Effects of forestry roads on reproductive habitat and exploitation of lake trout (*Salvelinus namaycush*) in three experimental lakes

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Abstract: This study was designed to test the effects of two potential impacts of forest access roads on lake trout (*Salvelinus namaycush*) lakes in the Boreal Shield ecozone: (*i*) loss of reproductive habitat through siltation and (*ii*) increased access and exploitation. During an 9-year study (1991–1999) in Whitepine Lake, access to seven original spawning sites and over 250 alternate spawning sites was progressively removed by covering the substrate with opaque plastic sheeting to simulate siltation. No effects on recruitment of lake trout have yet been detected. Mark–recapture estimates of juvenile (<370 mm fork length) abundance remained high, mean body size did not increase, and emergent alevins continued to be produced from the alternate spawning sites each year. Similar results occurred in a short-term study in Helen Lake. The lack of obvious effects of reproductive habitat loss was in sharp contrast with the rapid and severe effects that fishing pressure exerted on the lake trout population in Michaud Lake where access was improved by construction of a 12-km forest access road. These findings suggest that lake trout can tolerate substantial losses in spawning habitat, but natural populations, particularly in small lakes, must be protected from excessive exploitation.

Résumé : Notre étude visait à tester les effets de deux impacts potentiels des routes forestières sur les lacs à touladi (*Salvelinus namaycush*) de l'écozone du bouclier boréal : (*i*) perte d'habitat de fraye par colmatage, et (*ii*) augmentation de l'accès et de l'exploitation. Pendant une étude de 9 ans (1991–1999) menée au lac Whitepine, nous avons progressivement limité l'accès à sept frayères établies et à 250 frayères de substitution en couvrant le substrat de feuilles de plastique opaque simulant le colmatage. Nous n'avons pour le moment détecté aucun effet sur le recrutement du touladi. D'après des estimations obtenues par marquage–recapture, l'abondance des juvéniles (<370 mm de longueur à la fourche) est demeurée élevée, la taille corporelle moyenne n'a pas augmenté, et des alevins nageants continuaient à être produits par les frayères de substitution chaque année. Des résultats similaires ont été obtenus par une étude de courte durée menée au lac Helen. L'absence d'effets évidents par perte d'habitat de fraye contraste fortement avec les effets dévastateurs exercés par la pression de pêche sur la population de touladi du lac Michaud, où l'accès a été amélioré par la construction d'une route forestière de 12 km. Ces résultats permettent de penser que le touladi peut tolérer des pertes importantes d'habitat de fraye, mais que les populations naturelles, particulièrement dans les petits lacs, doivent être protégées contre une exploitation excessive.

[Traduit par la Rédaction]

Introduction

Extensive erosion and sediment input to lakes and streams can occur from poorly engineered roads and bridge approaches or from improperly installed culverts (Megahan and Kidd 1972; Plamondon 1982; Anderson and Potts 1987). If the roads and stream crossings are not properly maintained, the adverse effects can continue well after initial road construction. In the longer term, if access roads are left open to vehicle traffic, they will frequently lead to changing human use patterns of the area. Increased exploitation of fish populations, intentional and unintentional introduction of exotic species, and development of shorelines for cottages are some of the many changes likely to occur as remote areas are opened up by roads (Schindler 1998).

There are now very few parts of Ontario's Boreal Shield landscapes that are remote from access roads (Fig. 1). This network of roads and associated human-directed impacts represents a largely unplanned legacy from forestry, mining, and other resource extraction industries. However, to date, there have been few attempts, particularly in the Boreal Shield ecozone of Canada, to measure the impacts of road-related effects on aquatic ecosystems. To do this, we adopted an experimental manipulation approach to test and compare two potential effects of forest access roads on fish populations: sedimentation and excessive exploitation.

We concentrated our studies on small lakes that supported naturally reproducing populations of lake trout (*Salvelinus namaycush*), a species that receives special attention in forestry management plans, particularly in Ontario (Ontario Ministry of Natural Resources 1988). Less than 1% of Ontario's lakes contain this prized sport fish species (Martin

