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Impact of logging on yellow perch recruitment in Boreal Shield lakes

SFM Network Project Report

by

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ABSTRACT

The aim of this study is to determine if logging has a significant impact on the abundance of 0+ yellow perch (*Perca flavescens*) in 24 lakes of the Canadian Shield; the watersheds of 15 of these were not impacted while 9 underwent logging. We observed that the numbers of 0+ yellow perch, found in 22 of the 24 lakes, increased significantly in populations from logged lakes. This impact of logging was still significant when a series of biotic and abiotic variables on watershed and lake characteristics were accounted for in multiple regression analyses. While the long-term effects on the fish community can be hardly predicted, the observed increase in recruitment is likely to have negative effects on larger size classes of yellow perch in the short term, via the increase in inter-cohort competition for zooplankton, a resource shared among different yellow perch cohorts. This might have fluctuating effects on the most valuable exploited species, like northern pike and walleye, which use perch as forage fish. One or two cohorts of these prey fish will be less abundant when they reach the size range selected by pike and walleye. Consequently, to prevent their collapse, the exploitation of pike and walleye will have to be reduced in those years when there is a low abundance of adequately sized prey fish.

INTRODUCTION

The effects of logging on aquatic systems have been documented mostly in lotic ecosystems. These effects include an increase in turbidity, sedimentation, water temperature, streamflow, nutrient concentrations, and a reduction of shading (see references in Magnan and St. Onge, 2000). As a consequence of increased nutrient loading and/or reduced forest shading, streams might show an increase in primary productivity following deforestation (e.g., Gregory et al. 1987). The few studies done in lake ecosystems showed that the effects of logging on primary production are somewhat different. Despite the potential positive effects of increased nutrient loading on phytoplankton (Carignan et al. 2000), only relatively small effects have been observed on its biomass after deforestation (Planas et al. 2000). The reduced penetration of solar radiation in the water column, caused by an increase in the concentration of dissolved organic carbon (DOC) linked to the perturbation (Carignan et al. 2000), might explain such a result. Thus, it is not straightforward to predict whether the nutrient (phosphorus and nitrogen) and carbon enrichment caused by forest exploitation might be transferred to higher trophic levels. In fact, it is still largely unknown if allochtonous organic carbon can be efficiently transferred, directly (Kerner et al. 2003) or indirectly (via the microbial loop [Ojala and Salonen 2001]), to zooplanktonic consumers and, from these, to fish. 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) only if it induces an increase in the productivity of primary producers and/or of those organisms at the base of the food web that can be sustained by organic carbon (such as mixotrophic algae).

Previous post-impact studies on the effects of logging on lake systems (Magnan and St-Onge, 2000; St-Onge and Magnan, 2000; Tonn et al. 2003) showed that watershed perturbations are not likely to influence the structure of the fish community, at least in the short term (1-2 years after perturbation). In contrast, St-Onge and Magnan (2000) showed that small size classes of yellow perch (*Perca flavescens*) and white sucker (*Catostomus commersoni*) were negatively affected by logging, with potential consequences for the entire food web in the years following the perturbation. However, the growth of 1+ yellow perch seemed not to be affected by the watershed perturbation. Taken together, these effects of logging do not support the hypothesis of a positive effect of logging on fish productivity.

The sampling device (i.e., gillnets) used by St-Onge and Magnan (2000) in the first phase of the project gave a precise picture of the fish community but did not efficiently sample 0+ fish, which are probably the most likely to respond to the watershed perturbation in the short term. To overcome this problem, we used beach seining for the present study (second phase of the project), a technique better suited to sampling 0+ yellow perch. Moreover, to better analyze the effects of logging, we adopted a before–after control impact (BACI) experimental design for this study: lakes were sampled first, one or two years before the perturbation (i.e. logging) and again one or two years afterward. Given the short time lag between the watershed disturbance and fish sampling, we focused on the effects of logging on the recruitment of yellow perch, assuming that logging had no major effect on the structure of the fish community (St-Onge and Magnan, 2000; Tonn et al. 2003). Therefore, lakes were sampled by gillnetting only once prior to the perturbation in order to have a snapshot of the fish community, and not to assess the effects of logging.

