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Impact of logging and natural fires on fish communities of Canadian Shield lakes

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ABSTRACT

The goal of this study was to determine if natural fires and logging have a significant impact on abundance, growth, and size structure of fish populations in 38 lakes of the Canadian Shield (Québec, Canada). The watersheds of 9 of these lakes underwent logging and 9 underwent natural fires while the 20 remaining lakes were used as references. No significant differences were found among the three lake groups in the catch per unit of effort of the most abundant species: white sucker (C*atostomus commersoni*), northern pike (*Esox lucius*), yellow perch (*Perca flavescens*), lake whitefish (*Coregonus clupeaformis*), fallfish (*Semotilus corporalis*), brook charr (*Salvelinus fontinalis*), walleye (*Stizostedion vitreum*), and burbot (*Lota lota*). No significant difference was found in the back-calculated length of yellow perch and white sucker, for which age determinations were made, among control, burned, and logged lakes. However, we found that the proportion of small yellow perch and white sucker were significantly lower in populations of impacted lakes (burned and logged lakes pooled). The influence of logging and fires remained significant when a series of biotic and abiotic variables on watershed and lake characteristics were accounted for in multiple regression analyses. The lower proportion of small fish in impacted lakes could be due either to an increase in post-emergence mortality and (or) a shift of individuals to the pelagic zone.

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INTRODUCTION

The effects of logging are well documented in lotic ecosystems (Graynoth 1979, Brown 1983, Hartman and Scrivener 1990, Roberge 1996). Some of the most significant effects are the increase in turbidity and sedimentation (Everest et al. 1987, Hetherington 1987, Eaglin and Hubert 1993), nutrient concentrations (Nicolson et al. 1982, Pardo et al. 1995, Rosén et al. 1996), and streamflow (Troendle and King 1987, Van Der Vinne and Andres 1988, Heede 1991). Logging may also induce increases in water temperature (Lynch et al. 1984, Beschta et al. 1987, Garman and Moring 1991), decreases in dissolved oxygen (Ringler and Hall 1975, Graynoth 1979, Murphy and Milner 1997) and increases in primary productivity (Murphy et al. 1981, Noël et al. 1986, Gregory et al. 1987) through the removal of canopy cover. Forest fires were also reported to increase sediment transport (Beaty 1994, Cerdà et al. 1995, Megahan et al. 1995) and nutrient losses (Schindler et al. 1980, Spencer and Hauer 1991, Bayley et al. 1992). In lakes, deforestation, either through natural fires or logging, also tends to increase nutrients and organic carbon loading as well as increases in chlorophyll a and limnoplankton biomass (Carignan et al. 1999).

All these changes are susceptible to affect the top-down and bottom-up interactions, especially fish populations, which can reflect short term changes in limnetic eutrophication due to their ability for rapid growth compensation and their short life history cycles. As fish yield is strongly correlated to lake productivity (Ryder et al. 1974, Godbout and Peters 1988), forest clearance may increase fish productivity (Hawkins et al. 1983, Murphy et al. 1986). On the other hand, increased sedimentation following deforestation is also likely to have an impact on spawning habitats and therefore on fish recruitment (Scrivener and Brownlee 1989, Murphy and Milner 1997). Most existing studies on the impact of logging on fish populations deal with salmonids inhabiting brooks and streams. With the exception of Bérubé and Lévesque (1998), we do not know of any other studies that investigated the impact of these perturbations on fish of lake ecosystems.

Canadian sport fishers spent $7.4 billion on this activity in 1995, of which $4.9 billion was directly related to fishing (Economic and Policy Analysis Directorate 1997). Given the socio-economical importance of this fishery, it is of prime importance to describe and understand the impact of different levels of deforestation on fish communities to be able to predict changes in commercially important species following such perturbations. The objective of our study was to determine if changes in abundance, growth, and size structure of fish populations are correlated with changes in any lake characteristics following buring and (or) logging. The present study is based on a survey of fish populations in 38 lakes of the Canadian Shield; the watersheds of 20 of these were not impacted while 9 underwent logging and 9 underwent natural fires.

STUDY SITE

The data were collected in 38 headwater lakes on the Boreal Canadian Shield. All the lakes are located within a 50,000 km^2 area around Réservoir Gouin, Québec (48°50’N, 75°00’W, Fig.1). This region has a typical temperate climate, where snow represents half of the annual precipitation (900-1000 mm). The forest is primarily composed of black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), jack pine (*Pinus divaricata*), white birch (*Betula papyrifera*), and aspen (*Populus tremuloides*). Our study compared fish communities in lakes with three types of watershed treatments: 20 control lakes with undisturbed watershed (old-growth forest of at least 60 years); 9 “logged” lakes, whose watersheds had undergone forest clearance, and 9 “burned” lakes, whose watersheds had been severely burned by fire (Fig.1). In logged lakes, a buffer strip of about 20 m had generally been left between cutting zones and lakes. The lakes were selected on the basis of comparable size, depth, watershed morphometries (Table 1), and time of the impact. All the lakes were stratified during summer and their watershed slope ranged from 7.5 to 19.5% (mean = 11.1%). Most fires and clear-cuts occurred in 1995 (with the exception of lakes C24 and C2, which had been clear-cut in spring and summer 1994 respectively). With the exception of some forestry roads, the only way to access these lakes is by hydroplane. The fish communities of these lakes are thus generally unexploited or lightly exploited.

SUMMARY OF METHODS AND DATA ANALYSES

Detailed information on field methods, laboratory procedures and statistical analyses can be found in St-Onge and Magnan (2000). Therefore, only a brief summary is presented here.

