Evaluating Effects of Fish Stocking on Amphibian Populations in Wilderness Lakes

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Abstract—To balance wilderness lake use between recreational fisheries and protected habitat for native species, managers need to understand how stocking non-native predaceous fish affects amphibian populations within a landscape. The goal of this paper is to help managers design and conduct studies that will provide such information. Desirable study characteristics include multiple-visit surveys of all wetlands within a watershed to provide information on amphibian distribution, abundance, breeding, recruitment and seasonal variation in habitat use. By identifying the distribution of critical amphibian habitat and source populations, this approach should enable managers to target specific lakes for protection or restoration as fishless amphibian habitat without overly compromising wilderness fishing opportunities.

> Wild areas, large or small, are likely to have values as norms for land science. Recreation is not their only, or even principal utility.
>
> —Aldo Leopold, Sand County Almanac

In the last few years, the long-accepted practice of stocking "sport fish" in wilderness lakes has attracted both professional and public attention (Forstenzer 1998; Knapp 1994; Matthews and Knapp 1999; Murray 1994; Yuskavitch 1999). Concern that introduced trout may be threatening the persistence of native species has put pressure on managers to evaluate stocking practices and their impacts on native biota. After decades of providing recreational fisheries for backcountry anglers, state and federal agencies are now reconsidering how to manage wilderness lakes (Duff 1995; Fraley 1996; Gill and Matthews 1998; Rahel 1997).

Responding to these concerns, several agencies have initiated studies to examine the impacts of fish stocking in federally designated wilderness and other protected public lands. Many of these studies are focusing on fish-amphibian interactions to determine whether introduced trout may be contributing to the documented decline of amphibian species from the mountainous regions of the western United States (Blaustein and others 1994; Corn, in press; Fellers and Drost 1993; Fisher and Shaffer 1996; Hayes and Jennings 1986).

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Wilderness Fish Stocking

Despite the apparent novelty of concerns over wilderness fish stocking, organized dialogue among public interest groups, biologists and managers actually began more than two decades ago. In 1976, the American Fisheries Society and the International Association of Game, Fish, and Conservation Commissioners held a symposium entitled Management of Wilderness Area Waters (Gottschalk 1976). Recently, in October 1998, biologists and managers convened again to discuss the Effects of Fisheries Management on the Amphibians and Other Biota of Wilderness Lakes (Corn and Knapp, this volume). Both of these meetings emphasized that potential legal, social and biological problems exist for wilderness fish stocking, additional research is needed to evaluate the scope of the problem, and wilderness fish stocking policies require adaptive management between state fisheries agencies and federal land managers.

The legal, social and biological controversies surrounding wilderness fisheries issues can be summarized as follows. Due to the steep topography of the western United States, few fish colonized mountain watersheds since the last glaciation, so approximately 95% of roughly 16,000 high-elevation lakes were historically fishless. However, in the last century, sportsman clubs and state game agencies have stocked over 60% of these high mountain lakes, including about 95% of the larger (>2 ha surface area), deeper (>3 m maximum depth) lakes that looked like they might support fish (Bahls 1992). The widespread introduction of regionally exotic and locally non-native trout (such as eastern brook trout, *Salvelinus fontinalis*) into historically fishless lakes has dramatically altered these communities. Finally, most high-elevation lakes are located in wilderness and national parks, areas set aside to remain "untrammeled by man" and provide protected habitat for native species (Hendee and others 1990). Consequently, conflicts between state management of wilderness fisheries (section 4(d)(8) of the 1964 Wilderness Act; P.L. 88-577) and federal mandate to protect the biological integrity of wilderness (USDA 1986; USDA 1990) are inherent.

Comparative studies of high-elevation lakes with and without introduced trout have suggested that fish reduce or eliminate some amphibian species from stocked lakes (Bradford 1989; Braña and others 1996; Funk and Dunlap, in press; Knapp and Matthews, this volume; Liss and Larson 1991; Munger and others 1997; Pilliod and Peterson 1997; Tyler and others 1998a). Although the causes of this negative relationship remain uncertain, controlled experiments (Tyler and others 1998b) and field observations (Braña and others 1996; Tyler and others 1998a) indicate that fish predation on embryonic and larval life stages is responsible.

