Does Habitat Creation Contribute To Management Goals? An Evaluation of Literature Documenting Freshwater Habitat Rehabilitation or Enhancement Projects.

K. E. Smokorowski, K.J. Withers, and J.R.M. Kelso

Department of Fisheries and Oceans, Great Lakes Laboratory for Fisheries and Aquatic Science, 1 Canal Drive, Sault Ste. Marie, Ontario, P6A 6W4, CANADA

1998

Canadian Technical Report of Fisheries and Aquatic Sciences No. 2249

Fisheries and Oceans Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report 925.

Technical reports are produced regionally but are numbered nationally. Request for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des Sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques , de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés a titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur don't le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

CANADIAN TECHNICAL REPORT

OF FISHERIES AND AQUATIC SCIENCES

November 1998

Does Habitat Creation Contribute to Management Goals? An Evaluation of Documented Freshwater Habitat Rehabilitation or Enhancement Projects

By

K.E. Smokorowski, K.J. Withers and J.R.M. Kelso

Great Lakes Laboratory for Fisheries and Aquatic Sciences

Department of Fisheries and Oceans

1 Canal Drive

Sault Ste. Marie, Ontario

P6A 6W4

Cat. No. Fs 97-6/2249E ISSN 0706-6457

Correct citation for this publication:

Smokorowski, K.E., Withers, K.J., and Kelso, J.R.M. 1998. Does habitat creation contribute to management goals? An evaluation of literature documenting freshwater habitat rehabilitation or enhancement projects. Can. Tech. Rept. Fish. Aquat. Sci. No. 2249: vi + 74 p.

TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

Smokorowski, K.E., Withers, K.J., and Kelso, J.R.M. 1998. Does habitat creation contribute to management goals? An evaluation of literature documenting freshwater habitat rehabilitation or enhancement projects. Can. Tech. Rept. Fish. Aquat. Sci. No. 2249

Since the implementation of the "no net loss" policy for the management of fish habitat (DFO 1986), focus on fish habitat rehabilitation has sharpened. However, aquatic resource managers have implemented fish habitat rehabilitation, enhancement and creation efforts as a tool for ecological restoration for decades. Available published information from these past efforts to rehabilitate or create new freshwater habitat in a range of systems was reviewed in terms of cost, durability, aesthetics, side effects, method of assessment, and measurable benefits to aquatic ecosystems. Documentation of the 78 habitat rehabilitation projects was often poor with only 68% assessing costs, 4% considering aesthetics, and 24% considering side effects. Of the 30 projects (38%) that examined durability, 23 reported some type of structure deterioration. Only one example of a failed project was found in the published literature. Because 15% of the projects reviewed were incomplete (12 of 78), the success of those projects could not be assessed. Therefore the 65 completed projects, which reported to have achieved at least a portion of their habitat target (and were considered successful), implies a 98% habitat rehabilitation "success" rate (65 out of 66 completed projects). However in this sense, success was often measured in terms of achieving the habitat change without assessment of the biological benefit. An increase in fish production was detected for only four (5%) of the projects. A greater proportion of studies reported an increase in the biomass and/or abundance of target fish species (27%). However, generally, the source of the increase was not assessed – i.e. whether the increased biomass was produced by an increase in successfully growing and reproducing fish, or was it a redistribution/concentration of fish in the rehabilitated habitat. Evidence of redistribution/concentration was found in 17% of the projects. Improvements in assessment, monitoring, documentation and communication of results of rehabilitation projects are needed.