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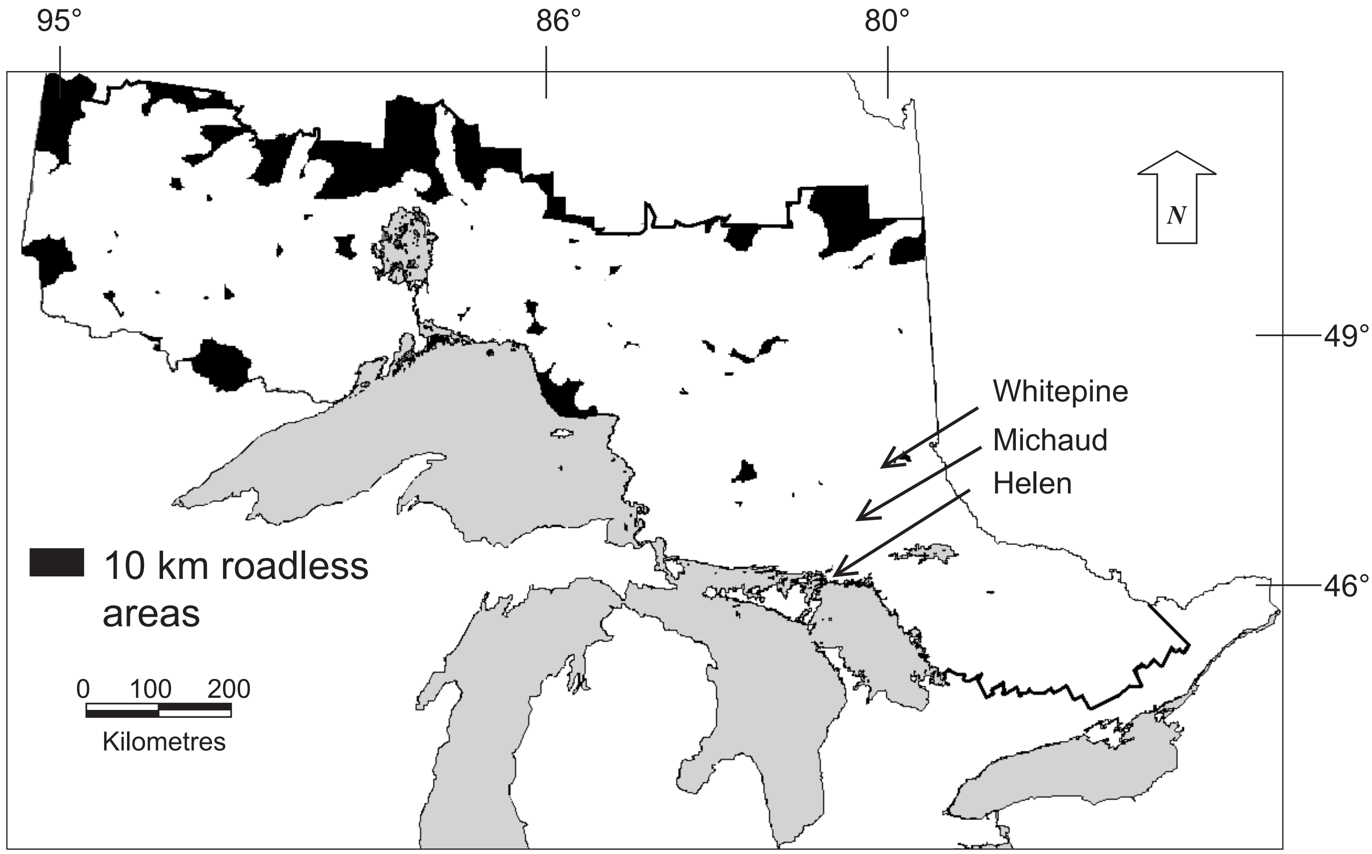
Fig. 1. Areas within the outlined Boreal Shield landscape of Ontario, Canada, that are >10 km from roads. Data provided by Ontario Ministry of Natural Resources. The locations of our study lakes are indicated.



and Olver 1976), and lake trout are considered to be highly sensitive to the disturbances that often accompany forestry operations. Under current guidelines in Ontario (Ontario Ministry of Natural Resources 1988), all lake trout lakes must have 30- to 90-m terrestrial buffer strips (depending on slopes) left around the entire shoreline, within which no road construction or tree harvesting is allowed. Road crossings of streams as potential point sources of sediment appear to represent more of a threat to nearshore spawning habitat of lake trout than silt inputs from clearcut logging areas. Clearcut areas in the low-relief landscape of much of the boreal forest appear to have little, and probably quite temporary, effects on sediment transport to lakes (Blais et al. 1998; Steedman and France 2000).

Spawning sites are identified as "critical fish habitat" in the guidelines and are considered essential areas that must be protected from sedimentation (Ontario Ministry of Natural Resources 1988). The reproductive habitat is considered particularly vulnerable because the lake trout is a demersal spawner that broadcasts its eggs over clean coarse substrates in very shallow (<2 m deep) nearshore (<10 m from shore) waters in small shield lakes (Martin 1957; DeRoche 1969; Gunn 1995). The developing embryos are deep in the interstitial spaces of the substrate for nearly 7 months (October–April) and can readily be suffocated by sediments eroding from the catchment (Sly and Evans 1996).

Ontario forestry guidelines and management plans usually give inadequate consideration to the very low productivity and high exploitation vulnerability typical of lake trout lakes (Ryder and Johnson 1972; Shuter et al. 1998). Estimates of the sustainable harvest levels for lake trout populations are usually <1 $kg \cdot ha^{-1} \cdot year^{-1}$ (Healey 1978; Martin and Olver 1980). Shuter et al. (1998), using a simulation model that they developed, predict that small (100 ha) lakes on the shield are more productive (maximum sustainable harvest of approximately 1.5 kg lake $trout \cdot ha^{-1} \cdot year^{-1}$) than larger (1000, 10 000 ha) lakes but are extremely vulnerable to overfishing. They estimated that small lakes may not be able to sustain more than approximately 7 h fishing $effort \cdot ha^{-1} \cdot year^{-1}$ (Shuter et al. 1998).

For our experiments, we used three small lakes to test the effects of spawning habitat loss and exploitation on lake trout populations. In the first lake, Whitepine Lake, we used opaque plastic sheeting and progressively covered, during 1992–1999, available nearshore spawning habitat to simulate the effect of a sediment discharge to the lake. A second lake, Helen Lake, was added to the study in 1999 to verify the results of the habitat manipulation experiment using a lake with a more complex fish community. In the third lake, Michaud Lake, we assessed the effects of exploitation on a remote lake when fishing resumed after a 7-year closure period, 1991–1997. Improved access to the lake was provided by the construction of a forest access road in 1994.