Fish sampling

Twenty-one lakes were sampled in 1996 (one year after the impacts) and 17 in 1997 (two years after the impacts). It was not possible to sample all the lakes during the same year due to logistical constraints. Each lake was sampled once between June and August. Fish were captured with experimental monofilament gillnets, 102.3 m long x 2.7 m deep, with stretched mesh panels of 20, 24, 33, 36, 50, 60, 76, 90, and 100 mm (filament diameter of 0.17, 0.20, 0.20, 0.20, 0.20, 0.32, 0.32, 0.32, and 0.32 mm, respectively). Gillnets were set perpendicular to the shore, with small and large meshes alternating from the shore among gillnets. The nets were localized at regular intervals around the lake, the first being randomly located using aerial photography. The fishing effort was 6 nets per night for lakes < 50 ha, 8 nets per night for lakes of 50-100 ha, 10 nets/night for lakes of 100-150 ha, and 12 nets/night for lakes > 150 ha. The nets fished for periods of 16 to 24 hours, always covering the periods between 18:00 and 09:00 hours. For all fish captured, total length (± 1 mm) and weight (± 0.1 g) were noted and, when possible, sex was identified visually. Appropriate bone structures were also removed for further age determination of white sucker (*Catostomus commersoni*), pike (*Esox lucius*), yellow perch (*Perca flavescens*), brook charr (*Salvelinus fontinalis*), lake whitefish (*Coregonus clupeaformis*), and walleye (*Stizostedion vitreum*).

Study species

The fish species compositions of the study lakes, unknown before this study, were quite diverse (Table 2). The most widespread species were white suckers (31 lakes), northern pike (27 lakes), yellow perch (25 lakes), and lake whitefish (11 lakes). We selected white suckers, yellow perch, and lake whitefish to evaluate the impact of fires or logging on fish populations; because they were the most frequent species. Northern pike was present in many lakes, but its abundance was too low to conduct reliable analysis (mean catch per unit of effort [CPUE] of 1.5 ± 1.5).

Study parameters

Relative abundance

For each study species, statistical analyses were performed to determine if there was any significant difference in its relative abundance (CPUE) among lake groups. We also pooled the data of logged and burned lakes in to a single group, hereafter referred as impacted lakes, to increase sample size. We also compared the percent CPUE of "small fish" of the three study species and that of 1+ yellow perch using the same procedure, because they appeared to be affected by fires and logging (see below for age determination of yellow perch). "Small fish" corresponded to the first mode of the size frequency distribution, which was estimated visually. In the size frequency distribution, the frequency of each length class represented the mean of the lake group.

Age and growth of yellow perch and white sucker

We used back-calculated length-at-age to compare growth of yellow perch and white sucker among the three lake groups (control, burned, and logged). To reduce the inter-annual variability, comparisons were made only among fish of the same cohort and of the same lag preceding or following the impact (e.g., fish of age 1, 1 year after logging). Since all fish sampling was not done in the same year, this approach allowed us to use data of the two years in the same analyses (see Results section). This procedure was carried out on the first three cohorts for yellow perch (age 1 to 3) and the first six cohorts for white sucker (age 1 to 6), for the two years preceding and following the impacts as well as for the year of the impacts. Statistical analyses were done to determine if there were any significant differences in fish length among lake groups. Finally, assuming that logging and fires may have similar effects on growth (if there is an effect), we pooled the data from logged and burned lakes into a single group (impacted lakes) to increase the sample size (see Discussion section).

Determinants of fish abundance

Multiple linear regressions were used to determine environmental and biological factors that best explained (i) percent one year old yellow perch in the population and (ii) percent CPUE of white sucker < 160mm in the population. No model was built to predict the relative abundance of small lake whitefish in the population because of the low sample size (nine lakes).

Variables on watershed and lake morphometry, water quality, phytoplankton, and zooplankton were used as independent variables in statistical analyses (Table 3). Further details on the estimation of the above variables can be obtained in Carignan et al. (1999), Planas et al. (1999), and Patoine et al. (2000). For water quality, phytoplankton, and zooplankton, we used the mean of the three summer samples in statistical analyses (for the summer when fish were sampled). The variable "logging or fires" was entered as a dummy variable where the value 0 was attributed to control lakes and 1 to those that underwent fires or logging.

SUMMARY OF RESULTS

Relative abundance

No significant differences were found in CPUE among the three lake groups for white sucker, northern pike, yellow perch, lake whitefish, fallfish, brook charr, walleye, and burbot (Table 4). For the other species, there was insufficient data to perform comparison tests. Similarly, no significant differences were found in CPUE of the most frequent species between control and impacted lakes (i.e., when burned and logged lakes were pooled; Table 4). The mean percent CPUE of small white sucker (< 160 mm) in the population was significantly lower in impacted lakes than in control lakes ($t = -2.15$, $p < 0.05$; Fig. 2). The mean percent CPUE of small yellow perch (< 75 mm) and small lake whitefish (<120 mm) also tend to be lower in impacted than in control lakes, but these differences were not significant (Fig. 2). For the 1996 sample, the mean percent CPUE of 1+ yellow perch in the population was significantly lower in logged lakes than in control lakes, with burned lakes showing an intermediate value (Fig. 3). The same pattern was observed for pooled samples of 1996 and 1997. The significant increase in the mean percent CPUE of 3+ yellow perch, probably results from the decrease in the mean percent CPUE of 1+ fish in the population (Fig.3).

Growth of yellow perch and white sucker

No significant differences were found in the back-calculated length of yellow perch (Table 5) and white sucker (Table 6) among control, burned, and logged lakes. No significant differences were observed when logged and burned lakes were pooled into impacted lakes (Tables 5 and 6).

Determinants of fish abundance

The best predictors of the percent CPUE of one-year-old yellow perch in the population were the biomass of northern pike (-), mean summer lake temperature (+), the dummy variable "logging or fires" (-), and depth of epilimnion (+), explaining respectively of 29.4, 24.6, 19.5, and 13.1% of the variation (Table 7). The length of brooks in the watershed (+) explained 0.5% of the variation (Table 7).

The best predictors of the percent CPUE of small white sucker were the density of microphytoplankton (+), the dummy variable "logging or fires" (-), latitude (+), and sampling date (+), which together accounted for 73.6% of the variation (Table 7).

CONCLUSIONS

Our study indicates that logging and fires affect the abundance of small yellow perch and white sucker. This is confirmed by the fact that the dummy variable "logging or fires" still appeared in the multiple regression models after all others biotic and abiotic variables were accounted for. Furthermore, the variable "logging or fires" explained a substantial proportion of the variation of 1+ yellow perch (19.5%) and small white sucker (24.1%). When logging and fires were considered separately as independent variables, they did not appear in any models to predict the CPUE of small perch and sucker. This is probably due to the splitting of samples size (four logged lakes and five burned lakes for white sucker; seven logged lakes and six burned lakes for yellow perch). In pooling logged and burned lakes, we assumed that both perturbations have similar impacts on small fish.