RÉSUMÉ

Smokorowski, K.E., Withers, K.J., and Kelso, J.R.M. 1998. Does habitat creation contribute to management goals? An evaluation of literature documenting freshwater habitat rehabilitation or enhancement projects. Can. Tech. Rept. Fish. Aquat. Sci. No. 2249

Depuis la mise en oeuvre de la politique d' "aucune perte nette" pour la gestion de l'habitat du poisson (MPO, 1986), on travaille de façon plus ciblée au rétablissement de l'habitat. Toutefois, les gestionnaires des ressources aquatiques ont recours depuis des décennies au rétablissement, à la mise en valeur et à la création d'habitat comme outils pour la restauration du milieu naturel. Nous avons examiné l'information publiée sur les efforts déployés dans le passé pour rétablir ou créer de l'habitat dulcicole dans divers systèmes sur les plans du coût, de la durabilité, de l'esthétique, des effets secondaires, de la méthode d'évaluation et des effets positifs mesurables sur les écosystèmes aquatiques. La documentation des 78 projets de rétablissement était souvent médiocre : 68 % seulement évaluaient les coûts, 4 % s'intéressaient à l'aspect esthétique et 24 % aux effets secondaires. Sur les 30 projets (38 %) qui examinaient la durabilité, 23 ont signalé une forme de détérioration des structures. Un seul exemple d'échec est décrit dans la littérature. Étant donné que 15 % des projets examinés n'étaient pas achevés (12 sur 78), il a été impossible d'évaluer leur degré de réussite. Les 65 projets achevés, pour lesquels la cible a été atteinte au moins en partie (et qui sont considérés comme des réussites), donnaient un taux de "succès" de 98 % dans le rétablissement de l'habitat (65 projets sur 66 menés à terme). Toutefois, on mesurait souvent le succès en termes de changements apportés à l'habitat, sans évaluation des effets sur le plan biologique. Une augmentation de la production de poissons a été observée dans 4 % seulement des projets. Une plus grande proportion des études rapportaient une augmentation de la biomasse et/ou de l'abondance des espèces de poissons cibles (47 %). Toutefois, dans l'ensemble, la source de cette augmentation n'était pas évaluée – l'augmentation de la biomasse était-elle causée par un accroissement du nombre de poissons qui réussissent à grandir et à se reproduire, ou s'agissait-il d'une redistribution/concentration des poissons dans l'habitat reconstitué? Il est nécessaire d'améliorer l'évaluation, la surveillance, la documentation et la communication des résultats des projets de rétablissement de l'habitat.

1.0 INTRODUCTION

Aquatic resource managers implemented fish habitat rehabilitation, enhancement, and creation efforts for decades as a tool for ecological restoration. Since 1986, when the Department of Fisheries and Oceans first introduced its Policy for the Management of Fish Habitat (DFO 1986), the guiding principle for fish habitat managers has been to achieve no net loss of the productive capacity of fish habitats. In the Policy, productive capacity is “the maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms upon which fish depend” (DFO 1986). Under the *Fisheries Act*, any activity that could result in a harmful alteration, disruption or destruction (HADD) of fish habitat is prohibited, unless authorized at the discretion of the Department of Fisheries and Oceans. The authorization of a HADD always includes some compensatory action designed to achieve “no net loss”. Combinations of fish habitat conservation, restoration and development have been extensively used by managers, with the implicit assumption that habitat availability and quality are directly related to fish production. In other words, it is assumed that the destruction of habitat causes a compensatory decrease in productive capacity, and restoration, enhancement or development of fish habitat increases the productive capacity of the system. However, the benefits of habitat rehabilitation efforts, particularly in terms of effect on productive capacity, have received little assessment and documentation is limited (Kelso and Wooley 1996).

A review of habitat modification projects found that studies showing neutral or negative biological effects have been published infrequently relative to studies with positive results (Hamilton 1989 *in* Frissel and Nawa 1992). An assessment of artificial habitat structures used in West Coast streams determined that median failure and damage rates were 18.5 % and 60% respectively, with a wide range of causes for failure (Frissel and Nawa 1992). The need to deal with the larger-scale ecological concerns such as reforestation of floodplains, rehabilitation of failing roads, and prevention of slope erosion was emphasized in order for direct channel structural modifications to succeed (Frissel and Nawa 1992). Basset (1994) reviewed habitat structures used in lakes in the eastern region of the U.S. from 1978-1991 and found that many evaluations lacked controls, pre-treatment data and statistical analysis, and most were not published. Evidence that enhancement of physical fish habitat increases fish production is often anecdotal, circumstantial and inadequate (Bohnsack 1989).

