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[Management Brief]

Seasonally Dependent Movement of Lake Trout between Two Northern Idaho Lakes

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Abstract.—The diel and seasonal movements of lake trout *Salvelinus namaycush* between Upper Priest Lake and Priest Lake, Idaho, were studied in 2000. Gill nets were used to capture and detect fish movements between the lakes. Lake trout were caught in the outlet of Upper Priest Lake and in the Thorofare (the narrow channel connecting the two lakes) primarily in the spring and fall, when water temperatures were cool. No lake trout were caught when the water temperature exceeded 15°C. Lake trout were primarily caught at night (94%). Multiple regression analysis indicated that nighttime lake trout catch per unit effort (CPUE) was significantly higher at lower lake surface water temperatures than at higher temperatures ($P < 0.01$). Daytime lake trout CPUE was significantly higher at low Priest Lake surface temperature than high temperature and at high Thorofare depth than at low depth ($P < 0.01$). Nighttime CPUE was significantly higher than daytime CPUE ($P < 0.01$). These results indicate that warm summer water temperatures function as a natural thermal barrier to movement between the lakes in July and August, and that it may be necessary to block lake trout movements between the two lakes at other times to effectively control the population in Upper Priest Lake.

The introduction of nonnative fishes into aquatic ecosystems can have detrimental consequences for native fish species and other biota (Kohler and Courtenay 1986; Dunham et al. 2004). In the Priest Lake system of northern Idaho, the effects of competition between native bull trout *Salvelinus confluentus* and introduced lake trout *S. namaycush* are of particular concern (Fredericks 1999). The two species are top piscivores and can have similar food habits and growth rates (Donald and Alger 1993). Studies have also indicated that these species have similar thermal tolerances and prefer temperatures below 15°C (Bjornn 1957; Martin 1957; Snucins and Gunn 1995). In Priest Lake, Bjornn (1957) found both species at depths of 12–18 m, where water temperatures were 7–13°C. It has been suggested that there is competition between the two species and that the competitive superiority of lake trout may result in the extirpation of bull trout from lakes where they coexist (Donald and Alger 1993).

The Priest Lake system supported a successful bull trout fishery prior the late 1970s, when a sharp decline in the fishery was first noticed (Rieman and Lukens 1979). By the late 1990s, the population had been extirpated from Priest Lake (area, 9,340 ha) and was restricted to the much smaller Upper Priest Lake (area, 541 ha); only 100 adult bull trout are believed to remain there (Fredericks 1999). Conversely, lake trout abundance increased substantially throughout the system during this period (Mauser 1986). Lake trout were not believed to inhabit Upper Priest Lake in the early 1980s, but by the late 1990s there were an estimated 1,000 lake trout in the lake (Fredericks 1999). Fredericks (1999) also reported that lake trout were able to migrate freely between the two lakes through a 3-km-long stream channel known as the Thorofare.

The increase in lake trout abundance and concurrent decrease in bull trout abundance led managers to believe that the bull trout population in Upper Priest Lake was at risk of extinction due to competition from lake trout (Fredericks 1999). Lake trout introduced to Bow Lake, Alberta, apparently caused the extirpation of bull trout from the lake (Donald and Alger 1993). Therefore, information on the movement patterns of lake trout between Priest Lake and Upper Priest Lake was needed to ensure the protection of the remaining bull trout population in Upper Priest Lake. The objectives of this study were (1) to characterize seasonal movements of lake trout through the Thorofare connecting the two lakes and (2) to relate these movements to basic physical and thermal habitat conditions encountered by lake trout in the lakes and the Thorofare.