The impacts of logging are well documented in fish and usually include a decrease in spawning habitat quality. In streams, the increase of temperature and sedimentation after timber harvest can affect the egg-to-fry survival by reducing the oxygen in spawning grounds and by forming physical barriers to emergence (Ringler and Hall 1975, Everest et al. 1987, Murphy and Milner 1997). In Carnation Creek, the survival to emergence declined from 29.1% to 16.4% for coho salmon (*Oncorhynchus kisutch*) and from 22.2% to 11.5% for chum salmon (*O. keta*) following logging (Scrivener et Brownlee 1989). Forest fires also influence the amount of sediment found in brooks and streams (Beaty 1994, Cerdà et al. 1995, Mégahan et al. 1995). In lakes, the removal of lakeside vegetation can also be assumed to affect spawning habitat quality. For example, suspended sediment, light enough to be carried around the lake shoreline by water movements, may be deposited in spawning grounds (Miller et al. 1997). In some Quebec lakes, Bérubé and Lévesque (1998) reported a reduction of sport fishing yield (abundance and biomass) of brook trout after clear-cutting. Possible damage to spawning and nursery habitats were suggested to explain in part these reductions in fishing success.

Most studies on the impact of fires and logging on fish populations have been done on salmonids because they require clean gravel or rubble substrate to spawn so their reproduction is generally affected by siltation (Berkman and Rabeni 1987). Yellow perch spawn in shallow water of lakes or in tributaries where single, convoluted egg-strands are attached to submerged plants or fallen trees, or deposited on sand and gravel (Echo 1955, Scott and Crossman 1973). For this reason, perch and other sport fishes like northern pike, bass, or walleye are assumed to be less sensitive than trout to the potentially adverse affects of timber harvesting (France 1997); this probably explains why no study has evaluated the impact of logging and fires on these species. In the present study, the reduction in abundance of 1+ yellow perch cannot be attributed to a reduction of egg-to-fry survival induced by logging or fires. This reduction was observed in 1996, one year after forest harvesting or fires. The one-year-old perch captured in 1996 were born in spring 1995, the summer before logging and fires occurred. Consequently, any impacts on 1+ yellow perch may have occurred in the seasons following the emergence of larvae.

White suckers require clean gravel to spawn (Scott and Crossman 1973) and thus could have a similar response to spawning habitat degradation by siltation as salmonids (Berkman and Rabeni 1987). As we did not made age determinations for white sucker, we cannot evaluate the effect of fires and logging on the first cohort. However, age–length relationships found in the literature suggest that few one-year-old individuals were captured in our gillnets.

Little information is available on post-emergence survival after clear-cuts and fires. Depending on the concentration and duration of exposure, suspended sediments can induce physiological stress, reduce growth, and cause direct mortality in fish (Newcombe and MacDonald 1991). In streams where watersheds have been almost completely burned, Bozek and Young (1994) found dead fish following storm flow caused by rain. Each fish appeared to have been asphyxiated by sediment. Typically, sediment completely embedded the fish gills. However, the dynamics of sediment loading is different in streams than in lakes. In streams, the velocity is strong enough to keep sediment in suspension and thus expose fish to a substantial stress (Chiasson 1993). In contrast, lake basins act as sinks (Miller et al. 1997) and sediment is deposited on the lake floor. Number of authors have suggested that adult fish are able to tolerate suspended sediment concentrations substantially greater than those commonly found in nature (Herbert & Merkens 1961, Muncy et al. 1979, Redding & Schreck 1987). For these reasons, it is unlikely that an excess of sedimentation would have caused direct mortality of fish in burned and logged lakes, especially in logged lakes due to presence of buffer strips.

Assuming that fine sediment can reach the lake shore of burned and logged lakes, macroinvertebrate habitats and survival could have been negatively affected (Miller et al. 1997), reducing the abundance of food for yellow perch and white sucker. Some studies have reported a reduction in macroinvertebrate density following timber harvesting or forest drainage (Hartman and Scrivener 1990, Vuori and Joensuu 1996). Thus, a lower food availability could have lowered the survival of younger fish. This hypothesis could also explain the absence of difference in growth of yellow perch between control and impacted lakes as fewer fish would have access to a reduced benthic resource (prey biomass per capita being similar among lakes groups). Some studies have reported an increase in salmonid biomass or growth when the gain in productivity apparently compensated for a decrease in habitat quality (Burns 1972, Murphy and Hall 1981, Grant et al. 1986). In our study, the increased phosphorous supply in burned lakes caused a significant (80%) upsurge in biological productivity, as evidenced by higher planktonic and attached chlorophyll levels, algal biomass, and zooplankton (Carignan et al. 1999, Planas et al. 1999, Patoine et al. 2000). In contrast, the increased total phosphorus levels in logged lakes did not result in higher productivity, probably because higher concentration of dissolved organic carbon reduced light availability or because of differences in biological availability of phosphorous released by burned and harvested watersheds (Carignan et al. 1999). As no difference was found in its growth, yellow perch did not respond to the increased productivity in burned lakes.

The gillnets used in this project were chosen to ensure the capture of all species and of a large size range of fish. However, these nets are not very efficient in capturing small fish like one-year-old yellow perch and small white sucker, and may have biased the sampling of these size classes. In similar lakes, small yellow perch are known to be most abundant in dense littoral vegetation of shallow and deep bays (Sandheinrich and Hubert 1984). White sucker is also known to be most abundant in the littoral zone (Tremblay and Magnan 1991). In our study, the gillnets were located perpendicular to the shore and may have been systematically set in habitats not selected by these two species in logged and burned lakes. It is possible that small perch and sucker shift to the pelagic zone following disturbances in the littoral zone of logged and burned lakes; this zone was not sampled with our protocol.

We do not know of any study that has investigated the impact of these perturbations in lake ecosystems with such a large sample size and on species other than salmonids. Our sampling design allowed us to observe significant differences in population structure among lake treatments but not to determine the mechanisms responsible for these patterns. Further studies will be needed to investigate the function of fish populations following watershed deforestation.