Methods

The three study lakes are all small (67–148 ha) headwater lakes located 40–90 km from Sudbury, Ontario (Fig. 1), and are located

Table 1. Description of the Whitepine Lake and Helen Lake lake trout spawning sites.

	Spawning sites used		Site characteristics				Spawning habitat covered		
Year	Number	Total area (m^2)	Surface area (m^2)	Water depth (m)	Distance from shore (m)	% of sites producing alevins	Egg deposition area (m^2)	Adjoining areas (m^2)	Total (m^2)
Whitepine Lake									
1991	7	40	0.5–21.0	0.3–1.5	1.4–4.5	na	0	0	0
1992	15	74.8	0.5–21.0	0.2–2.0	na	na	6	86	92
1993	18	64.9	0.5–21.0	0.1–1.2	na	44.4	13	86	99
1994	41	40.3	0.1–5.0	0.1–2.0	0.5–4.0	na	21	71	92
1995	44	82.7	0.2–10.0	0.3–0.8	0.3–0.9	na	6	0	6
1996	39	195.3	0.9–42.0	0.1–1.5	0.4–2.7	76.9	189	101.6	290.6
1997	52	126.3	0.1–15.0	0.1–1.4	0.4–6.0	44.3	195.3	28.4	223.7
1998	41	226.4	0.1–78.9	0.2–1.3	0.8–6.0	46.3	126.3	68.9	195.2
1999	41	98.1	0.1–13.2	0.2–1.5	0.2–15.0	51.2	226.4	378.6	605
Helen Lake									
1997	5	11.5	0.2–9.0	0.5–0.7	na	40	0	0	0
1999	9	44.2	0.2–15.0	0.3–0.8	na	55.5	11.5	138.5	150

Note: Spawning sites are defined as the area of egg deposition during the fall spawning period. Substrates are inspected immediately after ice-off in April and early May to identify spawning sites that produced alevins. On Whitepine Lake, the traditional spawning sites were gradually covered with plastic sheeting during 1992–1994. During 1996–1999 (Whitepine Lake) and 1999 (Helen Lake), all previous spawning sites were covered each year.

within the Boreal Shield ecozone. The two principal study lakes, Whitepine and Michaud, have very simple fish communities dominated by small-bodied lake trout, typical of populations with a planktivorous or insectivorous diet. Other species present include yellow perch (*Perca flavescens*), Iowa darter (*Etheostoma exile*), and white sucker (*Catostomus commersoni*) and a few species of cyprinids. The lakes had previously been used in a variety of acid rain related research projects (Gunn and Keller 1984, 1990; Gunn et al. 1987) and had very similar histories. In the early 1980s, they were both acidified (pH < 5.5) and their native lake trout populations were reduced to small remnant stocks of nonreproducing adults. Water quality improved throughout the 1980s because of reductions in emissions of SO_2 in Canada and the United States (Gunn and Keller 1990). Both lakes were stocked with hatchery-reared lake trout to assist in rehabilitation. In Whitepine Lake, the hatchery stocking only occurred in 1980 and 1981 and then was stopped because the native population resumed reproduction in 1982. Reproduction occurred yearly thereafter and a dense population of lake trout developed in Whitepine Lake by 1990. In Michaud Lake, the native fish disappeared before natural recruitment resumed and the hatchery stocking that began in 1984 was maintained periodically until 1992. Natural reproduction of the hatchery fish in Michaud Lake began in 1990. A permanent sanctuary status was established for Whitepine Lake in 1980 to prevent angling exploitation. On Michaud Lake, a temporary angling closure (1991–1997) was established.

Helen Lake (46°06′N, 81°33′W, 41.2 m maximum depth, 20.5 m mean depth) was a nearly pristine lake located within the wilderness setting of Killarney Provincial Park and was used as an alternate lake to test the habitat manipulation technique. It has good water quality, a native reproducing lake trout population, and a complex fish community. In addition to lake trout, it contains smallmouth bass (*Micropterus dolomieu*), rock bass (*Ambloplites rupestris*), cisco (*Coregonus artedi*), brown bullhead (*Ameiurus nebulosus*), bluegill (*Lepomis macrochirus*), pumpkinseed (*Lepomis gibbosus*), yellow perch, slimy sculpin (*Cottus cognatus*), Iowa darter, and bluntnose minnow (*Pimephales notatus*). Helen Lake is open to angling, but angling pressure is quite low because of its location and the fact that motorized access is prohibited.

