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ABSTRACT

Keeley, E. R., P. A. Slaney, and D. Zaldokas. 1996. Estimates of production benefits for salmonid fishes from stream restoration initiatives. Province of British Columbia, Ministry of Environment, Lands and Parks, and Ministry of Forests. Watershed Restoration Management Report 4: 22 p.

We collected and summarized data from 30 studies from the literature to assess the effects of stream restoration efforts on densities of salmonid fish and therefore potential production benefits. This synthesis indicates, in general, that stream restoration efforts provide significant increases in the densities of salmonid fish in streams. This was true for both the juveniles of anadromous salmonids (coho salmon, chinook salmon, and steelhead trout) and total numbers of non-anadromous or resident salmonids (brook, brown, cutthroat and rainbow trout). Similarly, the numbers of catchable-sized resident fish (≥ 15 cm) also appear to increase significantly after stream rehabilitation. Areas of spawnable gravel tend to increase from restoration efforts which should provide more area for spawning fish. Provided assessments of limited spawning area are accurate, restorations may increase the numbers of anadromous salmonids that spawn but do not rear in streams for extended periods (chum, pink and sockeye salmon). Artificially created or newly opened off-channel habitat (side channels and ponds) also provides significant areas for spawning and rearing, providing an average of 225 migrating chum fry · m^{2}, and 0.67 coho salmon smolts · m^{-2}.

We used average changes in fish densities and life-stage survival rates to calculate potential increases in adult numbers as a result of stream restoration efforts. Assuming changes to stream densities translate into increases in adult numbers, then coho salmon, chinook salmon, and steelhead trout adults should increase on average by 123 %. If the reported 8-fold increase in spawnable gravel translates into increased production of chum, pink and sockeye salmon, then adults produced per m^2 of stream should increase on average from 0.39 to 3.37 per m^2 of stream (88%). Juvenile and catchable-sized resident salmonids (brook, brown, cutthroat and rainbow trout) should increase on average from 25 to 73%. Finally, off-channel habitat may potentially produce 1.58 chum salmon adults and 0.066 coho salmon adults per m^2 of side channel and 0.068 coho salmon adults per m^2 of off-channel pond.

ACKNOWLEDGMENTS

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INTRODUCTION

The loss of natural stream landscapes through unsustainable forest practices, urbanization, and agricultural channelization is believed to be a major factor resulting in decreases of fish populations (Nehlsen et al. 1991; Slaney et al. 1996). Because natural stream ecosystems are a pre-requisite for abundant spawning and rearing habitat of stream fishes, the maintenance of valuable fish populations is directly related to the maintenance of healthy stream ecosystems (Murphy and Meehan 1991).

Unfortunately, many coastal and interior streams in the Pacific Northwest have been severely affected by human activities (Hall and Lantz 1969; Slaney 1977a, b; Hogan 1986; Tripp and Poulin 1986; Hartman et al. 1996). The development of B.C.'s Watershed Restoration Program was initiated to help streams recover from the impacts of past forest harvesting practices. The Province of B. C. hopes to accomplish this goal by re-establishing the range of physical and chemical characteristics normally or previously found in natural streams (Slaney 1994; Slaney and Martin 1997). The idea of restoring damaged habitats is not a new one, and since the 1930's a large body of literature has been generated (Koski 1992; Duff et al. 1995). With the continued decline of some salmonid fish stocks (Nehlsen et al. 1991; Slaney et al. 1996), despite the adoption of more stringent conservation guidelines (Department of Fisheries and Oceans 1986), there has been a growth of interest in restoring fish habitat as a means of preserving fish populations (Koski 1992; Gore and Shields 1995; Bradshaw 1996). A wide variety of stream restoration or habitat improvement techniques have been used across many different conditions (Duff et al. 1995). These techniques range from placing physical structures within the stream channel to replace lost habitat complexity, to improving migration routes and re-establishing original channels of stream reaches. By installing physical habitat structures to create rearing and spawning habitat for fishes, as well as returning the stream to naturally sinuous meanders, substrate characteristics, and by recruiting isolated channels and ponds into a drainage area, the Watershed Restoration Program seeks to rehabilitate the provinces' logging-damaged streams.

An important component of the restoration program is to develop an evaluation strategy to assess the effectiveness of restoration efforts and improve future programs (Keeley and Walters 1994); a component often lacking or inadequate in previous restoration programs (Kondolf and Micheli 1995). A key response variable to be monitored in B.C.'s Watershed Restoration Program is the effect of restoration efforts on fish populations (Slaney and Martin 1997). One preliminary approach in evaluating restoration programs is to estimate potential fish production benefits based on previous restoration efforts. The purpose of this technical report is to review the available literature on the effects of stream restoration on salmonid fish production. Using the data we compiled from the literature, we synthesized this information to establish a base-line of expected returns for fish production, given rehabilitation efforts. These data will then assist fisheries biologists in both benefit-cost analyses of stream restoration as well as provide a comparative tool from past projects in which they can evaluate their own restoration efforts. This synthesis focuses on salmonid fishes because most stream restoration projects have compiled information on this group of animals, providing a minimum level of information for comparisons and because salmonids are culturally and economically important to the province of B.C.

METHODS AND MATERIALS

We began our literature search by attempting to compile all published studies with records of fish abundance from as many restoration programs as possible. This included literature searches from primary fisheries journals such as The Canadian Journal of Fisheries and Aquatic Sciences, Transactions of the American Fisheries Society and North American Journal of Fisheries Management. We then used the citations from each article that mentioned other studies, in a manner relevant to stream restoration, to search for secondary data sources. We also used the extensive bibliography compiled by Duff et al. (1995) to search for additional data sources because it provides a comprehensive list of not only primary literature articles, but many of the "grey literature" references as well. Finally, we used telephone contacts to provincial, state, and federal agencies to locate any unpublished data sets.