MANAGEMENT APPLICATIONS

This study suggest that logging and fires have an influence on small yellow perch, white sucker, and perhaps lake whitefish, either through an increase in post-emergence mortality and (or) a shift of individuals to the pelagic zone. If this is the case, these mortalities may have a cascading effect on the most valuable exploited species like northern pike and walleye, which use perch, sucker, and whitefish as forage fish. One or two cohorts of these prey fish will be decreased at the time they will enter into the size range selected by pike and walleye. Consequently, exploitation of pike and walleye will have to be reduced during years of poor abundance of prey fish, to prevent their collapse.

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Table1. General characteristics of study lakes one year after disturbance (1996). The data are means of the three summer samples for alkalinity, pH, and Secchi depth.

Lake	Surface area (km^2)	Mean depth (m)	Alkalinity (ueq/L)	pH	Secchi depth (m)	% of watershed burned or logged
			Logged lakes			
C2	0.37	3.3	53.6	6.5	2.1	72.0
C9	0.66	5.8	51.8	6.6	3.9	44.5
C12	0.35	2.9	130.0	7.0	1.1	59.0
C23	0.29	2.2	49.8	6.2	1.6	48.3
C24	0.18	3.5	41.6	6.0	1.2	43.2
C29	0.30	4.1	101.8	6.9	4.7	63.6
C40	0.28	7.5	20.2	6.1	4.2	10.8
C44	0.32	6.0	48.3	6.6	4.5	8.5
C48	2.31	3.7	68.4	6.7	3.0	73.2
Mean	0.56	4.3	62.8	6.5	2.9	47.0
(± SD)	(0.67)	(1.7)	(33.4)	(0.3)	(1.5)	(23.8)
			Burned lakes			
FBP9	0.57	4.6	102.5	6.9	2.7	94.6
FBP10	0.36	6.0	158.8	7.1	4.7	94.5
FP2	0.35	4.4	22.0	5.8	1.8	50.1
FP15	0.48	7.3	58.2	6.6	2.9	98.9
FP24	0.17	4.2	44.3	6.6	5.0	100.0
FP27	0.64	10.0	84.5	6.9	5.6	91.3
FP30	0.34	5.4	72.3	6.8	2.6	92.2
FP31	0.45	5.3	40.3	6.5	3.9	100.0
FP32	0.23	4.6	102.1	6.6	3.0	100.0
Mean	0.40	5.8	76.1	6.6	3.6	91.3
(± SD)	(0.15)	(1.9)	(41.6)	(0.4)	(1.3)	(15.8)
			Control lakes			
N5	0.19	5.4	23.4	6.2	3.8	---
N16	0.80	4.6	26.8	6.3	5.7	---
N35	0.15	3.0	60.7	6.7	4.1	---
N43	0.29	2.7	76.5	6.7	2.1	1.0
N55	0.27	2.1	105.4	7.0	3.8	---
N56	0.27	2.8	45.0	6.6	3.9	---
N59	0.15	5.1	33.3	6.4	5.2	---
N63	0.60	3.8	35.3	6.4	4.1	---
N70	0.65	6.8	39.0	6.5	4.9	---
N82	0.32	8.5	42.3	6.5	4.1	---
N84	0.81	4.2	51.7	6.6	6.1	---
N88	0.57	5.3	67.3	6.7	4.0	---
N89	0.67	4.1	97.2	6.9	4.9	---
N106	0.41	4.6	51.6	6.6	5.5	---
N107	0.46	8.9	118.4	7.0	4.5	---
N120	0.39	4.8	50.5	6.6	6.7	---
N122	0.20	3.3	117.0	7.0	3.3	---
P25	0.33	4.6	66.7	6.8	4.8	---
P109	0.48	2.8	23.9	6.2	4.0	---
P110	0.81	4.6	42.3	6.5	4.5	---
Mean	0.44	4.6	58.7	6.6	4.5	---
(± SD)	(0.22)	(1.8)	(29.9)	(0.2)	(1.0)	---

Table 2. Occurrence of fish species in the three lake groups (control, burned and logged). Data are number of lakes.

Species	Control	Logged	Burned	*Total*
White sucker (C*atostomus commersoni*)	18	6	7	31
Northern pike (*Esox lucius*)	13	7	7	27
Yellow perch (*Perca flavescens*)	12	7	6	25
Lake whitefish (*Coregonus clupeaformis*)	4	3	4	11
Fallfish (*Semotilus corporalis*)	4	4	2	10
Brook charr (*Salvelinus fontinalis*)	4	2	1	7
Walleye (*Stizostedion vitreum*)	4	2	3	9
Burbot (*Lota lota*)	3	3	1	7
Lake charr (*Salvelinus namaycush*)	0	1	1	2
Rainbow smelt (*Osmerus mordax*)	2	0	0	2
Trout-perch (*Percopsis omiscomaycus*)	1	0	0	1
Brook stikelback (*Culaea inconstans*)	1	0	0	1
Ninespine stikelback (*Pungitus pungitus*)	1	0	0	1
Finescale dace (*Phoxinus neogaeus*)	4	1	0	5
Lake chub (*Couesius plumbeus*)	3	2	0	5
Golden shiner (*Notemigonus crysoleucas*)	1	3	1	5
Pearl dace (*Semotilus margarita*)	4	0	3	7
Blacknose shiner (*Notropis heterolepis*)	0	1	0	1
Spottail shiner (*Notropis hudsonius*)	2	0	0	2
Logperch (*Percina caprodes*)	0	0	1	1
Northern redbelly dace (*Phoxinus eos*)	2	0	0	2
Common shiner (*Notropis cornutus*)	1	0	0	1
Cyprinidae sp.	14	1	8	23

Table 3. Independent variables used in regression analyses.

