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DID THE PRE-1980 USE OF IN-STREAM STRUCTURES IMPROVE STREAMS? A REANALYSIS OF HISTORICAL DATA

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Abstract. In the 1930s, after only three years of scientific investigation at the University of Michigan Institute for Fisheries Research, cheap labor and government-sponsored conservation projects spearheaded by the Civilian Conservation Corps allowed the widespread adoption of in-stream structures throughout the United States. From the 1940s through the 1970s, designs of in-stream structures remained essentially unchanged, and their use continued. Despite a large investment in the construction of in-stream structures over these four decades, very few studies were undertaken to evaluate the impacts of the structures on the channel and its aquatic populations. The studies that were undertaken to evaluate the impact of the structures were often flawed. The use of habitat structures became an "accepted practice," however, and early evaluation studies were used as proof that the structures were beneficial to aquatic organisms. A review of the literature reveals that, despite published claims to the contrary, little evidence of the successful use of in-stream structures to improve fish populations exists prior to 1980. A total of 79 publications were checked, and 215 statistical analyses were performed. Only seven analyses provide evidence for a benefit of structures on fish populations, and five of these analyses are suspect because data were misclassified by the original authors. Many of the changes in population measures reported in early publications appear to result from changes in fishing pressure that often accompanied channel modifications. Modern evaluations of channel-restoration projects must consider the influence of fishing pressure to ensure that efforts to improve fish habitat achieve the benefits intended. My statistical results show that the traditional use of in-stream structures for channel restoration design does not ensure demonstrable benefits for fish communities, and their ability to increase fish populations should not be presumed.

Key words: applied geomorphology; erosion control; habitat improvement; in-stream structures; stream improvement.

Introduction

By the 1930s the use of in-stream structures for stream improvement was a nationwide practice that reached a scale that probably has not been matched until the last two decades. The Civilian Conservation Corp (CCC) in cooperation with state fisheries agencies installed 10,000s of structures throughout the United States in an effort to improve stocks of fish (Thompson 2005). By the 1980s the use of in-stream structures was well established, and many of the early designs were still widely used. Even today a large number of in-stream structures are exact copies of structures originally installed during the 1930s (Thompson and Stull 2002). To help justify public expense in the later projects, earlier studies were cited to provide evidence that the use of in-stream structures resulted in greater yields of target game species. Although many published studies relied on measured changes in physical characteristics of the channel as an indication of project success, evidence for the beneficial use of in-stream structures ultimately requires data on changes in fish populations. Few early studies contained this type of data. Furthermore, most of the early studies relied primarily on comparisons between population averages, with little or no statistical testing. Therefore these historical studies do not meet the more rigorous modern standards for scientific investigation. Because of the importance placed on the early evaluations, it is worth revisiting these early assessments of projects to determine if the published raw data provide statistical evidence that in-stream structures created improved conditions for fish. It is hypothesized that many of the early claims for the beneficial use of structures are erroneous because of problems with the experimental designs of the studies as they do not correctly account for changes in fishing pressure. The studies were also potentially biased because of the close relationships between the project designers and the evaluators. Finally, these flawed results were used to perpetuate the potentially incorrect notion that in-stream structures have a demonstrable benefit to fish populations.

Early use of in-stream structures

The use of in-stream structures was initiated in an attempt to counteract a series of impacts on fish

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populations that included loss of physical habitat, chemical pollution, and overfishing (Thompson and Stull 2002). The 1930s initiated a period of intense channel modification. During some years, federal and state agencies installed in-stream structures at a rate of over 15,000 structures per year (Thompson 2005). Thompson and Stull (2002) and Thompson (2005) documented the direct link between current and historical practices with the use of in-stream structure, and showed that the designs of many in-stream structures used in the 1930s are largely unchanged today. A brief comparison of specific designs illustrated in publications by Davis (1935), Tarzwell (1938), and Seehorn (1992) clearly show strong similarities in the types of deflectors, dams, and covers used during different decades. Because modern structures are so similar to those used in the past, historical evaluations of in-stream structures can provide valuable data on potential performance of recent projects.

Several years after the first projects were completed, reports began to appear that referred to the potential benefits of the in-stream structures. Later publications picked up on these early evaluations as evidence for the continued use of the designs. For example, Hazzard (1948) claimed research had proved that the trout yield could be greatly increased by the use of deflectors and shelters. Similarly, Boussu (1954:229) claimed that studies by Greeley (1935) Tarzwell (1936, 1938), and Shetter et al. (1946) "have shown that stream improvement, including artificial cover, can lead to an increase in number and size of trout in a given section of stream." Gard (1961:384) stated that "habitat improvement has long been recognized as a useful tool of wildlife management." Gard (1961) lists several seminal publications that include Hubbs et al. (1932), Tarzwell (1936, 1938), Shetter et al. (1946), Cronemiller (1955), and Warner and Porter (1960). Gard (1961:384) claims that "these studies indicate that benefits to trout result from stream improvement." Hunt (1976*b*:26) stated that habitat manipulation "has proven to be a successful technique for increasing stream trout populations." Similarly, Swales and O'Hara (1980) mention that over the last 50 years, extensive research into the effects of in-stream habitat improvement devices on the river fauna was carried out in North America. Furthermore, they suggest that many studies show devices were effective in increasing the fish populations of streams. Even recent publications by Moerke and Lamberti (2003) and Binns (2004) continue to reference Tarwell (1938), Shetter et al., (1946), Saunders and Smith (1962), Jester and McKirdy (1966), and Hunt (1971, 1976*a*) as evidence for the successful use of in-stream structures. However, many of these studies were conducted without the use of modern statistical tests and relied on comparisons of mean values of the various measures of fish populations without consideration for the importance of natural and measurement-error variance around those means.

