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Stocking for rehabilitation of burbot in the Kootenai River, Idaho, USA and British Columbia, Canada

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Summary

The burbot *Lota lota* is widespread globally, but the population in the Kootenai River, Idaho and British Columbia, Canada is at risk of extirpation because of habitat changes caused by operation of Libby Dam in Montana, 100 km upstream of the border with Idaho. We developed an age-structured simulation model to estimate the number of age-0 burbot (fall fingerlings) to stock annually to rebuild the population in the Kootenai River. We found with the estimated annual survival of about 38% that 110 000–900 000 age-0 burbot per year will need to be stocked to rebuild the burbot population in the Kootenai River in 25 years, depending on the rehabilitation goal, either 5500 age-4 burbot and older as an interim goal or 17 000 age-4 and older burbot as an ultimate goal (longer than 250 mm). If survival is higher at 61% then the stocking numbers could range from 12 000 to 35 000 age-0 fingerlings per year. After stocked burbot in the population reach age 4, discharge from Libby Dam must be regulated to provide suitable temperatures and flows during the burbot pre-spawning and spawning periods, to enable the population to reproduce and return to self-sustaining status. Our findings will serve as an example for similar efforts to restore depleted burbot populations elsewhere in the world.

Introduction

Although burbot *Lota lota* populations are widespread, many are not managed (Paragamian and Willis, 2000), so studies of population dynamics are few (Paragamian et al., 2008). Consequently, lack of conservation efforts is a worldwide issue despite the fact that many populations are in decline or have been extirpated (Maitland and Lyle, 1990, 1996; Keith and Allardi, 1996; Argent et al., 2000; Arndt and Hutchinson, 2000; Paragamian et al., 2000; Worthington et al., 2009). Of the few populations for which population rehabilitation is underway, effort that is focused on culture, although evolving, has shown promise to become useful for rehabilitating populations at risk (Dillen et al., 2008; Jensen et al., 2008a; Vught et al., 2008).

In Idaho, burbot are endemic only to the Kootenai River (Fig. 1; spelled Kootenay River in Canada; Simpson and Wallace, 1982), where this transboundary population is at risk of extirpation (Paragamian et al., 2008; Paragamian and Hansen, 2009). Construction and operation of Libby Dam by the US Army Corps of Engineers (USACE) in 1972 was implicated as the primary cause of burbot population collapse in Idaho and British Columbia (BC), Canada (Paragamian, 2000; Paragamian et al., 2005; Paragamian and Wakkinen, 2008). Libby Dam is located in Montana 100 km upstream of the border with Idaho (Fig. 1). Other ecosystem changes may also have affected burbot (Paragamian et al., 2000; Anders et al., 2002), and overfishing was implicated as a possible cause of population collapse in Kootenay Lake, BC (Ahrens and Korman, 2002). Burbot in the Kootenai River will be extirpated within the next 10 years in the absence of remediation (Paragamian and Hansen, 2009).

In 2000, the burbot population in the Kootenai River was petitioned for listing as threatened under the U.S. Endangered Species Act, but in 2003, the U.S. Fish and Wildlife Service found that listing was not warranted because the population did not represent a distinct population segment (U.S. Federal Register, 2003). Because burbot in the Kootenai River were culturally and recreationally important before population collapse, an International Burbot Conservation Strategy (Strategy) was developed by a community-wide working group to restore the population (KVRI, 2005; Ireland and Perry, 2008). The Strategy outlined rehabilitation measures, including changes to the operation of Libby Dam and development of conservation aquaculture to supplement the wild stock during population rehabilitation. However, population rehabilitation through hatchery supplementation or wild recruitment is unreasonable because flows from Libby Dam are not presently suitable for the burbot life history strategy for reproduction.