Our literature survey for data examining the effect of rehabilitation efforts on stream ecosystems was limited to those studies that met several selection criteria. Studies that appeared to be strongly effected by failing or underdesigned structures were not included in our data base. Although the durability of a technique to restore a stream will likely effect overall fish production benefits, we assumed that studies with high structural failure rates (*cf* : Frissell and Nawa 1992) were not representative of correctly located or well designed features (that we are assessing) and were therefore excluded from our analysis. Because salmonid fishes are of primary interest in many restoration studies (including the B. C. Watershed Restoration Program) we estimated potential benefits based on changes to salmonid populations. Studies were included in our data base if they provided an estimate of fish density per unit area of stream. In addition, each rehabilitated or treated area must have had a paired pre-treatment reference level or control area. This type of paired approach provides a much more powerful comparison to detect treatment effects by controlling for inter-study variability (Sokal and Rohlf 1981). If a study met these criteria, we recorded overall fish density and whenever possible we divided the data by species, age-class or size category for more detailed comparisons.

Statistical Analyses

All comparisons were made using a paired sample t-test (Sokal and Rohlf 1981). To ensure that differences between pre-treatment and post-treatment fish densities followed the assumption of being normally distributed, we used the univariate procedure of the SAS statistical program (SAS Institute 1988). When the normality assumption was not met, we used a $\log_{10}$ transformation to normalize the distribution and allow variances to become more homogeneous. Data in figures represents untransformed values plotted on an arithmetic or logarithmic axis.

Side Channels and Ponds

Fisheries biologists have attempted to increase fish habitat by excavating new channels or deepening partial channels where groundwater seepage exists near a proper river channel (Bonnell 1991). Off-channel ponds are also thought to provide important habitat to juvenile salmonids particularly during winter (Peterson 1982 a and b). We attempted to assess fish production benefits by examining data from studies where side channels and ponds were sampled to determine the capacity of this type of habitat to produce fish because this technique is commonly utilized to offset severe impacts to mainstem stream channels.

Estimating Fish Production Benefits

To model changes in production of adult-sized fish based on rehabilitation effects, we calculated numbers of fish produced per unit area of stream in treated areas and for areas with pre-treatment fish densities. Total numbers of adult fish were calculated using a simple model such as:

Number of adult fish (per area of stream) = number juveniles produced (per area of stream) · survival rate of juvenile lifestage.

For anadromous salmonids (coho salmon, *Oncorhynchus kisutch*; chinook salmon *O. tshawytscha*; and steelhead trout, *O. mykiss*) that spawn and have juveniles that rear for an extended period in the stream, we calculated the density of fish at each lifestage such as young-of-the-year (0+ fish), steelhead parr (yearlings and older fish: 1+ and 2+) and then estimated over-winter mortality to smoltification. To calculate number of adults produced we then multiplied smolt number by an ocean survival rate. We used survival rates from Bradford's (1995) review for coho and chinook salmon, and from Ward and Slaney (1988) for steelhead trout.

For anadromous salmonids that spawn in streams but do not rear in them (chum salmon, *Oncorhynchus keta*; pink salmon *O. gorbuscha*; and sockeye salmon *O. nerka*) we estimated potential changes in adult production by calculating changes in spawnable area due to restoration efforts. We then used Keeley and Slaney's (1996) compilation of redd area requirements for each of these species to calculate the number of fish that could spawn per unit area of stream. We divided average fecundity of each species (taken from Groot and Margolis 1991) by redd area and calculated the number of embryos produced per unit area of stream. We then multiplied number of embryos surviving to smoltification using Bradford's (1995) survival rates to calculate number of adults. This can be represented by the following equation:

Number of adults = number of embryos (per area of stream) · survival to smoltification · survival to adult

For non-anadromous or resident salmonids that live throughout their life-span in streams, we calculated fish production benefits by calculating the pre- and post-treatment densities of total salmonid numbers and catchable-sized trout (≥ 15 cm).

To assess potential production from newly created side-channels and ponds as habitat mitigation, we calculated densities of juvenile salmonids produced from each type of habitat based on estimates from the literature. We then multiplied each respective life-stage by its survival rate to calculate potential number of adults produced.

RESULTS

Anadromous Salmonids - Rearing Responses (coho salmon, chinook salmon, steelhead trout)

We found 8 studies that provided paired density estimates for juvenile salmonids from 14 different streams with data for both pre- and post-rehabilitation (Ward and Slaney 1981; Moreau 1984; House and Boehne 1985; 1986; Johnston et al. 1990; Espinosa and Lee 1991; Poulin et al. 1991; Slaney et al. 1994). This enabled us to compare overall effects on salmonid densities, as well as effects on coho and chinook salmon fry and steelhead trout fry and parr.

Overall, salmonid fish density was significantly higher in post-treatment over pre-treatment surveys (paired $t = 3.08$, $n = 15$, $P = 0.0081$; Fig. 1a). On average, densities increased by 123 % over pre-treatment levels; however, there was considerable variation despite our screening process (arithmetic mean difference = 0.53 fish · m^{-2}, ± 0.17 SE). When we compared density changes by species and age-class, we found in most cases that fish density increased significantly. Young-of-the-year coho salmon increased by 77 % (paired $t = 3.15$, $n = 8$, $P = 0.016$), young-of-the-year steelhead trout increased by 52 % (paired $t = 2.73$, $n = 9$, $P = 0.026$) and steelhead parr by 130 % (paired $t = 2.52$, $n = 10$, $P = 0.033$) (Fig. 1b). Chinook salmon juveniles also increased (Fig. 1b); however, these differences were not significant (paired $t = 1.52$, $n = 5$, $P = 0.20$), probably because of the small number of paired samples and low statistical power to detect an effect (Fig. 1b).

