Eradication of Nonnative Fish by Gill Netting from a Small Mountain Lake in California

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Abstract

Nearly all mountain lakes in the western United States were historically fishless, but most now contain introduced trout populations. As a result of the impacts of these introductions on ecosystem structure and function, there is increasing interest in restoring some lakes to a fishless condition. To date, however, the only effective method of fish eradication is the application of rotenone, a pesticide that is also toxic to nontarget native species. The objective of this study was to assess the effectiveness of intensive gill netting in eradicating the trout population from a small subalpine lake in the Sierra Nevada, California. We removed the resident trout population and a second trout population accidentally stocked into the study lake within 18 and 15 gill net sets, respectively. Adult trout were highly vulnerable to gill nets, but younger fish were not readily captured until they reached approximately 110 mm. To determine the utility of gill netting as a fish eradication technique in other Sierra Nevada lakes, we used morphometry data from 330 Sierra Nevada lakes to determine what proportion had characteristics similar to the study lake (i.e., small, isolated lakes with little spawning habitat). We estimated that gill netting would be a viable eradication method in 15–20% of the high mountain lakes in the Sierra Nevada. We conclude that although gill netting is likely to be more expensive and time consuming than rotenone application, it is a viable alternative under some conditions and should be the method of choice when sensitive native species are present.

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Introduction

Alpine and subalpine ecosystems in the United States are relatively well-represented in existing national parks and national forest wilderness areas (Foreman & Wolke 1992; Wright et al. 1994). Because of the land-use restrictions emplaced by national park and wilderness designations, a common perception is that high-elevation ecosystems are relatively free of anthropogenic impacts. As a result, these areas are frequently used as "core" areas in reserve design and gap analysis projects (Noss 1993; Scott et al. 1993; Kiester et al. 1996). Recent research, however, shows that direct and indirect anthropogenic effects on these areas are increasing and substantial, and they include those associated with the introduction or invasion of nonnative species (for recent reviews see Cole & Landres 1996; Murray 1996).

One of the goals of wilderness management is to exclude nonnative species to the extent possible. In direct conflict with this goal is the common practice by state fish and game agencies of stocking nonnative trout (*Oncorhynchus* sp. and *Salvelinus* sp.) into naturally fishless alpine lakes in wilderness areas to enhance recreational angling opportunities (Bahls 1992; Dudley & Embury 1995; Knapp 1996). Bahls (1992) estimated that of the approximately 16,000 high mountain lakes in the western United States, more than 95% were naturally fishless prior to stocking. Presently, about 60% of the total number of lakes and 95% of the deeper (> 3 m) and larger (> 2 ha) lakes contain nonnative trout (Bahls 1992). Although the stocking of trout into lakes and streams has long been viewed as an activity that benefits recreationists and has few negative consequences, results of recent research on the effects of nonnative trout on naturally fishless ecosystems are challenging this view. Studies of montane aquatic ecosystems in the western United States show that introduced trout can alter the composition of aquatic communities by preying on native amphibians (Bradford 1989; Liss & Larson 1991; Bradford et al. 1993), zooplankton (Anderson 1980; Stoddard 1987; Carlisle 1995), and benthic invertebrates (Bahls 1990; Carlisle 1995; Rowan 1996), and they suggest that some aquatic species may be regionally extirpated (Stoddard 1987) or even driven to extinction (Bradford et al. 1993). In addition to the direct effects of trout on prey organisms, the introduction of trout into mountain lakes can also initiate trophic cascades (Carpenter et al. 1985) that greatly alter lake productivity (Leavitt et al. 1994).

The subalpine and alpine portion of California's Sierra Nevada contains approximately 4000 lakes larger than 1 ha, and although nearly all were historically fishless, the majority of lakes now contain nonnative trout (Jenkins et al. 1994; Knapp 1996). Because predation by introduced trout has caused declines of native aquatic taxa, especially *Rana muscosa* (mountain yellow-legged frog; Bradford 1989; Bradford et al. 1993), there is increasing interest among researchers and wilderness managers in restoring a subset of mountain lakes to their former fishless condition. Although halting trout stocking would cause some lakes to lose their trout populations, 70–80% of trout populations in high-elevation Sierra Nevada lakes are self-sustaining (Knapp 1996; Knapp & Matthews, unpublished data). Therefore, most trout populations will persist indefinitely unless active eradication measures are taken.