The influence of fishing on trout populations

By the mid 1930s it was also clear that overfishing was a major problem that influenced fish populations. Lord (1935:229) discussed the clear reliance of fisheries managers on stocking practices due to heavy fishing pressures and stated "it is just this sort of heavy fishing that is surely depleting the trout supply in our brooks." Moore et al. (1934) suggested the poor growth rate of trout on a New York channel was a result of competition of many smaller trout. As Moore et al. (1934:77) suggested, trout populations were characterized by "poor growth rate by long-term exposure to angling, which removes only the larger fish." Thus intense fishing pressure could lead to a loss of large trout and a simultaneous increase in total number of smaller fish. Moore et al. (1934:70) also mentioned that "it is interesting to note that fish quickly moved into the area which had been cleared of fish." Consequently, data on the number of fish caught in a particular location could be more a function of where people fish throughout a fishing season than where fish are at the beginning of the fishing season. This observation shows that changes in fishing pressure could complicate interpretations of the influence of in-stream structures if fishing pressure changes as a result of modification of the study reach. Because the influence of heavy fishing pressure could be highly variable in time and location based on perceived quality of fishing, it is important to consider the relation of fishing pressure to the existence of channel modifications.

One apparent result of stream-improvement projects is a readjustment of the location where fishing occurs. Davis (1935:3) stressed that "no change should be tolerated which will tend to make the fish easier to catch." Lord (1935) suggested in comments at the end of a talk by Ritzler (1936:468), "if stream improvement does nothing more than to make more places to fish and relieve the intensity of fishing spots, it will allow trout to spread out." However, Clark (1945) reported several years later that the placement of in-stream structures resulted in a concentration of the fishing in the modified section of channel. If either Lord (1935) or Clark (1945) is correct about changes in fishing pressure, it is likely that the introduction of in-stream structures could change fishing patterns that could then influence fish populations. In some cases, state agencies also actively promoted newly modified sections of stream in a deliberate attempt to attract anglers. During the discussion at the end of a paper by Clarence Tarzwell (1935:133), Oliver Deibler states that:

> *... in order to attract the fisherman to this place, so that they could see what had been done and could get ideas which they could carry back, we had to offer some attraction .... After we had this stream project completed, we stocked it very heavily with three varieties of trout—brown, brook and rainbow (*Salmo gairdneri*)—all large trout, and invited the fisherman to come and enjoy some real fishing.*

The potential complications for a study of the impact of the structures on fish populations in this type of situation are obvious. These considerations become even more critical when fish populations are estimated based on the number or biomass of fish caught by anglers. Therefore, any test of the impact of in-stream structures must also consider the influence of changes in fishing pressure.

Another important issue concerns the duration of the population study. Platts and Nelson (1988) showed that short-term changes in fish population may be unrelated or weakly related to habitat attributes. Because larger trout require more than one season to reach their size, results that indicate a change in adult populations after a single year probably document fish migration, not changes in stream productivity. Walters (1997) even suggests that population dynamics are seldom fully exhibited in less than a decade or two. Therefore, study duration should be a decade or at least long enough to include the entire life cycle of the related organism if true changes in overall productivity are assessed.

Statistical Considerations

The need for a control population is particularly important because Platts and Nelson (1988) report that large-scale fluctuations in the population characteristics of trout are common even when management conditions are held constant. To statistically test a hypothesis on the influence of some type of treatment on a target population, it is necessary to compare population data with the treatment and a second population without the treatment. For studies focused on channel restoration techniques, the treatment represents a class variable that indicates the presence or absence of structures for a specified time along a particular location on a river. The conditions for the second population, or control group, should be similar except for the absence of structures (Boreman 1974). Control group populations were usually either measured earlier in a pre-modification time period along the same reach, or performed as time-synchronized measurements along an unmodified adjacent reach of the same river or a channel with similar characteristics. Although both types of control groups are used, populations from time-synchronized measurements along an unmodified adjacent reach are preferred because this technique is better able to account for natural changes in environmental conditions that may influence populations during the study period (Boreman 1974).

Analysis of variance (ANOVA) or simple *t* tests can be used to identify differences in populations between the sites or time periods with and without structures. However, comments by Moore et al. (1934) and Lord (1935) suggest that fishing pressure, a continuous variable, also influences measures of fish catch, usually collected as a creel census. Furthermore, fishing may also influence the numbers and size of remaining fish in an area (Moore et al. 1934, Lord 1935) and survivability (Platts and Nelson 1988). Additional major sources of potentially unaccounted-for variation between treatment and controls stem from differences in stocking rates and migration of trout. When pre- and post-modification data are presented for the same channel, variations in hydrology can also create important differences in basic biological productivity that cannot be easily detected by an ANOVA. For example, a large spring flood on a New York channel created disruption of spawning beds and resulted in a total number of juvenile trout that was only 1% of the number of similar-aged trout in the previous year (Boreman 1978). Benedetti-Cecchi (2001) suggests natural systems are usually highly variable, which makes statistical analysis more difficult. These types of dramatic changes in population would likely exceed any influence of in-stream structures. To determine the true impact of the structures, even minor differences in population that result from variations in hydrology must be addressed. Consequently, variables related to both fishing pressure and controls for changes in hydrology should be considered in conjunction with the presence or absence of structures.

A standard ANOVA or *t* test cannot handle both class and continuous independent variables. However, the potential covariance for the two independent variables leads to possible misinterpretation of analyses results if both variables are not considered simultaneously. For example, it is possible that structures have no influence on fish populations. Conversely, a change in fishing pressure might occur due to hype related to the project, and this fishing could influence the fish populations, especially the number of fish caught. A researcher could mistakenly attribute a measured change in fish populations to the structures if the influence of changes in fishing pressure were not directly investigated. Therefore, studies must also simultaneously account for the potential influence of fishing pressure.

To account for the influence of fishing pressure, a study could prohibit fishing, ensure fishing levels are exactly the same in areas with and without structures, or include a continuous variable for fishing pressure as a regression variable in an analysis of covariance (ANCOVA). Fishing rarely appears to be prohibited for non-endangered species in areas that were modified with structures, possible because of political constraints related to the use of public money to complete the projects. Because fishing will rarely be prohibited, ANCOVA will be most useful for the reanalysis of historical data.