Although several studies have documented the effects of introduced fish on amphibian populations on a lake-by-lake basis, few studies have addressed these effects within a spatial context. Future studies need to look at watersheds as systems, identifying sources and sinks and prioritizing areas of critical amphibian habitat, so that information is available to target specific lakes for management actions. The goal of this paper is to provide information to help managers design and conduct such studies, and evaluate possible management actions. Our recommendations were developed from reviewing the literature and conducting a five-year, landscape-scale amphibian and trout study in 73 headwater lakes in the Frank Church-River of No Return Wilderness, Idaho. This paper is structured around six key questions that managers should try to answer when setting up and conducting these studies.

1. What Pre-Existing Information Can Help Evaluate Threats and Plan a Study?

One of the first steps in evaluating the potential threats of trout stocking in an area is to determine which amphibian and fish species may occur there. At least some of this information may be obtained from existing sources, such as state databases maintained by natural heritage programs and state fish and wildlife agencies. State databases often include hard-to-find information such as museum records, agency reports and contributed field observations. State GAP Analysis programs may also provide some of these data, including current and predicted distribution maps. State and federal agency biologists may be able to provide a list of studies that have been conducted in a geographical area as they are usually more familiar with the considerable amount of data available in the gray literature (such as government reports). Finally, state fish and wildlife agencies can provide a fish stocking history of specific waters, although these data generally do not represent fully accurate and complete fish distributions because of historic name-changes, pilot error and fish colonization.

Identifying which species require attention, such as state and/or federally listed species, is important and may be information best obtained from a local or regional herpetologist for several reasons. First, formal designations may not reflect current or local status; some species may be declining locally, and there are time lags before species are placed on Endangered, Threatened or Species of Special Concern lists. In addition, the trend in molecular systematics is to split species, in which case single species may become two or more. For example, the spotted frog (formerly *Rana pretiosa*) was shown to be made up of two species, the Oregon spotted frog (*Rana pretiosa*) and the Columbia spotted frog (*Rana luteiventris*) (Green and others 1997). This change in taxonomy influences the status, distribution and management of these frogs. *Rana pretiosa* now refers only to populations in the Pacific Northwest. These have undergone serious declines compared to *Rana luteiventris*, which is widely distributed and common in the northern Rocky Mountains.

After identifying the potential species and their status in an area, the next step is to prioritize which amphibians should be targeted for surveys by determining whether any life stages of a species may occur in fish habitat. Amphibian species with minimal interaction with trout are likely those that breed in ephemeral wetlands (pools, wet meadows) and over-winter in terrestrial locations. Tree frogs, spadefoots and some salamanders fit these life history characteristics. Species with the greatest interaction with fish are those that breed and over-winter in permanent wetlands (lakes, ponds, creeks). Many anurans and some salamanders fall into this category, such as spotted frogs, mountain yellow-legged frogs (*Rana muscosa*), leopard frogs (*Rana pipiens*) and larval long-toed salamanders (*Ambystoma macrodactylum*).

Susceptibility to predation also should be considered when deciding on which species to focus. For example, many stream-dwelling salamanders and newts are able to coexist with trout because of behavioral and chemical defenses (Kats and others 1988; Petranka and others 1987; Sih and others 1992). Many toads also have toxic or repellent skin secretions in the egg, larval and adult life stages that enable them to coexist with predaceous fish (Jones and others 1999; Voris and Bacon 1966).

Future studies need to investigate variation in predation pressures of different trout species commonly stocked in mountain lakes. For example, in some circumstances, eastern brook trout may have stronger effects on zooplankton (Anderson 1980) and amphibian (Bahls 1990) communities than do other species of trout. However, other studies suggest that the feeding behaviors of brook and cutthroat trout (*Oncorhynchus clarki*) are fairly similar (Carlisle and Hawkins 1998).

