-2001.

The greatest changes in PSD and RSD occurred between the 1957-1958 samples

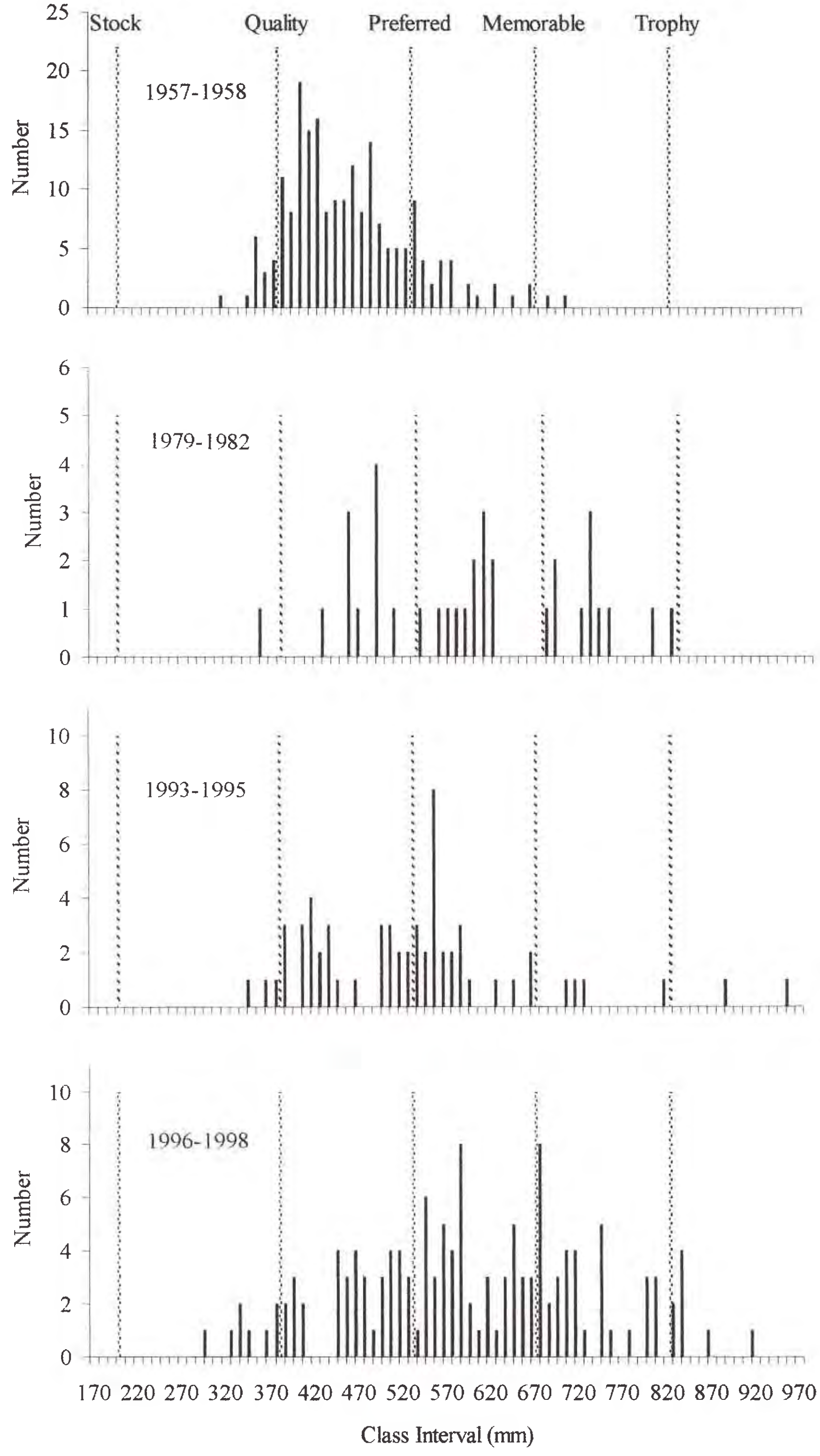

Figure 1. Length frequency distributions for burbot in the Kootenai River, Idaho and British Columbia for intervals between 1957 and 2004.