Whitepine Lake: habitat loss experiment

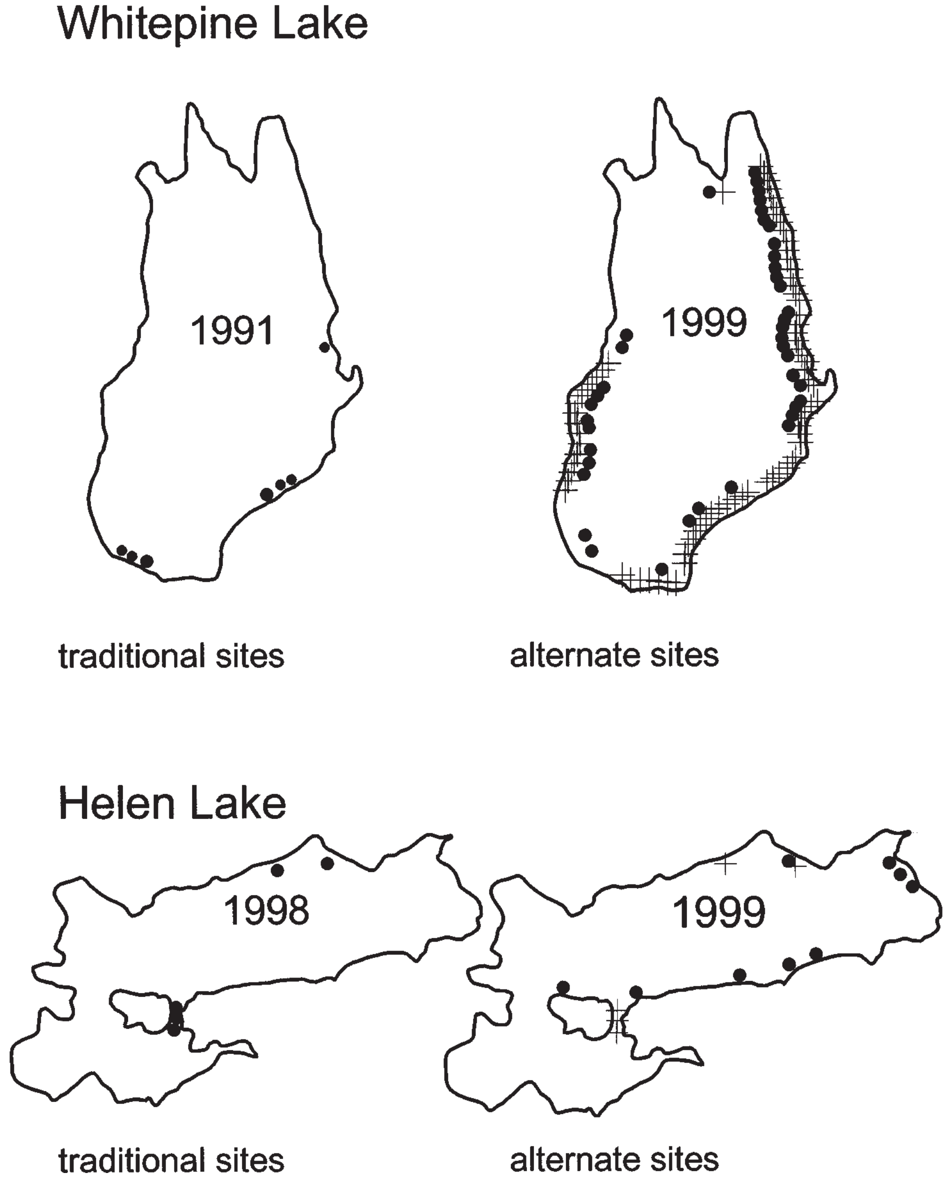
Whitepine Lake was used as the principal experimental lake to test the hypothesis that spawning habitat reduction in shoreline areas would lead to recruitment failures in native lake trout populations. Previous publications from this experiment dealt with the behavioural response of fish to the habitat disturbances (McAughey and Gunn 1995) and the accuracy of visual techniques of classifying spawning habitat (Gunn et al. 1996).

Whitepine Lake (47°17′N, 80°50′W) is a 67-ha lake (22 m maximum depth, 5.9 m mean depth) with a 4.7-km shoreline. It has a 328-ha terrestrial catchment area consisting of thin sandy soil over granitic bedrock with a few small wetland areas. The area was logged in the past and approximately 30% of the catchment was burned in 1975. At the start of this experiment in 1991, the forest cover was dominated by eastern white pine (*Pinus strobus*) except for the burned area where an early successional mixed cover existed. A band of trees and shrubs occurred along almost the entire shoreline and there was no evidence of severe water level fluctuations or excessive erosion or siltation. Few human disturbances existed in the area. Our small research cabin is the only building in the catchment area.

The habitat manipulation experiment began in October 1991 by mapping all of the traditional spawning sites used by lake trout. Spawning fish were located by cruising the entire shoreline each night of the spawning season (duration of 10–20 days in October) and spotting, with the aid of flashlights, spawning groups of lake trout over shallow (<2 m) nearshore areas of clean coarse substrate. Associated studies have shown that lake trout select 2- to 10-cm-diameter substrate in this lake (Gunn 1995). Identified sites were later confirmed by examining the substrate for the presence of deposited eggs. In 1991 and 1992, egg deposition rates were measured using funnel collectors buried in the substrate (Gunn 1995). In subsequent years, only the presence or absence of eggs was recorded. Frequent searches by boat and by diving eliminated the possibility that there were any offshore sites that went undetected in this study. This was also confirmed by tracking spawning fish tagged with ultrasonic transmitters (J.M. Gunn, unpublished data).