Here we wanted to test the hypothesis that the negative effects on small yellow perch observed by St-Onge and Magnan (2000) are due to an increase in inter-cohort competition caused by improved recruitment of 0+ yellow perch and not from a direct negative effect of logging on post-emergent larvae. Because yellow perch prefers submerged vegetation or fallen-tree areas rather than gravel substrates to spawn (Scott and Crossman 1973), it is unlikely that this species suffered from siltation caused by logging. On the other hand, 0+ perch are known to have a competitive advantage over larger individuals (Bystrom and Garcia-Berthou, 1999; Sanderson et al. 1999), and an increase in their numbers, caused by the enrichment subsequent to logging, might have caused a reduction in perch from adjacent cohorts.

Given the socio-economical importance of the Canadian sport fishery, it is important to understand how different levels of deforestation might affect fish communities to be able to predict their impact on commercial species. The objective of our study was to determine if changes in the abundance of 0+ yellow perch, a key species in these systems, are correlated with timber exploitation.

STUDY SITE

The data were collected in 24 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). 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 yellow perch recruitment among lakes with two types of watershed treatments: 15 “control” lakes with undisturbed watershed (old-growth forest of at least 60 years) and 9 “logged” lakes, whose watersheds had undergone forest clearance. Control and logged lakes were sampled in 2000 or 2001 (before the perturbation in logged lakes) and in 2002 (after the perturbation in logged lakes). 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 morphometry (Table 1), and time of the impact. All the lakes are stratified during summer. Only minor logging occurred in the watershed of these lakes prior to 2000 while major clear-cuts occurred between 2000 and 2002 in some of them. 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) and in Carignan et al. (2000). Therefore, only a brief summary is presented here.

Fish sampling

Seven lakes in 2000 and 17 in 2001 were fished with a 2 m x 10 m beach seine for the estimation of yellow perch (mostly 0+) abundance before the perturbation. In this phase, it was not possible to sample all the lakes during the same year due to logistical constraints. However, each lake was seine-fished once between June and August in 2002 to determine post-perturbation yellow perch densities. On average, 24-36 seining stations were sampled in each lake.

In both 2000 and 2001, gillnetting was used to estimate the relative numbers and biomasses of all the fish in the communities of 20 lakes before the perturbations occurred. Data for the other four lakes were obtained from a study conducted between 1996 and 1998 (St-Onge and Magnan 2000). No gillnetting was done after logging occurred.

Study species

The fish species composition of the study lakes, largely unknown before this study, is quite diverse (Table 2). The most widespread species were northern pike, yellow perch, and white sucker. We selected 0+ yellow perch to evaluate the impact of logging because a previous study revealed a negative effect of watershed perturbation (logging and fires) on the small size classes of this species (St-Onge and Magnan 2000).

Study parameters

Determinants of fish abundance

Multiple linear regressions were used to determine environmental and biological factors that best explained (i) variations in catch per unit effort (CPUE) of 0+ yellow perch and (ii) CPUEs of yellow perch older than 0+ (mostly 1+) following logging operations. In order to take into account the BACI protocol used here, the dependent variables used in analyses were represented by the variations in yellow perch CPUEs between the period preceding and the period following deforestation. Variables on watershed and lake morphometry and relative fish biomass (biomass per unit effort, hereafter BPUE, estimated by gill netting) were used as independent variables in statistical analyses (Table 3). Because it has been demonstrated that watershed perturbation differently affect lakes of different size (Carignan et al. 2000), lake area was used as covariable in multiple regression analyses. In the context of the present report, we focus on the potential effects of logging on yellow perch recruitment and do not discuss the effects of other environmental variables.

SUMMARY OF RESULTS

Determinants of fish abundance

With lake area included as a covariable in the multiple regression model, the best predictors of the variation in CPUE of 0+ yellow perch were the area of watershed logged between 2000 and 2002 and the BPUEs of yellow perch and lake whitefish captured by gillnetting (Table 4a). The stepwise selection was also run after excluding lake AB35, since it was considered an outlier compared to all other lakes (but we show the results of both analyses; see Table 4). This control lake had a very high CPUE of yellow perch ≥ 1+ (estimated by gill netting) and showed a drastic reduction in the CPUEs of 0+ following the perturbation. The elimination of this point led to a somewhat different result. Again, the watershed area logged was selected in the model, but neither the BPUEs of yellow perch nor those of lake whitefish were retained. In contrast, the BPUE of walleye was significantly related to the variation in 0+ CPUEs (Table 4b). It should be noted that logging was positively associated with 0+ CPUEs in both models, and explained a large fraction of its total variability. This can be clearly seen in Fig. 1 (left panels), where we present the effects of increasing logging impact (per unit of lake surface) on yellow perch recruitment.