We compiled published information from efforts to rehabilitate or create new freshwater habitats. The efforts reviewed include 1) providing structural habitat diversity in lakes and in streams, 2) stabilizing banks or modifying littoral zone morphology, 3) creating wetlands or plant macrophytes, 4) providing additional or enhanced spawning substrate, and 5) improving water quality. Assessment data from these applications were compiled to value each option in terms of cost, durability, biological effect, and aesthetics. The methods of assessment and the biological data were examined to determine whether adequate evidence had been provided linking the habitat enhancement project with an increase in the productive capacity of the system. In this review, the fish production is used as defined by Ivlev (1945, 1966 as cited in Ricker 1968) as the total elaboration of fish tissue during a period of time, including what is formed by individuals that do not survive to the end of the period of time. In this sense, fish production takes two of the most important features of a fish population into account: growth (instantaneous rate of increase in weight) and mean biomass (product of abundance and individual average weight) of the population into account (Ricker 1968).

2.0 METHODS

A search of the fisheries literature was conducted using a variety of search tools including the Internet, Biological Abstracts, Aquatic Sciences and Fisheries Abstracts, Current Contents, and Wildlife Worldwide. We consulted with Fish Habitat Management (DFO), the local Ontario Ministry of Natural Resources office, and researchers in the fisheries habitat field for additional literature sources. A combination of primary and secondary literature detailing work conducted in the field of fish habitat creation was reviewed, including the references used in each publication. Although the literature review mainly described projects designed to improve available fish habitat in the field, a selection of papers were included which involved habitat removal experiments, fish and fish habitat associations, and controlled laboratory experimentation.

The compiled literature was reviewed for information on the system characteristics (i.e. stream order, lake size etc.), cost, aesthetics, side effects, durability, method of assessment, and measurable benefits to aquatic ecosystems. The resulting information was summarized in tabular form, and classified according to one of the five general categories of habitat rehabilitation techniques as outlined earlier. We concentrated on freshwater fish habitat rehabilitation projects in North America. Frequently the publications reviewed did not include all solicited information; columns left blank, or containing vague information, indicate that those details were not available. Information from papers describing habitat enhancement(s) was further condensed by determining the proportion of reviewed projects that assessed cost, achieved the stated habitat target (success), gave evidence of increased fish production (i.e., increased growth and biomass, also included in counts of success), considered durability and reported deterioration, and considered aesthetics, side effects and failure.

3.0 RESULTS AND DISCUSSION

A total of 87 papers was found and reviewed, covering projects in systems with characteristics ranging from Lake Superior harbours to 1.4 ha inland lakes, and from 2^{nd} order tributaries to 5^{th} order streams. The habitat rehabilitation projects (78) used a variety of options including creating several forms of artificial reefs and shelters, embayment/wetlands, stream deflectors and shoreline stabilization techniques. Twelve of the 78 projects involving habitat enhancement are included in the review but have not been completed or had obtained only preliminary results by the date of the publication. Details of the rehabilitation projects, methods of biological assessment, and assessment results are presented in Tables 1 through 6. The remaining nine projects covering miscellaneous habitat studies (habitat removal, correlation studies, review studies) are presented in Tables 7 and 8.

3.1 Provide Structural Habitat Diversity in Lakes

Twenty of the 78 reviewed habitat rehabilitation projects were designed to increase the structural habitat diversity in lakes (Table 1). Options utilized included artificial reef or shelter creation (e.g. concrete/rock reefs, brush/tire bundles, log structures, cinder blocks), or the construction of dykes or breakwaters designed to create calm water areas (Table 1). Reported cost of individual projects depended on scale and materials used. Costs ranged from $3,500 for an individual reef-raft constructed from wood and plastic (Blokpoel 1995), to an estimated $14 million for the construction of over 1 km of armour-stone submerged breakwater reefs (Moy 1995).