Anadromous Salmonids - Non-Stream-Rearing Species (chum, pink, and sockeye salmon)

We found 5 studies that reported changes in spawnable gravel area before and after restoration efforts (Buer et al. 1981; Moreau 1984; West 1984; House and Boehne 1985, 1986). Although these studies measured changes in substrate composition (e.g., from silt to gravel), in most cases they did not examine changes in either egg deposition or spawner use per unit area of stream. Despite the fact the authors of these studies were convinced of the benefits of substrate changes, these results assume that they will translate into increased embryo survival and juvenile production. Regardless, spawnable gravel increased on average by a 8.5-fold increase over pre-rehabilitation levels, providing significant changes in potential spawning area (paired $t = 2.97$, $n = 5$, $P = 0.041$, Fig. 2).

Resident Salmonids - Rearing Responses (brook trout, *Salvelinus fontinalis*; brown trout, (*Salmo trutta*; cutthroat trout, *O. clarki* and rainbow trout, *O. mykiss*)

Six studies reported density estimates for stream resident salmonid fishes for both pre- and post-treatment evaluations (Saunders and Smith 1962; Burgess and Bider 1980; Binns 1994; Binns and Remmick 1994; Oliver 1994; Riley and Fausch 1995). Each of the studies provided data for one species (brook, brown, cutthroat or rainbow trout) and occasionally two allopatric species, in one of 11 different streams. As was the case for anadromous salmonid juveniles, stream resident fish densities increased significantly over pre-treatment levels (paired $t = 6.67$, $n = 11$, $P < 0.0001$, Fig. 3a), with an average increase of approximately 50 %. We were able to detect significant differences when we conducted a species-level analysis for brook trout (paired $t = 4.73$, $n = 7$, $P = 0.0032$, Fig. 3b), but low possible numbers of comparisons ($n = 2$) for brown, cutthroat and rainbow trout precluded a species-level analysis, although mean differences were higher in post-restoration areas for all species (Fig. 3b).

To examine stream restoration efforts on the larger, mature portion of stream resident salmonids as well as overall effects, we re-analyzed Hunt's (1988) compilation of 45 trout streams in Wisconsin that received stream rehabilitation. Each of these streams had pre- and post-treatment density estimates for salmonids (mainly brook and brown trout), and many of them had density estimates for catchable-sized trout (≥ 15 cm). In our re-analysis we only used 43 of the original streams because two of the streams may have been strongly influenced by stocking of hatchery fish. In addition, sample sizes for our comparisons did not always contain all 43 estimates because not all information was reported in the summaries for each stream.

Overall, we again found that restoration efforts had significant influences on fish densities, but they appear to be more modest with an average increase of 18 % (paired $t = 3.17$, $n = 36$, $P = 0.0032$; Fig. 4a). For catchable-sized trout, however, the changes were larger, with an average increase of 34 % over pre-restoration densities (paired $t = 4.03$, $n = 35$, $P = 0.0003$; Fig. 4b).