We previously used demographic data (Paragamian et al., 2008) to establish burbot rehabilitation targets in the Kootenai River (Paragamian and Hansen, 2009). Because density of the burbot population in the Kootenai River prior to closure of Libby Dam was unknown, we used burbot population density in Alaskan rivers (Evenson, 1993), indexed as catch rate in standardized hoop nets (catch / effort = C/f = CPUE), as surrogate targets for rehabilitation of burbot in the Kootenai River. Targets included an interim target abundance of 5500 individuals (45 fish km^{-1}; 3.0 fish ha^{-1}) within 25 years, when each adult produced 0.85 recruits per year, and an ultimate target abundance of 17 500 individuals (143 fish km^{-1}; 9.6 fish ha^{-1}), when each adult produced 1.1 recruits per year. We believe these targets are achievable because burbot populations elsewhere have been resilient when factors limiting population recovery were reduced (Bruesewitz, 1990; Taube and Bernard, 1995; Stapanian et al., 2006, 2008).

Our objective was to determine the number of age-0 burbot to stock, as fall fingerlings each year, to establish a burbot population with an interim population goal of 5500 and an ultimate population goal of 17 500 fish longer than 250 mm (age 4 and older) within 25 years in the Kootenai River.

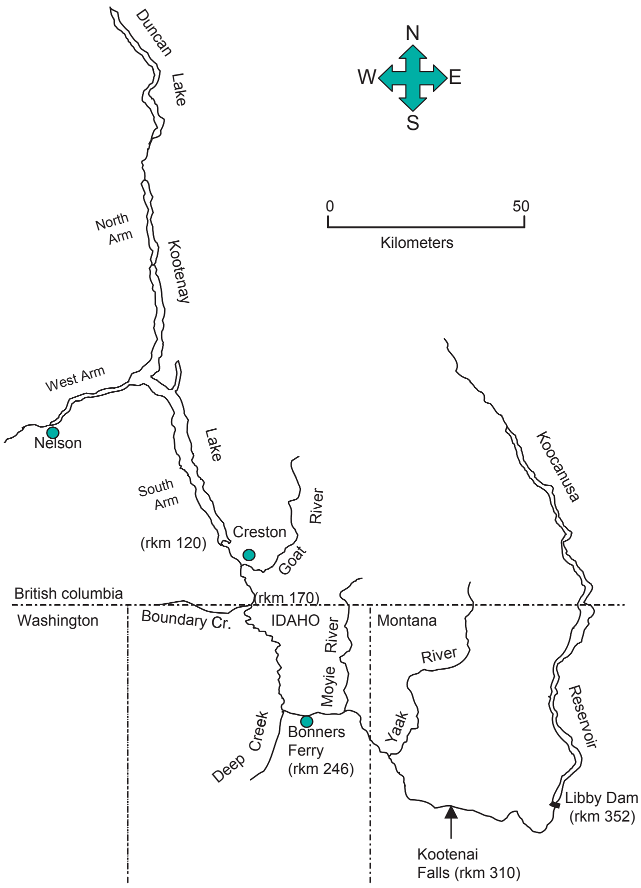

Fig. 1. Location of the Kootenai River, Kootenay Lake, Lake Koocanusa, Libby Dam, Bonners Ferry, the Columbia River, and important points. River distances from the northernmost reach of Kootenay Lake are in river kilometers (rkm) and are indicated at important points

We assumed that the USACE and the Bonneville Power Administration would improve habitat conditions in the river through flow regulation after an appropriate target level of abundance was established. Stocking guidelines for burbot have never been established, so we believe our analysis will be important for rehabilitation of other burbot populations world-wide.