The habitat manipulation began in 1992 by covering the spawning substrate with opaque plastic sheeting, which was left in place throughout the entire period of the experiment. The original spawning sites (seven sites, total surface area 40 m^2) were removed as follows: 15% by area in 1992, 35% in 1993, and 50% in 1994. Testing of the manipulation technique was done in 1995 by covering six previously used sites with sand as a more “natural” distur-

Fig. 2. Locations of traditional lake trout spawning sites and the spawning sites used after the habitat manipulation experiment was completed in Whitepine Lake (1991, 1999) and Helen Lake (1998, 1999). The locations of spawning sites that were covered for this experiment are indicated. Circles denote active spawning sites and crosses denote covered spawning sites.



bance. Fish avoided both the plastic sheeting and the sand-covered sites. Therefore, only the plastic sheeting method was used to cover spawning sites in 1996, 1997, and 1998. In addition to the annual assessment of spawning activity described above, we conducted detailed studies of annual abundance and size structure of the population. Population estimates were conducted in the spring (water temperature 6–15°C) by the continuous mark–recapture Schnabel method (Ricker 1975). Fish were captured by angling or by using short-duration (30 min) sets of small-mesh (38–51 mm stretched mesh) gill nets, and low handling mortality was confirmed through holding experiments (McAughey and Gunn 1995). Accurate age assessment of the fish using otoliths was not possible because of the impact that lethal sampling for aging structures might cause. Instead, estimates of juvenile (<370 mm) abundance were made in terms of body size, based on the assumption that the size-at-maturity relationships observed during the 1994 (Gunn et al. 1996) and 1997 spawning assessments applied throughout. To eliminate resampling the same fish, all captured and released juveniles were given a permanent adipose clip mark. To make sure that a year-class failure did not go undetected, we attempted to capture and mark at least 100 juveniles each year.

The physical characteristics (depth, distance from shore, substrate size, and depth of interstitial spaces) of all new spawning sites were measured shortly after egg deposition ended. The location of the eggs was marked with a numbered brick and a qualitative assessment of overwinter survival was then conducted by divers in late April – early May by excavating the sites and noting the presence or absence of live alevins.

Helen Lake: verification study

A test of the habitat manipulation technique was conducted in Helen Lake in 1999 to verify that the results in Whitepine Lake were not site specific or related to the absence of potential egg predators in the principal study site. Traditional spawning sites on Helen Lake were mapped in 1997 and 1998. In 1999, all five tradi-

Fig. 3. Size of lake trout captured in the index gill nets in Whitepine Lake, 1991–1999. Annual median, 25th percentile, 75th percentile, maximum, minimum, and sample size are indicated.

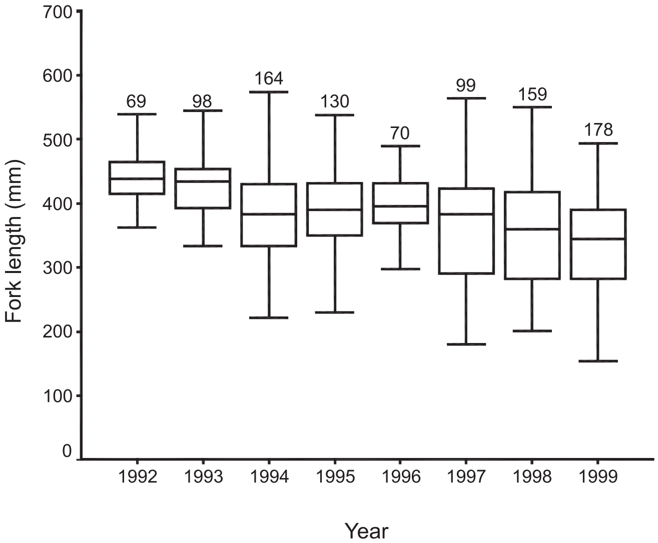


Table 2. Estimated abundance of juvenile (260–370 mm) lake trout in Whitepine Lake from the springtime surveys.

Year	Number marked	% recaptured	Estimated total number
1992	17	0	—
1993	63	22	180 (118–377)
1994	110	19	406 (284–709)
1995	77	10	507 (300–1653)
1996	45	16	169 (97–653)
1997	75	13	357 (220–938)
1998	89	6	955 (509–7738)
1999	139	9	1013 (647–2332)

Note: Abundance was estimated by Schnabel continuous mark–recapture of angled and gillnetted fish. Estimated number with 95% CI in parentheses is presented.

tional spawning sites were covered with plastic sheeting and the newly selected sites were located, marked, and assessed for alevin survival following the methods described above.

Michaud Lake: exploitation study

The exploitation experiment involved the assessment of the immediate impact of anglers on a remote lake, Michaud Lake, following construction of a forest access road and the lifting of the fishing ban. The final 12 km of a 26-km forest access road to Michaud Lake (46°49′N, 81°18′W, 148 ha, 24 m maximum depth, 7.0 m mean depth) was completed in 1994, providing access for snow machines and four-wheel-drive vehicles to within 100 m of the lake. In the summer of 1997, a netting survey was conducted to assess the relative abundance of lake trout in the lake. In the fall (October 1–30, 1997), a spawning assessment of adult lake trout in Michaud Lake was conducted and 220 adults were fin marked and released. On January 1, 1998, the fishing season opened under the standard regulations (unlimited entry and access, daily possession limit of three lake trout per angler). No attempt was made to encourage fishing on the lake. There were no public notices in newspapers or elsewhere (the published regulations were actually in error and still indicated that the lake was closed to fishing), and there were no road signs to assist in locating the lake among the many other lakes and forest roads in the area. The newly constructed road was not plowed, so anglers had to use snowmobiles for the final 12 km to reach the lake. Once the fishing began, a random stratified (by weekday or weekend day) creel survey was conducted to assess angling effort and harvest. The creel survey was maintained throughout the winter and early spring of 1998. Netting and spawning surveys were repeated in the summer and fall of 1998 to assess the effects of angling on the lake trout population.