Study Area

The Priest Lake system in northern Idaho includes Priest Lake, Upper Priest Lake, and their

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tributaries. The lakes are situated in the Selkirk Mountains amid a 1,550-km^2 coniferous forest watershed. Upper Priest Lake is located 30 km south of the Idaho–British Columbia border and 90 km north of the city of Coeur d'Alene. Upper Priest Lake has a mean depth of 18 m and a maximum depth of 32 m. A small dam at the outlet of Priest Lake maintains the elevation of both lakes at 743 m from the conclusion of spring runoff to mid-October, at which time water is released and the elevation is lowered to 742 m. The Thorofare is 70 m wide and generally 2–3 m deep. During summer months (June through early September), the Thorofare receives heavy boat traffic.

Methods

Fish movements during spring through fall.— Gill nets (experimental, monofilament, sinking) were used to capture lake trout moving between the lakes. The gill nets were of three sizes: (1) 91.4 × 2.4 m with three panels of 2.5-, 3.8-, and 5.1-cm mesh; (2) 54.9 × 1.8 m with five panels of 2.5-, 3.8-, 5.1-, 6.4-, and 7.6-cm bar-measure mesh; and (3) 45.7 × 1.8 m with six panels consisting of 1.8–6.4-cm bar-measure mesh. Gill nets were set during April 21–November 8, 2000. The nets were set at the outlet of Upper Priest Lake from April 21 to June 21, when spring runoff flows prevented their use in the Thorofare. At Upper Priest Lake, three experimental gill nets (91.4 × 2.4 m) were set overnight (sunset to 1000 hours) and three were set during the day (1000 hours to sunset) in water less than 3 m deep. At night, nets were set end-to-end, blocking the outlet of Upper Priest Lake. During daylight sets, the middle of the three gill nets was moved near shore and was positioned perpendicular to the shoreline to allow boat passage.

From June 27 to November 8, lower flow through the Thorofare enabled the setting of gill nets in the channel. From June 27 to July 12, the 45.7-m-long nets were used. After July 17, the 54.9-m-long nets were used. The gill nets were shorter than the width of the Thorofare but were set in groups of three and were staggered so that the entire width of the channel was fished. During July through September, when boat traffic was heaviest, only two nets were set during the daytime and no gill nets were set between 1000 and 1800 hours, the daily period of peak boating activity. In June and October, reductions in boat traffic allowed gill nets to be set between 1000 and 1800 hours.

In an attempt to minimize fish mortality, we fished the gill nets for less than 1 h before checking for fish. Because different sizes of gill nets were used in the study, gill-net catch rates were standardized into catch per unit effort (CPUE) expressed as fish per hour per 100-m^2 area of gill net. Gill-net sets were grouped into daytime and nighttime categories.

Several physical attributes were measured during the fish sampling period. Thorofare mid-channel depth was recorded with a staff gauge weekly from May through November 2000. Water clarity was measured weekly in both lakes by use of a Secchi disk. The thermal profiles of Upper Priest Lake, Priest Lake, and the Thorofare were obtained on April 21 and every 2 weeks from May 22 to November 8 by use of a Yellow Springs Instruments model 50 dissolved oxygen meter. Thorofare temperature was measured with Hobotemp thermographs every 2 h at two locations: 0.3 km downstream from Upper Priest Lake and 0.5 km upstream of Priest Lake. Velocity was measured at 0.2 and 0.8 of the depth for depths greater than 1 m and at 0.6 of the depth for depths of 1 m or less. Thorofare discharge and average velocity were estimated from the depth and velocity profile (Herschy 1995). By July 31, velocity became too low throughout the Thorofare to permit estimation of discharge by this method.

Least-squares multiple linear regression with backwards elimination was used to determine the relation between lake trout capture rate and the measured physical and water quality attributes of the study site. Standard regression methods (Kleinbaum et al. 1998) were used to examine relations between daytime and nighttime lake trout CPUE (dependent variables) and the following independent variables: Thorofare mean daily nighttime or daytime temperature (Ttemp), Upper Priest Lake temperature at 1 m depth (UPLtemp1), Priest Lake temperature at 1 m depth (PLtemp1), Upper Priest Lake Secchi disk depth (UPLSecchi), Priest Lake Secchi disk depth (PLSecchi), and Thorofare depth (Tdepth). The same regression methods were also used to test for a diel effect on lake trout gill-net CPUE. Independent variables in the model included the categorical diel variable (Diel), the variables retained in the two prior multiple regressions, and the interaction terms for the retained variables and the diel variable (e.g., PLtemp1×Diel).