Every lake project that had completed at least a portion of their assessment declared the rehabilitation a success, and success was defined in terms of an increase in the abundance and/or diversity of fish at the localized site of the structure (Table 1). Only one of the 20 studies (Table 8) gave evidence of a significant increase in sunfish production (number and size) after the addition of tire and Christmas tree reefs (covering 9500 m^2) in an 8100 ha lake in Virginia (Prince et al. 1985). The limited movement of sunfish, combined with large increases in periphyton primary productivity, the extensive use of the reefs as feeding stations, and the high seasonal availability of catfish eggs and fry as fish food, were cited as factors influencing the increase in sunfish production (Prince et al. 1985). However this was also the only study (of the 20) that included a biological monitoring program that would result in data usable to calculate fish production.

The durability of structures installed in lakes was assessed for less than half of the reviewed projects (8 out of 20 or 40%); half (4) reported subsequent structural damage (Tables 1 and 8). Damage occurred in the form of changed reef configuration (Binkowski 1985), removal of branches from brush bundles by beavers (Moring and Nicolson 1994), and, for woody structures, depended on the diameter and species of wood used (Bassett 1994). It appears that if the habitat modification was designed with the dual purpose of providing structure and mitigating water movement, then more strict maintenance was required and was often quite costly (e.g. Hector and Tulen 1995a).

3.2 Provide Structural Habitat Diversity in Streams/Rivers

Fifteen of the habitat rehabilitation projects were designed to increase the structural habitat diversity in streams or rivers (Table 2). Structures used in large rivers were similar to those used in lakes (dykes, embayments, islands). Habitat enhancement structures used in streams frequently included various forms of log sills, large woody debris, rock gabions, concrete berms and boulder groupings. The objectives of many stream rehabilitation projects were often to decrease current velocity to create backwater areas and increase the depth and availability of pools, to create shallow riffle areas, and to increase depth and cover available in streams (Table 2). Again, cost varied depending on the scale and type of project, ranging from $35 for a single boulder placement or $1200 per gabion (House and Boehne 1995a), to the estimated $1.2 million for the extensive rehabilitation of the lakes and canals on Belle Isle in the Detroit River (Denison 1995).

Two (15%) of the 13 stream rehabilitation projects reported that an increase in fish production had occurred (Table 8). Moore and Gregory (1988) concluded that increasing the amount of lateral habitat available for young-of-the-year cutthroat trout in a 3rd order stream in Oregon resulted in a 95% increase in total production over control reaches, and an 824% increase in total production over reduced lateral habitat sections (Table 2). The lack of a significant difference in size of fish between sections indicated that the observed increase in production in sections with increased lateral habitat was from an increase in abundance in those areas (Moore and Gregory 1988). However, there was also an observed 83% reduction in the average number of age-0 cutthroat trout in reduced lateral habitat sections, indicating that redistribution of fish may contribute to the observed increase in "production".

One of the best studies on stream rehabilitation and evaluation was provided by Hunt (1974, 1976) who conducted a detailed, long-term brook trout production evaluation in Lawrence Creek, Wisconsin. Lawrence Creek was divided into four Sections (A through D), and fish biomass and production, by age class, were compared over an 11-year period (1960-1970). Substantial habitat modifications were made to Section A (completed by 1964) to improve brook trout habitat by increasing pool availability and permanent overhanging bank cover. During the latter four years of this study, annual production in Section A was substantially improved (by 46%) over years prior to rehabilitation. However over the same time period, decreased production measured in Sections C and D resulted in relatively homeostatic annual brook trout production for the entire stream. Increases in annual production at Section A were apparent in the older age classes, due primarily to increased overwinter survival of larger fish. Thus the rehabilitation was a success from a management point of view due to the substantially enhanced sport fishery in this Section (Hunt 1972). However, since the improved angling in Section A resulted in an overall increased yield as a percentage of stream-wide annual production (from 10% in 1961 to 26% in 1967), the "success" may not be viewed as well from the populations' point of view.

Greater than half (8 out of 13 or 62%) of the projects reported on the durability of the structures installed in streams or rivers (Tables 2 and 8).   Structures installed in streams were subject to damage or removal by flooding and scouring (e.g. House and Boehne 1985a, House 1996, Slaney et al. 1994). Maintenance and minor repairs were required as early as one year after installation (Riley and Fausch 1995, White et al. 1992), and Milton and Towers (1990) admitted that the long-term permanency of structures was not known (Table 2).