Methods

We used vital statistics from Paragamian et al. (2008), along with a stochastic age-structured population model, to simulate future abundance for burbot in the Kootenai River over a range of hypothetical annual stocking rates. For each hypothetical stocking rate of age-0 burbot, abundance of burbot in subsequent years and ages was modeled, as a function of the annual survival rate (Quinn and Deriso, 1999):

$$N_{i+1,j+1} = N_{i,j} \times (S + \varepsilon)$$

In the model, $N_{i,j}$ = the number of burbot in each year *i* and age *j*; $N_{i+1,j+1}$ = the number of burbot in the next year $i + 1$ and age $j + 1$; S = the annual survival rate (constant across all ages); and ϵ = stochastic inter-annual variation in the survival rate. We assumed that abundance in the first year of the simulation was zero because the burbot population in the Kootenai River by 2006 (Paragamian et al., 2008) declined to only 47 fish and recruitment was negligible.

In the model, we simulated a range of fixed annual stocking rates for age-0 burbot $N_{i,j=0}$ that led to future abundance encompassing previously developed targets for population rehabilitation in 25 years (interim goal = 5500 burbot; ultimate goal = 17 000 burbot; Paragamian and Hansen, 2009). We also assumed there would be no recruitment from the wild stock or hatchery released fish in those 25 years and be density independent. To simulate stochastic inter-annual process error ϵ for each year, we treated the annual survival rate for each simulated year as a random normal variable with mean S = 38.2% and standard error SE = 0.049, the mean and standard error of the annual survival rate during 1997–2006 (Paragamian et al., 2008). We also modeled the effect of higher survival because survival in the Kootenai River may be lower than would be expected if the few individuals present were captured and handled less frequently (Paragamian et al., 2008). To that end, we modeled a higher survival rate, S = 61.3% (with the same level of inter-annual variation), the average annual survival rate among burbot populations in Lake Erie and Lake Superior (southwestern Lake Superior, S = 61%, Bailey, 1972; Lake Erie, S = 60%, Clemens, 1951; Lake Erie during 1994–2003, S = 67%, Stapanian and Madenjian, 2007; and western Lake Superior, S = 57%, Schram, 2000).

We simulated future population numbers for 1000 years over a range of fixed annual stocking rates to quantify the equilibrium burbot population abundance that corresponded to each stocking rate. We assumed that all age-4-and-older burbot were vulnerable to capture in the standard hoop nets used for monitoring the population (Paragamian et al., 2008) and would mature and reproduce at that age if suitable spawning conditions can be restored by flow modification at Libby Dam. We summarized the median, 2.5 percentile, and 97.5 percentile of simulated abundances as the likely range of age-4-and-older burbot abundance that resulted from each simulated stocking rate.

Results

If annual survival remains the same in the future as during 1997–2006, 110 000–900 000 age-0 burbot will need to be stocked annually to reach population rehabilitation goals for age-4-and-older burbot in the Kootenai River (Fig. 2). To build a burbot population equal to the interim rehabilitation goal of 5500 age-4-and-older individuals in 25 years, 165 000 age-0 burbot would need to be stocked annually into the Kootenai River. Because of inter-annual variation in survival, as few as 110 000 and as many as 280 000 age-0 burbot would need to be stocked annually. To build a burbot population equal to the ultimate rehabilitation goal of 17 000 age-4-and-older individuals in 25 years, 500 000 age-0 burbot would need to be stocked annually into the Kootenai River. Because of inter-annual variation in survival, as few as 340 000 and as many as 900 000 age-0 burbot would need to be stocked annually.

If annual survival increases in the future to be more similar to burbot populations elsewhere, 12 000–65 000 age-0 burbot will need to be stocked annually to reach population rehabilitation goals for age-4-and-older burbot in the Kootenai River (Fig. 3). To build a burbot population equal to the interim rehabilitation goal of 5500 age-4-and-older individuals in 25 years, 15 000 age-0 burbot would need to be stocked annually into the Kootenai River. Because of inter-annual variation in survival, as few as 12 000 and as many as 22 000