The eradication of fish from lake ecosystems is typically accomplished by means of the pesticide rotenone (Solman 1950). Although rotenone is an effective and widely used fish management tool (California Department of Fish and Game [CDFG] 1994), its use is controversial due to its lethality to nontarget organisms, such as amphibians, zooplankton, and benthic invertebrates (Cushing & Olive 1957; Anderson 1970; Neves 1975; Chandler & Marking 1982) and its short-term effects on water quality (CDFG 1994). Alternative means of fish eradication, including modification of angling regulations, physical removal with nets or traps, biological control, and blasting, are not believed to be effective (CDFG 1994).

The objective of this study was to evaluate the effectiveness of intensive gill netting in eradicating nonnative trout from a small subalpine lake in the central Sierra Nevada, California. Gill nets capture fish by entangling them and have been used to reduce fish densities in mountain lakes (Langeland 1986; Donald & Alger 1989; Hall 1991; De Gisi 1994). We are unaware, however, of any attempts to eradicate fish with gill nets. If gill netting proves to be a successful eradication method, our results could have important implications for fish eradication efforts in other similar lake ecosystems.

Study Area

The lake selected for trout eradication, Maul Lake, is located approximately 2 km east of Yosemite National Park in the Harvey Monroe Hall Research Natural Area (Hall RNA), Inyo National Forest, California (37°57′N, 119°17′E; Fig. 1). The Hall RNA is managed for its scientific and ecological values. Fish stocking is not permitted, and the elimination of nonnative trout from formerly fishless waters is encouraged where feasible (U.S. Forest Service 1992). Maul Lake was chosen for its relative inaccessibility (reachable only by a 3 km hike from a dirt road), potential suitability as a reintroduction site for mountain yellow-legged frogs, and the presence of barriers that isolate the lake from other fish populations.

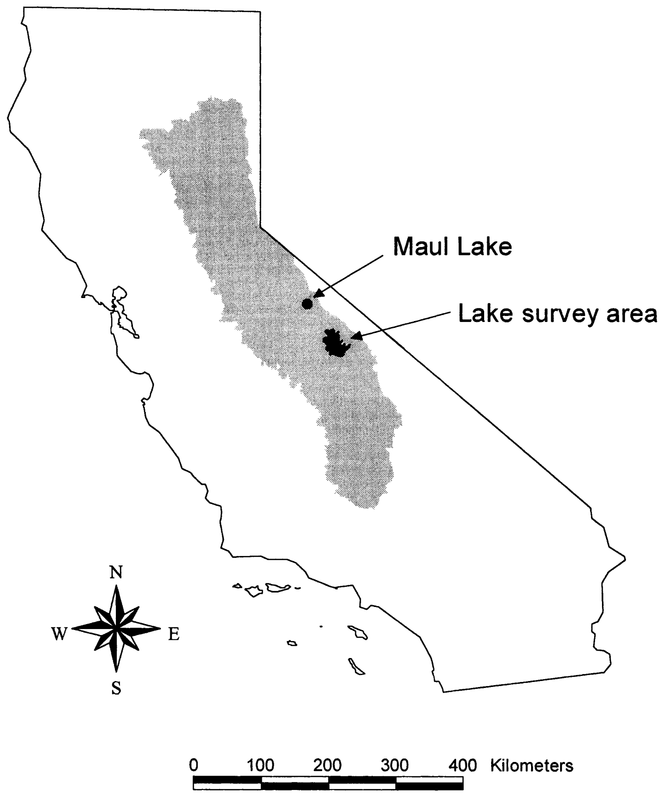

Figure 1. Map of California showing the Sierra Nevada (shaded area) and the locations of Maul Lake and the lake survey area.