3.3 Stabilize Banks or Modify Littoral Zone Morphology

In streams or rivers, the purpose of changing the characteristics of the terrestrial-aquatic interface is often to stabilize banks and reduce erosion. Varying combinations of riprap, tree revetments, fieldstone, gabion mats, and enhancement of riparian vegetation were used as treatments to stabilize stream banks (Table 3). Reported costs ranged from $6,397 for a vegetation and cribwall treatment (40 m @ ~$160/m, Grillmayer 1995a), to over $1 million ($170/m of bank) for riprap, lunker structure and conifer restoration treatment of nearly 8 km of river banks (Rizich 1995, Table 3). Cited side effects included the provision of additional spawning, shelter and foraging habitat and the project was considered successful if erosion was reduced, vegetation was reestablished, and/or fish were observed in the treated area. Success of some projects was declared simply if the shoreline was stabilized, without an assessment of the fish population (e.g. Steck et al. 1995,Thomas et al. 1995, Table 3). None of the stabilization projects gave evidence of increased fish production and all of the projects that considered durability indicated that most of the structures remained functional to the end of the monitoring period (Table 3).

Modifying the littoral zone morphology in lakes can involve excavation at the terrestrial-aquatic interface to increase the availability of shallow water habitat (i.e. create a shallower nearshore slope). Few published reports of this type of project were found, two of which were still in progress (Hector and Tulen 1995b, Hector and Colman 1995c, Table 3). Bray (1995) found that the new habitat was colonized by a variety of organisms and that water quality had improved (Table 3). Excavation appears to be a costly option as the least expensive project was estimated at $50,000 (Hector and Colman 1995c), and the most expensive was estimated at $607,800 for construction alone (Bray 1995).

3.4 Create Wetland or Plant Macrophytes

Eleven projects that involved the creation or improvement of a wetland were reviewed (Table 4). The most simple and inexpensive (range $7 – 43,000) method of wetland improvement was achieved through planting and protection of macrophytes in an established wetland area (e.g. Grillmaner 1995b, Vincent 1995c, Lee 1995, Table 4).

Projects involving the creation of a new wetland consisted of a combination of pond excavation and macrophyte planting, the cost of which ranged from $360,000 to an estimated $4.2 million. Fish surveys were either not conducted (e.g. Lee 1995, Hector and Colman 1995), were conducted by visual estimation (e.g. Reutter 1995, Eitniear 1995), or were not clearly described (e.g. Morrow 1995, Table 4). Success was often claimed simply if the macrophytes were reestablished, and durability was only considered in terms of carp damage to the macrophytes.

3.5 Provide Spawning Habitat

Methods used for creation or improvement of fish spawning habitat depends highly on the target species, as preferred spawning habitat is quite species-specific (Scott and Crossman 1973). Improvements to spawning habitat most frequently consist of increasing the available area of cobble/gravel substrate for specific target species (Table 5). The improvements may consist of installing cobble spawning shoals for species such as walleye (e.g. Lychwicky 1995, Geiling 1995c, Geiling et al. 1996), constructing artificial redds for salmonids (e.g. Gustafson et al. 1984, Newman 1995), or reducing sediment load on existing substrate (e.g. Alexander and Hansen 1983, Moyer et al. 1995, Avery 1996). In one case, the manipulation consisted of the dredging of channels through a dense mono-culture of cattails to create spawning and nursery habitat for northern pike (Mathers and Hartley 1995, Table 5).

Only five of the 13 projects reviewed reported on the durability of the created spawning habitat (Tables 5 and 8). Continuous excavations were required to maintain the reduced sediment load (Alexander and Hansen 1983, Avery 1996), and vegetation required continuous removal (Moyer et al. 1995, Mathers and Hartley 1995). The only reviewed project involving the construction of salmonid spawning habitat in streams that reported on durability concluded that the project was a failure (Kondolf et al.1996). Four years after construction, the artificial gravel spawning bed was washed out and the gravel was deposited downstream above the water level, rendering it useless for spawning. The suggested reason for failure was the lack of consideration given to the system's geomorphic context in the planning of the project. Frissel and Nawa (1992) suggested that commonly prescribed structural modifications often are inappropriate and counterproductive in streams with high or elevated sediment loads, high peak flows, or highly erodible banks.