Methods

To conduct the review of evaluations, an attempt was made to identify as many publications that discussed in-stream structures before 1980 as possible. A bibliography compiled by Wydoski and Duff (1978) helped to ensure no important references were missed. Each publication was searched to obtain any data on the influence of both structures and fishing pressure on fish populations. Publications that did not contain sufficient data to permit statistical tests of both structures and fishing pressure were generally discarded. However, a few frequently cited publications with limited data, in peer-reviewed journals, were also investigated and discussed because of the relative importance of these studies in the published literature. A total of 79 publications were checked, and 12 publications were found to contain data that met the criteria listed above.

Claims of changes in fish populations were tested by using the original data in the publications and modern statistical analyses. Flaws in experiment design were identified to highlight confounding influences that could potentially influence the statistical results. The reported response variables for the various studies often differ due to differences in data-collection methods and study objectives. Readers are encouraged to read the original publications for details of data collection, which cannot be easily summarized here. To help account for annual variations in biological productivity related to hydrology changes, whenever possible, original published data for modified sections of a channel were standardized as the percentage of the total measured quantity of the relevant variable for the modified and adjacent control reaches.

Whenever possible, different time periods or locations were compared using ANCOVA, with independent variables for structures and fishing pressure and dependent variables for the reported measures of fish populations. The number of observations included in the dependent variables for each analysis generally represents the product of the number of years of data multiplied by the number of reaches studied. Unfortunately, the number of observations was often small, which reduces the power of statistical tests especially in highly variable natural systems (Benedetti-Cecchi 2001). The class variable "structure" represents comparisons between time periods or locations that would include a possible influence of the addition of structures. "Fishing pressure" is a continuous variable usually measured as number of people, total number of days people fished, or total number of hours fishing in a section. The measures for number of people and number of days fishing are less informative because they include different duration efforts during a particular visit for the people who fished, while the hours-fishing variable provides a better overall measure of total time spent fishing. A stepwise selection procedure was used for the two independent variables to determine if one or both variables were significantly related to the measures of fish populations. Variables that were not significant at the $\alpha = 0.05$ level were discarded and the analysis was continued as an ANOVA for the structure variable or simple linear regression for fishing-pressure variable. For discussion purposes, the initial ANCOVA P value for discarded variables and the final variable from the ANOVA or regression analyses were all reported.

Although the basic level for statistical significance was set with $\alpha = 0.05$, multiple dependent variables were analyzed in most cases. Because analysis of multiple dependent variables increase the chances of Type II errors (Ott 1993), an adjusted P value was calculated with the Holm's sequential Bonferroni method (Roback and Askins 2005). According to this method, P values from the m tests are ranked from lowest to highest and compared to an increasingly stricter standard for significance with an adjusted α level (Roback and Askins 2005). A Holm's-adjusted P value level is calculated by multiplying the unadjusted P value by the rank, $P_{\mathrm{Holm}(j)} \geq P \times (m - j + 1)$, where P_{Holm} is the adjusted P value; P is the unadjusted P value; m is the number of comparisons; and j is the rank. With this method, the P value for the highest significance test is equivalent to a standard Bonferroni-method-adjusted P value. The P value for the lowest significance test is equal to the unadjusted P value. For this study, the number of comparisons, m, specifies tests conducted with the same independent variables in the same study. Therefore, data tested with fishing pressure in hours were treated differently than tests with fishing pressure measured in percentage of total fishing. The Holm's-adjusted P values are included in the Appendix A as a more appropriate level of significance for the hypothesis testing performed in this study. The total number of observations, n, is also reported in each table in Appendix A.

In some cases, simple ANOVA, Tukey-HSD comparison of means, and regression analyses were performed on data sets that could not accommodate the ANCOVA experimental design. These tests are explained in the various sections that discuss particular studies. Although these analyses are not as useful as the ANCOVA analyses, they do provide some important insight on frequently cited studies. For example, to test the hypothesis that fishing pressure alone could explain the observed population trends in a particular study, data were often pooled to the greatest degree possible and analyzed with least-squares, linear regression. For these analyses, the relation between fishing pressure and the various measures of fish populations were tested.

Ideally, all the data from all the studies would be combined and analyzed in a single test. Unfortunately, differences in the way variables were measured and the response variables used prevent widespread pooling of data. However, a final ANCOVA analysis was performed with a combined data set from four studies. The combined data set permitted better use of data that contained limited years for pre- or post-modification periods. For this analysis average values for pre- and post-modification periods in modified vs. control reaches were compared with respect to the influence of the structures and fishing pressure. Studies by Shetter et al. (1946), Hale (1969), Hunt (1969) and Latta (1972) all contained similar data on number and catch of trout that could be pooled. Because the dependent variables were calculated as the percentage change from pre-modification period, the analysis should help standardize for possible differences in overall productivity among the various sites. In this analysis, a similar accounting for possible variations due to hydrologic differences is accomplished through comparison of modified and control reaches.

For each seminal study, a brief background is presented in the *Results* section that details some of the site characteristics, survey methods, and principle agencies involved in the restoration projects. A description of the statistical analyses performed on the accompanying data sets is then provided. Results from the analyses and additional information on the statistical methods are included in the appendices. Finally the results from the particular analyses are described.

Results

Numerous studies were completed between 1930 and 1980. Because a complete discussion of each study is impossible given space constraints, limited details of the methods used and variables measured by the various researchers are provided. Additional details on many of these studies can be found in Thompson and Stull (2002), Thompson (2005) or the original sources.

Tarzwell (1938)

The first study with suitable data was a paired-watershed study performed by Tarzwell (1938) in Arizona (USA). A creel census was used to estimate the number of fish caught in 1936 and 1937 on a modified channel, Horton Creek, and unmodified channel, Tonto Creek. One problem with creel-census data is the possibility of missing data due to under-reporting by anglers. Tarzwell's former graduate advisor mentions this problem (Lord 1935) in an earlier project they collaborated on in Michigan (Tarzwell 1936). Subsequently, researchers also criticized the Tarzwell (1938) study because of variations in stocking practices in the modified and control channels (Shetter et al. 1946).