Maul Lake is located in the subalpine zone at an elevation of 3120 m; it has a surface area of 1.6 ha and a maximum depth of 6 m (Fig. 2). The lake is typically ice-free from early July until late October, and it has an ephemeral inlet and a single 1 m wide outlet. The outlet contains numerous 1 m-high waterfalls that serve as barriers to any trout migrating upstream from North Fork Lee Vining Creek. The first recorded stocking of fish into Maul Lake by the California Department of Fish and Game (CDFG) took place in the 1940s when *Salvelinus fontinalis* (brook trout) were introduced (CDFG, unpublished records). CDFG records indicate that the lake was subsequently stocked only with brook trout and that stocking was halted in 1961. Only brook trout were present in the lake in 1992 when we began this study. Unlike most salmonids that generally require inlet or outlet streams for successful spawning, brook trout can sometimes spawn successfully in lakes lacking inlets and outlets (Carline 1980; Fraser 1982). Brook trout in Maul Lake utilized a small patch of gravel on the west shore of the lake for reproduction (R. Knapp, personal observation).

Figure 2. Maul Lake, elevation 3120 m, located in the Harvey Monroe Hall Research Natural Area, Inyo National Forest, California. Photograph taken from near the outlet facing northeast.

Methods

Trout Eradication in Maul Lake

Brook trout eradication efforts began on 26 September 1992 and continued until 8 July 1994. Eradication was conducted with sinking monofilament gill nets manufactured by Lundgrens Fiskredskapsfabrik AB[1] in Stockholm, Sweden. We chose these nets because their light weight (approximately 1 kg/net) and small stuffed size (20 × 30 cm) facilitated their transport by backpack to the study lake. Nets were 36 m long and 1.8 m tall. Each net had six 6 m panels with bar mesh sizes of 10, 12.5, 18.5, 25, 33, and 38 mm. Nets were set so that the smallest mesh size panel was closest to shore and the largest mesh size panel was farthest out in the lake. This arrangement was chosen to allow the capture of young trout (< 100 mm) that are generally found only in nearshore habitats (Wurtsbaugh et al. 1975; Soiseth 1992). Three to six nets were set in the lake at a time by means of a float tube (nylon-covered innertube commonly used by anglers). Nets were anchored to the shore with small rocks and set perpendicular to the shoreline. The lake end of the net was weighted with a small rock, and a surface float attached to this end by 6 m of cord marked the location of the submerged net. After fish were removed from nets, nets were generally reset within 10 m of their previous location. We removed the nets just prior to ice-up in the fall of 1992 and 1993, and we reset nets as soon as the ice cleared in the spring of 1993 and 1994.

[1]Tradenames and commercial enterprises are mentioned solely for information. No endorsement by the U.S. Forest Service is implied.

The CDFG apparently stocked fingerling *Oncorhynchus mykiss* (rainbow trout) into Maul Lake in mid-July of 1994. The presence of rainbow trout was first noticed on 1 August 1994, and gill netting was begun immediately in an attempt to eradicate them. Although this unanticipated stocking set back our efforts to return Maul Lake to a fishless condition, we used this opportunity to determine how quickly a much larger number of trout could be eliminated and whether fingerling trout could be successfully removed with gill nets. To eradicate rainbow trout, netting was done during both the open-water period and under the ice. Nets were set just prior to ice-up and retrieved after ice-out.

Applicability To Other Sierra Nevada Lakes

The effectiveness of gill netting in eradicating nonnative trout from mountain lakes is likely to be constrained by lake morphometry, being most effective in relatively small lakes with barriers separating them from other fish populations (lakes similar to Maul Lake). To determine how widely applicable gill netting might be to trout eradication efforts in the Sierra Nevada, we collected data from July to September in 1995 and 1996 on the morphometry of 330 lakes and ponds in the Sierra Nevada that contained trout populations (Matthews & Knapp, unpublished data). The lakes were located within an 800 km^2 area in the John Muir Wilderness, Inyo and Sierra National Forests, California (37°25′N, 118°48′E; Fig. 1). This survey area is approximately 50 km south of Maul Lake, and, like the Maul Lake area, is typical of ecosystems found in the higher elevations of the Sierra Nevada.