3.6 Improve Water Quality

When the productivity of an aquatic system is limited by acid conditions, water quality will improve with the addition of limestone to increase pH (Table 6). A variety of limestone forms have been used, including a powdered form, to increase the pH of a lake (Snucins and Gunn 1995), and crushed gravel- or rock-sized limestone have been mixed in with spawning beds or shoals (Gunn and Keller 1980, Booth et al. 1993, Lacroix 1992, 1995, 1996). In all cases, pH was elevated and survival of the target species increased (Table 6). However, liming is a temporary solution and reapplication is necessary to prevent re-acidification (Snucins and Gunn 1995, Lacroix 1996).

3.7 Miscellaneous Habitat Studies

Although the main purpose of this report was to review the literature for examples of habitat enhancement and rehabilitation, we included nine other studies/experiments of interest relating to fish habitat (Table 7). The addition of complex structure (i.e. artificial reefs, Christmas tree bundles) to lakes is a common habitat rehabilitation practice, yet the role that this structure plays in shaping fish production and community structure remains largely untested. In a controlled laboratory experiment, Pardue (1973) tested the role of structure in invertebrate and bluegill production by adding increasing amounts of rough pine attachment boards to plastic pools (3 m diameter, 76 cm deep). A significant linear increase in net production of both bluegills and macroinvertebrates was found with increases in added rough pine boards (Pardue 1973). Pardue (1973) hypothesized that one significant factor limiting bluegill production was a lack of sufficient surface or attachment space for fish-food organisms.

Aquatic habitat alteration or destruction will continue as long as there is continued development near shorelines. However, confounding factors (e.g. changes in activity levels) usually accompany development which obscure the specific effect(s) of habitat alteration. To specifically test the effects of lost habitat, McAughey and Gunn (1995) “removed” (i.e. covered with plastic) 50% of the historic spawning habitat of lake trout and observed their behaviour (Table 7). The result was an increase in density of eggs on the remaining traditional sites, and the selection of new spawning areas to compensate for the loss. The results were preliminary, however, and the long-term effects of selecting alternative sites upon which to spawn were not yet known.

A number of comparative studies were found that assessed the fish community in areas of contrasting habitat (Table 7). Coho salmon were found in significantly greater numbers and biomass in stream reaches containing abundant large woody debris than in simple sections previously cleared of woody debris (House and Boehne 1986b, Fausch and Northcote 1992). Thirty year old brush shelters had both a greater concentration of macrophytes and centrarchids than adjacent areas, and although the shelters had collapsed they were still considered effective (Thomas and Bromley 1968, Thomas et al. 1968). One assessment of the use of artificial reefs by fish showed no preference for reefs over control areas by yellow perch, freshwater drum and walleye (Gerber et al. 1989). Another assessment showed some use of artificial reefs by lake trout for spawning, and a greater abundance of eggs, fry and YOY on artificial structures than natural (Fitzsimons 1996).

Finally, one study reported on the modification of a stream's thermal environment to render it more suitable for brown trout habitat (Spilter and Thomas 1995). Coolwater from the bottom of a reservoir (19 m depth) was diverted to the base of the dam to sustain stream water temperatures below 21°C, and provide 5 km of new trout habitat. The project cost $67 000 and routine maintenance was required, but was considered a success due to the survival of planted brown trout in the cooler waters.

3.8 Proportional Assessment of Habitat Rehabilitation Projects

Of the 78 projects involving habitat enhancements, 68% assessed cost, 4% considered aesthetics, and 24% considered side effects (Table 8). Only 38% (30) of the 78 projects examined the durability of the installed structures, and 23 of those 30 (78%) reported some type of structure deterioration. Because 15% of the projects reviewed were incomplete (12 of 78), the success of those projects could not be assessed. Therefore, the 65 completed projects, which reported to have achieved at least a portion of their habitat target (and were considered successful), actually represent a 98% "success" rate (65 out of 66 completed projects, Table 8).