The ANCOVA results for five different measures of fish catch show that the data are significantly related to changes in fishing pressure, reported as number of days fishing in each reach with an average of 3.2 hours per day (Appendix A: Table A1). Conversely, there were no changes in catch between channels, which would reflect the influence of structures. The R^2 values vary greatly for the different dependent variables, which may result from variations in the skill level of the anglers involved. A plot of number of legal sized trout caught vs. fishing pressure shows a strong linear trend with no apparent difference between modified and unmodified sites (Fig. 1a).

Shetter et al. (1946)

The best-known project evaluation conducted between 1942 and 1955 in the United States was completed by Shetter et al. (1946) on a Michigan brook with 24 deflectors. Swales and O'Hara (1980) claimed that the study by Shetter et al. (1946) represented the first comprehensive before-and-after evaluation, and documented an increase in both numbers and biomass of trout over a five-year period. However, the study did not represent a true before-and after-evaluation because earlier CCC (Civilian Conservation Corps) structures did exist at the site prior to the study, albeit in a damaged state (Shetter et al. 1946). The study included several different data sets with pre-modification survey durations of one or three years, and post-modification survey duration of three or five years in the modified section of a channel. Two control sections were also studied. Fishing pressure was measured in total hours of angling in each reach.

ANCOVA results are reported for data with total durations of four or eight years in the modified section only. After adjustment for multiple comparisons, no variable was significantly related to the influence of structures and two variables were significantly related to changes in fishing pressure in the modified section (Appendix A: Tables A2 and A3). ANCOVA results for catch data as a percentage of the total indicate only a significant influence of fishing pressure (Appendix A: Table A4). An ANOVA and Tukey-HSD comparison-of-means test was also performed to test for differences in catch among two control reaches and the modified reach for the post-modification period only. The modified reach was either statistically indistinguishable or had significantly lower catch than either of the control reaches (Appendix A: Table A5). Finally, regression analysis for fishing pressure in all sections vs. catch in all sections indicates a significant increase in catch with increased fishing (Appendix A: Table A6). A graph of these data shows some possible tendency for modified sites to yield higher catches, but for one year data from this same site also plotted below the trend line (Fig. 1b).

Boussu (1954)

Boussu (1954) worked for the Department of Game, Fish, and Parks, in Woonsocket, South Dakota, but modified Trout Creek in the neighboring state of Montana. The meandering channel passed through flat, cultivated and pastured lands. The channel was divided into 14 intermixed sections. Artificial cover was added to four sections while natural cover was removed from four sections. Five sections were maintained as control areas. There was no information on how sections were selected for various treatments. Eastern brook, rainbow (*Salmo gairdneri*), and brown trout populations were surveyed by electrofishing four times prior to and two time after modification. Pre-alteration surveys included two samples during the fishing season in July, while post-alteration surveys included no July samples. Furthermore, no effort was made to account for migration of

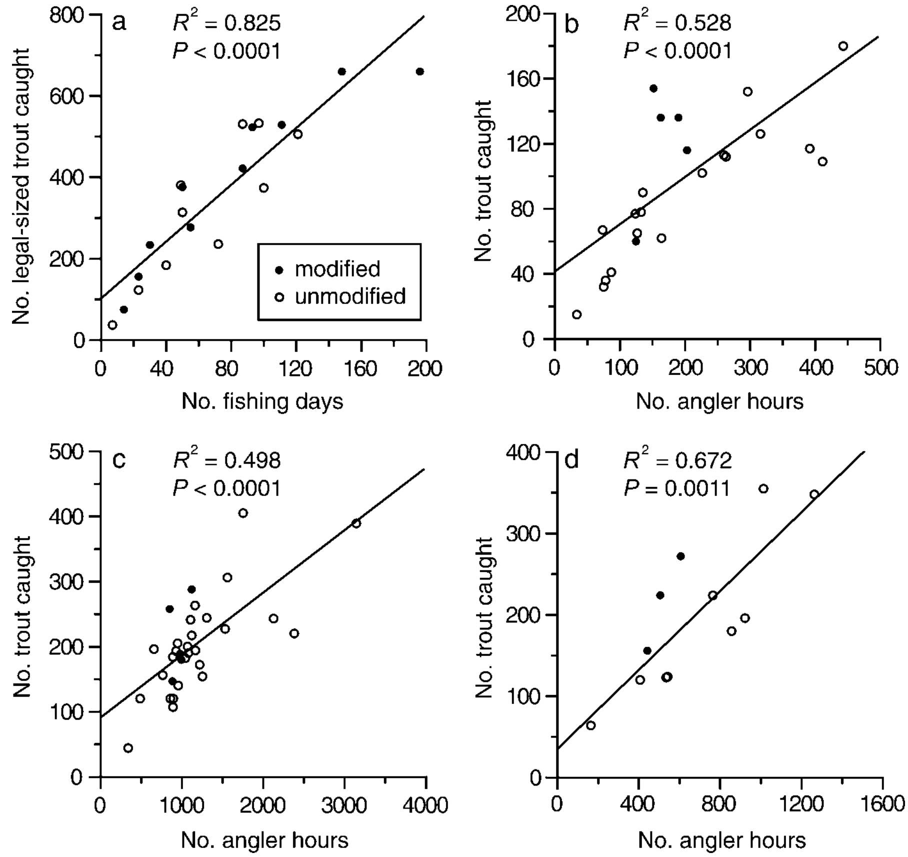

FIG. 1. Plots showing number of trout caught vs. measures of fishing pressure. Data for the plots were obtained from (a) Tarwell (1938), (b) Shetter et al. (1946), (c) Latta (1972), and (d) Hunt (1969, 1970, 1974, 1976*a*, *b*).

trout among sections. The article also does not report any data on stocking or fishing that may have existed.