Results and discussion

Habitat loss experiment: spawning site selection and quality

Lake trout proved to be highly adaptable to spawning habitat disturbances and repeatedly selected new sites in Whitepine Lake when previous spawning sites were covered. Similar results were found in Helen Lake where nine new sites were selected after the traditional sites were covered (Table 1; Fig. 2). In total, over 250 new spawning sites were selected in Whitepine Lake as a result of our experimental manipulations (Table 1; Fig. 2). The accumulated impact of removing access to over 1600 m^2 of substrate during this 9-year experiment in Whitepine Lake did not prevent fish from spawning; however, it did appear to represent a severe enough impact that fish were forced to select what appeared to be marginal habitat. All the newly selected spawning sites in Whitepine Lake had at least a small patch of substrate within the preferred range (2–10 cm in diameter), but many of the sites were very small (<0.2 m^2 surface area), had limited interstitial space beneath the substrate for eggs to settle in, and were in shallow water (<0.4 m) where eggs appeared to be highly vulnerable to both predation and ice damage (Table 1). In the few relatively large sites, eggs were thinly dispersed and appeared to have drifted considerable distances before they became wedged within the substrate. The large number of widely dispersed sites (Fig. 3) was further evidence of the severe disturbance imposed by the habitat removal. Lake trout usually spawn in mass at relatively few sites (Martin 1957; DeRoche 1969; Gunn 1995). It is rare to find an inland lake trout lake with more than 10 traditional spawning sites, including lakes much larger than Whitepine Lake (McMurtry 1986).

In the early years of the study, the lake trout exhibited strong fidelity to the seven traditional sites (Gunn 1995; McAughey and Gunn 1995). However, as the study proceeded, it became evident that prior experience with a site proved unnecessary. Learned behaviours or chemosensory cues from previous use of a site (Foster 1985; Hara 1994) may assist a fish in returning to a site, but our study shows that the innate behaviour of being able to readily identify useable habitat is very powerful in this species.

Evidence of recruitment failure

We were not able to accurately quantify egg deposition rate or survival rates of incubating embryos, but the new sites continued to produce alevins each year (Table 1), demonstrating that recruitment was not eliminated by the habitat disturbances. For example, in the final year of the study, 21 of the 41 sites (51.2%) on Whitepine Lake contained live alevins on May 2, 2000. The presence of live alevins in the majority of the sites on Whitepine Lake occurred even though the amount of potential habitat lost during the experi-

Fig. 4. Weekly estimates of the number of anglers (bars), fish captured per angler-hour (thin line), and accumulated harvest of lake trout (thick line) in Michaud Lake during the winter and spring of 1998, the year the lake opened to fishing.

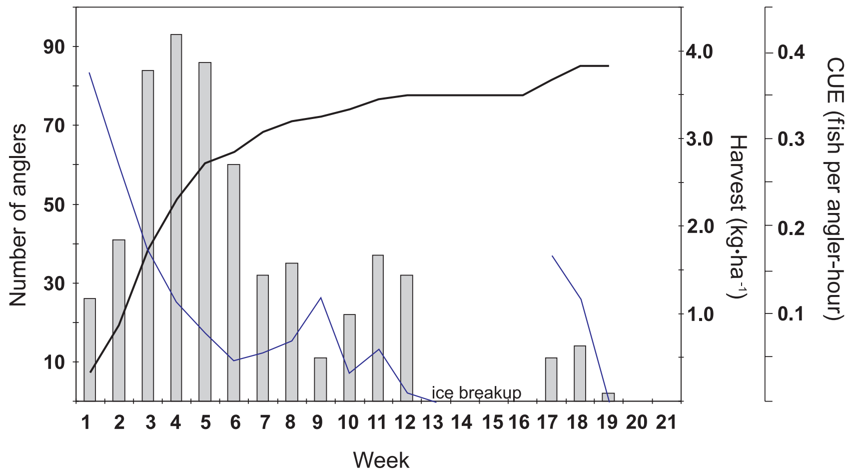


Table 3. Effects of 1998 winter fishing on abundance of lake trout in Michaud Lake.

Year	Date	Number of net sets	Lake trout catch
1997	August 6–12	60	1.23 (1.33)
1998	August 12–19	60	0.37 (0.90)

Note: The population was assessed using multimesh gill nets (15-m single panels of 19-, 25-, 38-, 51-, and 64-mm stretched mesh with 5-m spacers between panels) set at random locations within the hypolimnion. The lake trout catch is the number of fish captured during a 2-h net set. Mean with 1 SD in parentheses is given.

ment was more than 40 times that of the original area of substrate that supported the population in 1991. Similar results occurred in the 1-year manipulation of Helen Lake where five of nine (55.5%) newly selected sites contained alevins on April 18, 2000.