Results

Fish Movements during Spring through Fall

Lake trout were frequently caught in the spring (April–June) and fall (September–November 8),

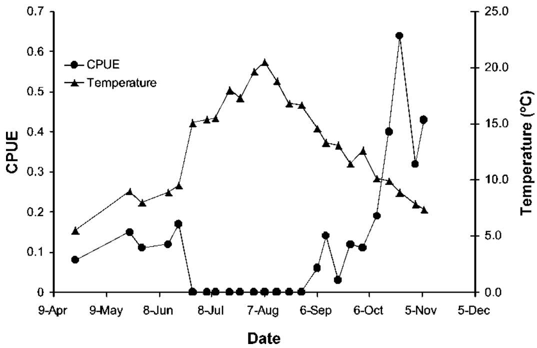

FIGURE 1.—Lake trout weekly nighttime CPUE (fish/h per 100-m^2 area of gill net) measured at the outlet of Upper Priest Lake, Idaho (April 21–June 21, 2000), and in the Thorofare (the connection between Priest Lake and Upper Priest Lake; June 27–November 8, 2000). Thorofare temperature is also shown.

but never during July and August (Figure 1). Thirty-four lake trout were caught in Upper Priest Lake between April 21 and June 21. Catch was highest in October ($n = 39$), November ($n = 25$), and September ($n = 9$). Three lake trout were captured in April, 17 in May, and 14 in June. One-hundred lake trout (94%) were captured at night and six (6%) were captured during the day. Daytime capture only occurred in the spring, when CPUE ranged from 0 to 0.06 fish/h per 100-m^2 area of gill net (Figure 1). Daytime sampling did not occur in April. Nighttime CPUE ranged from 0 to 0.64 fish/h per 100-m^2 area of gill net and was highest in October. The CPUE values equal to zero were coincident with water temperatures exceeding 15°C (Figure 1).

The water column in Upper Priest Lake was a homothermous 5°C in late April, became stratified in mid-June, attained a peak surface temperature of 21.5°C in late July, reached homothermy in late October at 10°C, and continued to cool to 8.2°C in early November at the last measurement taken. Water temperature below 14 m depth never exceeded 8°C. In Priest Lake, stratification was evident by mid-June (surface temperature, 12.8°C), surface water temperature peaked at 23.4°C in early August, homothermy was attained in mid-October at 12.5°C, and temperature cooled to 9.0°C by November 7. In the Thorofare, water temperature increased from 9.0°C in May to a peak of 20.8°C in early August and then fell to 6.6°C in early November (Figure 1). Secchi disk depths ranged from 4.8 to 10.6 m in Upper Priest Lake and from 5.25 to 9.3 m in Priest Lake.

The first multiple regression analysis procedure, which examined the relation between nighttime CPUE and the measured physical variables, indicated that nighttime CPUE was highly correlated with the near-surface temperatures of Upper Priest Lake and Priest Lake ($\text{CPUE} = 0.60 + 0.05 \cdot \text{UPLtemp1} - 0.07 \cdot \text{PLtemp1}$; $r^2 = 0.60$; $P < 0.01$). Collinearity diagnostics produced a condition index value of 31.9, indicating significant collinearity between the two independent variables. Therefore, simple regression was performed with separate models for the two independent variables. Nighttime CPUE of lake trout was significantly correlated with Upper Priest Lake temperature at 1 m depth ($\text{CPUE} = 0.49 - 0.03 \cdot \text{UPLtemp1}$; $r^2 = 0.41$; $P < 0.01$) and with Priest Lake temperature at 1 m depth ($\text{CPUE} = 0.51 - 0.02 \cdot \text{PLtemp1}$; $r^2 = 0.45$; $P < 0.01$). Both relations were significant and produced similar equations, but the models produced a decrease in closeness of fit. Nonetheless, the analysis indicated an inverse relationship between CPUE and near-surface water temperatures.