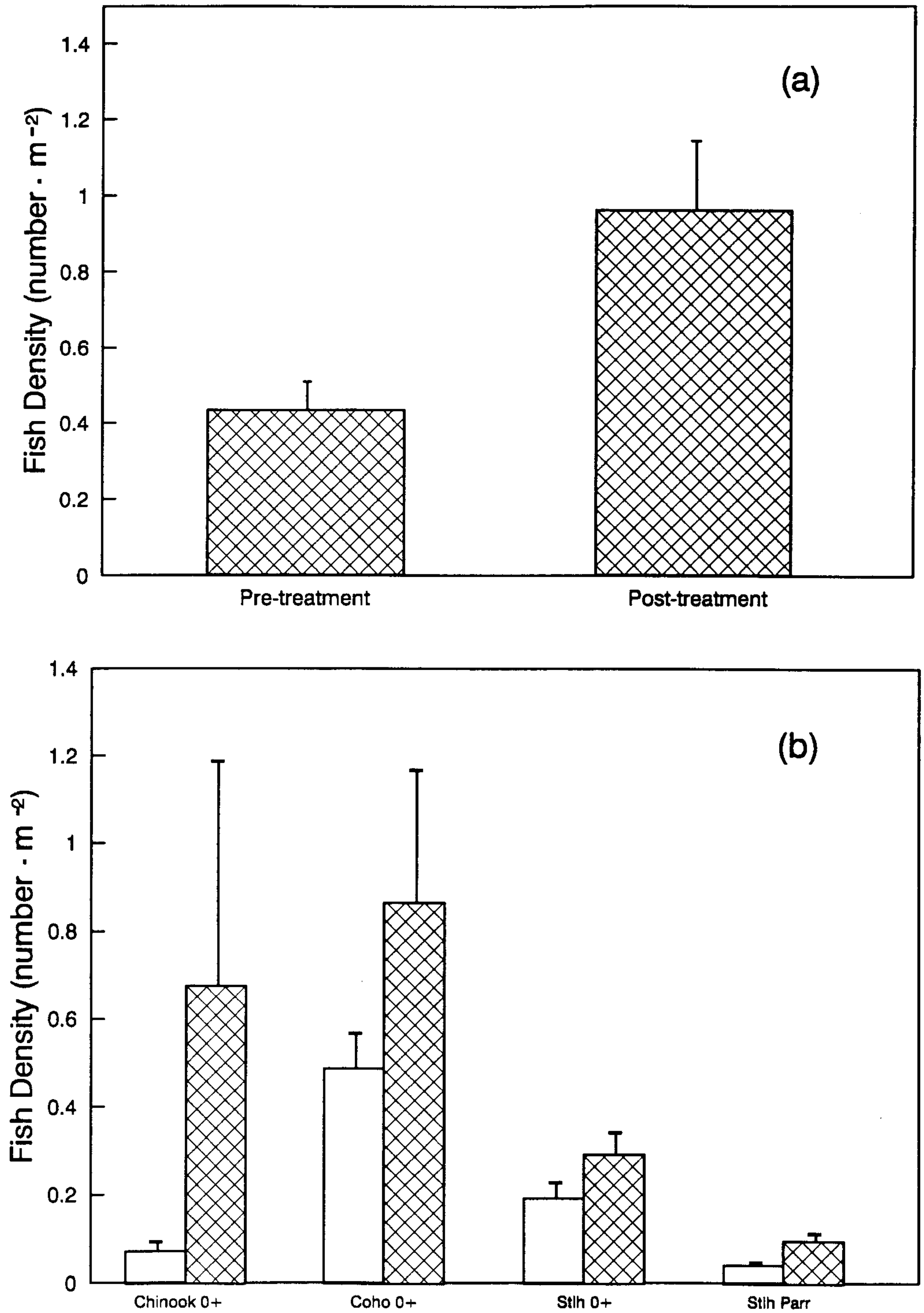

Figure 1 (a) Densities of anadromous salmonid fish juveniles (number · m^{-2} + 1 SE) before and after in-stream rehabilitation efforts. Data are from 14 different streams, see text for sources. (b) Densities of anadromous juvenile salmonids (number · m^{-2} + 1 SE) before (open bars) and after (hatched bars) in-stream rehabilitation efforts. Acronyms depicted as stlh refer to steelhead trout, 0+ designations refer to young-of-the-year. See text for data sources.

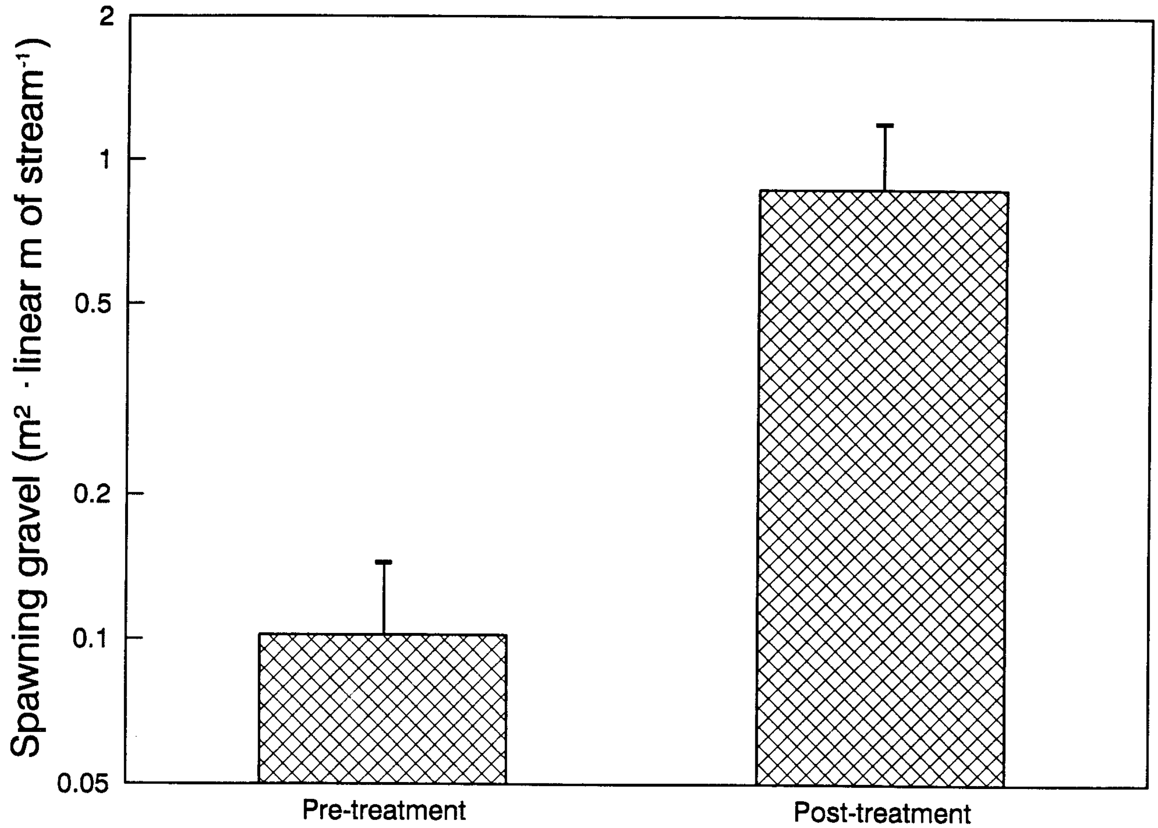

Figure 2. Amount of spawnable gravel (m^2 of gravel per linear meter of stream length + 1 SE) before and after stream restoration efforts. See text for sources of data.

