INFLUENCE OF BIO-POLLUTION ON ECOSYSTEM PROCESSES: THE IMPACT OF INTRODUCED LAKE TROUT ON STREAMS, PREDATORS, AND FORESTS IN YELLOWSTONE NATIONAL PARK

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✦ INTRODUCTION

Yellowstone National Park (YNP) is a treasured national resource and an important element of tourism and the recreational economy in Wyoming. Because of its unique geological features and abundant wildlife and fisheries, YNP is a tourist destination for millions of people annually. Although this national symbol is cherished for its pristine condition and has been protected from most human influence for over 100 years, human mediated invasions of non-indigenous species, such as several species of plants and animals, including an exotic snail (*Potamopyrgus antipodarum*), may alter this ecosystem.

Recently an unauthorized introduction of lake trout (*Salvelinus namaycush*) to Yellowstone Lake was documented. Recent investigation at the University of Wyoming, indicated that in-lake predation by lake trout on juvenile and sub-adult native Yellowstone cutthroat trout (*Oncorhyncus clarki bouvieri*) could negatively influence recruitment of cutthroat trout (Stapp and Hayward 2002). This may lead to significant reductions in numbers of spawning adult cutthroat if current management actions are ineffective, or if they are not continuously pursued (Stapp and Hayward 2002). While lake trout invasion in Yellowstone Lake will likely have detrimental effects on in-lake communities and processes, reductions in populations of native cutthroat trout can potentially impact other aquatic and terrestrial ecosystems *outside* of Yellowstone Lake.

Cutthroat trout in Yellowstone Lake annually migrate into tributary streams and rivers to spawn (Varley and Gresswell 1988), with runs up to 60,000 trout per season into small streams such as Clear Creek (Gresswell and Varley 1988). This spawning migration may significantly affect in-stream communities (cf. Power 1990) and alter nutrient cycling within tributary streams (Peterson et al. 1993) and in the adjacent riparian forests (Ben-David et al. 1998; Hilderbrand et al. 1999). Therefore, spawning cutthroat trout not only have trophic effects on their ecosystem but also act as "ecosystem engineers" (i.e., species that influence structure and function of ecosystems through non-trophic processes) because of their role in transporting large amounts of nutrients between ecosystems (Jones et al. 1994). Reductions in spawning adult cutthroat trout will likely alter in-stream processes. In addition, for piscivorous (fish-eating) predators, a significant decline in the number of adult spawning cutthroat trout may reduce recruitment and survival, and it could threaten viability of predator populations.

In this project we are investigating the role of cutthroat trout in structuring stream ecosystems, their importance to a representative fish-predator – the river otter (*Lontra canadensis)*, and possible effectson terrestrial plants through nutrient transport by otters to latrine sites (Ben-David et al. 1998; Hilderbrand et al. 1999). We hypothesize that the spawning migration of cutthroat trout will result in transport of nutrients from lake to streams, and from streams to terrestrial forests, through the activity of piscivorous predators. Because nitrogen (N) limits production in area streams (J. L. Tank and R. O. Hall unpublished data) and terrestrial ecosystems (Nadelhoffer et al. 1995) we focus our investigation of nutrient cycling on this element. These observations will enable us to predict how streams, trout predators, and the terrestrial landscape will be affected following cutthroat trout decline.

✦ METHODS

Sampling design

Surveys were conducted from June 11 to August 7, 2002. Areas surveyed included: Bridge Creek, Yellowstone River outlet, Pelican, Sedge, Cub, Clear, and Columbine Creeks, and the perimeter of Yellowstone Lake excluding South Arm and non-motorized zones in Southeast Arm and Flathead Mountain (Figure 1). This time period coincided with the beginning, peak and end of the spawning season of cutthroat trout. Nonetheless, because our permit allowed us access only to Yellowstone River outlet, Cub, Clear, and Pelican during the bear closure period, Bridge, Sedge, and Columbine Creeks were only surveyed at the post spawning period. This resulted in incomplete sampling (i.e., missing of pre and peak spawning) on those streams. In addition, because of temporal differences in the initiation of the spawning migration in different streams, our surveys captured only the peak and post run conditions on the Yellowstone River outlet.