Projects were considered successful when potential fish habitat was restored or created, and fish and other species utilized the habitat. However, success in this context does not imply that production of fish was increased. Only 5% of reviewed projects implied an increase in production (Table 8). A greater proportion of studies reported an increase in the biomass and/or abundance of target fish species (27%). However generally the source of the increase was not assessed – i.e. whether the increased biomass was produced by an increase in successfully growing and reproducing fish, or was it a redistribution/concentration of fish in the rehabilitated habitat. Occasionally authors would assert that the improved habitat was an effective fish concentrating device (17% of studies), without providing data supporting an overall localized increase in abundance or biomass (e.g. Binkowski 1985, Vincent 1995a, Cullis 1995). If the habitat structure's only effect was to concentrate existing fish, the overall effect could be detrimental to the fish population because of increased angling. Details of reported rehabilitation success varied from simply achieving the habitat target (e.g. Steck et al. 1995, Thomas et al. 1995, Edsall 1995, Reutter 1995), to a detailed consideration of the impact on affected species over extended periods of time (e.g. Hunt 1974 1976, House 1996, Foster and Kennedy 1995).

Similar results were found by Geiling et al. (1996), who reviewed the success of 40 walleye habitat enhancement projects conducted by the OMNR between 1974 and 1994. None of the projects were judged to have failed in terms of the desired habitat goals, but biological success was less certain. Assessment efforts varied greatly with only three of the 40 projects conducting a quantitative physical, chemical and biological assessment, and four conducting no assessment at all. Viable egg abundance was reported to have increased in 13 projects, yet adult populations were reported to have increased in only three projects, all three of which were coupled with the introduction or reintroduction of walleye. However, five projects did report that the habitat enhancement contributed to increased exploitation while maintaining abundance of spawning adults, and, in some cases, assessment results were preliminary (Geiling et al. 1996).

Only one published account of a failed habitat rehabilitation project (Kondolf et al. 1996) was found among the 87 projects reviewed, and it may be that studies with negative biological effects have been published infrequently relative to studies with positive results as suggested by Hamilton (1989 *in* Frissel and Nawa 1992). Millions of dollars have been invested in aquatic habitat rehabilitation, yet little information has resulted by which to value the expenditure. Clearly there is a need for improvements in the assessment, monitoring and reporting of habitat enhancement projects to determine whether this investment is justified, and to help managers and scientists understand the repercussions of their decisions.

Recently (May 1997) the American Fisheries Society dedicated an issue of Fisheries magazine to the importance of using watershed restoration techniques to maintain and improve stream fish populations. The lack of success of many stream restoration projects is largely attributable to the emphasis placed on instream habitat restoration on a small-scale, site-specific basis (Roper et al. 1997). For any instream restoration project to succeed there is a need for the cessation or alteration of the land use activities that degraded the system in the first place (Kauffman et al. 1997). Degradation has often been caused by changes in landuse in the watershed on an ecosystem wide basis, and thus it may be beneficial for restoration to be approached on this scale. Monitoring the restoration project should also be a priority, and an adaptive management approach should be adopted (see Hartig et al. 1996). Finally, to avoid repeating mistakes, documentation and communication of the results of the restoration projects are essential (Roper et al. 1997).

4.0 REFERENCES

Alexander, G.H., and Hansen, E.A. 1983. Sand sediment in a Michigan trout stream Part II. Effects of reducing sand bedload on a trout population. N. Am. J. Fish. Manage. 3:365-372.

Avery, E.L. 1996. Evaluations of sediment traps and artificial gravel riffles constructed to improve reproduction of trout in three Wisconsin streams. N. Am. J. Fish. Manage. 16:282-293.

Bassett, C.E. 1994. Use and evaluation of fish habitat structures in the lakes of the eastern United States by the USDA forest service. Bull. Mar. Sci. 55: 1137-1148.

Binkowski, F.P. 1985. Utilization of artificial reefs in the inshore areas of Lake Michigan. *In* Artificial Reefs. Marine and freshwater applications. *Edited by* F. D'Itri. Lewis Publishers, Inc., Chelsea, Mich. pp. 349-364.