No significant model was produced to explain the variation in the CPUEs of yellow perch older than 0+ captured by seining. Despite the high scatter in the data distribution, we observed a tendency towards a reduced CPUE for fish older than 0+ with increasing watershed perturbation levels (Fig. 1).

CONCLUSIONS

Our study indicates that logging is an important factor affecting the abundance of 0+ yellow perch. This is confirmed by the fact that the area of watershed logged still appeared in the multiple regression models after lake area and all the other measured biotic and abiotic variables were accounted for.

This result does not support the hypothesis that post-emergence mortality increased after logging (because of an increase in egg siltation), as Magnan and St-Onge (2000) also suggested. It rather suggests a potential pathway linking the watershed perturbations to an increase in secondary production. This is apparently at odds with the results of a previous study on the impact of logging conducted in the same area by Planas et al. (2000). These authors showed that a relatively small increase in nutrients due to logging did not cause an increase in primary production because of the concomitant increase in light limitation resulting from the increased water color. Therefore, based on this result, only weak effects on secondary production might be expected after logging. In contrast, our results suggest that an increase in secondary production is possible despite the lack of strong effects on primary producers. Zooplankton might have benefited from an increase in the flow of energy and matter transport by the microbial loop, enriched by the increased DOC caused by logging, or may have benefited from DOC directly by consuming colloidal or aggregated carbon particles (Kerner et al. 2003).

Another hypothesis might be invoked to explain the observed effects on 0+ fish. By increasing the DOC concentration, logging reduces UV penetration in the water column (Williamson et al. 1999) and consequently reduces the UV damage to yellow perch egg strands (Williamson et al. 1997). Williamson et al. (1997) showed that UV exposure can dramatically reduce yellow perch egg survival to hatching in lakes with low DOC content. By showing that yellow perch can adjust their spawning depth in relation to the DOC concentration, these authors suggested that yellow perch can avoid UV-induced damage in low DOC lakes, but that this action probably exposes eggs to lower incubation temperatures and to increased post-emergence mortality risk due to predation in deeper layers. Therefore, a reduction of UV penetration may reduce post-emergence mortality in yellow perch by different pathways.

Because the effects of logging on DOC and nutrients in this second phase of the project (2000-2002) are qualitatively similar to those observed in the first phase (1996-1998; R. Carignan, pers. comm.), we suggest that DOC and nutrients rather than siltation explain the observed results. Finally, at least two hypotheses that are not mutually exclusive—increased productivity or a reduction of UV penetration—might explain the effects of logging on 0+ fish.

Because of the complementarily of the sampling techniques between our study and the study conducted in first phase of the project, these results might help in the interpretation of the results of Magnan and St-Onge (2000) and St-Onge and Magnan (2000). These authors observed that watershed perturbation (logging and fire) was associated with lower numbers of small (< 75 mm) yellow perch. In our study, the decreasing trend in the CPUEs of yellow perch > 0+ with increasing logged areas is in accordance with their results. Magnan and St-Onge (2000) and St-Onge and Magnan (2000) excluded any direct effect of watershed perturbation on fish survival, but they suggested that the perturbation might have indirectly affected this size class by reducing the biomass of benthic invertebrates. Assuming that fine sediment can reach the shores of lakes with perturbed watersheds, macroinvertebrate habitats and survival could have been negatively affected (Miller et al. 1997), reducing the abundance of food for yellow perch. Some studies have reported a reduction in macroinvertebrate density following timber harvesting (e.g., Vuori and Joensuu 1996). It is not possible to test this hypothesis with the protocol used here. However, our results suggest that another mechanisms might have contributed to reducing the numbers of small yellow perch. The increase in yellow perch recruitment following the perturbation might have contributed to reducing the availability of zooplankton, an alternative prey for larger individuals. It has been demonstrated that 0+ fish have a competitive advantage over larger individuals (Bystrom and Garcia-Berthou 1999) and that the occurrence of a strong year class may lead to a drastic reduction of older cohorts in yellow perch populations (Sanderson et al. 1999). This may lead to cyclic population dynamics, with a few cohorts dominating for several years (Sanderson et al. 1999; see also Claessen 2002), with potential consequences for predators that prey upon yellow perch.