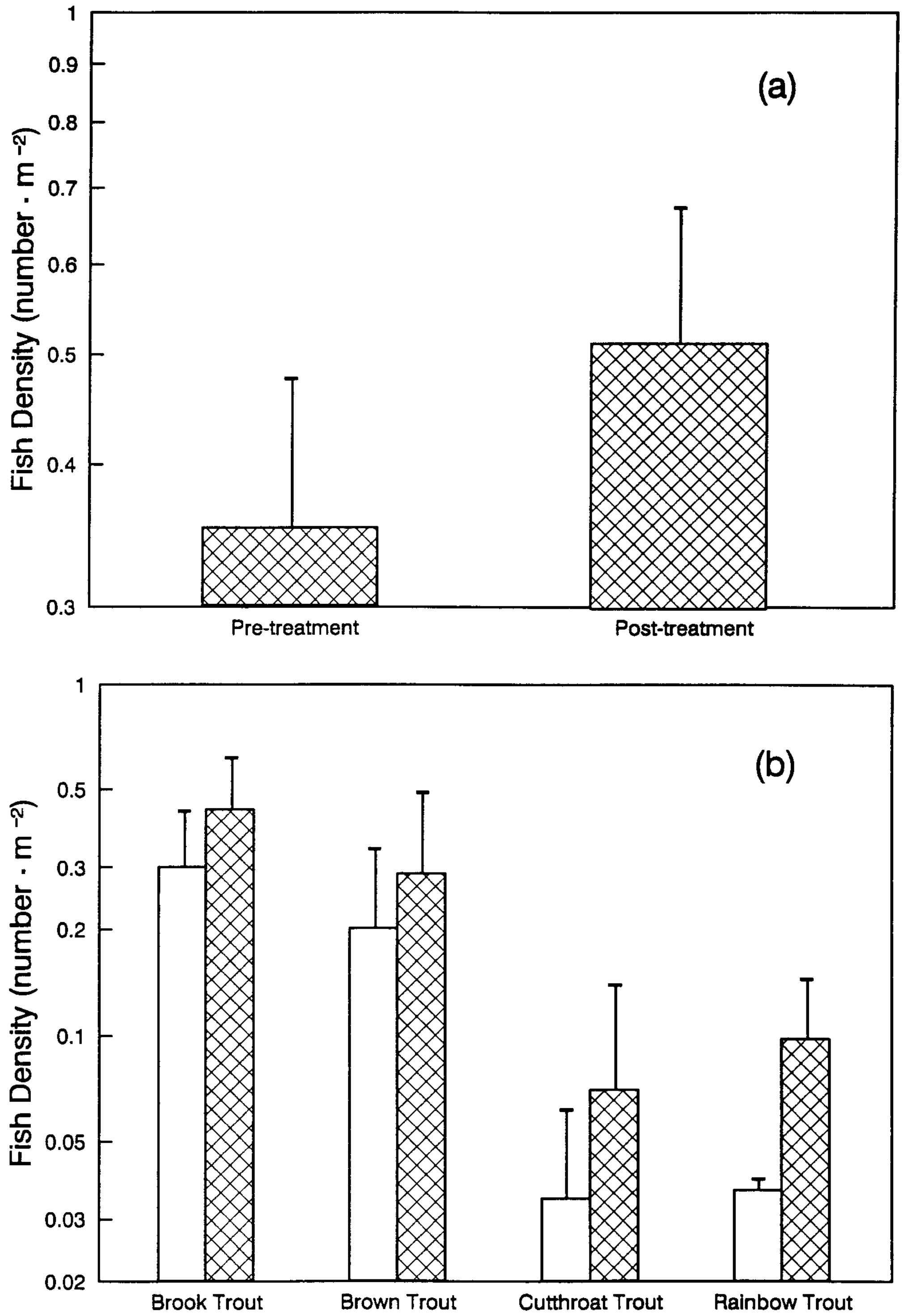

Figure 3 (a) Densities of resident salmonid fish (number · m^{-2} + 1 SE) before and after in-stream rehabilitation efforts. Data are from 11 different streams, see text for sources. (b) Densities of resident salmonid fish (number · m^{-2} + 1 SE) before (open bars) and after (hatched bars) in-stream rehabilitation efforts for 4 different trout species. See text for data sources.