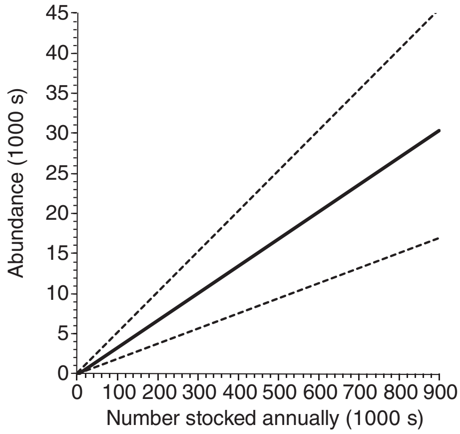

Fig. 2. Simulated equilibrium abundance of age-4-and-older burbot resulting from a range of numbers of age-0 burbot stocked and an annual survival rate of $S = 38.2\%$ in the Kootenai River. The solid line depicts the median and dashed lines depict the 2.5 percentile and 97.5 percentile of 1000 simulated abundances. All simulations were from a stochastic population model based on burbot population demographic parameters estimated by Paragamian et al. (2008)

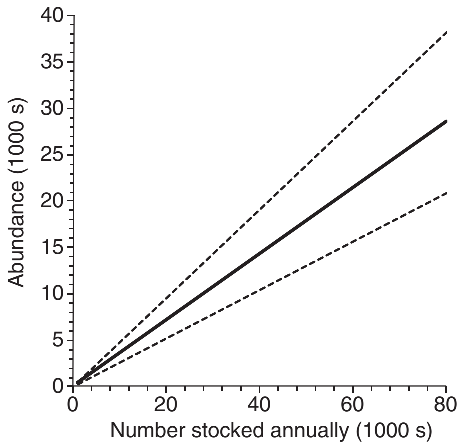

Fig. 3. Simulated equilibrium abundance of age-4-and-older burbot resulting from a range of numbers of age-0 burbot stocked and an annual survival rate of $S = 61.3\%$ in the Kootenai River. The solid line depicts the median and dashed lines depict the 2.5 and 97.5 percentile of 1000 simulated abundances. All simulations were from a stochastic population model based on burbot population demographic parameters estimated by Paragamian et al. (2008)

age-0 burbot would need to be stocked annually. To build a burbot population equal to the ultimate rehabilitation goal of 17 000 age-4-and-older individuals in 25 years, 48 000 age-0 burbot would need to be stocked annually into the Kootenai River. Because of inter-annual variation in survival, as few as 35 000 and as many as 65 000 age-0 burbot would need to be stocked annually.

Discussion

To rebuild the burbot population in the Kootenai River, large-scale methods for intensive culture and rearing of age-0 burbot will need to be developed. Early studies on intensive culture and extensive rearing of burbot have been promising (Harzevili et al., 2003; Jensen et al., 2008a,b; Idaho Department of Fish and Game, unpubl. data), but a suitable genetic stock of burbot for rehabilitation of the Kootenai River population is problematic because burbot abundance is too low in the Kootenai River to serve as a brood source. The burbot population in Columbia Lake, British Columbia, shares six of eight haplotypes with the population in the Kootenai River (Powell et al., 2008), so it may be an appropriate brood stock for production of juveniles for stocking into the Kootenai River. Further, burbot above Kootenai Falls were of Mississippi clade while burbot downstream were of Pacific and Mississippi clades (Powell et al., 2008). We therefore propose to use burbot from Moyie Lake, British Columbia, which are of the Pacific clade (Powell et al., 2008). However, genetic concerns may be moot because burbot are presently entrained through Libby Dam and migrating from above Kootenai Falls (Skarr et al., 1996), Montana. If suitable spawning conditions can be created, immigrants will add to the reproductive stock and thereby help to restore the original genetic makeup of burbot in the Kootenai River.