Our sampling design allowed us to observe significant differences in yellow perch recruitment between lake treatments but not to determine the mechanisms responsible for these patterns. More work is thus needed to elucidate the mechanisms by which logging induces changes in yellow perch recruitment. Moreover, longer-term studies are needed to investigate the effects of increased yellow perch recruitment on lacustrine fish communities following watershed deforestation in order to evaluate the effects on the yellow perch predators.

MANAGEMENT APPLICATIONS

This study provides evidence that logging increases 0+ yellow perch abundance and suggests that this might have a negative effect on older individuals. By potentially leading to population cycles in which one cohort of newly hatched individuals will dominate, logging might alter the predator-prey dynamics in these lakes (i.e., lower abundance of one or two cohorts of prey fish at the time they reach the size range selected by pike and walleye, with potential negative effects on these game fishes). This effect may be alleviated through time, but this hypothesis must be validated. As the observed increase in 0+ yellow perch is related to an impact factor (watershed area logged / lake area), the model built in this study could be used to determine the acceptable proportion of logging in a watershed to reduce the impact of this perturbation on fish communities.

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Table 1. General characteristics of study lakes. Logged lakes were defined as those having >10% of their watershed logged between the two seine-fishing dates.

Lake	Surface area (km^2)	Maximum depth (m)	Watershed area (km^2)	Fish species richness	Area of watershed logged* (km^2)	% of watershed logged*
			Control lakes			
AB34	0.270	17.8	3.474	5	0.00	0.0
AB35	0.873	21.7	2.637	6	0.00	0.0
AB40	0.175	9.1	1.155	5	0.00	0.0
CSL2	0.850	10.2	2.832	9	0.14	7.1
CSL5	0.153	9.2	2.423	7	0.00	0.0
DA4	0.258	6.7	3.900	8	0.00	0.0
DF4	0.303	6.4	1.968	5	0.00	0.0
DF5	0.446	13.7	4.393	8	0.02	0.6
K1	0.324	9.1	2.317	9	0.19	9.6
K2	1.421	12.2	9.137	8	0.00	0.0
N35	0.212	9.1	1.356	4	0.00	0.0
N43	0.297	9.5	5.395	4	0.00	0.0
N55	0.261	7.8	1.362	7	0.00	0.0
N70	0.654	20.4	2.349	9	0.00	0.0
N89	0.670	14.0	2.674	9	0.00	0.0
Mean	0.478	11.8	3.16	6.9	0.02	1.3
(± SD)	(0.353)	(4.8)	(2.02)	(1.9)	(0.06)	(3.2)
			Logged lakes			
AB220	0.359	18.3	2.519	7	0.22	10.0
DA9	0.160	9.2	5.920	6	0.85	15.4
DF2	0.294	6.7	1.152	7	0.43	50.1
DF7	0.318	10.8	3.065	4	2.14	78.1
DF9	0.421	10.5	2.234	10	1.14	62.9
K3	0.829	7.2	3.269	7	0.62	25.5
K4	0.192	8.0	1.048	2	0.36	41.8
K8	0.756	8.6	5.656	8	2.34	47.8
P109	0.505	10.7	2.740	10	1.38	61.8
Mean	0.426	10.0	3.07	6.8	1.05	43.7
(± SD)	(0.234)	(3.46)	(1.72)	(2.6)	(0.77)	(22.9)

* between the two seine-net samplings (2000-2002)