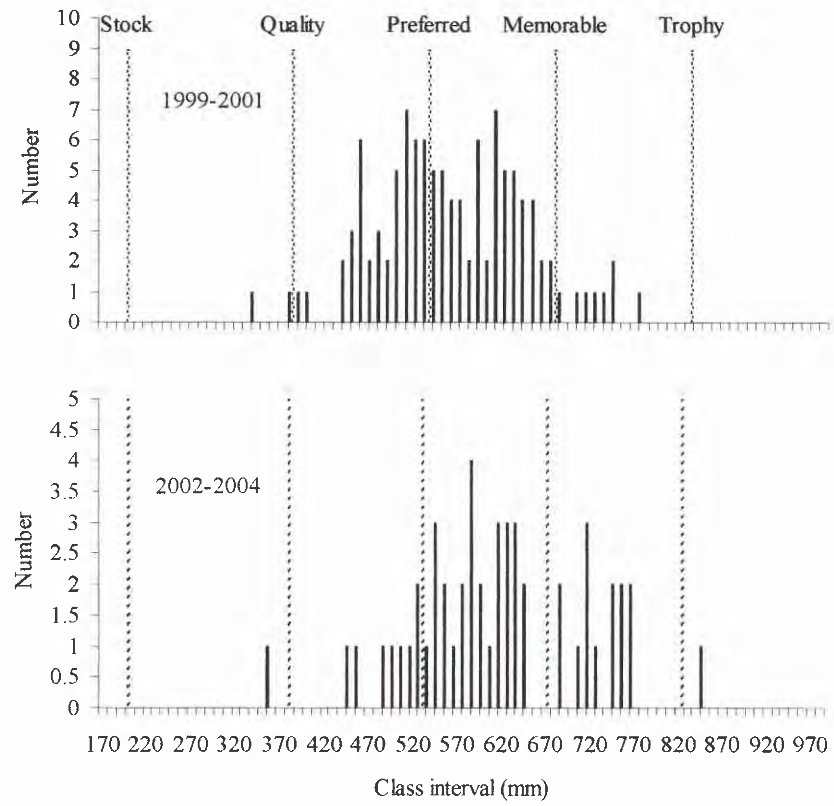

Table 1. Total length (TL) summary statistics for burbot sampled in the Kootenai River at intervals from 1957 through 2004.

Statistic	1957-1958	1979-1982	1993-1995	1996-1998	1999-2991	2002-2004
n	199	34	61	135	111	50
Mean TL (mm)	459	594	533	596	557	615
SD	(69)	(115)	(121)	(134)	(82)	(97)
Range	317-704	358-813	349-958	300-915	332-770	352-841

and the more recent samples (Table 2). PSD was similar throughout the intervals from 1957 to 2004 but increased from 17 to 86 by the last sampling interval. All other RSD values also increased although not incrementally. Since sample size was sufficient to approximate a normal distribution, we were able to calculate the 95% confidence intervals for 15 of the 24 PSDs and RSDs (Gustafson 1988).

Weights were not collected during the 1957-1958 burbot sampling, but mean relative weights in the five post-Libby Dam sampling intervals were significantly different ($F = 13.40$; $p < 0.001$) and increased over this period (Table 3).

Catch per unit effort varied from 1993 through 1998 (range = 0.029 to 0.054 burbot/net-day) and declined steadily thereafter (Fig. 2).

DISCUSSION

Willis et al. (1993) suggested that increases in PSD could be indicators of low recruitment and/or environmental disturbances. Changes in the Kootenai River occurred soon after closing of Libby Dam in 1973 and suggest that there was an almost immediate

Table 2. Population size structure indices (PSDs and/or RSDs) for burbot from the Kootenai River, Idaho and British Columbia for 1957-2004. Approximate 95% confidence intervals (Gustafson 1968) are in parentheses. Length categories are stock (S), quality (Q), preferred (P), memorable (M), and trophy (T).