2. What Techniques Are Appropriate for Landscape-Scale Studies?

There is a range of techniques that can be used to determine the distribution and abundance of amphibians in different habitats (see Heyer and others (1994) and Olson and others (1997)). For example, a variety of techniques can be employed to sample the different life stages of three common, lentic-breeding amphibians found in the Pacific Northwest (Table 1). Although no single technique is appropriate for sampling all species or even all life stages of one species across different habitats, one of the most common survey techniques is the visual encounter survey (VES).

Visual encounter surveys are particularly reliable for many lentic-breeding amphibians (especially ranid frogs) in habitats with relatively low structural complexity (sparse aquatic vegetation, firm substrate and delineated shoreline). In large marshes with dense vegetation, we recommend other techniques, such as trapping.

Because Thoms and others (1997) provide an excellent description of the VES technique, we will not elaborate here other than to emphasize a few points relevant to surveying lakes with fish. First, surveys should include any wetlands adjacent to lakes (such as ephemeral pools, wet meadows) because these sites are often utilized by breeding amphibians when fish are present in a lake. In addition, because amphibian larvae generally become less active and seek cover in lakes with fish (Taylor 1983; Tyler and others 1998a), dip-netting aquatic vegetation, submerged woody debris and unconsolidated bottoms may be particularly important to detect this life stage (Wassersug 1997).

Enumerating the life stages of amphibians observed during VES's can provide important abundance information, even though these data may or may not be indicators of

Table 1—A summary of collection and detection techniques for three common lentic-breeding amphibians found in the Pacific Northwest.

Species life stage	Location	Season	Techniques[a]	Difficulty[b]	Remarks
Long-toed Salamander (*Ambystoma macrodactylum*)					
Adult - breeding	lakes, ponds, creeks	late winter/early spring	aft, pit, ves, cov	easy	
Adult - active	wetlands, uplands	spring - summer	cov, pit	difficult	best during rain
Eggs	lakes, ponds, oxbows	late winter/early spring	ves	easy	eggs deposited at ice-out
Larvae	lakes, ponds, oxbows	all year, may over-winter	aft, dip, snk	easy	in shallows & open water
Metamorphs	under cover at shoreline	late summer	pit, cov	difficult	
Juveniles	uplands	spring - summer	pit, cov	difficult	
Western Toad (*Bufo boreas*)					
Adult - breeding	lakes, ponds, creeks	spring - summer	ves, cal, lit	variable	
Adult - active	wetlands, uplands	spring - fall	ves, drv	variable	crepuscular
Eggs	lakes, ponds, oxbows	spring - summer	ves	moderate	may be covered by silt
Larvae	lakes, ponds, oxbows	all year, may over-winter	ves, dip	easy	aggregate in shallows
Metamorphs	shoreline	summer - fall	ves, pit, cov	easy	may be very numerous
Juveniles	wetlands, uplands	spring - fall	ves	difficult	
Columbia Spotted Frog (*Rana luteiventris*)					
Adult - breeding	lakes, ponds, oxbows	spring	ves, dip, pit	variable	calls difficult to hear
Adult - active	riparian, wetlands	spring - fall	ves, dip, pit	easy	near water or in wet meadows
Eggs	lakes, ponds	spring	ves	easy	floating, communal oviposition sites
Larvae	lakes, ponds, oxbows	spring - summer	ves, dip, aft	easy	may hide in bottom detritus
Metamorphs	shoreline, meadows	late summer - fall	ves, pit	easy	
Juveniles	riparian, wetlands	spring - fall	ves, dip, pit	easy	

[a]Techniques: aft-aquatic funnel traps, cal-calling surveys, cov-turning cover, dip-dip netting, drv-night driving, lit-spot lighting, pit-pitfall traps, sho-electroshocking, snk-snorkeling, ves-visual encounter surveys. Techniques in table are listed in the order of effectiveness.
[b]Difficulty: Estimate of the difficulty of detecting individual animals under optimal conditions using appropriate techniques.

population size. Amphibian population sizes are notoriously variable, partly as a function of the number present (which is complicated by episodically high mortality or recruitment, and seasonal movements) and the weather conditions during the survey. For example, determining whether low numbers of individuals observed during a survey is due to a population crash, seasonal migration away from a lake or low observation rates associated with weather is difficult. Furthermore, the VES may be particularly unreliable for enumerating amphibians in certain habitats. In a survey of 115 marshy wetlands in Utah's west desert, fewer than 200 adult spotted frogs were observed, despite the presence of nearly 7,000 egg masses (Ross and others 1994).