Surveys were conducted from a small boat along the lake shoreline and on foot along tributary streams. A survey team included at least 3 people equipped with bear repellent, survival gear, and a handheld marine radio. Surveys conducted in bear closure areas were coordinated with NPS Fisheries staff (through team leader Todd Koel). Total stream length surveyed was 43.3 km. Total length of lake shoreline surveyed was 175 km. River otter latrine sites were identified by trails leading from water, presence of feces, and tracks. Random sites were systematically selected at the location of the survey group every hour on the hour. This systematic sampling began at the start of each survey period. We resorted to this sampling scheme because it was impossible to *a priori* select sites randomly because of error associated with converting GIS points to GPS locations (i.e., pre-chosen sites would often be located away from a stream).

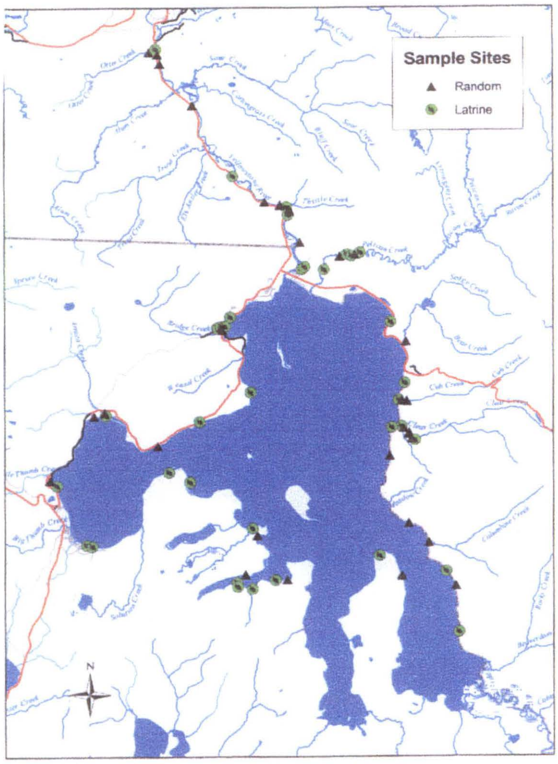


Figure 1 - Locations of otter latrines and random site along the shore of Yellowstone Lake and tributary streams between June 11 and August 7, 2002.

At randomly selected sites along surveyed streams we collected water samples for analysis of ammonium, nitrate, and total N (Holmes et al. 1999, APHA 1995). Samples were collected in scintillation vials, frozen, and stored for later analysis. In addition, 1 cutthroat trout was captured on 8/2/02 at the mouth of Clear Creek for measurement of ammonium excretion.

Data collection

Activity sites of otters were identified, and the location of each site was determined using a handheld GPS unit. Each site was then characterized with respect to topography, composition of terrestrial vegetation, composition of river substrate, and presence of feces. Vegetation and river substrate were assessed for a 10-m arc with its pivotal point at the highest concentration of otter sign. We estimated relative cover of vegetation visually. Cover was estimated for both the overstory and understory. Classes for the overstory included spruce, poplar/aspen, alder, pine, and other. The understory was classified into brush, ferns and forbs, moss, and other. Vegetation types were assigned ranks of cover from 1 to 5 (1 = 0-20%, 2 = 20-40%, 3 = 40-60%, 4 = 60-80% 5 = 80-100%). We used the same method to categorize river substrates into the classes: sand, gravel, cobbles, small rocks, and large rocks. Stream shading was also estimated in the same 10-m arc. We measured vegetated slopes to the nearest 5° with a hand-held compass, and aspect of the site was recorded in eight compass directions. The distance of each site to water was measured to the nearest 0.5-m, and water temperature at the entrance to the site was measured to the nearest 0.1°C with a digital thermometer. At each site the number of old (deposited more than 24 hours before the survey), and fresh feces were recorded. Fresh feces were collected individually in 100% ethanol for DNA analysis. Random sites were characterized using identical methods.

Latrine sites were revisited between 2 and 5 times through the survey period to determine changes in activity in relation to the spawning schedule of cutthroat trout. At each visit we recorded the number of old and fresh feces, and collected fresh feces. At each site we also recorded changes in water level and temperature, and in the stream sites, counted the number of visible cutthroat trout. At several sites, we deployed Trailmaster© remote camera systems.

At each latrine and random site, we collected samples of vegetation for stable isotope analysis. New growth was collected from Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta*), alder (*Alnus* sp.), currant (*Ribes* sp.), *Vaccinium* sp., willow (*Salix* sp.), sagebrush (*Artemisia* sp.), and grass (Table 1). We obtained digital pictures of each site as a means to identify individual plants for repeated samples. In addition, on 8 random sites and 10 latrine sites increment cores of lodgepole pine were obtained. On 10 random and 15 latrine sites increment cores of Engelmann spruce were collected. Vegetation and core samples are currently being analyzed for values of $\delta^{15}N$.

