

Logging-induced variations in dissolved organic carbon affect yellow perch (*Perca flavescens*) recruitment in Canadian Shield lakes

Andrea Bertolo and Pierre Magnan

Abstract: There is increasing interest in the effects of allochthonous carbon on lake food webs. By temporarily increasing levels of dissolved organic carbon (DOC) in lakes, logging can help us understand how carbon from the watershed could affect lake biota. The goals of this study were to determine whether (i) logging has a significant effect on the abundance of young-of-the-year (YOY) yellow perch (*Perca flavescens*) in Canadian Shield lakes and (ii) any changes in yellow perch recruitment could be related to increases in nutrients (N and P) and (or) DOC following logging. To do this, we examined 22 Canadian Shield lakes: the watersheds of 13 were not impacted, while 9 underwent logging (1%–78% of the watershed area). We found that the relative abundance of YOY yellow perch increased after logging in proportion to the ratio between the area of the logged watershed and the lake volume. We show that this effect is likely explained by an increase in DOC following logging. This might be related to (i) an increase in secondary productivity due to a positive effect of terrestrial carbon on the microbial loop and (or) (ii) an increased hatching success and (or) larval survival due to a greater protection from UV radiation by DOC.

Résumé : Les effets du carbone allochtone sur les réseaux trophiques lacustres font l'objet d'un intérêt grandissant. En augmentant les niveaux du carbone organique dissous (COD) dans les lacs, les coupes forestières peuvent servir de modèle pour comprendre comment le carbone provenant du bassin versant peut affecter le compartiment biotique des lacs. Les objectifs de cette étude étaient de déterminer (i) si les coupes forestières ont un effet significatif sur l'abondance des jeunes perchaudes (*Perca flavescens*) de l'année (YOY) dans les lacs du bouclier canadien et (ii) si d'éventuels changements dans le recrutement de la perchaude peuvent être mis en relation avec l'augmentation des éléments nutritifs (N et P) et (ou) de COD suite aux coupes forestières. Nous avons échantillonné 22 lacs du bouclier canadien, dont 13 n'avaient subi aucune perturbation et 9 avaient subi des coupes forestières dans leur bassin versant (1–78 % de la superficie du bassin). L'abondance relative des jeunes perchaudes a augmenté suite aux coupes forestières, proportionnellement au rapport entre la superficie du bassin affecté par les coupes et le volume du lac. Nous montrons que cet effet est probablement expliqué par une augmentation du COD suite aux coupes forestières. Ceci pourrait être en relation avec (i) une augmentation de la productivité secondaire due à un effet positif du carbone d'origine terrestre dans la boucle microbienne et (ou) (ii) à une augmentation du succès de l'éclosion et (ou) de la survie larvaire due à une protection accrue contre les rayons UV par le COD.

Introduction

While there is an increasing interest on the effects of allochthonous carbon on lake food webs, its effects on higher trophic levels are still not fully understood (Steinberg et al. 2006). Carignan et al. (2000) found that logging increased ion (i.e., K^+ , Cl^- , and Ca^{2+}), nutrient (i.e., N and P) and dissolved organic carbon (DOC) loads. Even though

clear effects of logging were found on lake water chemistry, relatively small effects have been observed on phytoplankton biomass after deforestation (Planas et al. 2000). The reduced penetration of solar radiation in the water column, caused by the increased DOC, might explain such a result. Thus, it is not straightforward to predict to what degree the nutrient (P and N) and carbon enrichment caused by forest exploitation will be transferred to higher trophic levels.

Received 19 October 2006. Accepted 9 January 2007. Published on the NRC Research Press Web site at <http://cjfas.nrc.ca> on 5 February 2007.
J19611

A. Bertolo¹ and P. Magnan. Département de Chimie-Biologie, Université du Québec à Trois-Rivières, C.P. 500, Trois-Rivières, QC G9A 5H7, Canada.

¹Corresponding author (e-mail: andrea.bertolo@uqtr.ca).

In fact, it is still largely unknown if allochthonous organic carbon might be efficiently transferred, directly or indirectly, via the microbial loop to zooplanktonic consumers and from these to fish (Steinberg et al. 2006). As fish yield is strongly correlated to lake productivity (Godbout and Peters 1988), forest clearance may increase fish productivity only if it induces an increase in the productivity of primary producers and (or) bacteria.