Despite these caveats, in some circumstances, abundance data may be fairly reliable and provide information not represented by presence-absence analyses (see section 5). In our spotted frog surveys, we usually observed only 50% of the frogs at each site (even when we thought we had seen all the frogs), yet we were able to confidently categorize frog populations as low or high after obtaining similar results from several visits. We verified these results using mark-recapture, which certainly provides the most unambiguous information on abundance and seasonal habitat use, but may be beyond the scope of most studies.

3. How Should Sampling Effort Be Spatially and Temporally Distributed?

Ideally, all wetlands in a study area should be sampled, providing a complete survey (Fellers 1997). However, time and monetary constraints rarely permit this level of effort, so we suggest stratified sampling at the watershed level. In other words, surveying all wetlands within randomly or systematically chosen watersheds (for example, selecting on topography or stocking history). Watershed-level sampling should provide the most unbiased, complete information about the distribution, breeding and habitat use patterns of amphibians across a landscape at a scale that can be used by managers to effectively manage for fish and amphibians (Pilliod and Peterson, unpublished data).

An advantage to subsampling at the watershed scale is a reduction in the amount of travel time between distant sites. When working in remote locations, surveying all wetlands within fewer watersheds is usually more efficient than surveying only a few wetlands in each.

A limitation of this approach is that it concentrates survey efforts at a few locations. Subsampling wetlands over a larger area would improve generality; however, this approach loses the spatial context of amphibian distribution, abundance, and habitat use patterns that is needed to make effective management decisions. In the first year (1994) of our study, we subsampled wetlands across seven watersheds, based on stocking history (Pilliod and others 1996). In each watershed, lakes to be sampled were chosen from 1:24,000 topographical maps. This site-selection strategy missed unmapped smaller ponds and wet meadows that were important breeding habitat for amphibians. As a result, in 1994, we greatly underestimated the amount of frog reproduction and completely missed one of the major source populations in a watershed. Subsampling at the wetland level erroneously indicated a worse situation for frogs than did comprehensive surveys conducted at the watershed level in subsequent years (Pilliod and Peterson 1997).

If resources are available, sites should be visited several times per year. Visiting a site only once provides potentially unreliable occurrence data (it is usually difficult to detect all species and life stages that occur at a site). In addition, some amphibian species use different habitat depending on the time of year or weather conditions, resulting in seasonal variability in occurrence and abundance. Performing two to three surveys in a year at all wetlands in a watershed should provide adequate and reliable information about occurrence and relative abundance, as well as important life history and habitat use information. If possible, conducting an additional survey in the spring of the following year will allow evaluation of between-year variability in the populations, as well as provide data on the survival of metamorphs through their first winter.

In our study, we tried to survey each site two to three times per year. The first survey was conducted in early July, one to two weeks after ice-out. This early-season survey enabled us to detect oviposition sites, count egg masses or tadpoles, count adults congregated at oviposition sites and count juveniles (an indicator of relative recruitment from the previous year's cohort). A second survey was conducted in early to mid-August to verify the reliability of VES data and to document use of summer foraging areas. Finally, we conducted a third survey in early September, when air temperatures were beginning to drop but before nighttime temperatures were cool enough to form ice. This late-season survey allowed us to document congregations of adults and juveniles at over-wintering locations, which were often sites not used by frogs in the spring and summer. For example, in the spring and summer, most frogs were isolated from trout in shallow breeding ponds or wet meadows. However, in the fall, many frogs congregated at deeper lakes, most of which contained trout, presumably to over-winter at ice-free depths. Late surveys also enabled us to document reproductive success, in terms of the number of metamorphs observed, compared with the number of egg masses or tadpoles previously counted.