Table 1. Vegetation samples collected at river otter latrine sites and random sites in Yellowstone Lake and tributaries between June 11 and August 7, 2002. Samples are currently being prepared for stable isotope analysis.

Species	Scientific name	Number collected at latrines	Number collected at random site
Alder	Alnus sp.	7	6
Aspen	Populus tremuloides	2	1
Currant	Ribes sp.	22	13
Douglas-fir	Pseudotsuga menziesii	2	0
Engelmann spruce	Picea engelmannii	33	24
Grass		51	44
Lodgepole pine	Pinus contorta	26	33
Sagebrush	Artemisia sp.	2	11
Subalpine fir	Abies lasiocarpa	6	3
Vaccinium	Vaccinium sp.	13	8
Willow	Salix sp.	2	2

GIS analysis

Locations of otter activity sites were plotted on a digital map of Yellowstone Lake and tributary obtained from the Wyoming Geographical Information Science Center (WYGISC). ArcView 3.2 was used to map latrine and random sites (Redlands, CA; Figure 1). Length of stream and lakeshore surveyed were calculated by measuring distances between all sample locations, using ArcView.

Statistical analysis

We employed step-wise logistic regression (SPSS for Windows 7.0, Hosmer and Lemeshow 1989) to develop a model that could be used to describe habitat selection by otters. We controlled for multicollinearity by eliminating one of any pair of variables with $\underline{r} > |0.3|$. We ensured that the data did not depart from a logistic-regression model with a Hosmer-Lemeshow goodness-of-fit test. The best model was selected based on AIC scores, model goodness-of-fit, and significant contributions of variables. To determine selection for (use > availability) or against (use < availability) habitat variables, we tested those variables that entered the model using contingency tables (Pearson's χ^2 test) for the categorical variables and Mann-Whitney tests for continuous variables (Hosmer and Lemeshow 1989).

✦ RESULTS AND DISCUSSION

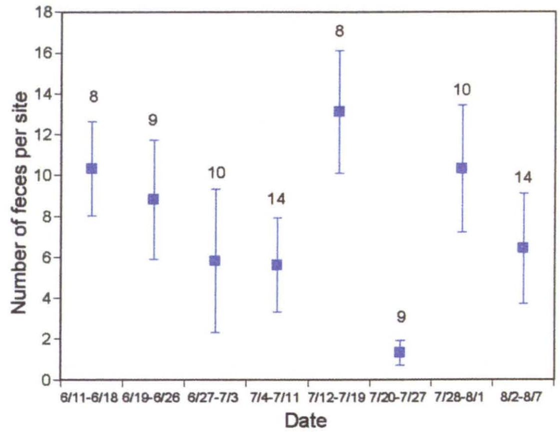
Between June 11 and August 7, 2002, a total of 13 water samples were collected from Bridge, Cub and Clear Creeks (Table 2). Analysis of these samples indicated that streams have extremely low nitrate concentrations (below our detection limit of µg NO_3-N/L). This suggests nitrogen limitation and that any added N from fish migration will likely increase primary and secondary production in these streams. Ammonium concentrations and total N are currently being analyzed.

Table 2. Number of water samples collected in Bridge, Cub, and Clear Creeks in Yellowstone National Park between June 11 and August 7, 2002.

Creek	Number of samples	Date	Cutthroat spawning status	NO_3 (µg/L)
Bridge	2	6/18/02	post-run	< 5
Cub	1	6/17/02	beginning-run	<5
Cub	3	6/27/02	peak-run	<5
Clear	3	6/19/02	peak-run	<5
Clear	4	8/7/02	post-run	<5

During the survey we found a total of 37 river otter latrine sites along streams and lakeshore and characterized 33 random sites (Figure 1). A total of 80 fresh feces were collected for DNA analysis and 565 old feces for diet analysis. These analyses are currently under way. Density of latrines along streams was 0.35 sites/km of river, and 0.13 sites/km along the lakeshore. In addition, the average number of feces per site per week ranged from 1.25 to 13.1 (Figure 2). The density of latrines we found for both streams and lake was relatively low. In comparison, similar surveys conducted in Rocky Mountain National Park (RMNP) and through the Seedskadee National Wildlife Refuge (SNWR) in summer 2002 recorded densities of 2.3 sites/km stream (RMNP; Herreman and Ben-David, 2002) and 1.2 activity sites/km (SNWR; Boyd and Ben-David, 2002). In contrast, the number of feces per site we recorded was similar to that reported in those surveys, with an average of 6.1 feces per site in RMNP and 16.05 feces per site in SNWR (Boyd and Ben-David, 2002; Herreman and Ben-David, 2002). These comparisons suggest that while activity levels of river otters in Yellowstone Lake and tributaries are similar to other systems in the intermountain west, the actual abundance of otters in our study may be lower.