The experimental design and limited data presented make it difficult to test the various treatments due to the limited number of repeat measurements. Therefore, the data were combined and all results for the pre- and post-modification periods were compared to determine if the combined influence of the alterations resulted in significant differences in population measures. None of the eight variables were significantly different in the two time periods (Appendix A: Table A7). These results suggest that measured changes simply document fish migration from natural habitat areas that were intentionally destroyed to areas with introduced structures.

Wilkins (1960)

Wilkins (1960) presented data from a Tennessee Game and Fish Commission project on a shallow, 0.6-mile (1-km) section of North River, Tennessee. A combination of 13 dams and deflectors were used based on designs in Tarzwell (1938). One year of pre-modification and four years of post-modification data were collected. Wild and hatchery trout were collected with the cresol method and grouped based on length. No control reach was utilized. Although no quantitative data on fishing pressure was reported, Wilkins (1960:6) stated:

> *Because of the unproductive appearance of the experimental area before improvement, it had been largely overlooked by fisherman, and preliminary fish sampling produced fair numbers of rainbow trout (*Salmo gairdneri*) from three to eleven inches [28 cm] in length. Following construction of the devices, a decline in the number of wild fish in successive samples was associated with increased fishing pressure as many anglers were attracted to the novel area.*

Because of the lack of data on fishing pressure, the dependent variables were tested with simple ANOVA analysis. None of the 13 dependent variables were significantly related to the addition of the channel modifications (Appendix A: Table A8).

Saunders and Smith (1962)

A frequently cited study was completed by Saunders and Smith (1962) on Hayes Brook located on Prince Edward Island, Canada. Thirteen habitat dams, 12 deflectors, and several covers were added to the channel in 1959. Brook trout were sampled by electrofishing and clipping or tagging. Twelve years of pre-modification data were collected and two post-modification surveys were conducted. However, Saunders and Smith (1962) analyzed the surveys collected one month after structures were placed as pre-modification data. No justification for the classification of these data is provided. Also, up to one third of the brook trout in the study reach migrated out of the study area in some years. No control reach was utilized and no data on fishing pressure were presented.

ANOVA tests were required because of the lack of data on fishing pressure. To determine the possible influence of mistreatment of the one-month post-modification survey, analyses were performed with the 1959 survey removed, and with both post-modification surveys. Five dependent variables were significantly related to the presence of structures when the 1959 survey is removed, but no significant differences existed when both 1959 and 1960 surveys are analyzed as post-modification surveys (Appendix A: Tables A9–A11).

Jester and McKirdy (1966)

Jester and McKirdy (1966) reported data from a six-year study in New Mexico on 10 different rivers. There were limited data presented on fish populations, but more extensive data on catch rates. Jester and McKirdy (1966:329) used average catch-rate data before and after modification to support the claim "the ultimate objective of better fishing has been achieved." However, data used for the averages include four sites where only before or after data were collected, but not both. Furthermore, four of the seven remaining sites showed an average decrease in catch rate following modification. ANOVA results do not show any statistically significant change in catch rate at the seven sites between pre- and post-modification periods (Appendix A: Table A12).

Hale (1969)

Hale (1969), who was a biologist with the section of Fisheries in Minnesota, reported results of a study conducted on the West Branch of the Split Rock River (Minnesota), that was modified with deflectors and shelters. The study was well designed in many ways. The study period extended 10 years with three years of pre-modification data, four years of no data collection during construction and three years of post-modification data. The experimental design utilized two adjacent one-mile (1.6-km) sections with an upstream, higher-gradient unmodified section and downstream, lower-gradient modified section. Brook trout population inventories were conducted with electrofishing and a creel census. Fish stocking was held steady before and during the entire study. However, only limited data on fishing pressure were presented.

Because data on fishing pressure were limited to average angler hours pre- and post-modification on the modified and control sections, it was not possible to conduct an ANCOVA. ANOVA results for the presence of structures on numbers of trout in the modified section only indicate no significant relations when adjusted for multiple comparisons (Appendix A: Table A13). Similar results were found when testing the data as percentage of trout numbers in the modified section to the total numbers of trout in the control and modified section, although one relation was almost significant when adjusted for multiple comparisons. Regression analyses indicate significant relations between both the number of wild trout caught and the number of all trout caught vs. angler hours. Four other measures of trout populations were not significantly related to angler hours (Appendix A: Table A14).

Latta (1972)

Latta (1972) supervised a 16-year study conducted by the Michigan Department of Natural Resources on a section of the Pigeon River (Michigan) that had been modified in 1954. Deflectors, a barrier dam, and cover structures were added to a 2.1-km length of channel. Fish population inventories utilized electro fishing and creel census to measure native brook and brown trout only. Hatchery trout existed in the reach but were not recorded. Populations were measured on a modified and control section of the channel. The study included five years of pre-modification and five years of post-modification surveys. The group then removed the in-stream structures and any natural logs uncovered by the structures and collected data for six additional years. However, immediately after removal of the structures, the group added sand to an average depth of 10 cm along a 2.1-km-long section of the channel to fill in the morphology created by the structures. A dam burst upstream of the two study reaches also reportedly dumped a large volume of sand into the system which moved through the study area as a pulse. Therefore, the period following removal of the in-stream structures was heavily influenced by high volumes of sand input and should not be considered equivalent of the pre-modification period. The study included data on angler hours, and Latta (1972:14) stated that "because of the confounding fishing pressure, I hesitate to say that there was a real increase in the catch and standing crop of brook trout with the addition of structures to Section A (the modified section)." Latta (1972:3) also reported that there was "little interchange of trout with the water outside of the experimental area, but substantial interchange between sections," which shows that the location of angling was potentially important for catch data.

The extensive data set permitted ANCOVA analyses for 25 dependent variables vs. presence of structures and angler hours. The dependent variables were analyzed relative to periods before and after structures were present for both change in populations in the modified section, and percentage of population relative to populations in the modified and control sections. After adjustment for multiple comparisons, no variable for a direct measure of population in the modified section was

TABLE 1. ANOVA results for combined data set with four measures of fish catch for the percentage increase in a modified section of stream relative to control sections.