Conducting landscape-scale studies involving multiple comprehensive surveys requires a significant amount of time and effort. We do not want to discourage studies with limited resources, but realizing that limited data can be misinterpreted is important. Using available resources for obtaining more complete information about a few areas is better than sparse and incomplete information across a larger region. The consequences of this approach are that information for management will be available for some areas, but not for others.

4. Can Amphibian Surveys Be Integrated Into Fisheries Studies to Evaluate Fish Stocking?

The considerable overlap of information gathered during fisheries and amphibian studies provides an opportunity for fisheries biologists to collect information about amphibians while conducting fish surveys. We wish to encourage this collaboration, but we emphasize the importance of effectively integrating herpetological sampling with existing fisheries research. For example, simply surveying for amphibians at sites visited for fisheries research may provide useful baseline information about amphibian occurrence, but inadequate data on abundance and habitat use within a watershed. Fisheries studies rarely include ephemeral sites such as ponds and flooded meadows, which usually do not contain trout, but are often used by breeding amphibians. Furthermore, most fisheries studies visit each site once, missing information on seasonal habitat use of amphibians.

For fisheries biologists to provide data appropriate for managing for fish and amphibians, we recommend the following. Two field biologists, trained in amphibian identification, should accompany the fisheries crews, performing amphibian VES's at stocked lakes and all other wetlands within a watershed. As this team will spend more time in each watershed and return to watersheds to complete mid- and late-summer surveys, they may only be able to visit one third to one half of the watersheds that fish crews visit. Although this strategy will result in fewer areas surveyed, this approach should provide the necessary data for making effective management decisions in those areas.

5. What Information Is Needed to Evaluate Effects of Fish Stocking?

Most studies have approached this question on a lake-by-lake basis, documenting the occurrence and occasionally abundance of amphibians in lakes with and without trout. However, few studies have addressed these relationships within a spatial context (but see Bradford and others 1993). We recommend documenting the spatial and temporal distribution and abundance of the different life stages of amphibians in all wetlands to identify the spatial configuration of source populations and critical amphibian habitat within a watershed. This information can then be used to target specific lakes or groups of lakes that should be managed as amphibian reserves, instead of recreational fisheries.

Studies of this nature need to document occurrence, as well as abundance, of post-metamorphic amphibians because amphibians often colonize fringe habitat; occurring as very small sub-populations maintained by frequent immigration. For example, in our research, we found that spotted frogs were just as likely to occur in stocked and fishless lakes (78% and 84%, respectively), yet the abundance of frogs was significantly lower in the stocked lakes (fig. 1). Typically, the stocked lakes contained fewer than 10 post-metamorphic frogs. Munger and others (1997) found similar results for spotted frog and long-toed salamander populations in the Sawtooth Wilderness, Idaho. These studies suggest that documenting presence-absence of a species, without considering abundance, may be inadequate for determining the effects of introduced trout on amphibian populations.

Furthermore, many studies have assumed that the presence of amphibian reproduction at a site indicates a sustainable population, however this also may be misleading. In our study, we observed spotted frog tadpoles in 40% of the stocked lakes, yet few of those tadpoles survived to metamorphosis or through their first winter; resulting in very low recruitment of juveniles into those populations (fig. 2). This low recruitment indicates that stocked lakes may be population sinks, maintained only by colonization from source populations in surrounding fishless lakes (Hoffman and Pilliod 1999).