Figure 2. Average number of feces per latrine site (± SE) collected along the shore of Yellowstone Lake and tributary streams between June 11 and August 7, 2002. Numbers above error bars represent number of sites sampled in each week.



Because otter densities appeared lower than expected we conducted interviews with several Park employees and volunteers as well as with W. Wengeler (UC Davis) and R. Landis (filmmaker of “Yellowstone Otters”). Almost every person we interviewed said they had noticed a real decline in otter sightings in the last few years. Although these interviews were not conducted under rigorous scientific protocols, they provided support to our conclusion that otter numbers around Yellowstone Lake have declined in recent years.

Our attempt at installing Trailmaster© remote camera systems to monitor otter activity at latrines was unsuccessful in part because of the low densities of otters and conditions on Yellowstone Lake. At the time the cameras arrived most of the activity at latrines occurred at the southern part of the lake. On numerous days we were unable to reach that part of the lake in our skiff. In more accessible sites, activity of otters was so low that we were unable to obtain any footage.

Another difficulty we encountered was related to the use of digital images to identify individual plants for repeated sampling. This method proved problematic, as pictures did not provide enough distinction between individual sites and vegetation for accurate relocation in the field. We hope to correct for this problem in the future by using alternate methods of marking sites and plants.

For the 2002 field season, the best logistic-regression model identified vegetative slope, large rocks and presence of spruce as the variables most significant in discriminating latrine and random sites on streams (Table 3; Figure 3). This model correctly identified 76.3% of all locations to their correct affiliation. Otters selected for high presence of spruce and large rocks with shallower stream banks. These results agree with findings of other studies, which found high reliance of otters on old-growth forests and large rocks as aquatic substrate (Ben-David et al. 1996; Bowyer et al. 1995, Herreman and Ben-David 2001). For lake sites the best model identified shading, forbs, and all other vegetation types (i.e., the category "other" in both overstory and understory) as the variables best separating latrine and random sites. This model correctly identified 81.8% of all locations to their correct affiliation. Random sites were characterized by higher presence of forbs and other vegetation (i.e., latrine sites had higher presence in all other vegetative categories combined), and latrines were characterized by higher amounts of shading (Table 3; Figure 4). Results from this analysis however, should be interpreted with caution because we had only 12 random sites on the Lake. Nonetheless, these results may indicate that river otters select for sites with higher overall vegetative cover that produces extensive shading. We anticipate further elucidating the differences in habitat selection between stream and lake sites by collecting additional data next summer.

Table 3. Results of logistic regression analysis exploring habitat variables that best separate river otter latrines and random sites in Yellowstone National Park between June 11 and August 7, 2002.

Site type	Variables			Correct classification %	
		Coefficient	*P*-value	Random	Latrine
Stream	Large rocks	1.211	0.073	80.95	70.59
	Spruce	0.473	0.08		
	Vegetative slope	-0.115	0.011		
Lake	Forbs	-1.411	0.037	63.64	90.91
	Other (overstory)	-1.434	0.097		
	Other (understory)	-1.218	0.079		
	Shading	0.09	0.083		