Recent experimental releases of age 3 and 4 burbot into the Kootenai system, of Moyie Lake stock, in autumn 2009 were promising (Neufeld et al., 2011). These hatchery reared burbot, implanted with ultrasonic transmitters, exhibited high initial survival and rapid, wide dispersal from one stocking site, with some staying nearby traditional burbot spawning locations (Neufeld et al., 2011). In a river in Belgium, intensively reared burbot larvae failed to produce measurable numbers shortly after stocking, whereas extensively reared fingerlings survived several months (Dillen et al., 2008; Vught et al., 2008), which further suggests that burbot can be successfully cultured and reared for subsequent stocking to rehabilitate depleted populations. Culture and rearing methods must now be developed at a scale that is large enough to rebuild the population of burbot in the Kootenai River.

Our recommendation to build a burbot population through stocking relies on the assumption that burbot will reproduce if flow conditions in the Kootenai River are modified to be suitable for burbot reproduction (Paragamian and Wakkinen, 2008). To that end, discharge from Libby Dam should average 176 m^3 s^{-1} (range = 113–300 m^3 s^{-1}) for at least 90 days from mid-November through mid-February, the burbot pre-spawning and spawning periods (Paragamian, 2000; Paragamian et al., 2005; Paragamian and Wakkinen, 2008; Paragamian and Hansen, 2009) and should occur when stocked burbot reach age-4 the first year of maturity (McPhail and Paragamian, 2000). If suitable flow conditions are provided, we assume that burbot will reproduce and thereby fuel population recovery, as with other species that were restored through stocking. For example, stocked lake trout aided population recovery in Lake Superior (Hansen et al., 1995), though reproductive effectiveness of hatchery-origin fish differed among areas. In eastern Lake Superior, hatchery-origin and wild-origin adult lake trout were equivalent in their contribution to recruitment (Richards et al., 2004), whereas in western Lake Superior, stocked lean lake trout were only 2.6% as effective as wild lake trout in their contribution to recruitment (Corradin et al., 2008). Consequently, burbot population recovery in the Kootenai River may be slower than previously predicted if stocked adults do not reproduce as effectively as wild adults.

Our simulations assumed that survival of stocked burbot would be similar to survival of wild burbot in the Kootenai River during 1997–2006 (Paragamian et al., 2008), which will be more likely if burbot used for conservation aquaculture are of wild origin, as has been found in comparisons of post-stocking survival of wild and hatchery origin fishes. For example, survival of wild brown trout was 1.3–4.5 times higher than domestic brown trout after 1 year in two Wisconsin streams (Avery et al., 2001), two times higher after 2 years in four Michigan lakes (Alexander, 1985), three times higher after 1 year and 26 times higher after 2 years in one Wisconsin stream (Avery, 1974), and six times higher after 2 years in six Michigan streams (Wills, 2006). Similarly, survival of stocked fish was also higher for wild origin than hatchery origin brook trout (Flick and Webster, 1964), cutthroat trout (Miller, 1954), and walleye (McWilliams and Larscheid, 1992), though the survival advantage of wild-origin stocked fish may depend on stocking location (sockeye salmon; Hyatt et al., 2005) and genetic similarity of stocked wild-origin and hatchery-origin fish (coho salmon; Rhodes and Quinn, 1999).

We do not know if large-scale culture methods can be developed, if stocking can rebuild the burbot population, or if flow regulation from Libby Dam will be altered in time to save the burbot population in the Kootenai River before it disappears. Early attempts to rear burbot have been encouraging, but large-scale rearing is needed to rebuild the population in the Kootenai River. Further evaluations are needed of release strategies and post-release survival in relation to stocking location, time of release, and size at release. If the population can be rebuilt, flows from Libby Dam will need to be regulated to enhance the likelihood that burbot can reproduce. The stock status of burbot should be monitored with standardized hoop net effort indexed to assess the interim goal of 5500 adult burbot at 0.484 fish per net day and the ultimate goal of 17 500 at 1.23 fish per net day (Paragamian and Hansen, 2009). Despite substantial impediments to burbot population rehabilitation in the Kootenai River, we believe the population will be rehabilitated and that our efforts will be an example for efforts elsewhere in the world.

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Conflict of interests

The authors of this manuscript had no conflicts of interest in regards to the findings or content.

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