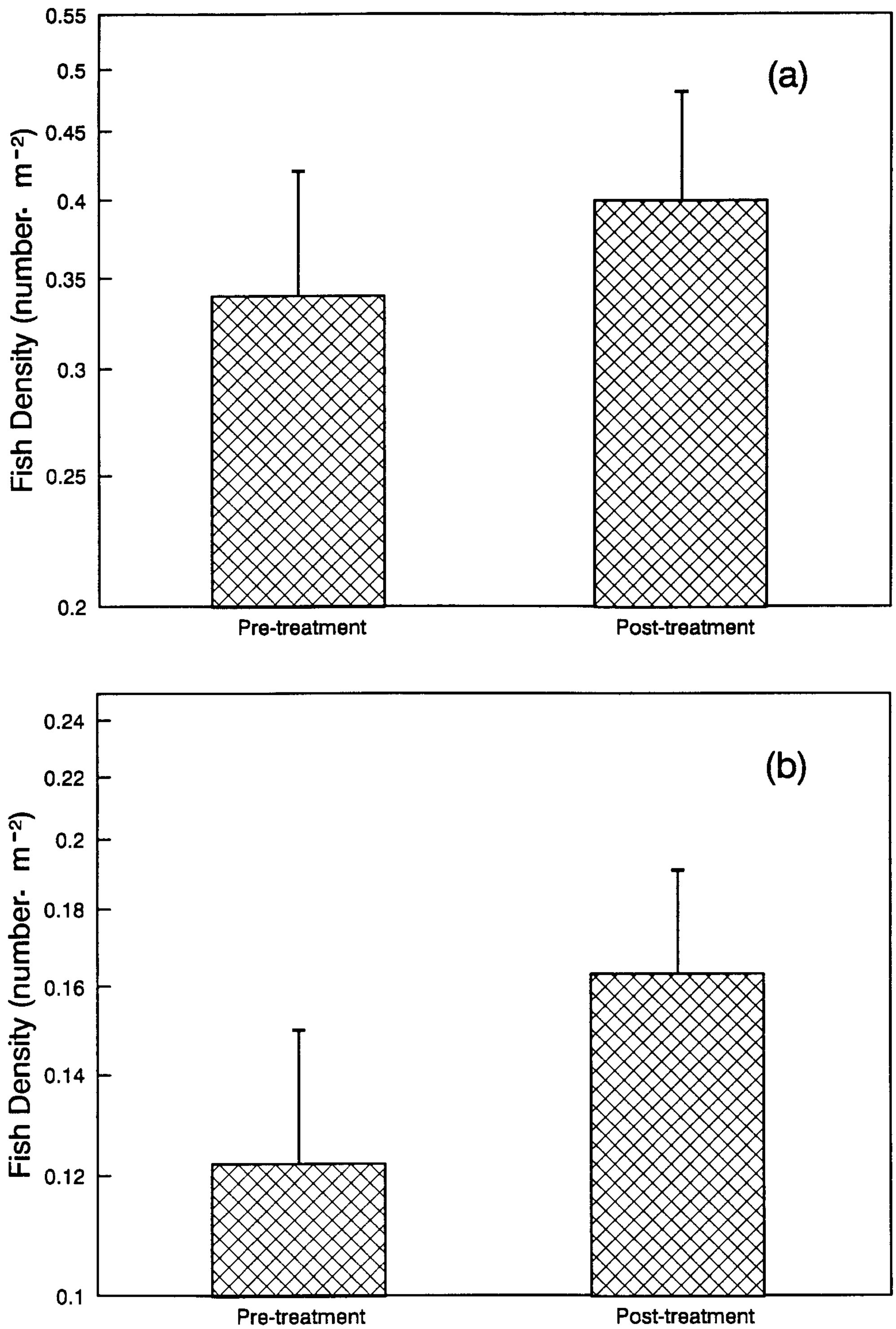

Figure 4 (a) Densities of salmonid fish (number · m^{-2} + 1 SE) in Wisconsin streams before and after stream restoration efforts. Data are from Hunt's (1988) compilation. (b) Densities of catchable-sized (≥15 cm) salmonid fish (number · m^{-2} + 1 SE) in Wisconsin streams before and after stream restoration efforts. Data are from Hunt's (1988) compilation.

Side Channels and Ponds

Side-channels appear to be highly productive for salmonids, although chum and coho salmon have been the most extensively examined in terms of evaluating potential benefits. We used data from Lister et al. (1980), King and Young (1986), Swales et al. (1986), and Sheng et al. (1990), to estimate fish densities from side-channels. For chum salmon, we found that the number of migrating fry ranged from 4 per m^2 to 552 per m^2 (mean = 225 fish · m^{-2}). Much of this variability appears to depend on spawner density (Fig. 5a). The number of migrating chum fry increased with increasing spawning female density (r = 0.71, n = 13, P = 0.003), but tended to reach a maximum density of 500 per m^2, when female spawner density reached about 1 per m^2. Coho salmon also spawn, rear and overwinter in side- channels (Cederholm et al. 1988). Although we could not find similar spawner and fry production density data, that we found for chum salmon, we did find smolt production estimates for coho salmon. Side-channels produced from 0.013 to 2.01 smolts per m^2 , and on average produced 0.67 smolts per m^2. Coho smolt production increased linearly with side channel area, according to the equation:

$\log_{10}$ coho smolts = 1.62 $\log_{10}$ channel area (m^2) - 2.38 (n = 9, r^2 = 0.42, P = 0.058).

From studies available in the literature, coho and chum salmon were the dominant fish species found in the channels; however, other species occasionally occurred in these areas. Chinook salmon juveniles were found also at average densities of 0.009 fish · m^{-2} in 6 of 13 off-channel areas and trout juveniles (mainly steelhead) were found in 7 of 13 channels at densities of 0.37 fish · m^{-2}.

Off-channel ponds also provide suitable habitat for large numbers of salmonids. We used the data compiled by Keeley and Slaney (1996) from 12 studies that measured the use of off-channel ponds for rearing habitat (Bustard and Narver 1975; Lister et al. 1980; Peterson 1982a; Swales et al. 1986; Beniston et al. 1987; Swales et al. 1988; Beniston et al. 1988; Cederholm et al. 1988; Lister and Dunford 1989; Swales and Levings 1989; Cederholm and Scarlett 1991; M. Foy, Fisheries and Oceans, Vancouver, B.C.). Densities of fish in these ponds ranged from 0.02 to 5.40 per m^2 (mean = 1.09 fish · m^{-2}), but was dependent on the size of the pond occupied:

$\log_{10}$ fish number = 0.51 $\log_{10}$ pond area (ha) + 3.47, n = 19 , r^2 = 0.64, $P < 0.001$; Fig. 5b).

Off-channel ponds tend to be dominated by coho salmon, which were found at the highest densities of all salmonids and were always present in the 19 ponds we found data for (mean = 1.01 fish · m^{-2}). In 5 of the ponds, chinook salmon and steelhead trout juveniles were found at densities averaging 0.046 fish · m^{-2} and 0.23 fish · m^{-2} respectively, and in one pond Dolly Varden char (*Salvelinus malma*) was found at a density of 0.004 fish · m^{-2} .