Categories	Variables	Unity
Geographical	latitude	decimal
	longitude	decimal
	altitude	m
Lake morphology	lake area	km^2
	fetch	km
	lake perimeter	km
	shore line development	
	mean lake slope	%
	mean littoral slope	%
	lake volume	m^3
	epilimnion volume	m^3
	littoral volume	m^3
	littoral area	m^2
	maximum depth	m
	mean depth	m
	epilimnion depth	m
Watershed morphology	watershed area	km^2
	drainage area	km^2
	watershed perimeter	km
	drainage density	$km \cdot km^{-2}$
	length of brooks on watershed	km
	run off	$m^3 \cdot an^{-1}$
	water residence time	an
	mean watershed slope	%
	marsh on watershed	km^2
Physical and chemical	Secchi depth	m
	mean lake temperature	°C
	mean lake oxygen	$mg \cdot l^{-1}$
	mean epilimnion temperature	°C
	mean epilimnion oxygen	$mg \cdot l^{-1}$
	thermocline depth	m
	dissolved organic carbon	$mg \cdot l^{-1}$
	total phosphorous	$\mu g \cdot l^{-1}$
	total nitrogen	$\mu g \cdot l^{-1}$
	nitrate (NO_3)	$\mu g \cdot l^{-1}$
	ammonium (NH_4)	$\mu g \cdot l^{-1}$
	pH	
	alkalinity	$\mu eq \cdot l^{-1}$
Phytoplankton	chlorophyll-a	$\mu g \cdot l^{-1}$
	picophytoplankton density	$\mu g \cdot l^{-1}$
	nanophytoplankton density	$\mu g \cdot l^{-1}$
	microphytoplankton density	$\mu g \cdot l^{-1}$
Zooplankton	total volume of particles	$mm^3 \cdot m^{-3}$
	volume of particle < 1000µm	$mm^3 \cdot m^{-3}$
	volume of particle > 1000µm	$mm^3 \cdot m^{-3}$
	AFDW* of particle of 50-100µm, 100-200µm, 200-500µm, and > 500µm	$mg\ AFDW \cdot m^{-3}$
Fish	abundance or biomass of northern pike	$nb \cdot net^{-1}$ or $g \cdot net^{-1}$
	abundance or biomass of walleye	$nb \cdot net^{-1}$ or $g \cdot net^{-1}$
	abundance or biomass of white sucker	$nb \cdot net^{-1}$ or $g \cdot net^{-1}$

*: AFDW = ash free dry weight

Table 4. Catch per unit of effort of fish species in the three lake groups (control, burned, and logged). Data represent the mean ± standard deviation. Number of lakes are in parentheses.

Species	Control	Logged	Burned	P_1	P_2
White sucker (C*atostomus commersoni*)[1,2]	10.2 ± 12.0 (18)	8.4 ± 9.9 (6)	3.6 ± 2.9 (7)	0.5694	0.3496
Northern pike (*Esox lucius*)[1]	2.0 ± 1.5 (13)	1.9 ± 1.2 (7)	2.6 ± 0.8 (7)	0.3525	0.7096
Yellow perch (Perca flavescens)[1,2]	23.4 ± 35.9 (12)	11.7 ± 9.2 (7)	9.6 ± 4.6 (6)	0.7464	0.4611
Lake whitefish (*Coregonus clupeaformis*)[1,2]	10.3 ± 5.6 (4)	6.4 ± 7.0 (3)	5.5 ± 8.4 (4)	0.3552	0.1239
Fallfish (*Semotilus corporalis*)[1]	5.5 ± 6.1 (4)	1.4 ± 0.6 (4)	1.9 ± 2.6 (2)	NT	0.2921
Brook charr (*Salvelinus fontinalis*)[1]	5.5 ± 6.9 (4)	5.8 ± 7.7 (2)	25.8 (1)	NT	0.4599
Walleye (*Stizostedion vitreum*)[1]	9.4 ± 4.6 (4)	7.1 ± 0.1 (2)	6.9 ± 3.8 (3)	NT	0.4018
Burbot (*Lota lota*)	0.2 ± 0.1* (3)	0.3 ± 0.1 (3)	0.8* (1)	NT	0.3331

P_1: probability of ANOVA (between control, burned and logged)
P_2 : probability of T-Test (between impacted and control)
[1] : Anova performed on log-transformed data.
[2] : T-Test performed on log transformed data
* : difference determined by Tuckey's test
NT: non-tested due to low sample size

Table 5 . Back calculated length of yellow perch the year before, the year of, and the year after logging and fire impacts. Statistical analyses were done on separate treatment levels (ANOVA) and in pooling fires and logged lakes into a single group (*t*-test).

age group	lake group	2 years before perturbations			1 year before perturbations			year of perturbations			1 year after perturbations			2 years after perturbations		
		mean	SD	N	mean	SD	N	mean	SD	N	mean	SD	N	mean	SD	N
I	control	48.02	7.41	7	49.18	6.05	9	48.58	8.73	11	52.45	5.23	11	51.16	5.87	6
	burned	44.46	4.04	5	47.46	10.44	5	49.14	3.45	6	48.02	4.13	6	46.41	4.84	3
	logged	47.17	4.49	4	47.61	6.34	6	49.89	3.75	7	51.00	3.88	6	50.24	2.95	4
	ANOVA	NS	NS		NS	NS		NS	NS		NS	NS		NS	NS	
	t test	NS	NS		NS	NS		NS	NS		NS	NS		NS	NS	
II	control	80.37	8.53	5	76.98	11.70	7	79.49	5.74	10	82.48	5.05	11	81.34	5.15	6
	burned	68.92	7.67	3	70.65	5.49	5	75.34	6.43	5	80.67	7.93	6	79.17	2.84	3
	logged	81.67	8.61	3	73.32	3.92	4	75.55	7.34	6	81.48	6.69	7	83.30	6.22	4
	ANOVA	NS	NS		NS	NS		NS	NS		NS	NS		NS	NS	
	t test	NS	NS		NS	NS		NS	NS		NS	NS		NS	NS	
III	control	104.06	24.02	2	104.16	14.57	5	101.92	11.45	7	111.93	13.14	10	109.97	9.84	6
	burned	102.87	---	1	92.95	13.27	3	94.84	7.27	5	102.37	8.70	5	116.02	14.09	3
	logged	96.29	---	1	106.47	11.31	3	93.57	3.64	4	102.21	5.87	6	112.75	10.40	4
	ANOVA	NS	NS		NS	NS		NS	NS		NS	NS		NS	NS	
	t test	NS	NS		NS	NS		NS	NS		$p < 0.05$	NS		NS	NS	

Table 6 . Back calculated length of white sucker the 2 years before, the year of, and 2 years after logging and fire impacts. Statistical analyses were done on separate treatment levels (ANOVA) and in pooling fires and logged lakes into a single group (*t*-test).