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

Species	Control	Logged	**Total**
Northern pike (*Esox lucius*)	15	8	23
Yellow perch (*Perca flavescens*)	13	9	22
White sucker (*Catostomus commersonii*)	12	7	19
Lake whitefish (*Coregonus clupeaformis*)	9	5	14
Fallfish (*Semotilus corporalis*)	9	5	14
Walleye (*Stizostedion vitreum*)	9	5	14
Burbot (*Lota lota*)	10	3	13
Spottail shiner (*Notropis hudsonius*)	6	4	10
Cyprinidae sp.	3	4	7
Sculpin (*Cottus* sp.)	5	1	6
Golden shiner (*Notemigonus crysoleucas*)	3	2	5
Lake chub (*Couesius plumbeus*)	3	1	4
Emerald shiner (*Notropis atherinoides*)	3	1	4
Logperch (*Percina caprodes*)	2	1	3
Brook stickelback (*Culaea inconstans*)	0	1	1
Rainbow smelt (*Osmerus mordax*)	0	1	1
Finescale dace (*Phoxinus neogaeus*)	0	1	1
Ninespine stickelback (*Pungitus pungitus*)	0	1	1
Creek chub (*Semotilus atromaculatus*)	0	1	1

Table 3. Independent variables used in regression analyses.

Categories	Variables	Unit
Geographical	latitude	decimal
	longitude	decimal
	altitude	m
Lake morphology	lake area	km^2
	area of other lakes in the watershed	km^2
	lake perimeter	km
	shore line development	
	mean lake slope	%
	lake volume	m^3
	maximum depth	m
Watershed morphology	watershed area	km^2
	drainage area	km^2
	watershed perimeter	km
	spring run off (2002)	$m^3 \cdot y^{-1}$
	spring run off (2001)	$m^3 \cdot y^{-1}$
	spring run off (2000)	$m^3 \cdot y^{-1}$
	spring run off (1999)	$m^3 \cdot y^{-1}$
	marsh on watershed close to the lake	km^2
	marsh on watershed close to the hydrology	km^2
	watershed area logged between 2000 and 2002	km^2
	watershed area logged between 1999 and 2000	km^2
	watershed area logged before 1999	km^2
Seine fishing	Date in 2002	Day of the year
	Difference in the day of the year between pre- and post-perturbation samplings	days
	Variation in CPUEs of 0+ or > 0+	ind. $\cdot$ seine-net^{-1} $\cdot$ trial
Relative fish biomass*		
	Northern pike	g FW $\cdot$ gill-net^{-1} $\cdot$ night^{-1}
	Yellow perch	g FW $\cdot$ gill-net^{-1} $\cdot$ night^{-1}
	White sucker	g FW $\cdot$ gill-net^{-1} $\cdot$ night^{-1}
	Lake whitefish	g FW $\cdot$ gill-net^{-1} $\cdot$ night^{-1}
	Walleye	g FW $\cdot$ gill-net^{-1} $\cdot$ night^{-1}
	Burbot	g FW $\cdot$ gill-net^{-1} $\cdot$ night^{-1}
	others**	g FW $\cdot$ gill-net^{-1} $\cdot$ night^{-1}

*estimated by gillnetting prior to logging

** pooled BPUE of small-bodied species

Table 4. Best models predicting the numbers of 0+ yellow perch a) with all data available; b) without lake AB35 (excluded from the analysis because too influential). Lake area was forced in the model as a covariable. The probability (*P*) associated with each independent variable, the standard error of the coefficient (SE), the partial R^2 associated with each variable[a], and the adjusted R^2 are also listed.

Model		SE	Stand. coeff.	$P > t$	R^2	adj R^2
a) Variation in CPUE of 0 + y. perch =				0.0003	68.9	61.2
- 31.1		17.3	0	0.09		
- 26.6	Lake area	30.3	- 0.13	0.40	3.1	
+ 42.2	Watershed area logged*	12.5	0.46	0.004	25.9	
- 0.07	Yellow perch BPUE	0.004	0.47	0.016	26.8	
+ 0.01	Lake whitefish BPUE	0.01	0.005	0.016	13.0	
b) Variation in CPUE of 0 + y. perch =				0.006	50.7	42.1
- 42.0		17.0	0	0.024		
- 25.2	Lake area	29.1	- 0.15	0.400	0.0	
+ 41.3	Watershed area logged*	12.1	0.58	0.003	30.2	
+ 0.01	Walleye BPUE	0.004	0.47	0.016	20.6	

[a] Calculated as the standardized regression coefficient times the correlation coefficient between the dependent variable and this independent variable (Tabachnick and Fidell 1983).

* Watershed area logged between 2000 and 2002.