The second multiple regression analysis procedure examined the relation between daytime CPUE and the measured physical variables. The analysis indicated that daytime CPUE was correlated with Priest Lake near-surface water temperature and Thorofare depth ($\text{CPUE} = -0.006 - 0.002 \cdot \text{PLtemp1} + 0.05 \cdot \text{Tdepth}$; $r^2 = 0.58$; $P < 0.01$).

The data indicated distinct patterns of diel movement within a given season. Lake trout moving through the Thorofare were captured more often at night (94%) than during the day (6%). Numbers captured and gill-net CPUE were consistently higher at night than during the day. Multiple regression analysis indicated that there was a significant difference in nighttime and daytime CPUE values, and that the near-surface water temperature and Thorofare depth were correlated with the differences ($\text{CPUE} = 0.72 - 0.72 \cdot \text{Diel} - 0.04 \cdot \text{PLtemp1} + 0.02 \cdot \text{UPLtemp1} - 0.20 \cdot \text{Tdepth} + 0.02 \cdot \text{Diel} \times \text{PLtemp1} + 0.30 \cdot \text{Diel} \times \text{Tdepth}$; $r^2 = 0.69$; $P < 0.01$).

Discussion

Results of this study indicate that lake trout moved through the Thorofare between the lakes in higher numbers in the spring and fall, when waters were cooler, whereas the fish did not move through in measurable numbers during the summer, when waters were warmer. Lake trout captures ceased by the time the Thorofare water temperature rose above 15°C in late June, and captures did not resume until water temperature fell below 15°C in September (Figure 1). The pattern of greater movement in cooler water and reduced movement in warmer water is similar to results reported elsewhere. Martin (1957) reported that lake trout occupied all depths in Red Rock Lake, Ontario, before summer stratification. As the epilimnial water warmed and the surface temperature reached 14–15°C, the fish remained in deeper and cooler water. Later in the fall, when surface temperature dropped below 15°C, lake trout were again readily captured in the shallow areas. Other studies have suggested that 15°C is the upper temperature threshold limiting vertical movement by lake trout (Kennedy 1941; Elrod and Schneider 1987; Snucins and Gunn 1995). Snucins and Gunn (1995) reported that lake trout in Whitepine Lake, Ontario, were frequently found in the epilimnion when the water temperature was less than 13°C, but movements into the epilimnion were rare when the water temperature was greater than 15°C. Thus, given the results of our study and existing information, it is reasonable to expect that lake trout will not be found in the Thorofare when the water temperature exceeds 15°C.

The greater catch rate of lake trout at night than during the day in the Thorofare indicates a significant difference in nighttime and daytime CPUE, which is similar to other studies suggesting that lake trout are more active at night (Martin 1957) and usually enter shallow areas of lakes only at night (Martin 1957; Loftus 1958; Walch and Bergersen 1982; Sellers et al. 1988). Nighttime movements into shallow areas may be related to the pursuit of prey (Martin 1957) or to spawning (Loftus 1958). For example, Loftus (1958) reported that spawning lake trout in the Montreal River, a tributary to Lake Superior, were much more abundant in the river at night than during the day. Fish remained in the lake in deep water near the mouth of the river during the day, entered the river at night to spawn, and returned to the lake by midnight. Martin (1957) reported that gill nets set during the day in Lake Louisa, Ontario, and Redrock Lake were much less successful than those set at night. He concluded that lake trout were less active during the day than at night and thus were less vulnerable to capture during the day. Although the observed differences in daytime and nighttime catch rates in our study were similar to those reported in other studies, daytime net avoidance due to net visibility may have contributed to the lower daytime catch rates.