The mark–recapture estimates of juvenile abundance on Whitepine Lake also failed to show any of the expected effects of the experimental treatment. We had predicted that juvenile abundance would decline as a result of the habitat loss, expecting the decline to begin soon after all the traditional spawning sites were removed in 1994. The mean size of fish in the index gill nets was also expected to increase with time if abundance of juveniles, and resulting competition for food, declined.

There was no decline in the abundance of juveniles (260–370 mm fork length) detected during the study (Table 2). The average size of fish in the population also did not increase (Fig. 3), giving further evidence that recruitment was unaffected by the habitat loss. Age assessment data are not yet available for fish collected during recent years, but from age–size relationships obtained earlier (Gunn et al. 1996), it is clear that most of the abundant juveniles in Whitepine Lake are recruits from the new spawning sites. The difficulty in capturing very young fish (<3+) with our assessment methods means that year-class declines may still be detected in the future as a result of possible reduction in the survival of the egg to alevin stages in the latter years of the study. However, the continued production of alevins at the alternate sites throughout the study suggests that the habitat manipulations would have to be continued for many more years to be able to detect a complete loss of recruitment.

Exploitation following improved road access

The effects of exploitation on Michaud Lake were not subtle. Anglers were able to access the lake in midwinter by way of the new road. Anglers used snowmobiles and all-terrain four-wheel-drive vehicles to travel right to the lake itself. Catch rates were very high when the fishery opened in the first week of January 1998 (0.4 fish·angler^{-1}·h^{-1}), and most anglers were able to catch their allowable limit of three fish each day (angler-day) (Fig. 4). The number of angler-days increased steadily, reaching a maximum of 93 in the fourth week of January.

The sustainable yield level (kilograms per hectare) for Michaud Lake, a 148-ha lake, was estimated to be 1.35 kg·ha^{-1} from the following equation of Payne et al. (1990):

$$\log_{10}(\text{harvest}) = 0.50 + 0.83\log_{10}(\text{area}).$$

The estimated maximum sustainable yield level was exceeded less than 3 weeks after anglers accessed the lake (Fig. 4). Fishing success rate declined through the winter, but anglers continued to harvest lake trout until ice melt forced an end to the fishery. Once the road was dry enough to permit truck travel, anglers brought boats to the lake and began fishing again on April 24, 1998. Fishing success rates improved for a brief period in the open-water period but declined rapidly. Anglers largely abandoned the lake in early May.

In this brief fishery, the estimated harvest reached 3.8 kg·ha^{-1} in less than 5 months. The creel survey crews observed a total of 395 harvested fish. Twenty-two percent of the creel survey sample was fin clipped, providing a mark–recapture estimate of 765 (95% CI = 607–963) for the pre-angling adult portion of the population. This population was reduced by approximately 72% (final population estimate 210 (95% CI = 52–408) in the winter and spring fishery. The midsummer index netting survey provided consistent evidence of the population decline. Average catch rates of lake trout declined by 70% between 1997 and 1998 (Table 3).

In conclusion, the results of this study suggest that lake trout are not particularly vulnerable to damage from the physical alterations to spawning habitat that may occur through the construction of forest access roads in Boreal Shield areas of Ontario. First, there are management guidelines in place (e.g., Ontario Ministry of Natural Resources 1988, 1990, 1991) for the construction of roads that, if followed, should limit siltation of streambeds and inlet areas of lakes. Unlike other *Salvelinus* species such as brook trout (*Salvelinus fontinalis*) (Curry et al. 1997; Curry and Devito 2000), lake trout appear to rarely if ever use streams or the area immediately adjoining inlet streams for spawning. In a survey of 95 lake trout lakes, McMurtry (1986) found that no lake trout spawning sites were within 20 m of a stream inlet. Our study shows that if siltation of shorelines did actually occur, lake trout would seek spawning sites elsewhere and could maintain recruitment at these alternate sites. Siltation events would have to be extremely extensive and long-lasting to completely eliminate reproduction in this long-lived species.

The fact that we have not yet detected a substantial effect of progressive spawning habitat loss on lake trout recruitment in two experimental lakes does not mean that there is an unlimited supply of suitable spawning habitat on shield lakes or that lake managers should be any less diligent about protecting fish habitat from disturbances. Spawning habitat loss is surely one of a suite of stressors that have a cumulative effect on lake trout. However, our experimental results clearly suggest that resource managers need to question whether fish harvest controls and improved motor vehicle access to lake trout lakes have received sufficient attention in forest and fisheries management planning. We think that forest access roads and the increases in angling pressure that they create have a far greater impact on Boreal Shield lake trout populations than spawning habitat loss due to sedimentation.

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References

Anderson, B., and Potts, D.F. 1987. Suspended sediment and turbidity following road construction and logging in western Montana. Water Resour. Bull. **23**: 681–690.

Blais, J.M., France, R.L., Kimpe, L.E., and Cornett, R.J. 1998. Climatic changes in northwestern Ontario have had a greater effect on erosion and sediment accumulation than logging and fire: evidence from ^{210}Pb chronology in lake sediments. Biogeochemistry, **43**: 235–252.

Curry, R.A., and Devito, K. 2000. Hydrogeology of brook charr (*Salvelinus fontinalis*) spawning and incubation habitats: implications for forestry and land use development. Can. J. For. Res. **30**. In press.

Curry, R.A., Brady, C., Noakes, D.L.G., and Danzman, R.G. 1997. Use of small streams by young brook trout spawned in a lake. Trans. Am. Fish. Soc. **126**: 77–83.