	1957-1958		1979-1982		1993-1995		1996-1998		1999-2001		2002-2004	
	n	PSD/RSD	n	PSD/RSD	n	PSD/RSD	n	PSD/RSD	n	PSD/RSD	n	PSD/RSD
S	199		34		61		133		111		50	
Q	184	92 (±6)	33	97[a]	59	97[a]	127	94 (±5)	109	98(±5)	49	98[a]
P	33	17[a]	23	68 (±23)	32	53 (±22)	93	69 (±10)	68	61 (±13)	43	86 (±13)
M	2	1[a]	11	32[a]	7	12[a]	44	33 (±17)	8	7[a]	14	28[a]
T	0	–	0	–	3	5[a]	8	6[a]	0	–	1	2[a]

[a]Likely represents a sample size insufficient to approximate a normal distribution.

impact of the dam on recruitment and well-being of the Kootenai River burbot, supporting the findings of Paragamian (2000), Paragamian et al. (2005), and Paragamian and Wakkinen (2008). These studies implicated warmer temperatures and higher discharges during the winter migration and spawning period as impacts on recruitment of burbot. Increases in mean length may have been a result of the combined effects of increases in the average age and size of fish, failing recruitment, and a declining population. Failing recruitment was confirmed by Paragamian et al. (2008). For comparison, T. Horton (pers. comm., Montana Fish Wildlife and Parks) found an average RSD-P of 31 in the more stable burbot population in a reach of the Missouri River in Montana.

Relative weights of burbot during the years following closure of the Libby Dam progressively increased as population density decreased, suggesting that W_r may have been density dependent. However, the increase in W_r occurred despite decreased productivity in the Kootenai River system below the dam because of nutrient trapping within Koocanusa Reservoir. Woods (1982) and Snyder and Minshall (1996) found that the Kootenai River below Libby Dam was phosphorus- and nitrogen-limited, inhibiting primary and secondary production. Kootenay Lake, BC, farther downstream of our study reach, was also nutrient-limited (Daily 1981). Fisher et al. (1996) recommended establishment of different W_r values because they found differences in lotic vs lentic populations of burbot. The change in mean W_r likely could be related to a biased W_r equation (Gerow et al. 2004 and 2005). If smaller burbot tend to be naturally "skinnier," a biased equation would indicate that the fish are in poor condition when they are not. If there is in fact a biased equation, this could provide an explanation for the increase in mean W_r. A lack of recruitment would decrease the abundance of the size classes of fish that a biased equation would inaccurately label as being in poor condition and would result in a greater mean W_r. M. Abrahamse (pers. comm., University of Wyoming) found in his preliminary data analysis of the burbot W_s equation that stock-quality length burbot have the lowest W_r values.

Willis et al. (1993) suggested that there were four sampling considerations in the quantification of length frequency samples with PSD and RSD – sample size, selection of sampling sites, gear related bias, and seasonal influences. In our study, sample size was most likely affected by population density because in most years we expended to the maximum our allotted logistic effort while burbot numbers were diminishing (Paragamian et al. 2008). For example, from 1993 through 2004, we averaged 1,292 net-days of effort in capturing burbot (Paragamian and Laude 2008). But despite our effort to capture as many burbot as possible from 1993 through 2004, some samples for calculations of PSD and RSD did not meet the requirements of size sufficient for approximation of a normal distribution (Gustafson 1988). Sampling sites and effort were relatively uniform from 1996 through 2004, while 1993-1995 were years we spent defining sample locations. The number of burbot capture locations and effort in 1957-1958 were limited, effort was not tabulated, and sampling was conducted only in ID as it was from 1979 to 1982.

Sampling during the pre-spawn and spawning season could have biased length and age of the catch of burbot. Sampling efforts by season were most consistent during 1993-2004 and 1957-1958 because they included the spawn migration, spawning, and the immediate post-spawn period. The burbot in the Kootenai River is believed to spawn during the last week in January and the first two weeks in February (Paragamian 2000). Because the burbot is less active during the spring and summer months because water temperatures are warmer (Nikčević et al. 2000, Pääkkönen et al. 2000), we restricted sampling to its most vulnerable time of the year. In the 1957-1958 sample, it is likely that many of the smaller stock length fish were males, since males mature earlier than females and at much shorter lengths (Evenson 2000). Arndt and Hutchinson (2000) found that the smallest males ranged from 242 to 297 mm TL and the smallest females ranged from 295 to 365 mm TL in results of weir trapping during a spawning run on a tributary to Columbia Lake, BC. We suspect that the most serious bias would have been during the 1979-1982 sampling because samples included the post-spawn (spring and summer) period when the burbot is less active.