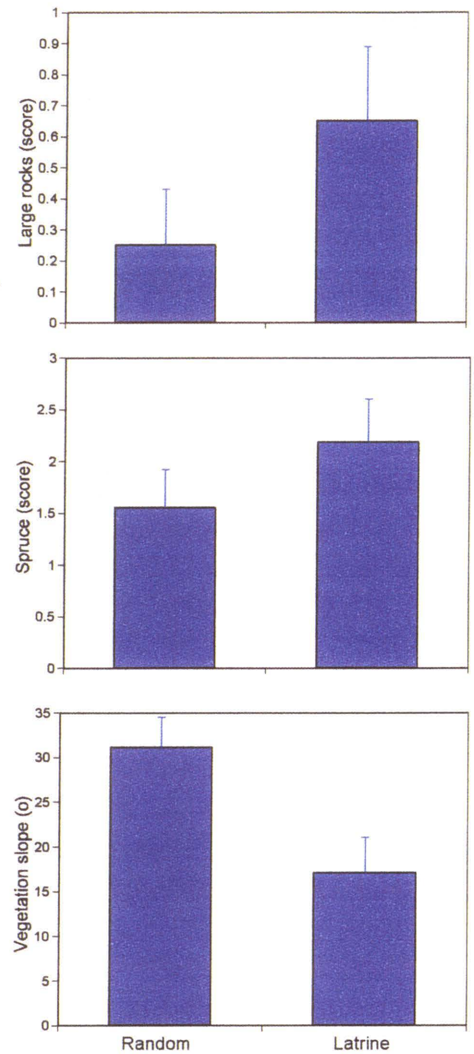


Figure 3. Habitat characteristics (mean ± SE) of river otter latrines (n = 17) and random sites (n = 24) characterized along tributary streams of Yellowstone Lake between June 11 and August 7, 2002. These variables were identified as best separating latrine and random sites by logistic regression analysis.

In conclusion, our results indicate that habitat selection and levels of activity of river otters in Yellowstone Lake and tributaries are similar to those of otters elsewhere, but numbers may be lower than we initially expected. Whether these lower numbers are related to the decline of cutthroat trout is yet to be established. Alternative hypotheses include: 1. Reduction in otter numbers in recent years may be caused by increased concentrations of mercury in stream waters because of reduced water flow 2. Exposure to canine distemper virus from an epidemic in coyotes in the late 1990s caused increased mortality in otters. Two other major gaps in our knowledge exist: 1. The actual number of otters in our study area still awaits determination from DNA analyses. 2. We could not evaluate whether the low numbers around Yellowstone Lake were a result of decreased population size or increased movements of otters into adjacent areas such as the Yellowstone River inlet. We expect to gain more insights regarding these issues from the analysis of tree cores and from a winter survey we would like to conduct in March with the cooperation of Park biologists.

✦ ACKNOWLEDGEMENTS

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✦ REFERENCES

Ben-David, M., R. T. Bowyer, L. K. Duffy, D. D. Roby, and D. M. Schell. 1998. Social behavior and ecosystem processes: river otter latrines and nutrient dynamics of terrestrial vegetation. Ecology 79: 2567-2571.

Ben-David, M., R. T.Bowyer, and J. B. Faro. 1996. Niche separation by mink (*Mustela vison*) and river-otters (*Lutra canadensis*): co-existence in a marine environment. Oikos 75: 41 - 48.

