

Ecological Effects of Stocked Trout On North Cascades Naturally Fishless Lakes

By William J. Liss and Gary L. Larson

One generalization that has emerged from research into the ecological role of fish in aquatic communities is that fish can play an important role. When stocked in historically fishless bodies of water, fish have the potential to eliminate or severely reduce in abundance indigenous species of invertebrate and vertebrate prey organisms and thus dramatically change aquatic community composition and development. In general, management concerns center on balancing recreational opportunities provided by stocked fish and conserving the integrity of aquatic communities that have developed for thousands of years in the absence of fish.

The lakes of North Cascades National Park service Complex in northern Washington were formed by glacial activity thousands of years ago and, until relatively recently, were devoid of fish. Some lakes were stocked with trout in the early 20th Century, long before establishment of the park in 1968. At present, of the 160 or so significant high mountain lakes, about 61 contain fish, either through natural reproduction or by periodic stocking. The major species are cutthroat and rainbow trout.

Park staff now face the difficult task of deciding the future of fish stocking of lakes within park boundaries. This research was undertaken to clarify the ecological role of stocked trout and their potential effects on the biological communities of naturally fishless high mountain lakes. We have completed two of three scheduled field seasons and are analyzing data collected during the second season. This paper then, is an interim report and deals primarily with our accomplishments prior to beginning field work and during our first field season.

Before the start of each field season we meet with a peer review panel of limnologists, all with research experience on lake communities, to review our work of the past year and our research proposal for the succeeding field season. This has provided constructive reviews and had a significant impact on research directions. Park staff, especially Jon Jarvis, Gary Mason, and Bob Wasem, have provided logistic support and personnel assistance. Beth Deimling, Bob Hoffman, Gregg Lomnicki, and Bob Truitt, all research assistants at Oregon State University, have major responsibility for conduct of field work, processing samples, and data analysis. Collaboration of our colleague, Dave McIntire, also is appreciated.

A Diverse, Dynamic System

The park is a diverse, dynamic system—an area of steep, rugged mountains, some reaching elevations of over 2500 meters, with many permanent glaciers. The mountains and valleys were shaped by glacial activity over the last 10,000 years. Prevailing weather patterns are from the Pacific Ocean, about 50 miles west of the park. Precipitation is highest west of the Cascade crest, which runs through the park. Most of the glaciers are found on the west side; areas east of the crest are much drier.

The park's high mountain lakes are generally rather small, most having a surface of less than 10 hectares, although some are quite large. They occur at elevations ranging from less than 500 m to over 2000 m. Lower elevation, west slope watersheds have well-

developed soils and are heavily forested. Higher elevation watersheds may have little soil development and be very sparsely vegetated; many of the highest watersheds are largely rock and ice. The park's oldest lakes probably are thousands of years old, but new lakes are forming even today as the glaciers recede.

Our research began with a literature review of the ecological impacts of fish on aquatic communities (Goetze et al 1989), and development of a watershed and lake classification system for the park (Lomnicki et al 1989). The literature suggests that vertebrate predation can alter aquatic community structure and organization. **Structure** of aquatic communities can be defined as the kinds of species composing a community, their abundances, distributions, and average sizes. This structure is simply a description of the "form" of a community. **Organization** involves interactions or interrelations, at least partially inferred, among species or groups of species that give a community its cohesiveness and ultimately underlie its "form."

Fish have been shown to alter the size-structure, species composition, and species abundances of crustacean zooplankton. Fish may selectively prey on the largest or most visible species, eliminating these species or severely reducing their abundance and causing the zooplankton community to be dominated by smaller forms (e.g. Zaret 1980). These changes are thought by some researchers to alter grazing rates on phytoplankton and cause changes in the species composition, size-structure, and abundance of these minute algae (Carpenter et al 1985). Fish may change the biomass and relative proportions of taxa composing benthic macroinvertebrate communities (Gilinsky 1984; Walters and Vincent 1973; Andersson et al 1978; Tuunianen 1970). Elimination of benthic species has been reported (Macan 1966a,b; Reimers 1979). Fish also may alter the behavior and abundance of salamanders (Efford and Mathias 1969; Taylor 1983; Semlitsch 1987).

Many Factors Involved

While there is considerable evidence suggesting that stocked fish can alter communities in naturally fishless lakes, the results often are not clearcut. Community structure and organization are by no means determined solely by presence or absence of vertebrate predators. Species that successfully colonize a lake and make up a community must, at some time, have originated in other lakes, streams, and bodies of water. The system of aquatic communities that provides colonists to a lake is the species pool. The composition of species in a lake depends heavily on this pool of available colonists.

In addition, the physical and chemical characteristics of the lake habitat influence the kinds of species present and the nature of species interrelationships. Lakes with different kinds of habitats may have somewhat different communities, even within the same species pool, and these communities may respond differently to fish stocking.