In a study comparing control vs. impacted lakes, St-Onge and Magnan (2000) showed that logging was associated with a reduction in the numbers of small size classes of both yellow perch (*Perca flavescens*) and white sucker (*Catostomus commersonii*) (<75 and <160 mm, respectively) 1–2 years following the perturbation. While these results suggest that logging could affect fish communities by reducing the survival of juvenile fish, they do not support the hypothesis of a positive effect of logging through an increase in fish productivity. The sampling device (i.e., gill nets) used by St-Onge and Magnan (2000) did not allow the sampling of small-bodied and young-of-the-year (YOY) fish, which are probably the most sensitive to watershed perturbations and variations in lake productivity. The objectives of our study were to determine whether (i) logging has a significant effect on the abundance of YOY yellow perch in Canadian Shield lakes and (ii) any changes in yellow perch recruitment could be related to increases in nutrients (N and P) and (or) DOC following logging. We used a before–after control–impact (BACI) experimental design to address these objectives. Lakes were sampled once (1–2 years) before and once (1–2 years) after the perturbation (i.e., logging).

Materials and methods

Study area

Twenty-two thermally stratified headwater lakes were selected on the basis of comparable size (fetch greater than 1 km), basin morphometry (maximum depth exceeding 5 m), and catchment properties (<6% of catchment covered by wetlands). The lakes were accessible only by plane and are located within a 50 000 km² area surrounding the Gouin Reservoir, Quebec, Canada (48°50'N, 75°00'W). The forest is primarily composed of black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), jack pine (*Pinus divaricata*), white birch (*Betula papyrifera*) and trembling aspen (*Populus tremuloides*). Only minor logging occurred in the watersheds of these lakes prior to 2000, while clearcuts occurred between 2000 and 2002 in nine of them (Table 1). Because of their remoteness, the fish communities of these lakes are generally unexploited or only lightly exploited. This should reduce any bias related to potential increases in fishing pressure due to the presence of better access roads following logging. The most common fish species in the study lakes were yellow perch ($n = 22$), northern pike (*Esox lucius*) ($n = 21$), white sucker ($n = 16$), walleye (*Sander vitreus*) ($n = 14$), lake whitefish (*Coregonus clupeaformis*) ($n = 14$), and fallfish (*Semotilus corporalis*) ($n = 12$). On average, yellow perch represented $74.6\% \pm 31.6\%$ (mean \pm standard deviation, SD) of the total catches by seine.

Fish sampling

We used a beach seine to estimate the catch per unit of effort (CPUE) of YOY yellow perch; this technique is well suited to sampling juvenile fish. For logistic reasons, 7 lakes were sampled in 2000 and 15 in 2001 (before perturbation), while all lakes were resampled in 2002 (1–2 years after perturbation). Each lake was seined once between June and August. On average, 34 ± 10 samples (mean \pm SD) were taken in each lake at randomly selected littoral stations.

Plankton and water chemistry analyses

Water for the analyses of chemical variables, chlorophyll *a* (Chl), and zooplankton was sampled in June and August 2000, 2001, and 2002 (the same years as the seine fishing). We used average summer values in statistical analyses. Sampling for chemical variables and phytoplankton took place in the euphotic zone, while zooplankton samples were taken over the entire water column with a 53 μ m mesh cantilevering net. Total phosphorus (TP) was measured using the molybdenum blue method, whereas total nitrogen (TN) was measured as NO₃ after alkaline persulfate digestion. Chl was extracted using hot 90% ethanol, and absorbance was measured spectrophotometrically. DOC was measured within 72 h by infrared gas analysis after sample acidification and He sparging followed by Pt-catalyzed oxidation at 700 °C. Zooplankton samples were fractionated into two size classes (smaller or larger than 500 μ m) before estimating dry weight. Each zooplankton size class was filtered separately onto precombusted GF/A (Whatman) glass fiber filters, dried at 40 °C for 18 h, weighed, ashed at 500 °C for 18 h, and weighed again to estimate dry weight. See Carignan et al. (2000), Patoine et al. (2000), and Planas et al. (2000) for details on the analytical methods.