Within the 800 km^2 lake survey area, all water bodies shown on 7.5′ topographic maps were surveyed for fish (n = 1213 lakes and ponds) as part of a larger research project investigating the effects of nonnative trout on mountain lake ecosystems (Matthews & Knapp, unpublished data). The presence or absence of trout in each water body was determined by visual surveys or gill nets. In lakes or ponds shallow enough that the entire bottom was visible from shore, the presence or absence of fish was determined by visual surveys conducted on walks around the lake perimeter. In deeper water bodies (typically those deeper than 2 m), we set one gill net for 8–12 hours.

If we determined that fish were present in a water body (n = 330), additional lake morphometry information was collected, including maximum depth, width of inlets and outlets, and amount of trout-spawning habitat in inlets and outlets. Maximum lake depth was determined by sounding with a weighted line. The average width of all inlet and outlet streams was visually estimated (from the lake upstream 100 m for inlets, and downstream 100 m for outlets). The area of spawning habitat (water depth: 5–20 cm; water velocity: 20–70 cm/sec; substrate size: 0.5–5 cm; Bjornn & Reiser 1991; Knapp & Vredenburg 1996) was also visually estimated within these 100 m stream reaches. Lake surface area was obtained by digitizing lake perimeters from 7.5′ topographic maps.

To estimate the proportion of lakes in the survey area from which trout could likely be eradicated by gill nets, we performed two queries of the database of 330 lakes with trout. Both queries were designed to select lakes with stream and spawning habitat characteristics similar to those of Maul Lake: small inlets (total width of all inlets $\leqslant$ 0.5 m), small outlets (total width of all outlets $\leqslant$ 1 m) and minimal stream spawning habitat (total area of stream spawning habitat $\leqslant$ 1 m^2). Streams of this size are often ephemeral and are therefore unlikely to support self-sustaining trout populations and to serve as migration corridors into the lake from upstream or downstream. Lakes with no more than 1 m^2 of spawning habitat typically contain trout populations of relatively low density (Knapp & Matthews, unpublished data). In addition to these stream and spawning habitat characteristics, the first query selected lakes no deeper and no larger than Maul Lake (maximum lake depth $\leqslant$ 6 m; surface area $\leqslant$ 1.6 ha), and the second query selected lakes no more than 10 m deep and 3 ha in surface area. The lakes chosen by the second query likely represent the maximum size and depth at which gill nets similar to those used in Maul Lake would be effective in eradicating a trout population. The efficiency of our gill nets in eradicating trout from lakes deeper than 10 m and larger than 3 ha is likely to be relatively low because of the decreasing volume fished by the nets. The first query, then, suggests the minimum number of lakes with characteristics that should make gill nets highly effective fish-eradication tools, while the second query suggests a maximum number.

Results and Discussion

Trout Eradication in Maul Lake

Brook trout eradication began on 26 September 1992 and was completed on 8 July 1994 (Fig. 3a). The total number of brook trout captured was 97. During this time, nets were set and pulled 18 times and remained in the lake for 0.3–5 days per set (median set duration = 1.0 days). The total netting duration was 25 days, and the total number of net-days was 108. Catch rates were initially high but were reduced to zero or near zero after only seven net sets (Fig. 3a). Of the fish captured on or before 13 September 1993 98% were adult fish (> 220 mm). Fish captured after this date (4 October 1993–8 July 1994) were less than 195 mm long and likely represented fish from the 1993 year class (hatched in Spring 1993 from eggs laid in Fall 1992). After 8 July 1994, a gill