Prey refuges, which can mediate the effects of predation, are a component of habitat (Crowder and Cooper 1982; Timms and Moss 1984). Fluctuations in chemical and physical conditions may reduce, enhance, or override effects of fish predation. Impacts on the community also may depend upon the species, density, and age and size structure of vertebrate pred-



Doubtful Lake is a subalpine lake formed in a glacial cirque in North Cascades NPS Complex. (Photo by Beth Deimling)

ators (Stein et al 1988).

Most high mountain lakes of the North Cascades are oligotrophic, that is low in nutrients and poorly productive. Yet there is considerable diversity in characteristics of lakes and their watersheds, which may give rise to diversity of aquatic community types. Watershed and lake classification provide a useful tool for identifying, ordering, and understanding diversity of aquatic habitats and communities. Lakes, like all aquatic systems, reflect characteristics of their watersheds.

Lakes within the park are classified or grouped according to climatic, geologic, topographic, and vegetative aspects of their watersheds, and by watershed area, lake elevation, lake morphometry (surface area and relative depth), and type of inlet and outlet. All these characteristics may influence lake habitat including chemistry, hydrology, length of ice-free period, seasonal temperature patterns, and type of bottom substrate.

The classification, then, allowed us to begin to define different aquatic community habitats within the park, and associate these habitats with watershed characteristics. In addition, the classification system provided a basis for selecting comparable lakes for study and will serve as a tool in developing a lake monitoring program.

Research Season Limited

Field research began in the summer of 1989. Field seasons are relatively short, extending from June into September for the lowest elevation lakes. Many high lakes may not become ice-free and accessible until mid to late July. Lakes often are located in rugged, remote terrain and so present severe logistical difficulties for the researcher transporting sampling equipment. Access to nearly all lakes is either by backpacking or helicopter.

The goal of research is to evaluate the impacts of

stocked trout on the structure and organization of aquatic communities in naturally fishless lakes. The components of the aquatic community on which we focused included benthic macroinvertebrates, crustacean zooplankton, rotifers, phytoplankton, and amphibians—particularly salamanders. Fish were sampled to determine size structure, food habits, and relative abundance. Lake chemistry and temperature profiles were taken and components of the benthic substrate were identified and mapped.

Since very little was known of the structure of aquatic communities within the park, our first field season task was to conduct an extensive survey of lakes. The 1989 field season was devoted to assessing the general limnological characteristics of 52 lakes, which represented a wide range of lake classes. Most were sampled only once that season. The survey afforded some important understanding of the species composition of aquatic communities and species distributions among communities within the park, and led to some hypotheses concerning fish impacts, which directed further studies and provided context for more intensive field studies conducted in ensuing years. Analysis of the 1989 survey data led to the tentative view that predation impacts on aquatic communities in the park may be dependent on the density and size structure of vertebrate predator populations and may vary with lake class.

Vegetation zone (alpine, subalpine, and forested) and aspect (east/west) are components of the classification system that emerged as important indicators of local climate, soil conditions, and limnological characteristics of lakes (Liss et al 1990). Physical and chemical properties of lakes and benthic habitat characteristics varied among vegetation zones. In general, taxa of zooplankton, benthic invertebrates, and phytoplankton were more diverse in forested lakes than in subalpine and, particularly, alpine systems. Many taxa, some of them relatively rare, were found exclusively in forested systems. This suggests that analysis of fish impacts should be partitioned by vegetation zone.

Fish Effect on Salamanders

Important vertebrate predators within aquatic systems in the park are fish and salamanders. Both prey upon benthic macroinvertebrates and zooplankton. Fish seem to affect the abundance and behavior of salamanders. When fish were not present in a lake, salamander abundance was relatively high. Salamanders were observed to move freely within the lake during daylight hours, suspend in the water column, and bask openly on submerged rocks and logs. When fish were present, abundance of salamanders

appeared to be reduced and they were far more secretive, lying hidden in crevices of submerged boulders during the day, perhaps emerging to feed at night. Salamander larvae were found in fish stomachs. Preliminary observations suggest that post-hatch mortality of larval salamanders is very high in lakes with fish. We will be performing experiments during the 1991 field season to determine the extent to which this mortality may be attributable to fish predation.

Both reproducing and non-reproducing fish stocks are present in the park. Reproducing populations are composed of individuals of different ages and sizes. Park lakes with highest fish densities tend to be composed of reproducing fish populations. Our initial observations suggest that these may be the lakes in which fish impacts on salamanders and invertebrates may be most evident. Lakes in which fish do not reproduce are stocked periodically with fry. Fish in these lakes tend to be of more uniform size and age. Since fish may change their feeding habits as they age

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(Rabe 1967; Hansen 1971), a cohort of stocked fish may have different impacts on the community when it is composed of numerous small fish than when it is made up of few, large fish. This raises the possibility of cyclic changes in aquatic invertebrate community structure as a cohort of stocked fish matures.

Unraveling Complexities

Research during the 1991 field season, as in the 1990 season, will be directed toward unraveling the complexities of interactions among components of the aquatic communities. Two types of approaches will be employed. One involves comparison of communities in lakes with different levels of vertebrate predation within each vegetation zone. In the subalpine, this will entail comparison among lakes in which no vertebrate predators are present, lakes in which only salamanders occur, and lakes with low to high densities of fish. In forested lakes, the same design will be employed, although we have not found any lakes in this vegetation zone that do not have some type of vertebrate predator. For each community we will focus on assessment of species composition, average body size of major species, relative species densities, and habitat utilization.