Statistical analysis

Analyses of variance (ANOVA) were used to compare physico-chemical and plankton variables between unperturbed lakes and lakes that experienced logging in their watershed. Multiple linear regressions were used to determine environmental factors that best explained variations in CPUE (i.e., Δ CPUE) of both YOY yellow perch and older individuals following logging. We also analyzed the before–after logging variations in the CPUE of other fish species (yellow perch excluded) and in the total fish CPUE (including yellow perch) caught in seines. To take into account the BACI protocol, the dependent and independent variables used in analyses were represented by their variation between the period preceding and the period following deforestation: changes in dissolved organic carbon (Δ DOC); total phosphorus (Δ TP); total nitrogen (Δ TN); chlorophyll *a* (Δ Chl); and the biomass of total zooplankton (Δ ZOO), small zooplankton (<500 μ m) (Δ ZOO_{<500}), and large zooplankton (>500 μ m) (Δ ZOO_{>500}). To examine differences in seining dates before and after logging (Table 1), we used the difference in the day of the year between the two samplings (Δ day) as a covariable. The ratio between the watershed area logged and the lake volume (hereafter CUT/VOL) was used as a measure of the potential impact of logging on lake physico-chemistry (Carignan et al. 2000).

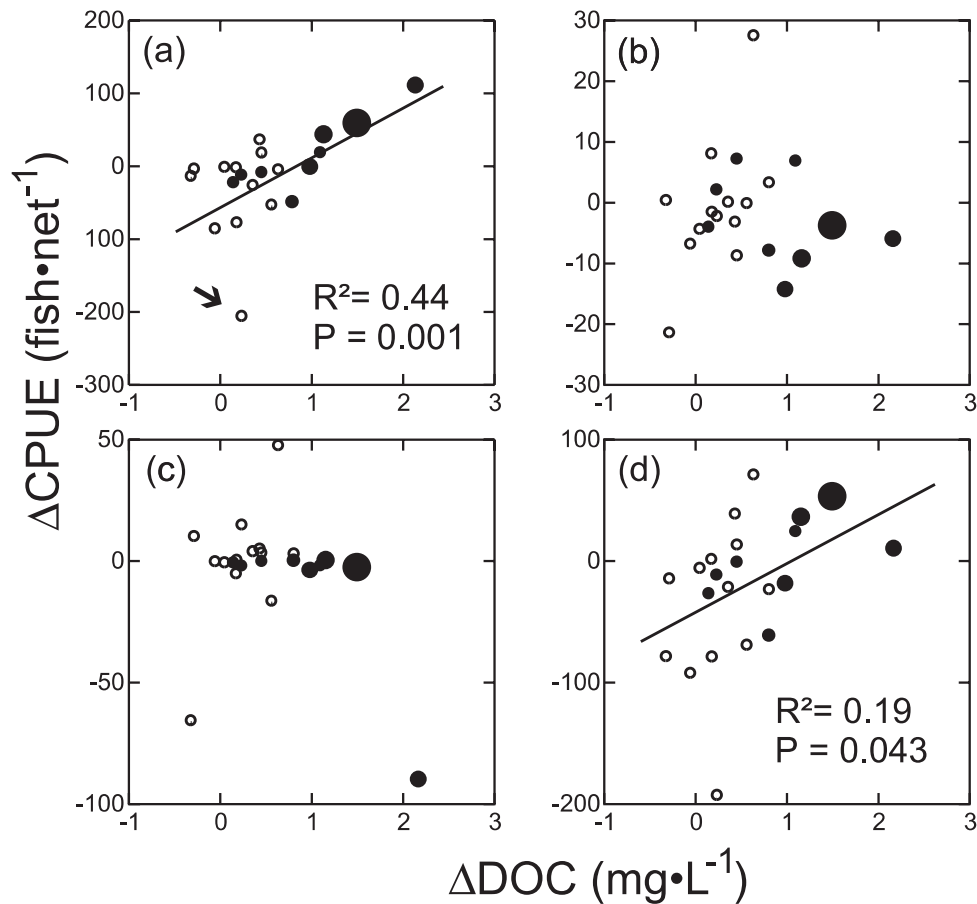
Independent variables included in the models were selected by a stepwise selection procedure in multiple regres-

Table 1. General characteristics of study lakes.