Dependent variable	Structure P	Finshing-pressure P†	Final whole-model R^2‡	Data trend	Holm's adjusted P
No. trout ($n = 6$)	0.8666	0.1179	n.s.	none	0.1179
No. trout caught ($n = 8$)	0.1368	0.0002	0.915	increase	0.0008
Biomass of trout caught ($n = 4$)	0.8617	0.0023	0.995	increase	0.0069
No. trout caught/h ($n = 8$)	0.5467	0.0981	n.s.	none	0.1962

Notes: Data are from Shetter et al. (1946), Hale (1969), Hunt (1969), and Latta (1972). The response variables include average measures in four studies in modified vs. control reaches. The sample size (n) represents the number of reaches sampled (each study had a modified and a control reach). The structure variable compares sections with structures to sections without structures. The fishing-pressure variable is measured as a percentage of angler hours in the modified vs. all reaches.

† For fishing pressure, the P value represents the results of a simple linear regression after the class variable was removed.

‡ An entry of "n.s." indicates that the model was not significant.

significantly related to the influence of structures, and two variables were significantly related to changes in fishing pressure in the modified section (Appendix A: Table A15). ANCOVA results for catch data as a percentage of the total indicate seven significant relations between the presence of structures and measures of fish population with six of these analyses exhibiting covariant influences of fishing pressure (Appendix A: Table A16). However, only two of these relations for structures indicate significant differences between periods before and during the time when structures were present. The remaining five relations indicate lower population measures in the sand-impacted period after structures were removed relative to the two earlier time periods. Conversely, 16 analyses exhibit a significant influence of fishing pressure on measures of fish populations, with six analyses exhibiting covariant influences of structures. Regression analysis for fishing pressure in all sections vs. population measures in all sections indicate a significant influence of fishing on seven of eight dependent variables analyzed (Appendix A: Table A17). A plot of number of trout caught vs. angler hours shows a great deal of scatter with no apparent differences between modified and unmodified reaches (Fig. 1c).

*Hunt (1969, 1970, 1974, 1976*a, b*)*

Hunt published at least five documents that pertain to evaluations of channel modifications in Wisconsin before 1980 (Hunt 1969, 1970, 1971, 1974, 1976*a*, *b*). Lawrence Creek was used simultaneously by the Wisconsin Department of Natural Resources for studies on natural production of trout, the effects of in-stream structures on trout, and the influence of changes in fishing regulations on populations of trout. Although Hunt (1976*b*) mentions dramatic changes in fishing pressure and data on catch/hour, no numerical data on fishing pressure are presented in the 1969, 1974, or 1976 publications focused on in-stream structures. Limited data on fishing pressure are available in the 1970 and 1971 publications. Hunt (1974:12) also stated that:

> *... the trout population in Lawrence Creek appeared to function as a homeostatic unit on a streamwide basis. Somehow the level of production in any one section or age group was related to production that year in other sections and other age groups.*

This finding suggests that any activity that influences one segment of the trout population in one location will eventually influence the entire population structure throughout the creek. In a later article, Hunt (1988) suggested studies on in-stream structures should include estimates of angling pressure because this could confound results. However, Hunt (1974) does not clearly indicate how the earlier results can be reliably analyzed with the potential for multiple influences on trout populations.

The data sets from the six publications were combined to provide the variables needed to perform ANCOVA. Based on differences in fishing regulations in the two lower control sections (Hunt 1970), only the uppermost control section was used for comparison. The publications contain additional years of data, and a large number of dependent variables. Only three pre-modification and three post-modification years are available for analysis because data collection efforts for the two studies were not well coordinated. To limit the multiple-comparisons problem, the dependent variables were limited to 15 of the most important variables. After adjustment for multiple comparisons, no variable for a direct measure of population in the modified section was significantly related to the influence of structures, and two variables were significantly related to changes in fishing pressure in the modified section (Appendix A: Table A18). ANCOVA results for catch data as a percentage of the total indicate no significant relations between the presence of structures or fishing pressure and measures of the fish population (Appendix A: Table A19). Regression analysis for fishing pressure in both sections vs. population measures in both sections indicate a significant influence of fishing in two of 14 dependent variables analyzed (Appendix A: Table A20). A plot of number of trout caught vs. angler hours shows

TABLE 2. Summary table of 215 statistical analyses performed to determine the influence of in-stream structures and fishing pressure on various measures of fish populations.

Independent variable	No. analyses (% of total)	Expected no. Type I errors	No. significant relations with Holm's adjusted *P* (% of analyses)
Structures only (ANOVA)	72 (34%)	4	5 (7%)†
Fishing pressure only (regression)	33 (15%)	2	12 (36%)
Both variables analyzed	110 (51%)	6	
Structures only retained (ANOVA)			3 (3%)‡
Fishing only retained (regression)			25 (23%)
Both retained (ANCOVA)			6 (5%)§

† All five of the relations are questionable because of Saunders and Smith's (1962) misclassification of the post-modification period.
‡ No relations indicate structures that increase levels relative to control period or reach.
§ Four relations indicate that there is no significant difference between the period with structures and the control period.

moderate scatter with some possible tendency for modified sites to exceed the average trend line (Fig. 1d).

Additional studies and data analysis

The combined data from Shetter et al. (1946), Hale (1969), Hunt (1969), and Latta (1972), shows no influence of structures on number of trout or catch (Table 1). However, fishing pressure was significantly related to both the number and biomass of trout caught. These trends are in general agreement with the results from the four individual studies.

Appendix B lists the additional publications before 1980 that were reviewed in this study and also includes the full references for these additional studies. The majority of the literature published before 1980 does not include data on fish populations, so no detailed account of those studies is presented. It is also worth noting that only 4 of the 79 publications reviewed were completed by individuals who did not work for the agency involved with the installation of the structures. Over one third of the literature sources studied were also published by the agencies supervising the modification work.