DeRoche, S.E. 1969. Observations on the spawning habits and early life of lake trout. Prog. Fish-Cult. **31**: 109–113.

Foster, N.R. 1985. Lake trout reproductive behavior: influence of chemosensory cues from young-of-the-year by-products. Trans. Am. Fish. Soc. **114**: 794–803.

Gunn, J.M. 1995. Spawning behavior of lake trout: effect on colonization ability. J. Gt. Lakes Res. **21**(Suppl. 1): 323–329.

Gunn, J.M., and Keller, W. 1984. Spawning site water chemistry and lake trout (*Salvelinus namaycush*) sac fry survival during spring snowmelt. Can. J. Fish. Aquat. Sci. **41**: 319–329.

Gunn, J.M., and Keller, W. 1990. Biological recovery of an acid lake after reductions in industrial emissions of sulphur. Nature (Lond.), **345**: 431–433.

Gunn, J.M., McMurtry, M.J., Bowlby, J.N., Casselman, J.M., and Liimatainen, V.A. 1987. Survival and growth of stocked lake trout in relation to body size, stocking season, lake acidity and biomass of competitors. Trans. Am. Fish. Soc. **116**: 618–627.

Gunn, J.M., Conlon, M., Kirk, R.J., and McAughey, S.C. 1996. Can trained observers accurately identify lake trout spawning habitat? Can. J. Fish Aquat. Sci. **53**(Suppl. 1): 327–331.

Hara, T.J. 1994. The diversity of chemical stimulation in fish olfaction and gustation. Rev. Fish. Biol. Fish. **4**: 1–35.

Healey, M.C. 1978. Dynamics of exploited lake trout populations and implications for management. J. Wildl. Manage. **42**: 307–328.

Martin, N.V. 1957. Reproduction of lake trout in Algonquin Park, Ontario. Trans. Am. Fish. Soc. **86**: 231–244.

Martin, N.V., and Olver, C.H. 1976. The distribution and characteristics of Ontario lake trout lakes. Ont. Minist. Nat. Resour. Fish. Wildl. Res. Branch Rep. 97. Ontario Ministry of Natural Resources, Toronto, Ont.

Martin, N.V., and Olver, C.H. 1980. The lake charr, *Salvelinus namaycush*. *In* Charrs: salmonid fishes of the genus *Salvelinus*. *Edited by* E.K. Balon. Dr. W. Junk, The Hague, The Netherlands. pp. 205–277.

McAughey, S.C., and Gunn, J.M. 1995. The behavioral response of lake trout to a loss of traditional spawning sites. J. Gt. Lakes Res. **21**(Suppl. 1): 375–383.

McMurtry, M.J. 1986. Susceptibility of lake trout (*Salvelinus namaycush*) spawning sites in Ontario to acid meltwater. Ont. Fish. Acidification Tech. Rep. Ser. 86-0001. Ontario Ministry of Natural Resources, Toronto, Ont.

Megahan, W.F., and Kidd, W.J. 1972. Effects of logging and logging roads on erosion and sediment deposition from steep terrain. J. For. **80**: 136–141.

Ontario Ministry of Natural Resources. 1988. Timber management guidelines for the protection of fish habitat. Ont. Min. Nat. Resour. Rep. Ontario Ministry of Natural Resources, Toronto, Ont.

Ontario Ministry of Natural Resources. 1990. Environmental guidelines for access roads and water crossings. Ont. Min. Nat. Resour. Rep. Ontario Ministry of Natural Resources, Toronto, Ont.

Ontario Ministry of Natural Resources. 1991. Code of practice for timber management operations in riparian areas. Ont. Min. Nat. Resour. Rep. Ontario Ministry of Natural Resources, Toronto, Ont.

Payne, N.R., Korver, R.M., MacLennan, D.S., Nepszy, S.J., Shuter, B.J., Stewart, T.J., and Thomas, E.R. 1990. The harvest potential and dynamics of lake trout populations in Ontario. Lake Trout Synthesis Population Dynamics Working Group Report. Ontario Ministry of Natural Resources, Toronto, Ont.

Plamondon, A.P. 1982. Increase in suspended sediments after logging and duration of effect. Can. J. For. Res. **12**: 883–892.

Ricker, W. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. No. 191.

Ryder, R.A., and Johnson, L. 1972. The future of salmonid communities in North American oligotrophic lakes. J. Fish. Res. Board Can. **29**: 941–949.

Schindler, D.W. 1998. A dim future for boreal waters and landscapes: cumulative effects of climatic warming, stratospheric ozone depletion, acid precipitation, and other human activities. BioScience, **48**: 157–164.

Shuter, B.J., Jones, M.L., Korver, R.M., and Lester, N.P. 1998. A general life history based model for regional management of fish stocks: the inland lake trout (*Salvelinus namaycush*) fisheries in Ontario. Can. J. Fish. Aquat. Sci. **55**: 2161–2177.

Sly, P.G., and Evans, D.O. 1996. Suitability of habitat for spawning lake trout. J. Aquat. Ecosyst. Health, **5**: 153–175.

Steedman, R.J., and France, R.L. 2000. Origin and transport of aeolian sediment from new clearcuts into boreal lakes, northwestern Ontario, Canada. Water Air Soil Pollut. **122**: 139–152.