Lake	Area (km ²)	Max depth (m)	Watershed area (km ²)	Seining date (dd-mm-yy)		Logging year*	TP (µg·L ⁻¹)		TN (µg·L ⁻¹)		Chl (µg·L ⁻¹)		DOC (mg·L ⁻¹)		CUT* (%)	CUT/VOL* (m ⁻¹)
				BF	AF		BF	AF	BF	AF	BF	AF	BF	AF		
				BF	AF		BF	AF	BF	AF	BF	AF	BF	AF		
AB220	0.359	18.3	2.52	24-06-01	11-06-02	—	6.4	7.3	187.0	242.0	1.9	2.3	4.1	4.4	0.0	0.00
AB35	0.873	21.7	2.63	17-06-01	14-06-02	—	6.9	9.0	241.0	301.5	2.8	2.9	5.4	5.6	0.0	0.00
CSL2	0.850	10.2	2.83	09-07-01	21-07-02	—	7.0	6.8	200.5	238.7	1.6	2.6	5.7	6.3	0.0	0.00
CSL5	0.153	9.2	2.42	04-07-01	19-07-02	—	9.3	9.7	294.8	311.9	2.4	3.1	10.5	10.6	0.0	0.00
DA4	0.258	6.7	3.90	02-08-01	01-07-02	—	9.4	8.7	254.5	264.5	2.3	1.7	8.5	9.0	0.0	0.00
DA9	0.160	9.2	5.92	28-07-01	28-06-02	—	10.0	10.9	326.3	365.0	2.3	3.6	9.7	10.4	0.0	0.00
DF2	0.294	6.7	1.15	09-08-00	01-08-02	2000–2002	9.1	10.2	222.0	285.3	2.2	3.3	7.2	8.3	50.1	0.51
DF4	0.303	6.4	1.97	13-08-01	04-08-02	—	8.9	9.1	283.3	274.0	2.1	2.3	9.2	9.4	0.0	0.00
DF5	0.446	13.7	4.39	14-08-01	06-08-02	2001–2002	6.1	6.6	242.0	232.5	1.5	1.7	8.0	8.1	0.6	0.01
DF7	0.318	10.8	3.06	11-08-01	30-07-02	2001–2002	9.1	11.0	245.7	284.7	2.8	1.8	11.0	12.5	63.4	1.80
DF9	0.421	10.5	2.23	25-06-00	18-07-02	2000–2001	15.7	14.9	395.0	458.0	3.6	2.8	12.7	14.9	62.9	0.81
K1	0.324	9.1	2.32	25-07-01	05-07-02	2001–2002	11.0	11.2	245.5	282.0	2.6	3.0	6.5	6.7	9.6	0.21
K2	1.421	12.2	9.14	22-07-01	07-07-02	—	9.3	8.7	302.8	331.0	2.1	1.9	8.4	9.2	0.0	0.00
K3	0.829	7.2	3.27	06-07-00	12-07-02	2000–2001	10.8	9.6	242.0	278.8	2.6	2.7	6.1	6.6	25.5	0.27
K4	0.192	8.0	1.05	28-06-00	14-07-02	2000–2001	11.1	11.9	265.5	301.0	3.4	3.5	7.3	8.2	41.8	0.64
K8	0.756	8.6	5.66	02-07-00	09-07-02	2000–2002	15.0	15.4	318.5	356.2	3.2	3.5	9.9	11.1	47.8	1.30
N35	0.212	9.1	1.36	20-07-00	19-06-02	—	7.8	8.1	239.0	245.3	2.3	3.0	4.4	4.1	0.0	0.00
N43	0.297	9.5	5.39	16-07-01	27-07-02	—	8.1	9.5	269.0	277.0	1.9	2.2	9.5	9.4	0.0	0.00
N55	0.261	7.8	1.36	29-06-01	23-06-02	—	11.6	10.9	253.3	306.8	3.6	4.2	5.0	5.2	0.0	0.00
N70	0.654	20.4	2.35	12-07-00	26-06-02	—	8.2	5.5	257.0	249.0	2.1	2.2	5.8	5.5	0.0	0.00
N89	0.670	14.0	2.67	14-07-01	28-07-02	—	5.1	4.1	153.3	181.0	1.4	1.8	3.7	4.1	0.0	0.00
P109	0.505	10.7	2.74	04-08-01	03-07-02	2001–2002	6.9	7.3	235.4	245.8	1.4	2.4	6.1	7.0	60.6	0.77

Note: Total phosphorus (TP), total nitrogen (TN), chlorophyll *a* (Chl), and dissolved organic carbon (DOC) are summer averages (from samplings in June and August) measured before (BF; 2000 or 2001) or after (AF; 2002) logging. CUT, percent watershed area logged between the two seining dates; CUT/VOL, ratio between the watershed area logged (m²) and the lake volume (m³).
*Logging that occurred before seining was not taken into account.