DISCUSSION

Because it is impossible to boil down the large number of different studies and types of variables into a simple analysis, it is the preponderance of evidence and consistency in the findings from the various studies that provide the necessary confidence in the results. The statistical reanalysis of the early evaluations demonstrates that many of the claims in these articles and the literature that cites them are not well supported by data. Table 2 shows the total number of analyses that indicate a significant relation for either structures or fishing pressure. If we utilize the more reliable benchmark associated with the Holm's sequential Bonferroni-method-adjusted *P* value, the independent variable "structure" was significant in a total of 14 of the 182 analyses. Five ANOVA analyses indicate a significant relation, but all five tests are undermined by Saunders and Smith's (1962) misclassification of post-modification data. ANCOVA results produced three relations with structure only, with the reduced model eventually analyzed as ANOVA, and six relations with both structures and fishing pressure. The three structure-only relations suggest trout catch was higher in the control vs. the modified reach or one control vs. another control reach (Appendix A: Table A5), and higher in the modified reach vs. a sand-filled reach (Appendix A: Table A16), but no result indicates populations were higher in the modified reach vs. the control reaches. Meanwhile four of the six ANCOVA models show a difference in the Latta (1972) data between the pre-modified channel and sand-filled channel, but no difference between pre-modified and post-modified channels (Appendix A: Table A16). Only two reliable analyses out of 182 analyses that include the variable "structure," 1% of the analyses, indicate these modifications may benefit trout populations.

In comparison, even using the Holm's sequential Bonferroni-method-adjusted *P* value, 43 significant relations exist with "fishing pressure" as an independent variable. These represent 30% of the analyses that include a variable for fishing pressure. Thirty-two of these 43 significant relations, 74% of the analyses, contain some measure of catch in the dependent variable. Plots of four of these relations show little or no visible difference attributable to the presence of structures (Fig. 1). Although not usually discussed at length in any of the studies, it is not surprising that the statistical results indicate more fish are caught when fishing pressure increases. Only the data from Latta (1972) and Hunt (1969, 1970, 1971, 1974, 1976*a*, *b*) suggest any additional impact of fishing. According to their data, several measures of fall standing crop seem to increase with heavier fishing. The number of young-of-year fish and biomass of older fish also appear to increase.

Several disturbing deficiencies were noted in the literature before 1980. Data on stocking levels frequently were not provided (e.g., Tarzwell 1938, Boussu 1954, Wilkins 1960). Many of the studies also contained very limited pre-modification or post-modification data to determine the long-term impact of the in-stream structures (e.g., Tarzwell 1938, Boussu 1954, Wilkins 1960, Saunders and Smith 1962). Perhaps the biggest problem was the close relation between project designers and evaluators in most studies (Appendix B). Walters (1997) discussed the tendency for some government agencies to claim an unwarranted degree of certainty of a positive outcome associated with particular policy initiatives. This approach may be spurred by a desire to maintain credibility with political decision makers and to defend policies (Walters 1997). With regard to the use of in-stream structures, it is easy to envision that political pressure would tend to favor optimistic evaluations of in-stream structures. This situation is particularly critical given the fact that most projects were publicly funded under the supervision of federal and state agencies, which were also ultimately responsible to demonstrate to the taxpayers the efficient use of these same funds. Therefore, the majority of evaluations before 1980 lack the high level of objectivity that would ideally exist to assess the projects. This problem may be compounded recently by the realization that river restoration has become a highly profitable business with annual expenditures in excess of U.S. $1 billion (Bernhardt et al. 2005).

It is possible to discount the claims made in several articles. Studies by Tarzwell (1938), Boussu (1954), Wilkins (1960), and Jester and Mckirdy (1966) provide no statistical evidence that structures directly benefit fish populations (Appendix A: Tables A1, A7, A8, and A12). The study by Shetter et al. (1946) suggests structures might influence fishing success rate, but not fish populations (Appendix A: Tables A2–A5). The study by Hale (1969) also contains no evidence of the influence of structures once corrections for multiple comparisons are made (Appendix A: Table A13). However, several other studies do contain some evidence for a possible influence of structures that bears further investigation.

The study by Saunders and Smith (1962) is frequently cited as evidence for the beneficial use of in-stream structures. However, the results are completely dependent on the way data in 1959 are treated. If the data are treated in a similar way to data collected by earlier researchers (e.g., Boussu 1954), any data collected after structures were introduced should be considered post-modification data, and the influence of structures is not significant. Yet, Saunders and Smith (1962) choose to use only a single survey, 1960, for their post-modification data. The reason for the single post-modification survey was not explained in the article. The survey for 1960 indicates high population numbers, so the influence of structures appears significant. However, it is important to note that because no control reach was measured it is impossible to determine if the increased populations measured in 1960 resulted from the introduction of structures or favorable hydrologic conditions. Additional post-modification data would have helped to address some of the limitations of the study. It is also impossible to determine the influence of fishing pressure on the data. Therefore, the study does not represent a reliable test of the influence of structures.

Results from Michigan reported by Latta (1972) indicate that 2 out of 50 analyses show higher numbers of trout in post- vs. pre-modification surveys when controlled for multiple comparisons. All other significant relations with the structure variable show only differences between the period of intense sand introduction and earlier time periods. Even if the Holm's sequential Bonferroni method successfully controlled family-wise error at $\alpha = 0.05$ for the 50 analyses, two or three hypotheses would tend to be falsely accepted when no true differences existed in the populations, Type I error (Ott 1993). Once again, this suggests that the study may not provide convincing evidence structures significantly influenced fish populations.

Only a portion of the extensive data set compiled by Hunt (1969, 1971, 1970, 1974, 1976*a*, *b*) was suitable for ANCOVA. Once adjustments for multiple comparisons were made, data from three years before and three years after modifications for the adjacent modified and control reaches showed no evidence that structures influence fish populations (Appendix A: Tables A18 and A19). Meanwhile, fishing pressure influenced the number of trout caught, biomass of trout caught, biomass of age III trout and biomass of age 0-IV trout (Appendix A: Tables A18 and A20). However, data after 1967 were not included in the analysis because corresponding data on fishing pressure could not be found.