age group	lake group	2 years before perturbations			1 year before perturbations			year of perturbations			1 year after perturbations			2 years after perturbations		
		mean	SD	N	mean	SD	N	mean	SD	N	mean	SD	N	mean	SD	N
I	Control	77.16	21.97	8	74.84	21.71	7	78.00	26.09	6	91.37	11.41	3	106.96	-	1
	Burned	103.61	21.49	3	96.90	46.66	3	91.18	34.95	4	88.65	23.47	4	-	-	-
	Logged	75.53	26.37	4	64.81	14.09	3	72.71	5.14	2	92.55	2.49	2	-	-	-
	ANOVA	NS			NS			NT			NT			NT		
	t test	NS			NS			NS			NS			NT		
II	Control	95.18	21.81	8	99.31	20.87	8	103.26	13.41	7	113.37	10.05	6	133.17	14.04	3
	Burned	129.26	35.41	4	132.91	21.17	3	133.78	57.67	3	122.79	34.13	4	138.89	7.83	4
	Logged	87.81	16.22	3	105.26	16.39	4	103.94	4.60	3	120.38	21.59	2	-	-	-
	ANOVA	NS			NS			NS (1,2)			NT			NT		
	t test	NS			NS			NS (1)			NS			NS		
III	Control	119.34 [a]	29.22	9	125.79 [a]	26.89	8	136.38	23.20	8	142.54 [a]	16.56	7	160.46	8.49	5
	Burned	168.42 [b]	33.52	4	178.85 [b]	42.05	4	179.65	25.29	3	206.57 [b]	49.43	3	214.87	63.74	4
	Logged	163.27 [ab]	39.55	3	132.537 [ab]	20.98	3	159.73	27.24	4	168.03 [ab]	36.28	3	-	-	-
	ANOVA	$p < 0.05$			$p < 0.05$			NS			$p < 0.05$ (1)			NT		
	t test	$p < 0.05$			NS			$p < 0.05$			NS			NS (1, 3)		

NT: non-tested; NS: non-significative; 1: log-transformed data; 2: homogeneous variance assumption unrespected; 3: normality of data unrespected; a, b, c: differences detected by Tuckey's test.

Table 6 (cont.) . Back calculated length of white sucker the 2 years before, the year of, and 2 years after logging and fire impacts. Statistical analyses were done on separate treatment levels (ANOVA) and in pooling fires and logged lakes into a single group (*t*-test).

Age group	lake group	2 years before perturbations			1 year before perturbations			year of perturbations			1 year after perturbations			2 years after perturbations		
		mean	SD	N	mean	SD	N	mean	SD	N	mean	SD	N	mean	SD	N
IV	Control	146.46[a]	39.55	8	147.89[a]	39.48	9	157.38[a]	34.73	8	178.06[a]	38.60	8	184.89	24.17	4
	Burned	216.00[ab]	51.78	3	204.03[ab]	26.60	4	221.89[b]	38.62	4	274.92[b]	41.49	3	297.62	39.57	3
	Logged	224.36[b]	35.82	4	214.98[b]	40.10	3	178.04[ab]	8.87	3	217.52[ab]	52.72	4	-	-	-
	ANOVA	$p < 0.05$[(1)]			$p < 0.05$			$p < 0.05$			$p < 0.05$			NT		
	t test	$p < 0.01$			$P < 0.01$			$p < 0.05$			$p < 0.05$			$p < 0.05$		
V	Control	167.89	47.47	9	174.19[a]	49.98	8	175.93[a]	49.01	9	190.76[a]	44.09	8	243.01	61.62	5
	Burned	224.85	45.09	2	255.11[ab]	59.59	3	252.77[b]	18.11	4	284.41[b]	47.61	4	353.95	31.37	3
	Logged	240.45	30.02	3	279.21[b]	36.87	4	260.7[b]	47.39	3.00	223.27[ab]	23.53	3	-	-	-
	ANOVA	NT			$p < 0.01$			$p < 0.05$			$p < 0.05$			NT		
	t test	$p < 0.05$			$p < 0.01$			$p < 0.01$			$P < 0.05$			$p < 0.05$		
VI	Control	184.34	55.81	8	191.09	58.86	9	202.97[a]	60.86	8	202.23[a]	59.88	9	250.24	52.34	4
	Burned	354.69	3.55	2	279.46	75.83	2	297.07[ab]	60.37	3	315.59[b]	11.81	4	385.73	51.82	4
	Logged	290.29	76.78	2	283.93	43.987	3	329.337[b]	50	4	298.357[b]	54.164	3	-	-	-
	ANOVA	NT			NT			$p < 0.01$			$p < 0.01$			NT		
	t test	$p < 0.01$[(3)]			$p < 0.05$			$p < 0.01$			$p < 0.01$			$p < 0.05$		

NT: non-tested; NS: non-significative; 1: log-transformed data; 2: homogeneous variance assumption unrespected; 3: normality of data unrespected; a, b, c: differences detected by Tuckey's test.

Table 7. Best models predicting the percent of one-year-old yellow perch and small white sucker (< 160 mm in the population). The probability (p) associated with each independent variable, the standard error of the coefficient (SE), the partial R^2 associated with each variable[a], the adjusted R^2, and the standard error of the estimate (S_{xy}) are also listed.

Model			$p > t$	SE	R^2	adj R^2	S_{xy}
% of one year old yellow perch in population =					81.3	73.1	16.6
-	2.11		0.0067	0.6766			
-	0.18	Northern pike biomass[c]	0.0012	0.0505	29.4		
+	1.67	Mean summer lake temperature[c]	0.0006	0.3899	24.6		
-	0.25	Logging or fires[b]	0.0142	0.1046	19.5		
+	0.15	Depth of epilimnion	0.0102	0.1371	13.1		
+	0.23	Length of brooks on watershed[c]	0.0457	0.0898	0.5		
+	0.36	Nanophytoplankton density[c]	0.0184	0.1144	(0.02)[d]		
-	0.34	White sucker abundance[c]	0.0094	0.0448	(5.8)[d]		
% of white sucker of length < 160mm in population =					80.2	74.0	14.5
-	20.21						
+	0.66	Microphytoplankton density[c]	0.0000	.1113	30.7		
-	0.31	Fires or logging	0.0002	.0645	24.1		
+	0.40	Latitude	0.0006	.0928	10.0		
+	0.01	Sampling date	0.0017	.0017	8.8		
-	0.21	Littoral area[c]	0.0728	.1113	(6.7)[e]		