Fig. 1. Relationship between the before–after impact variation in dissolved organic carbon (ΔDOC) and the before–after impact variation in catch per unit effort (ΔCPUE) of (a) young-of-the-year (YOY) yellow perch (*Perca flavescens*), (b) yellow perch >0+, (c) other fish species, and (d) total fish in seines. Results of linear regressions are shown when significant. Open circles indicate lakes with unperturbed watersheds; solid circles indicate lakes with logged watersheds. The sizes of the solid circles are proportional to the watershed perturbation (CUT/VOL). The arrow in panel a indicates lake AB35, which was excluded from the analysis (see text).



sion analysis (α to enter = 0.10; α to stay = 0.05). Analyses were performed both including and excluding zooplankton data because these data were available only for 20 out of 22 lakes.

Results and discussion

CUT/VOL was significantly correlated with ΔDOC (Spearman's $r = 0.67$, $P = 0.0006$), but not with nutrients (ΔTP and ΔTN), phytoplankton biomass (ΔChl), or zooplankton biomass (ΔZOO , $\Delta\text{ZOO}_{<500}$, $\Delta\text{ZOO}_{>500}$). ANOVA confirmed that ΔDOC differed significantly between unperturbed and logged lakes ($F_{[1,20]} = 11.2$, $P = 0.0033$), but also showed that both $\Delta\text{ZOO}_{<500}$ and ΔZOO were significantly higher in logged lakes than in unperturbed lakes ($F_{[1,18]} = 4.8$, $P = 0.0419$ and $F_{[1,18]} = 5.6$, $P = 0.0299$, respectively).

CUT/VOL was significantly correlated with ΔCPUE of YOY yellow perch (Spearman's $r = 0.51$, $P = 0.015$). No significant correlations were found between CUT/VOL and the before–after variation in the CPUE of older yellow perch, other fish species caught in seines, and total fish ΔCPUE ($P = 0.24$, $P = 0.07$, and $P = 0.10$, respectively). ANOVA showed that YOY yellow perch ΔCPUE tended to

differ between unperturbed and logged lakes ($F_{[1,20]} = 4.0$, $P = 0.060$). No significant differences were found in ΔCPUE for >0+ yellow perch, other fish species, and total fish.

ΔDOC was significantly correlated with ΔCPUE of YOY yellow perch (Spearman's $r = 0.49$, $P = 0.0218$; Fig. 1a) and ΔCPUE of total fish (Spearman's $r = 0.51$, $P = 0.0153$; Fig. 1d). No correlation was found between ΔDOC and the ΔCPUE of yellow perch >0+ or other fish species (Figs. 1b–1c). ΔTP , ΔChl , and variations in zooplankton biomass (ΔZOO , $\Delta\text{ZOO}_{<500}$, $\Delta\text{ZOO}_{>500}$) were not correlated to any of the ΔCPUE variations. ΔTN was only significantly correlated to the ΔCPUE of yellow perch >0+ ($r = 0.46$, $P = 0.030$).

The stepwise selection procedure selected ΔDOC (+) and ΔTP (–) to explain the ΔCPUE of YOY yellow perch. This model explained 52% of the variation in the dependent variable. However, the model was sensitive to lake AB35 (an unperturbed lake), which experienced the highest reduction in the CPUE of both YOY yellow perch as well as a relatively large increase in TP. Besides improving the normality of the data, excluding this point improved the relationship with ΔDOC , whereas no relationship was found with ΔTP (Fig. 1). A similar result was obtained for total ΔCPUE , with only

Δ DOC (+) selected in the model ($R^2 = 0.19$, $P = 0.0430$). The best model to explain the Δ CPUE yellow perch >0+ included Δ TN (+) and Δ Chl (+) ($R^2 = 0.37$, $P = 0.0118$). No variable was selected to explain the Δ CPUE of other fish species.