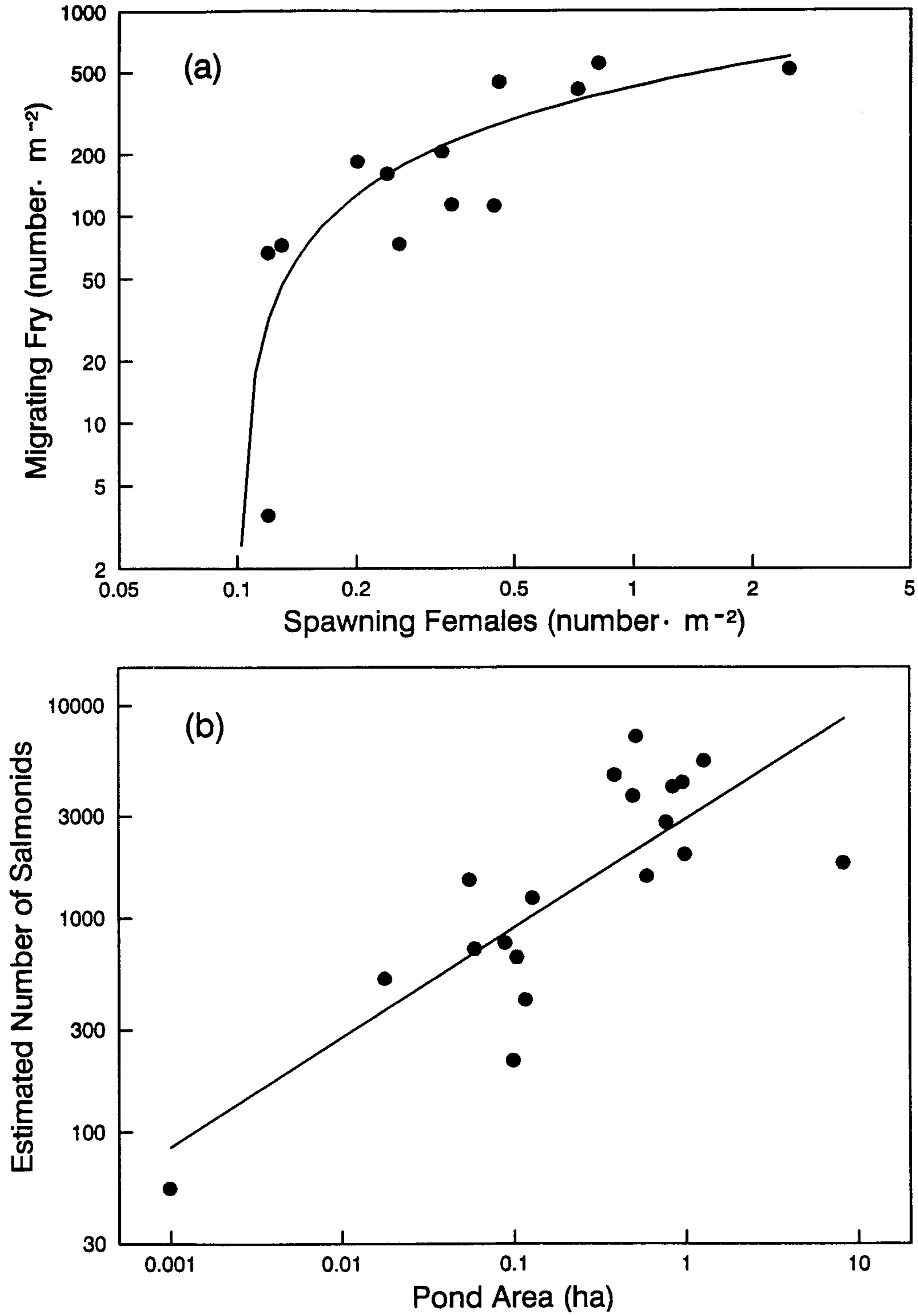

Figure 5 (a) The relationship between the numbers of spawning female chum salmon and spring migrating chum salmon fry from side-channel habitat. See text for data sources. (b) The relationship between off-channel pond area and estimated population size of salmonid fish present in the ponds (all juvenile salmonids combined). See text for data sources.

Potential Fish Production Benefits

In calculating fish production benefits, we assumed average differences observed will be translated into actual differences after restoration. Despite the fact that we were unable to detect significant effects in some instances, this was probably due to a paucity of data rather than lack of treatment effects. This argument is supported by the fact that post-treatment densities were always higher in comparison to pre-treatment densities, even if differences were not always significant (*e.g.*, $P > 0.05$).

Potential gains from instream habitat restoration were highest for coho salmon, followed by chinook and steelhead trout (Table 1). For non-stream rearing anadromous salmonids, increasing spawning areas could produce numbers of adults that range from 0.53 per m^2 for chum salmon to 7.19 per m^2 for sockeye salmon (Table 1).

For stream resident salmonids, the overall numbers of salmonids per area of stream increased significantly and catchable-sized fish increased over pre-restoration levels, on average, from 63% for rainbow trout to 40% for cutthroat trout (Table 2). Because trout ≥ 15 cm often represent a significant proportion of mature resident fish, these individuals should help maintain the numbers of potential recruits in future spawning events.

New or newly accessible habitat created from side channels and ponds also appears to offer significant potential increases in production of chum salmon and coho salmon. Side channels were calculated to produce 1.58 adults per m^2 for chum salmon and 0.066 adults per m^2 for coho salmon (Table 3). Off-channel ponds on average held 1.01 juvenile coho salmon per m^2 and may therefore produce 0.068 adult coho per m^2 (Table 3).

Table 1. Summary of estimated fish production benefits for both stream rearing and non-stream rearing anadromous salmonids.

Anadromous Salmonids - Stream Rearing Species

Species		Fry (number · m^{-2})	Survival Rate[a]	Smolts (number · m^{-2})	Survival Rate[b]	Adults (number · m^{-2})
coho	pre	0.49	0.68	0.33	0.098	0.033
	post	0.87	0.68	0.59	0.098	0.058
chinook	pre	0.073	0.68	0.05	0.041	0.002
	post	0.68	0.68	0.46	0.041	0.019

[a] Based on over-winter survival rates calculated by Crone and Bond (1976).
[b] Based on average marine survival rates calculated by Bradford (1995).

Species		Fry (number·m^{-2})	Parr (number·m^{-2})	Survival Rate	Smolts (number· m^{-2})	Survival Rate[a]	Adults (number·m^{-2})
steelhead	pre	0.19	0.042	0.33	0.014	0.16	0.0022
	post	0.29	0.097	0.33	0.032	0.16	0.0051

[a] Based on average marine survival rates calculated by Ward and Slaney (1988).