A comparison of evaluations conducted before 1980 and after 1995

A brief comparison of more recently published articles on the evaluation of the use of in-stream structures shows some of the same problems identified in earlier studies. The number of stream-restoration projects in the United States increased exponentially in the last decade, but only 10% of these projects include assessment work (Bernhardt et al. 2005). Although catch data are not generally used anymore, few data on fishing pressure are collected. For example, Jungwirth et al. (1995), Moerke and Lamberti (2003), and Binns (2004) all failed to systematically measure fishing pressure. However, Binns (2004:915) noted "informal observation of anglers suggested increased angler use at Wyoming habitat enhancement projects." He also reports that special fishing regulations were used in several Wyoming projects to control fishing harvest. However, it is not clear if the projects with reduced fishing were included in the study.

Some modern studies fail to show demonstrable benefits of modifications on fish populations. Moerke and Lamberti (2003) and Jones and Tonn (2004) found no statistically significant increase in fish populations in response to channel modifications. Binns (2004) claimed significant increases in abundance and biomass for the total trout and mean catchable trout. However, the significance test for mean catchable trout biomass was only 0.06, a value that is not usually considered statistically significant. Meanwhile, Jungwirth et al.

(1995) repeated the error of only using mean values, not statistical tests to evaluate the influence of modifications in an Austrian river. Conversely, Riley and Fausch (1995) and Gowan and Fausch (1996) found that abundance of adult trout and biomass statistically increased after modifications. However, no growth benefit was associated with the structures, and overwinter survival was not influenced by the modifications. The studies attributed the increase in abundance to migration to the modified sections from other stream locations, not increased survivability, recruitment, or growth.

The problem of potential political pressure on evaluators to report successful project outcomes also continues to exist. For example, Binns (2004) evaluated a project completed by the agency that employs him, and he only searched for potential confounding impacts on fish populations for sites that failed to show increases in abundance or biomass. At three sites the author attributes differences in fish populations to increased fishing pressure in the modified reaches. Conversely, at all other study sites the author attributes measured increases in abundance and biomass to the presence of the in-stream structures without a similar mention of possible influences of fishing pressure. This approach shows a bias towards rejection of the null hypothesis that structures exhibit no beneficial impact.

It is also worth noting growing concerns about the long-term stability and environmental impact of in-stream structures. As noted as early as the 1930s (Aitken 1935) and as recently as the 1990s (Frissell and Nawa 1992), in-stream structures are often damaged or destroyed by floods and sediment transport. Negative long-term impact of in-stream structures on the recruitment of riparian vegetation, input of large woody debris and creation of valuable undercut-bank habitat were also recently documented (Thompson 2002, 2005). These studies show that the long-term benefit of installing in-stream structures needs to weighed against the environmental impacts of the devices on other aspects of the aquatic and riparian ecosystem.

Implications for the evaluation of channel restoration on fish populations

The results from my present study highlight the need to control for various sources of variation when the effects of channel-restoration technique on fish populations are tested. The more recent publications also show a continuation of some of the problems identified in earlier studies. In particular, P values should be adjusted with the Holm's sequential Bonferroni method to minimize Type II errors associated with multiple comparisons. The number of observations, especially the number of control and treatment sites, should be increased to improve the power of statistical tests (Benedetti-Cecchi 2001). Studies should include time-synchronized population measures in a control reach to account for hydrology-related and long-term variations in populations. Fishing pressure must also be controlled or measured to determine the influence of this activity on fish populations. ANCOVA provides one logical means to include the influence of fishing.

Because fish can move to fill voids vacated by harvested fish, the location of angling will exert a tremendous influence on population measures that include catch data. If studies do not account for this influence, it is very easy to misinterpret statistical results and attribute an increased catch to the location of fishing, not the volume of fishing. Because fishing pressure in a particular location consistently increases with the addition of structures, it is easy to erroneously attribute increased catch to the presence of the structures. Furthermore, fishing pressure influences other measures of fish populations that included number and biomass of trout because of competition and predation among various age classes of fish. Only some of the more recent evaluations of in-stream structures attempt to account for this important factor.

The statistical analyses also show that the use of in-stream structures does not provide a demonstrable benefit to fish populations in studies conducted before 1980. The reason for the lack of a significant benefit could be due to low statistical power for the tests due to small sample size in many tests, a confounding negative influence of heavy fishing near structures, or the inability of structures to modify the limiting factors in the study reaches. Mixed results were also published in the more recent publications. Furthermore, the data raise concerns about current channel-restoration practices because the design of many structures used today closely mimics designs used in these historical studies (Thompson 2005). Although the trend in fisheries management has been focused on investments in project implementation at the expense of monitoring (Kondolf and Micheli 1995, Bernhardt et al. 2005), the reanalysis of historical data shows that we need to increase our investment in monitoring and evaluation of restoration projects to ensure the money spent on implementation is not wasted.

Conclusions

Statistical analysis of biological data published before 1980 on the impact of in-stream structures on fish populations indicates little or no demonstrable beneficial influence of the modifications. Many of the reported increases in fish populations were actually the result of increased fishing pressure and response variables that include some measure of catch. The statistical results demonstrate the importance of proper experimental design with adequate controls for variation in stream conditions, especially changes in fishing pressure. Some more recent publications continue to make these mistakes, and all publications should be scrutinized with special attention given to the possible covariant influence of fishing pressure on fish populations. Only studies that control for changes in fishing pressure, influence of stocking practices, and variation in annual productivity should be considered valid statistical designs to evaluate the influence of in-stream structures on fish populations.

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APPENDIX A

Tables of statistical results from the study, with literature cited (*Ecological Archives* A016-030-A1).

APPENDIX B

Summary table of publications included in the literature review, together with full citation information (*Ecological Archives* A016-030-A2).