No significant relationship between Δ day and any of the dependent variables described above was found, suggesting that our results are not biased by the seining date. Within-lake variability in total CPUE was significantly higher before logging (CV = 84.7) than after (CV = 14.1) ($\chi^2 = 25.9$, $P < 0.0001$), but no correlation was found between the CV of total CPUE and CUT/VOL in 2002 (Spearman's $r = -0.06$, $P = 0.78$).

Our study indicates that logging, by increasing DOC, is an important factor affecting the abundance of YOY yellow perch (Fig. 1a). This result refutes the hypothesis suggested by St-Onge and Magnan (2000) that post-emergence mortality increased after logging. Because yellow perch prefers to spawn on submerged vegetation or fallen trees rather than on gravel substrata, it is unlikely that perch suffered from siltation caused by logging. This result rather suggests a potential pathway linking the watershed perturbations to an increase in secondary production. This is apparently at odds with the observed changes in nutrients and Chl and 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 caused by logging did not initiate an increase in primary production because of the concomitant increase in light limitation caused by an increase of water colour; 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 (YOY yellow perch and zooplankton) is possible despite a lack of effect on primary producers. To our knowledge, an important contribution of carbon subsidies from the watershed to fish production has been observed only in very small lakes (Cole et al. 2006), which are likely to receive proportionally larger supplies of allochthonous carbon. Even though the variation in zooplankton biomass was not correlated to CUT/VOL and the Δ CPUE of YOY yellow perch, both total and small zooplankton increased in logged lakes. Zooplankton may have benefited from an increase in the flow of energy and matter transmitted by the microbial loop, which was boosted by the increased DOC after logging, or they may have benefited directly from DOC by consuming colloidal or aggregated carbon particles (Kerner et al. 2003; Steinberg et al. 2006).

It is also possible that logging reduced ultraviolet (UV)-induced damage to yellow perch eggs and (or) larvae by increasing the DOC concentration and thus reducing the penetration of UV in the water column (Huff et al. 2004). Exposure to UV can dramatically reduce yellow perch egg survival to hatching in lakes with low DOC contents (Huff et al. 2004). The fact that the Δ CPUE of YOY yellow perch was strongly correlated with Δ DOC, but not with the variation in zooplankton biomass, lends additional support to the UV-protection hypothesis over the productivity one. However, average DOC concentrations in the study lakes before logging were relatively high (Table 1), and changes in UV penetration should have been biologically meaningful only

in the shallower layers of the water column. Considering that yellow perch tend to spawn in shallow waters in such lakes (Huff et al. 2004) and that yellow perch larvae are positively phototropic (see references in Huff et al. 2004), we cannot exclude a DOC-mediated effect of UV on yellow perch recruitment in our lakes.

Yellow perch older than 0+ did not show any response to logging or to variations in DOC. This is not in contradiction with the UV-protection hypothesis, since these individuals can easily reduce their exposure to UV by regulating their depth.

St-Onge and Magnan (2000) observed, as with logging activities, that fires in watershed areas were associated with lower numbers of small-sized (<75 mm) yellow perch, even though this perturbation was not associated with an increase in DOC. It is thus possible that another mechanism explained their results. St-Onge and Magnan (2000) excluded any direct effect of the watershed perturbation on fish survival but hypothesized that the perturbation might have indirectly affected this size class by reducing the biomass of benthic invertebrates. Assuming that fine sediment can reach the lakeshore in perturbed watersheds, macroinvertebrate habitats and survival could have been negatively affected (Miller et al. 1997), reducing the abundance of food for older yellow perch. This would also explain why >0+ yellow perch did not respond positively to DOC in our study. Some studies have reported a reduction in macroinvertebrate density following timber harvesting (e.g., Vuori and Joensuu 1996). The increase in yellow perch recruitment following logging might have increased the intraspecific competition with other cohorts, with a negative effect on larger individuals. It has been shown that YOY have a competitive advantage over larger individuals 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).

Our study showed that yellow perch recruitment increases following logging and that this increase is correlated with the related DOC increase. Future work will be needed to elucidate the mechanisms by which logging and increased DOC induce changes in yellow perch recruitment.