Anadromous Salmonids - Non-Stream Rearing Species

Species		Fry (number· m^{-2})	Freshwater Survival Rate[a]	Migrating Fish (number· m^{-2})	Marine Survival Rate[a]	Adults (number· m^{-2})
chum	pre	129.30	0.069	8.92	0.007	0.062
	post	1106.05	0.069	76.32	0.007	0.53
pink	pre	143.45	0.070	10.04	0.028	0.28
	post	1227.04	0.070	85.89	0.028	2.39
sockeye	pre	123.80	0.093	11.51	0.073	0.84
	post	1059.00	0.093	98.49	0.073	7.19

[a] Based on average life-stage survival rates from Bradford (1995).

Table 2. Estimates of fish production of salmonid fry and catchable-sized, resident, trout (≥ 15 cm) for pre- and post-restoration of fish habitat.

Resident Salmonids - Stream Rearing Benefits

Species		Total fish[a] (number · m^{-2})	Catchable-sized fish[b] (≥ 15 cm; number · m^{-2})
brook	pre	0.30	0.054
	post	0.44	0.074
brown	pre	0.20	0.14
	post	0.29	0.18
cutthroat	pre	0.034	0.035
	post	0.070	0.058
rainbow	pre	0.036	0.12
	post	0.097	0.16

[a] Total numbers of salmonid fish · m^{-2}, data are compiled from six studies, see text for references.
[b] Data for brook, brown and rainbow trout are from Hunt (1988). Rainbow trout densities are based on overall responses in salmonid fish densities due to a paucity of data for rainbow trout. Cutthroat trout densities are based on data from Binns and Remmick (1994).

Table 3. Estimates of fish production benefits from side channel and ponds.

Side-channels

Species	Fry (number · m^{-2})	Survival Rate[a]	Smolts (number · m^{-2})	Survival Rate[a]	Adults (number · m^{-2})
chum	225	0.007	-	-	1.58
coho	-	-	0.67	0.098	0.066

[a] For chum salmon, based on marine survival rate for migrating fry calculated by Bradford (1995). For coho salmon, based on marine survival rate for smolts calculated by Bradford (1995).

Off-channel ponds

Species	Fry (number · m^{-2})	Survival Rate[a]	Smolts (number · m^{-2})	Survival Rate[a]	Adults (number · m^{-2})
coho	1.01	0.68	0.69	0.098	0.068

[a] Based on average life-stage survival rates calculated by Bradford (1995).

DISCUSSION

Our analysis of changes in fish density and areas of usable spawning gravel suggest that stream restoration initiatives have provided significant benefits to salmonid fish populations. These changes appear to exist for juveniles of stream-rearing anadromous salmonids, as well as populations of salmonids which reside within the stream throughout their life-span. Increases in juvenile recruitment from impacted streams, are frequently the target of restoration efforts in British Columbia (Slaney and Martin 1997). Potential benefits for juvenile salmonids appear quite large because juvenile life-stages respond strongly (Fig. 1). Although we did not find information that systematically monitored changes to non-stream rearing anadromous salmonids (chum, pink, and sockeye salmon), we found significant increases to areas of spawnable gravel that should provide increases in fish production (House and Boehne 1985).

Newly created or accessible off-channel habitat (side channels and ponds) also provides important area for significant numbers of salmonids (Fig. 5a and b). The relationship between off-channel pond area and fish numbers, indicate that smaller ponds produce more fish per unit area than large ponds (Fig. 5b). Hence, these data suggest that ponds less than 1 ha would be most efficient to produce in areas where this technique is applied. Clearly, coho and chum salmon appear to use off-channel areas most effectively, as our synthesis indicates and as other researchers have found (M. Foy, pers. comm. Fisheries and Oceans, Vancouver, B. C.). Steelhead trout and other fish species are also found in off-channel areas, but in much lower numbers. This may be due to the observation that some species prefer to rear in areas with higher velocities and are often found overwintering in areas with large substrate, within a main stream channel (Rimmer et al. 1984; Campbell and Neuner 1985). Whether the smaller numbers of some species occur because they do not prefer off-channel habitat, or whether off-channel projects to date have not often been conducted in areas with them, remains to considered for future projects in the Watershed Restoration Program.

The paired analysis that we employed controlled for much of the inter-study variability and we detected significant differences in many of our comparisons. Despite, the benefits demonstrated by our synthesis, there exists a great deal of variability in the response of stream restoration techniques. For example, anadromous juveniles responded strongly to restoration, increasing densities on average by 123% (Fig. 1a). However, the variability of density responses made comparisons at finer scales more difficult, especially with reduced sample sizes (Fig. 1b). Undoubtedly, much of this variability is related to the effectiveness of various restoration techniques. We attempted to remove some of this variability by employing a selection criteria. A more powerful analysis would have been possible if more studies would have reported fish responses by restoration technique, as well as amount of effort employed per treatment area. Future restoration projects should incorporate a plan to evaluate fish responses by type and amount of effort per area of stream. In addition, a pre- and post-treatment evaluation would ideally be paired with a similar control stream. This type of evaluation would help detect streams whose fish populations are continuing to decline and have not yet reached equilibrium (Riley and Fausch 1995).

Based on increases in fish densities and survival rates, estimated increases in adult fish numbers should provide valuable returns for stream restoration efforts. In cases where populations of spawning fish are reaching critically low levels to maintain a viable population size, these increases in adult numbers may be the sole chance for unique stocks of fish to be maintained

(Nehlsen et al. 1991). Although we have only considered salmonid fishes in this synthesis, we believe that increases in fish populations may act as an indicator of increased stability and health of all organisms in a stream ecosystem. Hopefully, future restoration efforts can assess changes to the biodiversity of many groups of organisms because the health of any single group is often related to the health of many other groups within an ecosystem (Hunsaker and Levine 1995; Johnson et al. 1995; Power et al. 1995; Sparks 1995).

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