Although numbers of fish moving through the Thorofare could not be estimated and the size selectivity of gill nets limited the size distribution of fish captured, our study provides insight into the patterns of lake trout movement between Priest Lake and Upper Priest Lake. For fisheries managers attempting to limit movements of lake trout into Upper Priest Lake and thereby reduce lake trout interaction with bull trout, the observed lake trout movement patterns suggest that water temperatures greater than 15°C function as a natural thermal barrier to movement between lakes in July and August and perhaps an additional week or two before and after this 2-month period. Although lake trout CPUE was significantly lower during the day than at night, daylight by itself did not function as an effective barrier for lake trout moving through the Thorofare. To prevent lake trout from moving into Upper Priest Lake, some sort of physical barrier would be necessary in September, October, May, and June and possibly in the winter months as well. Our results indicate that a natural thermal barrier might function effectively in the summer (July and August), when boat traffic is heaviest and when the potential for conflict between boaters and a physical barrier is the greatest.

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References

Bjornn, T. C. 1957. A survey of the fishery resources of Priest and Upper Priest Lakes and their tributaries, Idaho. Master's thesis. University of Idaho, Moscow.

Donald, D. B., and D. J. Alger. 1993. Geographic distribution, species displacement, and niche overlap for lake trout and bull trout in mountain lakes. Canadian Journal of Zoology 71:238–247.

Dunham, J. B., D. S. Pilliod, and M. K. Young. 2004. Assessing the consequences of nonnative trout in headwater ecosystems in western North America. Fisheries 29(6):18–26.

Elrod, J. H., and C. P. Schneider. 1987. Seasonal bathythermal distribution of juvenile lake trout in Lake Ontario, New York. Journal of Great Lakes Research 13:121–134.

Fredericks, J. 1999. Exotic fish species removal: Upper Priest and Lightning Creek drainages. Idaho Department of Fish and Game, Annual Progress Report. Grant E-20, Segment 1. Coeur d' Alene.

Herschy, R. W. 1995. Stream flow measurement, 2nd edition. Elsevier Applied Science, Barking, UK.

Kennedy, W. A. 1941. The migration of fish from a shallow to a deep lake in spring and early summer. Transactions of the American Fisheries Society 70: 391–396.

Kleinbaum, D. G., L. L. Kupper, K. E. Muller, and A. Nizam. 1998. Applied regression analysis and other multivariable methods, 3rd edition. Duxbury Press, Pacific Grove, California.

Kohler, C. C., and W. R. Courtenay, Jr. 1986. American Fisheries Society position on introductions of aquatic organisms: a philosophical perspective. Fisheries 11(2):39–42.

Loftus, K. H. 1958. Studies on river-spawning populations of lake trout in eastern Lake Superior. Transactions of the American Fisheries Society 87:259–277.

Martin, N. V. 1957. A study of the lake trout, *Salvelinus namaycush*, in two Algonquin Park, Ontario, Lakes. Transactions of the American Fisheries Society 86: 231–244.

Mauser, G. R. 1986. Enhancement of trout in large north Idaho lakes. Idaho Department of Fish and Game, Federal Aid in Fish Restoration, Project F-73-R-8, Performance Report, Boise.

Rieman, B., and J. R. Lukens. 1979. Priest Lake creel census. Idaho Department of Fish and Game, Federal Aid in Fish Restoration, Project F-73-R-1, Job 11, Project F-73-R-9, Performance Report. Boise.

Sellers, T. J., B. R. Parker, D. W. Schindler, and W. M. Tonn. 1988. Pelagic distribution of lake trout (*Salvelinus namaycush*) in small Canadian Shield lakes with respect to temperature, dissolved oxygen, and light. Canadian Journal of Aquatic Sciences 55: 170–179.

Snucins, E. J., and J. M. Gunn. 1995. Coping with a warm environment: behavioral thermoregulation by lake trout. Transactions of the American Fisheries Society 124:118–123.

Walch, L. A., and E. P. Bergersen. 1982. Home range and activity patterns of lake trout in central Colorado. Fisheries Research 1:311–318.