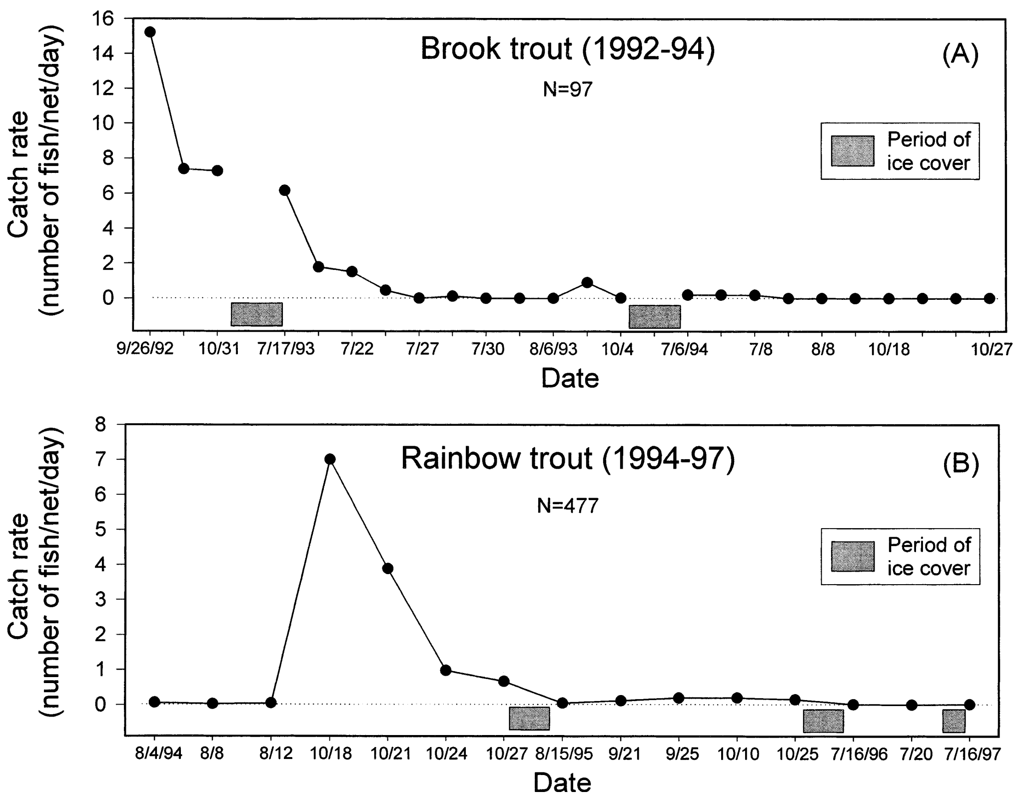

Figure 3. Catch rate (number of fish/net/day) as a function of date for the brook trout population (a) and the rainbow trout population (b) in Maul Lake. Shaded rectangles under each graph indicate periods during which the lake was ice-covered.

netting effort of 3679 net-days over more than two years failed to produce any additional brook trout.

Eradication of rainbow trout began on 1 August 1994, approximately 15 days after they were stocked in Maul Lake, and was completed on 16 July 1997 (Fig. 3b). During this period, 477 rainbow trout were captured. Nets were set and pulled 15 times and were fished for 2.8–33 days per set during the open-water period and 228–294 days per set during ice cover (median set duration = 4.2 days). The total netting duration was 881 days (94 days during the open water period; 787 days during ice cover), and the total number of net-days was 4562 (524 net days during the open water period; 4038 net days during ice cover). In contrast to the high initial catch rates for brook trout (Fig. 3a), initial catch rates of the fingerling rainbow trout were very low (Fig. 3b), apparently because the small size of fish ($\overline{X} \pm 1$ SD = 61 ± 6 mm) allowed most to pass through even the smallest mesh size panel. Catch rates increased markedly on 18 October 1994, by which time fish were substantially larger (118 ± 16 mm). After 18 October, catch rates dropped quickly to near zero. Setting gill nets under the ice proved effective for capturing fish, with 86 fish removed from the nets after ice-out on 15 August 1995, 15 fish after ice-out on 16 July 1996, and seven fish after ice-out on 16 July 1997. The fact that no freshly caught fish were found in the nets on 16 July 1997 suggests that all rainbow trout may have been successfully eradicated from the lake. Gill netting is continuing in Maul Lake to ensure that eradication is in fact complete.