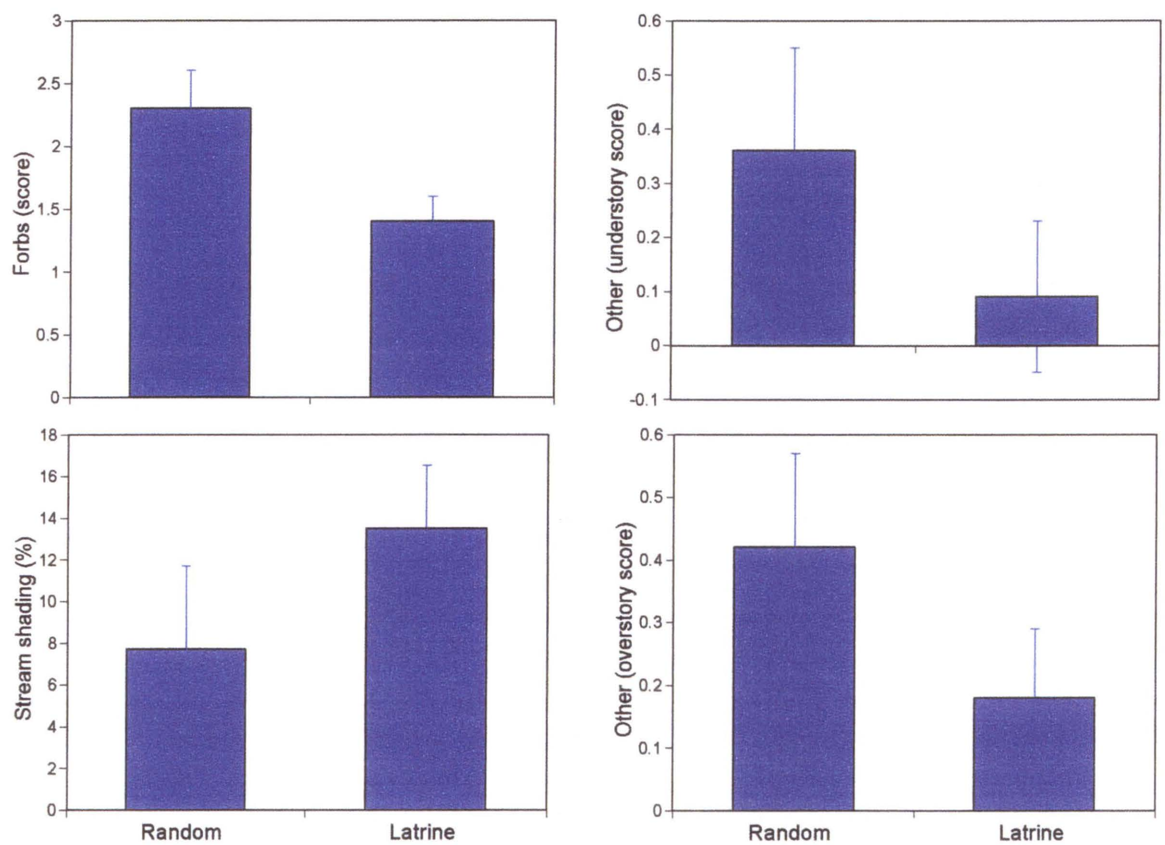

Figure 4. Habitat characteristics (mean ± SE) of river otter latrines (n = 22) and random sites (n = 12) characterized along shores of Yellowstone Lake between June 11 and August 7, 2002. These variables were identified as best separating latrine and random sites by logistic regression analysis.

Boyd J. and M. Ben-David. 2002. Survey of river otters in the Green River. Progress report. U. S. Fish and Wildlife Service, Seedskadee National Wildlife Refuge.

Bowyer, R. T., W. J. Testa, and J. B. Faro. 1995. Habitat selection and home ranges of river otters in a marine environment: effect of the *Exxon Valdez* oil spill. - J. Mammal. 76: 1 - 11.

Bowyer, R. T., G. M. Blundell, M. Ben-David, S. C. Jewett, T. A. Dean, and L. K. Duffy. (*in press*) Effects of the *Exxon Valdez* oil spill on river otters: injury and recovery of a sentinel species. Wildlife Monograph.

Gresswell, R. E., and J. D. Varley. 1988. Effects of a century of human influence on cutthroat trout in Yellowstone Lake. Pages 45-52 *in* R. E. Greswell, editor. Status and management of interior stocks of cutthroat trout. American Fisheries Society. Symposium 4, Bethesda, Maryland.

Herreman J. and M. Ben-David. 2001. Population survey for river otters in the Rocky Mountain National Park. Progress report. U. S. National Park Service.

Herreman J. and M. Ben-David. 2002. Population survey for river otters in the Rocky Mountain National Park. Progress report. U. S. National Park

Hilderbrand, G.V., T. A. Hanley, C. T. Robbins, and C. C. Schwartz. 1999*a*. Role of brown bears (*Ursus arctos*) in the flow of marine nitrogen into terrestrial ecosystems. Oecologia 121: 546-550.

Hosmer. D. W. and Lemeshow. S. 1989. Applied logistic regression. - John Wiley and Sons Inc. USA.

Jones, C. G., J. H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. Oikos 69:373-386.

Nadelhoffer, K. J., M. R. Downs, B. Fry, J. D. Aber, A. H. Magill, J. M. Mellilo. 1995. The fate of 15N-labeled nitrate additions to a northern hardwood forest in eastern Maine, USA. Oecologia 103: 292-301.

Peterson B. J., L. A. Deegan, J. Helfrich, J.E. Hobbie, M. Hullar, B. Moller, T.E. Ford, A. Hershey, A Hiltner., G. Kipphut, M.A. Lock, D.M. Fiebig, V. McKinley, M.C. Miller, J.R. Vestal, R. Ventullo, and G. Volk. 1993. Biological responses of a tundra river to fertilization. Ecology 74: 653-672.

Power, M. E. 1990. Effects of fish on river food webs. Science 250:411-415.

Stapp, P., and G. D. Hayward. 2002. Effects of an introduced piscivore on native trout: insights from a demographic model. Biological Invasions 4: 299-316.

Varley, J. D., and R. E. Gresswell. 1988. Pages 13-24 *in* R. E. Greswell, editor. Status and management of interior stocks of cutthroat trout. American Fisheries Society. Symposium 4, Bethesda, Maryland.