[a]Calculated as the standardized regression coefficient times the correlation coefficient between the dependent variable and this independent variable (Tabachnick and Fidell 1983).
[b]Dummy variable
[c]Log-transformed data
[d]Suppressor variable (see texte).
[e]Non-interpretable variable

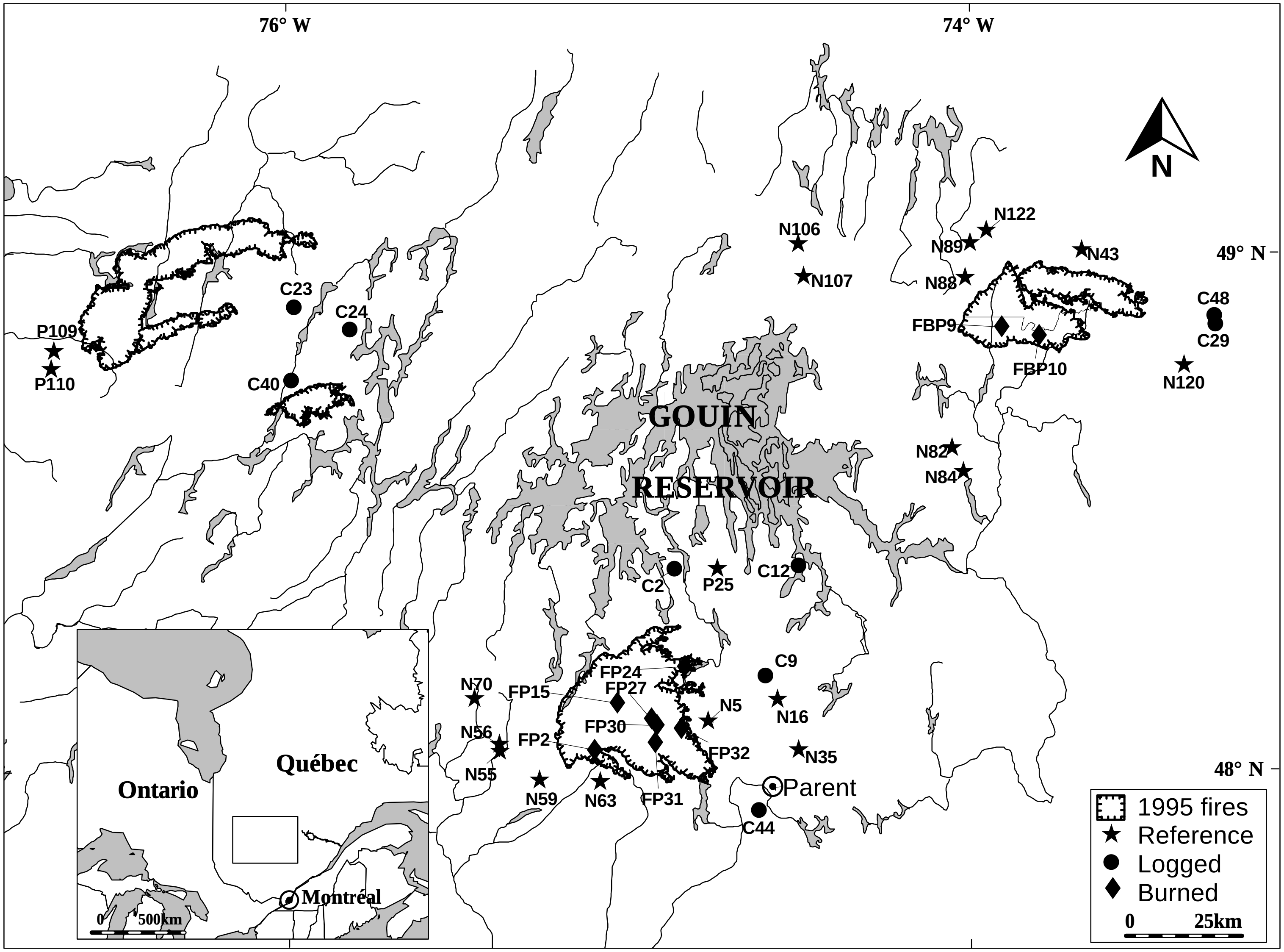

Fig. 1. Location of study lakes.