Lakes will be sampled two to four times per season, depending on elevation. Alpine lakes will not be studied extensively because few are stocked with fish.

The second approach pertains primarily to lakes with non-reproducing fish. Community structure in two subalpine and three forested lakes, each with only a few, large fish remaining within the cohort, was determined. Predation intensity, particularly on zooplankton, may be rather low in these systems. The large fish then were removed by intensive gill-netting (only relatively small lakes that afford high probability of removing nearly all fish were chosen). The lakes were restocked with fry toward the end of the 1990 season. These smaller fish may be more intensive planktivores than larger fish and so have a greater impact on zooplankton and the pelagic community.

Community structure will be determined again during the 1991 field season and compared to structure from 1990. Sampling these systems we hope can continue during a monitoring phase of the project to evaluate whether some form of cyclic change in communities associated with periodic stocking can occur.

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References

- Andersson, G., H. Berggren, G. Cronberg, and C. Gelin. 1978. Effects of planktivorous and benthivorous fish on organisms and water chemistry in eutrophic lakes. *Hydrobiologia* 59:9-15.
- Tuunainen, P. 1970. Relations between the benthic fauna and two species of trout in some small Finnish lakes treated with rotenone. *Ann. Zool. Fenn.* 7:67-120.
- Carpenter, S.R., J.F. Kitchell, and J.R. Hodgson. 1985. Cascading trophic interactions and lake production. *BioScience* 35:634-639.
- Crowder, L.B. and W.F. Cooper. 1982. Habitat structural complexity and the interactions between bluegills and their prey. *Ecology* 63:1802-1813.
- Efford, I.E. and J.A. Mathias. 1969. A comparison of two salamander populations in Marion Lake, British Columbia. *Copeia* 4:723-736.
- Gilinsky, E. 1984. The role of fish predation and spatial heterogeneity in determining benthic community structure. *Ecology* 65:455-468.
- Goetze, B., W.J. Liss and G.L. Larson. 1989. Ecological implications of fish introductions into temperate lakes: a review. Final Report, Cooperative Agreement CA-9000-8-0006, Subagreement 11, National Park Service (NPS).
- Hansen, D.J. 1971. Evaluation of stocking cutthroat trout, *Salmo clarki*, in Munsell Lake, Oregon. *Trans. Amer. Fish. Soc.* 100:55-60.
- Liss, W.J., B. Deimling, R. Hoffman, G.L. Larson, G. Lomnický, and D. McIntire. 1990. Ecological effects of stocked fish on naturally barren high mountain lakes: North Cascades NPS Complex. NPS Annual Report.
- Lomnický, G., W.J. Liss and G.L. Larson. 1989. Towards a classification of the watersheds and lakes of North Cascades NPS Complex. Final Report, Cooperative Agreement CA-9000-8-0006, Subagreement 11, NPS.
- Macan, T.T. 1966a. The influence of predation on the fauna of a moorland fish pond. *Arch. Hydrobiol.* 61:432-452.
- Macan, T.T. 1966b. Predation of *Salmo trutta* in moorland fish pond. *Internat. Verein. Theor. Angew. Limnol. Verh.* 16:1081-1087.
- Rabe, F. 1967. The transplantation of brook trout in an alpine lake. *Progr. Fish-culturist* 29:53-55.
- Reimers, N. 1979. A history of stunted brook trout population in an alpine lake: a life span of 24 years. *Calif. Fish. & Game* 65:106-215.
- Stein, R.A., S.T. Threlkeld, C.D. Sandgren, W.G. Sprules, L. Persson, E.E. Werner, W.E. Neill, and S.I. Dodson. 1988. Size structured interactions in lake communities. *Interactions in Lake Communities*, S.R. Carpenter(ed), p.161-179. Springer-Verlag, NY.
- Taylor, J. 1983. Orientation and flight behavior of aneotenic salamander (*Ambystoma gracile*) in Oregon. *Amer. Midl. Nat.* 109:40-49.
- Timms, R.M. and B. Moss. 1984. Prevention of growth of potentially dense phytoplankton populations by zooplankton grazing, in the presence of zooplanktivorous fish, in a shallow wetland ecosystem. *Limnol. Oceanogr.* 29:472-486.
- Semlitsch, R.D. 1987. Interactions between fish and salamander larvae: costs of predator avoidance. *Oecologia* 72:481-486.
- Walters, C.J. and R.F. Vincent. Potential productivity of an alpine lake as indicated by removal and reintroduction of fish. *Trans. Am. Fish. Soc.* 102:675-697.
- Zaret, T.M. 1980. *Predation and Freshwater Communities*. Yale Univ Press, New Haven.



Pelton Basin in North Cascades National Park Service Complex. (Photo by Beth Deimling)