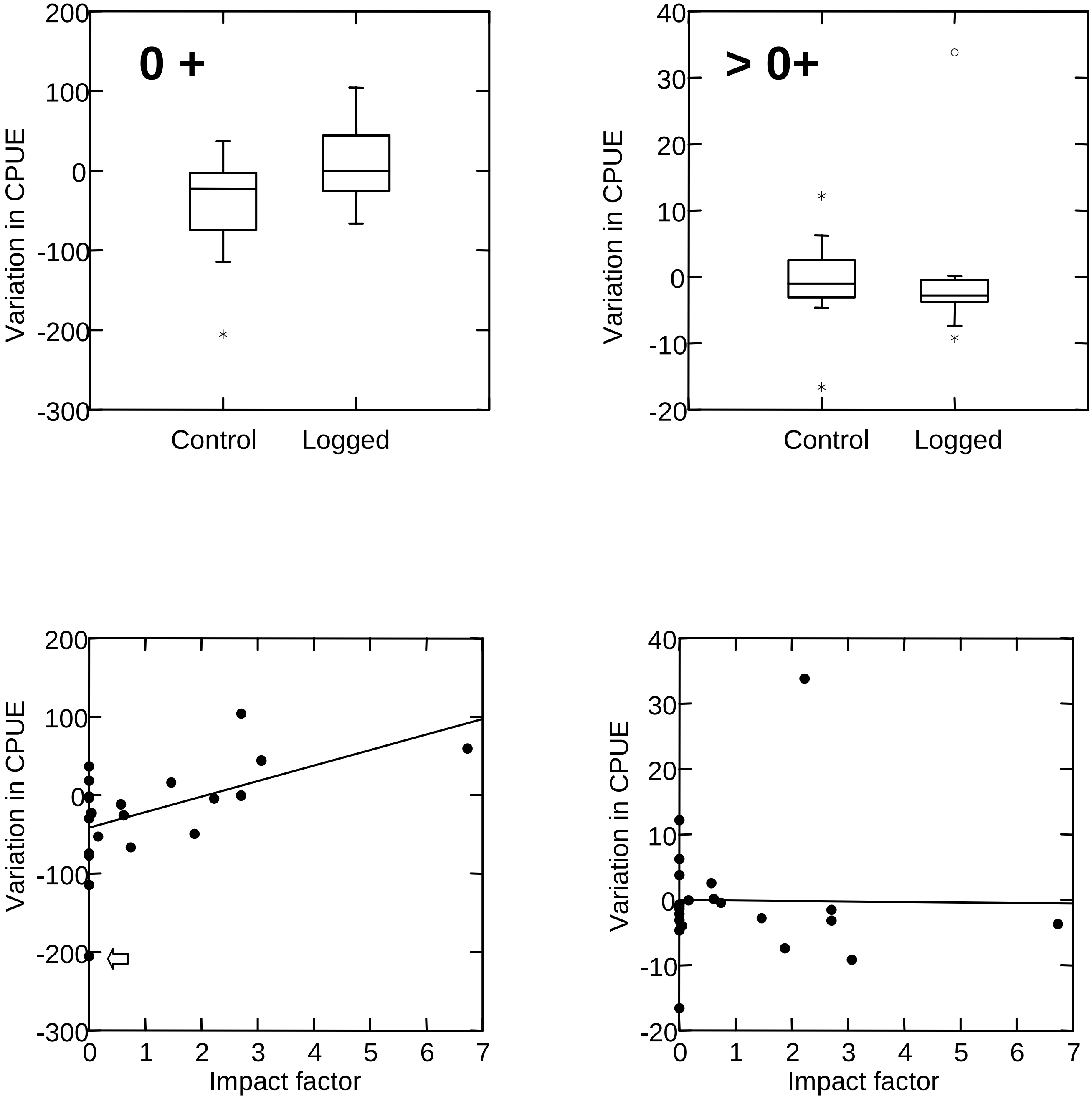

Fig. 1. Effects of logging on yellow perch CPUEs. Upper panels: boxplots of the before-after differences in CPUEs (i.e. CPUE after logging – CPUE before logging) in control and logged lakes. Logged lakes were defined as those having > 10% of their watershed logged between the two seine-fishing dates. Lower panels: before-after differences in CPUEs *vs*. logging impact factor (i.e. watershed area logged / lake area). Left panels: 0+ data; Right panels: > 0+ data The arrow indicates lake AB35 (see text).