PSD and RSD as calculated by Fisher et al. (1996) are likely accurate, but some bias in our estimates towards higher and stable PSDs occurred because of gear bias (Willis et al. 1993). Unlike many other species that are vulnerable to other standard sampling techniques (e.g., gill nets, trawling, electrofishing), the burbot is difficult to capture with most sampling methods because it is a benthic predator and often occupies large deep lakes and rivers (McPhail and Paragamian 2000). Although cod traps have been effective for capturing burbot in lakes (Spence 2000), the hoop net is the primary method by which the burbot is sampled in rivers in North America (Parker et al. 1988, Bernard et al. 1991, Paragamian 2000, Spence 2000, Horton and Strainer 2008). Studies by Bernard et al. (1991) indicated that the burbot can be caught in hoop nets at about 350 mm TL but is not fully recruited until 450 mm TL. Hoop nets used in its capture are selective for fish much larger than 200 mm TL, the initial length of stock length fish (Fisher et al. 1996), and will sample a higher proportion of quality length fish at 380 mm TL. As a consequence, our data showed little change in PSD despite diminished recruitment (Paragamian et al. 2008), but RSDs increased through the study intervals and indicated recruitment failures.

Willis et al. (1993) suggested that PSD and RSD alone were not always sufficient to describe population changes but were more useful when combined with fish condition (W_r) and CPUE. Our findings support this idea. CPUE has been used to compare burbot stock densities in the Kootenai River and other waters (Parker et al. 1988, Paragamian et al. 2008, Hardy et al. 2008) and was a suitable indicator of the burbot population change (Paragamian et al. 2008). Had these changes in RSD and CPUE been noted in the late 1970s, conservation measures may have been implemented sooner (KVRI 2005).

Table 3. Relative weight summary statistics for burbot sampled from the Kootenai River for intervals from 1979 through 2004. No weights were collected during 1957-1958.

Statistic	1979-1982	1993-1995	1996-1998	1999-2001	2002-2004
n	34	54	135	110	50
Mean	74.9	88.4	93.9	89.3	98.2
SE	2.4	1.9	1.2	1.5	2.9
SD	13.9	14.0	14.1	16.2	20.7

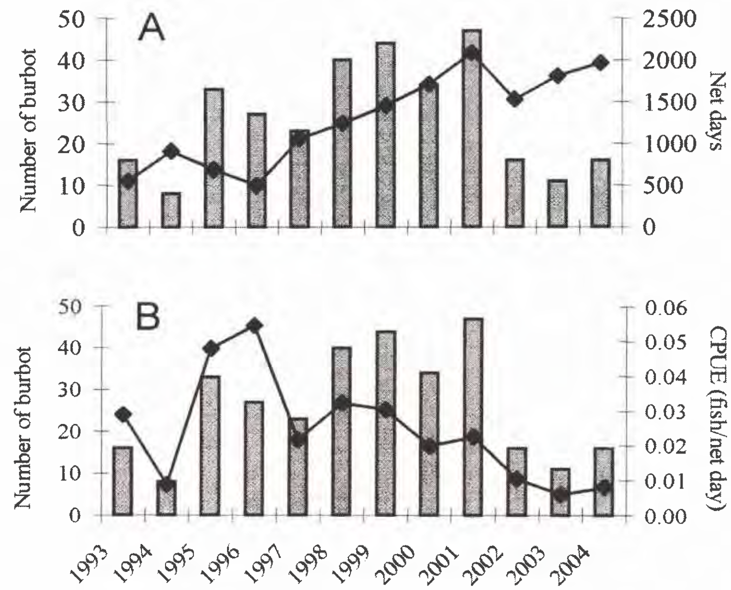

Figure 2. Kootenai River burbot catch (histograms) and sampling effort (A) and CPUE (B) from 1993 to 2004. Data shown include winter hoop net effort only.

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