Applicability To Other Sierra Nevada Lakes

Although intensive gill netting was successful in eliminating both brook and rainbow trout, several aspects of the study lake improved the likelihood of eradication. Maul Lake is relatively small, allowing much of the lake volume to be sampled simultaneously with gill nets. The lack of significant streamflow into or out of the lake resulted in relatively poor spawning habitat for brook trout, which in turn was probably responsible for the low-density brook trout population that could be removed relatively quickly. In addition, the presence of barriers on the outlet eliminated the possibility of trout from downstream locations reinvading the lake during the eradication project.

Our analysis of the 330 lakes with trout in the survey area indicated that 53 (16%) of these lakes met our minimum size criteria (maximum lake depth $\leqslant$ 6 m; surface area $\leqslant$ 1.6 ha; total width of all inlets $\leqslant$ 0.5 m; total width of all outlets $\leqslant$ 1 m; total area of stream spawning habitat $\leqslant$ 1 m^2). Sixty-four lakes (19%) met our maximum size criteria (maximum lake depth $\leqslant$ 10 m; surface area $\leqslant$ 3 ha; total width of all inlets $\leqslant$ 0.5 m; total width of all outlets $\leqslant$ 1 m; total area of stream spawning habitat $\leqslant$ 1 m^2). Assuming that our sample lakes were typical of those found throughout the subalpine and alpine portions of the Sierra Nevada, we estimate that 15–20% of high mountain lakes in the Sierra Nevada have characteristics that would allow the eradication of trout by means of gill nets. This percentage could likely be increased by using gill nets in combination with fish barrier construction and spawning habitat destruction.

Comparison of Gill Netting and Rotenone Application

Rotenone application is generally believed to be the only available means of eradicating trout from lakes (CDFG 1994). Our research, however, shows that gill netting is likely to be a viable alternative to rotenone in a subset of Sierra Nevada lakes. Therefore, we present a brief comparison of the costs, benefits, and limitations associated with the two techniques. The cost of the brook trout eradication by gill nets (26 September 1992–27 October 1994) was approximately $5600 (4 gill nets, $1000 one-time expense; salaries and travel $4600). In comparison, in 1993 the CDFG eradicated brook trout from a 3.6-ha subalpine lake (located 60 km north of Maul Lake) using rotenone at a cost of approximately $6500 ($4950 for a helicopter spray rig—one-time expense; $1550 for fuel, rotenone, salaries, and travel; S. Parmenter & C. Milliron, CDFG, personal communication). After the purchase of the helicopter spray rig, rotenone is therefore likely to be somewhat less expensive than gill netting. In addition, rotenone can accomplish eradication in a matter of days instead of the months or years required when using gill nets. Rotenone is also effective on a wide range of lake sizes, while gill netting (with nets similar to ours) is likely to be ineffective in large lakes (> 3 ha), deep lakes (> 10 m), lakes with self-sustaining trout populations in inlets and outlets, and lakes with abundant trout spawning habitat. Rotenone, however, is highly toxic to a wide variety of nontarget organisms, including amphibians, zooplankton, and benthic invertebrates (Cushing & Olive 1957; Anderson 1970; Neves 1975; Chandler & Marking 1982), and these negative effects can persist for at least several years (Anderson 1970). In contrast, gill netting has no negative effects on non-target organisms.

The lack of gill net effects on nontarget organisms is especially important when sensitive native species are present in a water body being considered for trout eradication. For example, we have identified several Sierra Nevada lakes that contain nonnative trout and small, remnant populations of the mountain yellow-legged frog (Matthews & Knapp, unpublished data). Eradication of trout from these lakes is critical for the recovery of these amphibian populations, but rotenone application, while quick and relatively inexpensive, may reduce or eliminate the frog population. In addition to the utility of gill nets in eradicating trout for management purposes, the use of gill nets to remove trout may also have substantial scientific value. For example, we are currently studying the recovery of ecosystem structure and function in several Sierra Nevada lakes after the removal of trout with gill nets (Knapp & Sarnelle, unpublished data). While gill netting allows the fish to be removed with no disturbance to other ecosystem components, the use of rotenone might introduce unacceptable confounding factors into the experiment associated with its effects on nontarget organisms and ecosystem processes.