Acknowledgements

We thank R. Proulx, D. Boula, E. Garcia, W. Giroux, F. Guillemette, P. Lafrance, D. Mont , Y. Paquette, A. Patoine, P. St-Onge, and L. Duhaime for their field and laboratory assistance. We are also grateful to P. East and M. Lapointe for their invaluable assistance at many stages of this research and to P. D'Arcy for his logistical support. L. Devine and F. Darchambeau provided helpful comments on earlier versions of this paper. We thank Richard Carignan for nutrient and DOC data and Dolores Planas and Bernadette Pinel-Alloul for Chl and zooplankton data. A.B. was supported by the Canada Research Chair in Freshwater Ecology. This project was supported by grants from the Sustainable Forest Management Network Center of Excellence and the Natural Sciences and Engineering Research Council of Canada to P.M. This study is a contribution of the Groupe de recherche interuniversitaire en limnologie et en environnement aquatique (GRIL).

References

- Carignan, R., D'Arcy, P., and Lamontagne, S. 2000. Comparative impacts of fire and forest harvesting on water quality in Boreal Shield lakes. *Can. J. Fish. Aquat. Sci.* **57**: 105–117.
- Cole, J.J., Carpenter, S.R., Pace, M.L., Van de Bogert, M.C., Kitchell, J.L., and Hodgson, J.R. 2006. Differential support of lake food webs by three types of terrestrial organic carbon. *Ecol. Lett.* **9**: 558–568.
- Godbout, L., and Peters, R.H. 1988. Potential determinants of stable catch in the brook trout (*Salvelinus fontinalis*) sport fishery in Quebec. *Can. J. Fish. Aquat. Sci.* **45**: 1771–1778.
- Huff, D.D., Grad, G., and Williamson, C.E. 2004. Environmental constraints on spawning depth of yellow perch: the roles of low temperatures and high solar ultraviolet radiation. *Trans. Am. Fish. Soc.* **133**: 718–726.
- Kerner, M., Hohenberg, H., Ertl, S., Reckermannk, M., and Spitz, A. 2003. Self-organization of dissolved organic matter to micelle-like microparticles in river water. *Nature (London)*, **422**: 150–154.
- Miller, L.B., McQueen, D.J., and Chapman, L. 1997. Impacts of forest harvesting on lake ecosystems: a preliminary literature review. B.C. Ministry of the Environment, Lands and Park Wildlife Branch, Victoria. Wildl. Bull. No. B-84.
- Patoine, A., Pinel-Alloul, B., Prepas, E.E., and Carignan, R. 2000. Do logging and forest fires influence zooplankton biomass in Canadian Boreal Shield lakes? *Can. J. Fish. Aquat. Sci.* **57**: 155–164.
- Planas, D., Desrosiers, M., Groulx, S.R., Paquet, S., and Carignan, R. 2000. Pelagic and benthic algal responses in eastern Canadian Boreal Shield lakes following harvesting and wildfires. *Can. J. Fish. Aquat. Sci.* **57**: 136–145.
- Sanderson, B.L., Hrabik, T.R., Magnuson, J.J., and Post, D.M. 1999. Cyclic dynamics of a yellow perch (*Perca flavescens*) population in an oligotrophic lake: evidence for the role of intraspecific interactions. *Can. J. Fish. Aquat. Sci.* **59**: 1534–1542.
- Steinberg, C.E.W., Kamara, S., Prokhotskaya, V.Y., Manusadzianas, L., Karasyova, T.A., Timofeyev, M.A., Jie, Z., Paul, A., Meinelt, T., Farjalla, V.F., Matsuo, A.Y.O., Kent Burnison, B., and Menzel, R. 2006. Dissolved humic substances — ecological driving forces from the individual to the ecosystem level? *Freshw. Biol.* **51**: 1189–1210.
- St-Onge, I., and Magnan, P. 2000. Impact of logging and natural fires on fish communities of Laurentian Shield lakes. *Can. J. Fish. Aquat. Sci.* **57**: 165–174.
- Vuori, K.-M., and Joensuu, I. 1996. Impact of forest drainage on the macroinvertebrates of a small boreal headwater stream: do buffer zones protect lotic biodiversity? *Biol. Conserv.* **77**: 87–95.