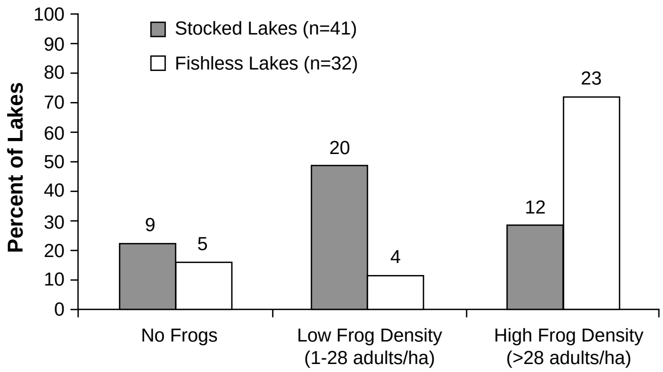

Figure 1—Differences between adult spotted frog occurrence and abundance in stocked (patterned bars) and fishless (open bars) lakes. Although frogs were just as likely to occur in stocked and fishless lakes (X^2 = 0.464, df = 1, p = 0.496), stocked lakes had significantly lower densities of adult frogs than fishless lakes (X^2 = 13.799, df = 1, p<0.001). Densities were estimated as the average number of frogs observed per area searched (lake perimeter x 4) at each lake from 1994 to 1998. High and low frog densities represent lakes with frog densities above or below the median density for all lakes (28 adults/ha). The number of lakes in each category is given above each bar.

Figure 2—The percentages of stocked (patterned bars) and fishless (open bars) lakes without spotted frog breeding, with breeding but no recruitment, and with breeding and recruitment. The majority of stocked lakes had no breeding, whereas the majority of fishless lakes had both breeding and recruitment (X^2 = 11.043, df = 2, p = 0.004). Recruitment was based on the proportion of one-year-old juveniles observed in the spring relative to the number of adults and juveniles from the previous year. The number of lakes in each category is given above each bar.

In addition, studies need to examine the seasonal habitat use patterns of amphibians within a watershed, to avoid missing important habitat conflicts between fish and amphibians. Despite a common misconception that amphibians hatch, live, and die in the same body of water, many amphibians require and utilize different habitat over the course of a year or lifetime (Duellman and Trueb 1986). Because many amphibians over-winter in similar habitats as fish (ice-free water) and most deep lakes now contain introduced trout (Bahls 1992), amphibians may have to over-winter in lakes with fish (Bradford 1989). Winter predation on amphibians is known to occur even under ice (Emery and others 1972; Griffith, Personal Communication), possibly contributing to low recruitment and low numbers of adults typical of lakes with fish. Furthermore, if frogs migrate from shallow, fishless wetlands to deep, stocked lakes to over-winter, winter predation of frogs from surrounding fishless wetlands could reduce recruitment in those populations as well. The loss of fishless over-wintering habitat may be one of the leading landscape-scale threats to amphibian persistence in mountain lake ecosystems and needs to be addressed in future studies.

Finally, understanding the influences of fish predation on amphibian distribution and abundance, requires an understanding of how habitat characteristics influence the presence of amphibians and fish, and mediate fish predation on amphibians. Several studies have identified certain physical, chemical, and biological lake characteristics that, if not addressed, could confound interpretations of fish effects on amphibians. For example, Bradford (1989) found that maximum lake depth influenced the occurrence of trout and mountain yellow-legged frog tadpoles, because shallow lakes (<1.5 m) did not provide over-wintering habitat for either taxa. Tyler and others (1998a) found long-toed salamander densities were associated with both water chemistry (total Kjeldahl nitrogen) and introduced trout. In lakes with low nitrogen (<0.045 mg/L), salamander densities were low, even when trout were absent. Hence, evaluating the effects of introduced trout was only appropriate in lakes with high nitrogen concentrations. Bradford and others (1998) found that mountain yellow-legged frogs did not successfully breed in acidic lakes (pH <6.0) and rarely bred in lakes with trout. Consequently, they examined the effects of introduced trout only in non-acidic lakes. Finally, biological characteristics, such as shoreline emergent vegetation, may provide refugia for amphibians from fish predators, such that amphibian populations may be able to persist with trout (Hecnar and M'Closkey, 1997; Hoffman and Pilliod, 1999).

6. How Can This Information Be Used to Evaluate Potential Management Actions?

Like many ecological problems, the anthropogenic effects of trout stocking on amphibians can vary for different species and even different populations of the same species under a variety of conditions. This variability makes it difficult to make general management recommendations that will adequately protect all species and their habitats. However, research can greatly improve the evaluation and implementation of effective management actions that may balance the needs of the recreational public with conservation of native species. Ideally, any alterations in stocking practices should strive for the lowest cost-benefit ratio in terms of decreasing threats to amphibian persistence with the fewest changes to current recreational fishing opportunities.