We conclude that, under some conditions, the use of gill nets is a viable alternative to rotenone for eradication of trout populations from mountain lakes. We stress, however, that although gill netting may be an effective fish population management tool and may have substantial scientific value, there are many situations in which gill netting will not be effective. Under these conditions, the application of rotenone is currently the only effective means of eradicating trout from lakes.

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LITERATURE CITED

Anderson, R. S. 1970. Effects of rotenone on zooplankton communities and a study of their recovery patterns in two mountain lakes in Alberta. Journal of the Fisheries Research Board of Canada **27:**1335–1356.

Anderson, R. S. 1980. Relationships between trout and invertebrate species as predators and the structure of the crustacean and rotiferan plankton in mountain lakes. Pages 635–641 in W. C. Kerfoot, editor. Evolution and ecology of zooplankton communities. University Press of New England, Hanover, New Hampshire.

Bahls, P. F. 1990. Ecological implications of trout introductions to lakes of the Selway Bitterroot Wilderness, Idaho. M.S. thesis. Oregon State University, Corvallis, Oregon.

Bahls, P. F. 1992. The status of fish populations and management of high mountain lakes in the western United States. Northwest Science **66:**183–193.

Bradford, D. F. 1989. Allotopic distribution of native frogs and introduced fishes in high Sierra Nevada lakes of California: implication of the negative effect of fish introductions. Copeia **1989:**775–778.

Bradford, D. F., F. Tabatabai, and D. M. Graber. 1993. Isolation of remaining populations of the native frog, *Rana muscosa*, by introduced fishes in Sequoia and Kings Canyon National Parks, California. Conservation Biology **7:**882–888.

Bjornn, T. C., and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication **19:**83–138.

California Department of Fish and Game. 1994. Rotenone use for fisheries management. Programmatic environmental impact report (SCH #92073015). Inland Fisheries Division and Environmental Services Division, Sacramento, California.

Carline, R. F. 1980. Features of successful spawning site development for brook trout in Wisconsin ponds. Transactions of the American Fisheries Society **109:**453–457.

Carlisle, D. M. 1995. The effects of exotic trout on invertebrate assemblages of Uinta mountain lakes. M.S. thesis. Utah State University, Logan, Utah.

Carpenter, S. R., J. F. Kitchell, and J. R. Hodgson. 1985. Cascading trophic interactions and lake productivity. BioScience **35:** 634–639.

Chandler, J. H., Jr., and L. L. Marking. 1982. Toxicity of rotenone to selected aquatic invertebrates and frog larvae. Progressive Fish-Culturist **44:**78–80.

Cole, D. N., and P. B. Landres. 1996. Threats to wilderness ecosystems: impacts and research needs. Ecological Applications **6:** 168–184.

Cushing, C. E., and J. R. Olive. 1957. Effects of toxaphene and rotenone upon the macroscopic bottom fauna of two northern Colorado reservoirs. Transactions of the American Fisheries Society **86:**294–301.

De Gisi, J. S. 1994. Year class strength and catchability of mountain lake brook trout. M.S. thesis. University of British Columbia, Vancouver, British Columbia, Canada.

Donald, D. B., and D. J. Alger. 1989. Evaluation of exploitation as a means of improving growth in a stunted population of brook trout. North American Journal of Fisheries Management **9:**177–183.

Dudley, T., and M. Embury. 1995. Non-indigenous species in wilderness areas: the status and impacts of livestock and game species in designated wilderness in California. Unpublished file report. Pacific Institute for Studies in Development, Environment, and Security, Oakland, California.

Foreman, D., and H. Wolke. 1992. The big outside: a descriptive inventory of the big wilderness areas of the United States. Crown Publishers, Harmony, New York.