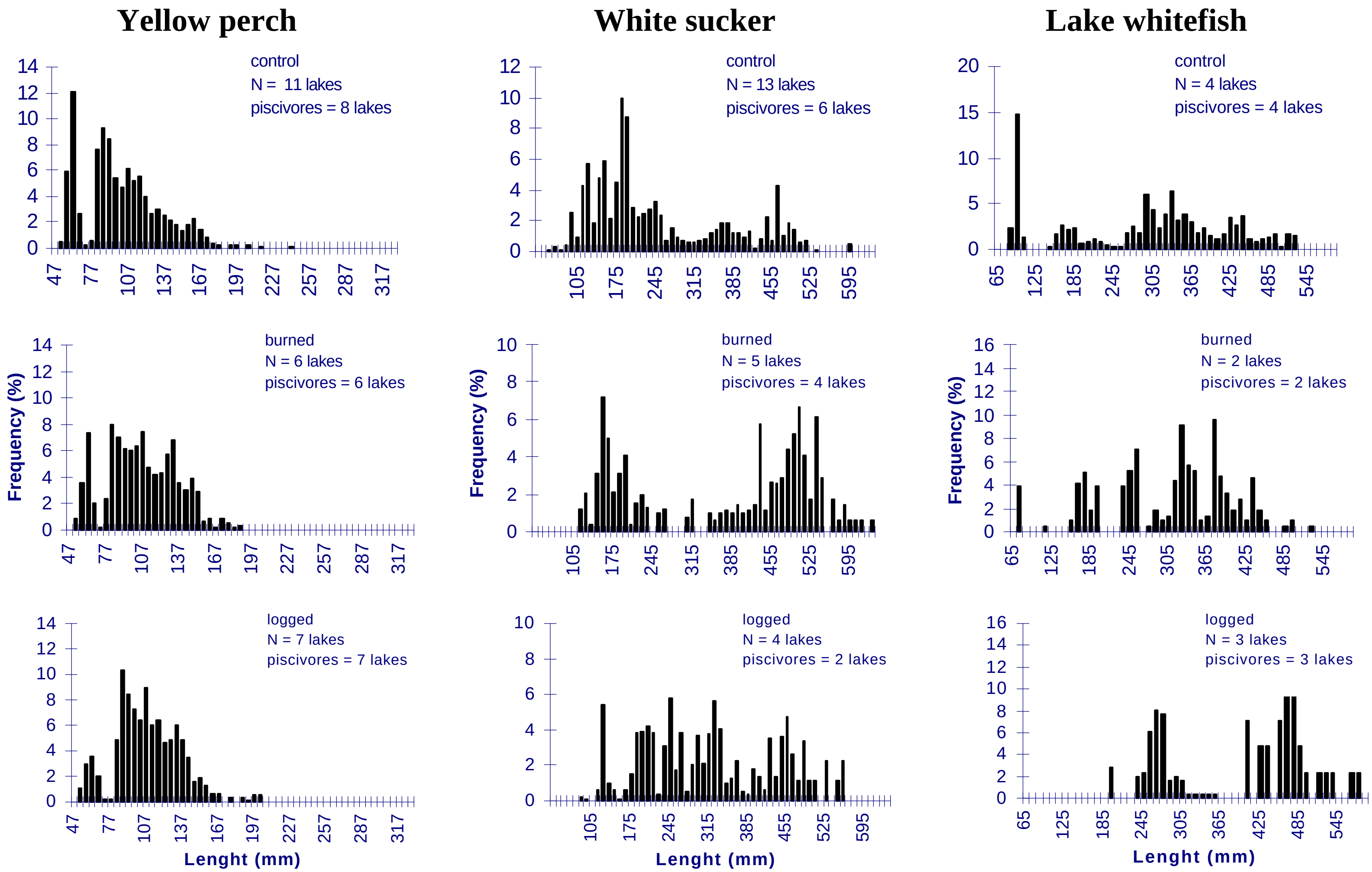

Fig. 2. Length frequency distribution of yellow perch, white sucker, and lake whitefish populations sampled in 1996 and 1997. For each length class, frequency represents the mean of the lake group.

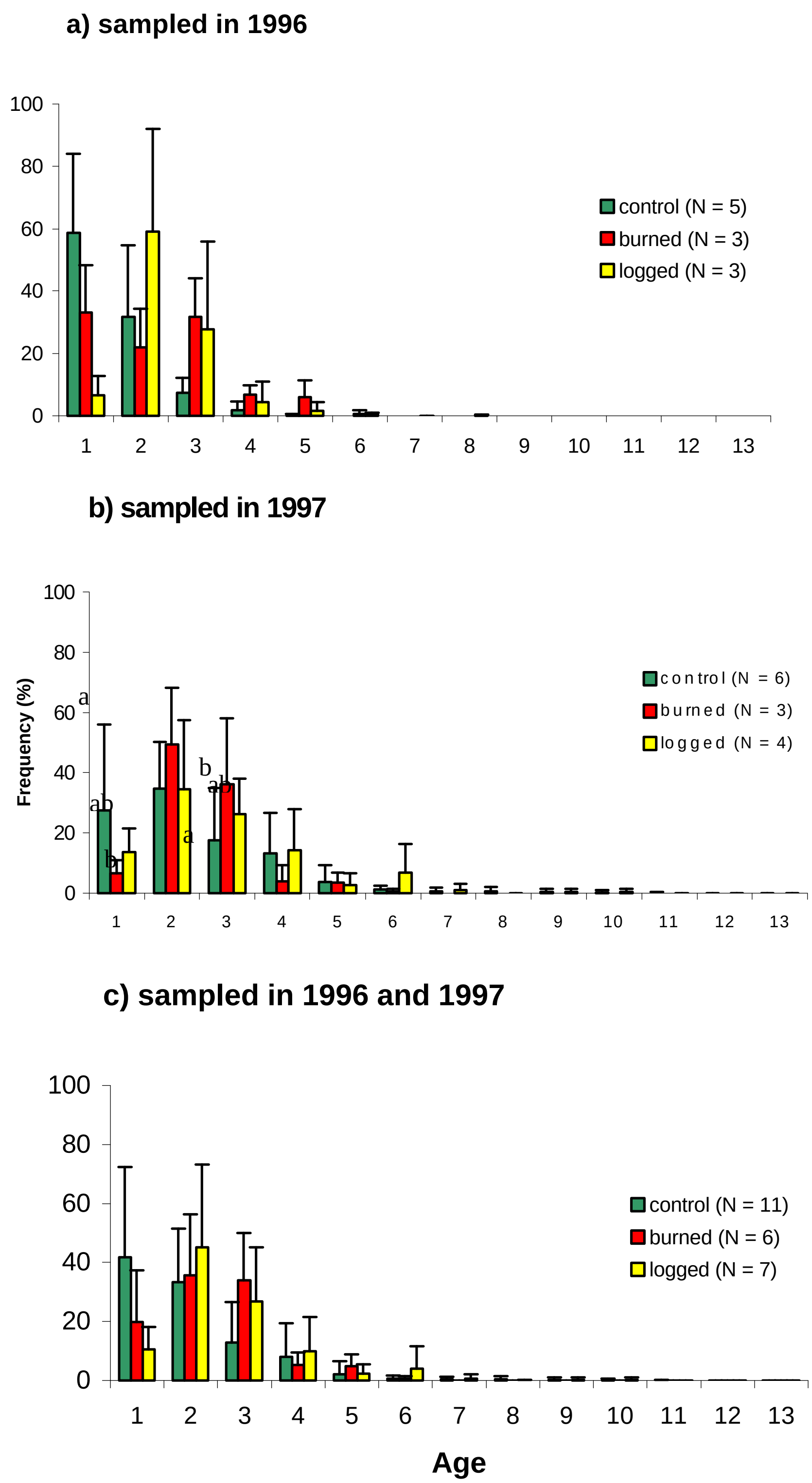

Fig. 3. Age frequency distribution of yellow perch. For each age class, frequency represent, the mean of the lake group.