Possible management actions include: (1) ceasing stocking in all lakes, (2) ceasing stocking and possibly removing fish from some lakes, (3) reducing stocking frequency and density, (4) reducing naturally reproducing populations of fish by restricting access to spawning areas and/or gill netting, (5) changing species stocked (cutthroat may be less predatory than rainbow or brook trout), (6) stocking sterile fish, or (7) making no changes in stocking practices if fisheries threats to amphibian persistence are negligible.

Cessation of stocking in all wilderness lakes would most likely benefit amphibians and reduce threats to persistence (fig. 3). Undoubtedly, this action would be extremely unpopular for many anglers and could result in less support for wilderness. Economic impacts on outfitters and guides may also occur. Despite the potential socioeconomic costs of this management strategy, some wilderness proponents argue these costs will be minimal and will not overly jeopardize public support for wilderness (Murray and Boyd 1996). This view appears to be supported by resolutions from potentially opposing groups like the Society for Conservation Biology (SCB) and Trout Unlimited. The SCB recommends "phas[ing] out incongruent stocking practices and restor[ing], where appropriate and feasible, previously damaged ecosystems" (SCB 1995). Trout Unlimited states that it "oppose[s] salmonid stocking in historically documented non-salmonid waters where scientific evaluation indicates that such stocking would be likely to adversely affect native biodiversity" (Trout Unlimited 1998).

An example of the potential costs and benefits of restoring wilderness lakes through the cessation of fish stocking comes from the National Park Service, which recommended phasing out and eventually terminating all fish stocking (NPS 1975). In Sequoia, Kings Canyon and Yosemite National Parks, fish stocking was curtailed in the 1970's and completely halted in 1991. This management decision resulted in the loss of recreational fisheries from 29% to 44% of previously stocked lakes (Knapp 1996). Due to a reduction in the proportion of lakes containing fish, as well as historic differences in stocking intensity, the mountain yellow-legged frog currently has a greater distribution in Kings Canyon National Park, compared with the neighboring John Muir Wilderness, where lakes have continued to be stocked and frog persistence is at risk (Matthews and Knapp 1999).

A similar pattern was observed in the Bitterroot Mountains, Montana where six of 18 stocked lakes (33%) no longer supported trout populations in 1996, following cessation of stocking in 1984 (Funk and Dunlap, in press). Funk and Dunlap (in press) found that long-toed salamanders recolonized five of these currently fishless, but previously stocked lakes within two decades, even in lakes over 5 km from the nearest salamander populations. These studies indicate that widespread cessation of stocking does not result in the loss all trout populations and that amphibians will recolonize lakes after fish disappear.

Cessation of fish stocking, and even removal of fish, in some but not all lakes may be more amenable to recreational anglers. If conducted properly, this management strategy could provide the necessary amphibian habitat for species recovery. The success of this management action, however, is dependent on which lakes are selected for fish elimination. Choosing lakes to be restored to a fishless condition based solely on anthropogenic variables, such as difficulty of access and amount of angler use, may have little effect on reducing threats to amphibian persistence (fig. 3). However, restoring fishless lakes based on their potential for amphibian recolonization and their importance as amphibian habitat should improve the success of this action.

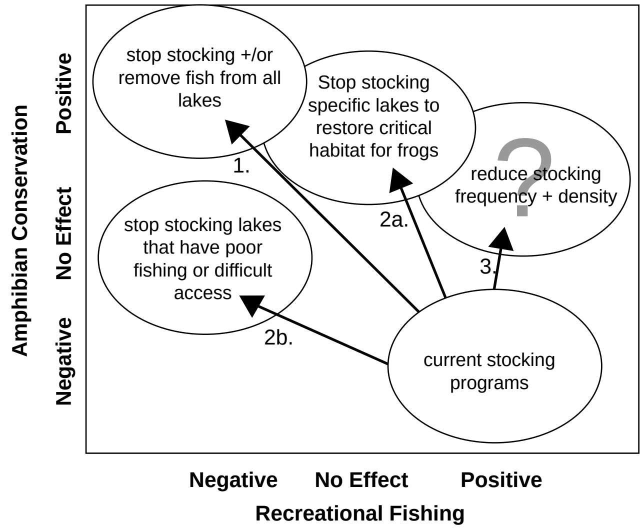

Figure 3—Diagram illustrating the effects of different management actions on recreational fishing and amphibian conservation. 1. Cessation of stocking in wilderness lakes can only help amphibians, however this will be unpopular with anglers. 2a. Restoring some lakes to their fishless state may increase amphibian persistence if lakes provide critical amphibian habitat, but have little affect if not (2b). 3. Reducing fish densities may benefit both frogs and fish, but this remains to be tested.