Fraser, J. M. 1982. An atypical brook charr (*Salvelinus fontinalis*) spawning area. Environmental Biology of Fishes **7:**385–388.

Hall, D. L. 1991. Growth, fecundity, and recruitment responses of stunted brook trout populations to density reduction. Dissertation. University of British Columbia, Vancouver, British Columbia, Canada.

Jenkins, T. M., Jr., R. A. Knapp, K. W. Kratz, S. D. Cooper, J. M. Melack, A. D. Brown, and J. Stoddard. 1994. Aquatic biota in the Sierra Nevada: current status and potential effects of acid deposition on populations. Report no. A932–138. California Air Resources Board, Sacramento, California.

Kiester, A. R., J. M. Scott, B. Csuti, R. F. Noss, B. Butterfield, K. Sahr, and D. White. 1996. Conservation prioritization using GAP data. Conservation Biology **10:**1332–1342.

Knapp, R. A. 1996. Non-native trout in natural lakes of the Sierra Nevada: an analysis of their distribution and impacts on native aquatic biota. Sierra Nevada Ecosystem Project: Final Report to Congress. Volume III, Chapter 8. Assessments, commissioned reports, and background information. Centers for Water and Wildland Resources, University of California, Davis, California.

Knapp, R. A., and V. T. Vredenburg. 1996. Spawning by California golden trout: characteristics of spawning fish, seasonal and daily timing, redd characteristics, and microhabitat preferences. Transactions of the American Fisheries Society **125:** 519–531.

Langeland, A. 1986. Heavy exploitation of a dense resident population of Arctic char in a mountain lake in central Norway. North American Journal of Fisheries Management **6:** 519–525.

Leavitt, P. R., D. E. Schindler, A. J. Paul, A. K. Hardie, and D. W. Schindler. 1994. Fossil pigment records of phytoplankton in trout-stocked alpine lakes. Canadian Journal of Fisheries and Aquatic Sciences **51:** 2411–2423.

Liss, W. J., and G. L. Larson. 1991. Ecological effects of stocked trout on North Cascades naturally fishless lakes. Park Science **11:**22–23.

Murray, M. P. 1996. Natural processes: wilderness management unrealized. Natural Areas Journal **16:**55–61.

Neves, R. 1975. Zooplankton recolonization of a lake cove treated with rotenone. Transactions of the American Fisheries Society **104:**390–393.

Noss, R. F. 1993. A bioregional conservation plan for the Oregon Coast Range. Natural Areas Journal **13:**276–290.

Rowan, D. E. 1996. Effect of fish and habitat factors on benthic invertebrate communities in high-elevation lakes. M.S. thesis. New Mexico State University, Las Cruces, New Mexico.

Scott, J. M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T. C. Edwards, Jr., J. Ulliman, and R. G. Wright. 1993. Gap analysis: a geographical approach to protection of biological diversity. Wildlife Monographs **123:**1–41.

Soiseth, C. R. 1992. Autecology of young-of-the-year brook trout (*Salvelinus fontinalis*) in the Emerald Lake system (Sierra Nevada, California). M.S. thesis. University of California, Santa Barbara, California.

Solman, V. E. F. 1950. History and use of fish poisons. Transactions of the American Fisheries Society **69:**141–157.

Stoddard, J. L. 1987. Microcrustacean communities of high-elevation lakes in the Sierra Nevada, California. Journal of Plankton Research **9:**631–650.

U.S. Forest Service. 1992. Harvey Monroe Hall Research Natural Area Management Plan. Unpublished file report. Inyo National Forest, Mono Lake Ranger District, California.

Wright, R. G., J. G. MacCracken, and J. Jall. 1994. An ecological evaluation of proposed new conservation areas in Idaho: evaluating proposed Idaho national parks. Conservation Biology **8:**207–216.

Wurtsbaugh, W. A., R. W. Brocksen, and C. R. Goldman. 1975. Food and distribution of underyearling brook and rainbow trout in Castle Lake, California. Transactions of the American Fisheries Society **104:**88–95.