For fish elimination, we recommend targeting: (1) stocked lakes that already have some amphibian breeding occurring, (2) lakes that appear to provide deep-water overwintering habitat for amphibians in surrounding shallow, fishless lakes, (3) lakes that have the potential for fish elimination (low or no natural reproduction), and (4) lakes that are the least important for recreational anglers. Of these recommendations, the first three should take priority over the last. In our study, over 40% of the stocked lakes had at least some frog reproduction, yet few of these lakes had any frog recruitment. Eliminating fish from a lake where frogs are already breeding should result in faster frog recovery than eliminating fish in a lake that has no amphibian reproduction. Furthermore, restoring lakes that provide over-wintering habitat for amphibians can benefit amphibians both locally and potentially across a watershed. Finally, when selecting a lake for fish elimination, choosing a lake that will require the least amount of invasive management (fish removal) is important. Nonreproducing fish can be eliminated from a lake by simply removing that lake from the stocking schedule. However, if fish removal is required, techniques such as gill netting (Knapp and Matthews 1998), coupled with blocking spawning habitat, are preferable to piscicides, such as rotenone and antimycin A. Both of these chemicals may harm other aquatic vertebrates, including amphibians (Fontenot and others 1994; Schnick 1974), and their use in wilderness is controversial.

The relatively easy, potentially risky, and yet untested management strategies include reducing the frequency, density, species, and/or fertility of fish stocked (fig. 3). This action has the potential to benefit both anglers and amphibians. In the best circumstance, densities of trout could be reduced, even to the point of providing fishless or near fishless habitats for short intervals of time (several years). This strategy may be attractive to the angling public, if larger trout are caught during periods of low fish density (when lakes are designated as "trophy waters"). If amphibians could produce a successful cohort during these intervals, this action could help sustain populations of those amphibians that are long-lived. However, this strategy does not take into consideration the stochastic variables that can greatly influence amphibian recruitment, namely weather. In addition, larger fish have a greater gape and may prey on adult amphibians that were invulnerable to smaller fish (Semlitsch and Gibbons 1988; Zaret 1980). In amphibian populations, threats to older, reproductively mature individuals may be the most damaging to a population's persistence (Green 1997). In yet other circumstances, natural fish reproduction may reduce the effectiveness of this strategy at changing the density or size structure of fish populations. Clearly, further investigation of this strategy is warranted.

Finally, managers should keep in mind that most systems are not isolated, and fish stocking practices in adjacent regions can significantly affect restoration efforts. For example, fish dispersal from upstream locations may colonize wetlands that are actively managed as fishless habitats. In addition, fish predation in streams may act as barriers to migration, dispersal and hence colonization of amphibians (Bradford and others 1993).

Despite the range of possible management actions, we believe the best management strategy is to use species and watershed-specific biological information to make management decisions. This information can be obtained only through carefully designed and conducted studies that provide adequate information about the distribution, abundance and life history characteristics of amphibian species across local landscapes. Hopefully, using appropriate information at the watershed scale will enable managers to restore critical amphibian habitat and the biological integrity of wilderness lakes. Creating a few fishless lakes to provide the necessary habitat requirements of amphibians in a watershed may disproportionately reduce the threats of fish stocking on amphibian persistence. For example, having two amphibian source populations in a watershed, instead of one, may increase the probability of amphibian persistence in that watershed by an order of magnitude. With proper management, we believe amphibian populations can be recovered and protected while maintaining recreational fishing opportunities in many wilderness lakes.

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