Binns, N.A. 1994. Long-term responses of trout and macroinvertebrates to habitat management in a Wyoming headwater stream. N. Am. J. Fish. Manage. 14: 87-98.

Blokpoel, H., and Jarvie, S. 1995. Use of reefrafts to create habitat for birds and fish, p.51-54. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Booth,G.M., Wren, C.D., and Gunn, J.M. 1993. The efficacy of shoal liming for rehabilitation of lake trout (*Salvelinus namaycush*) populations in acid stressed lakes. N. Am. J. Fish. Manage. 13: 766-774.

Braun, R., and Tilton, D. 1995. Wayne County Detroit metropolitan airport crosswinds marsh wetland mitigation project, p. 239-242. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Bray, K. 1995. McKellar River habitat creation project, p. 106-111. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Craig, R. 1995. Severn Sound tributary rehabilitation and erosion control program, p. 112-120. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Crispin, V., House, R., and Roberts, D. 1993. Changes in instream habitat, large woody debris, and salmon habitat after restructuring of a coastal Oregon stream. N. Am. J. Fish. Manage. 13:96-102.

Cullis, K. 1995. Neebing-McIntyre floodway habitat restoration, p.21-26. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Danehy, R.J., Reingler, N.H., and Gannon, J.E. 1991. Influence of nearshore structure on growth and diets of yellow perch (*Perca flavescens*) and white perch (*Morone americana*) in Mexico Bay, Lake Ontario. J. Great Lakes Res. 17:183-193.

Degerman, E., and Appelberg, M. 1992. The response of stream dwelling fish to liming. Environ. Pollut. 78:149-155.

Denison, D.L., Riseng, C.M., and Rausch, L.P. 1995. Belle Island canal rehabilitation, p. 187-190. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Dexter, J. 1995. Sand Creek bank and channel restoration, p. 231-235. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Edsall, T.A. 1995. Effects of beach nourishment on the nearshore environment, Lexington Harbor, Lake Huron, p. 259-262. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Eitniear, T. 1995. Peterson Wetland Restoration Project, p. 282-286. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Fausch, K.D., and Northcote, T.G. 1992. Large woody debris and salmonid habitat in a small coastal British Columbia stream. Can. J. Fish. Aquat. Sci. 49: 682-693.

Fitzsimons, J.D. 1996. The significance of man-made structured for lake trout spawning in the Great Lakes: are they a viable alternative to natural reefs? Can. J. Fish. Aquat. Sci. 53(Suppl. 1): 142-151.

Foster, N.R., and Kennedy, G.W. 1995. Evaluation of Tawas artificial reef as fish spawning habitat, p.267-271. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Fuselier, L., and Edds, D. 1995. An artificial reef as restored habitat for the threatened neosho madtom. N. Am. J. Fish. Manage. 15:499-503.

Geiling, D. 1995a. McVicar creek Mouth Island Creation, p.39-44. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Geiling, D. 1995b. McVicar Creek Rehabilitation, p. 45-50. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Geiling, D. 1995c. Current River estuary walleye spawning habitat, p 27-31. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Geiling, D. 1995d. Construction of self-cleaning spawning substrate, p.32-38. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Geiling, W.D., Kelso, J.R.M., and Iwachewski, E. 1996. Benefits from incremental additions to walleye spawning habitat in the Current River, with reference to habitat modification as a walleye management tool in Ontario. Can. J. Fish. Aquat. Sci. 53(Suppl. 1): 79-87.

Gerber, J.M. 1987. Fish use of artificial reefs in the Central Basin of Lake Erie. Masters thesis, The Ohio State University, Columbus, OH. Abstract Only.

Grillmayer, R. 1995a. Soil bioengineering for streambank protection and fish habitat enhancement, p. 82-98. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Grillmayer, R. 1995b. Transplanting aquatic vegetation in Collingwood Harbour, p. 73-81. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Gunn, J.M., and Keller, W. 1980. Enhancement of the survival of rainbow trout (*Salmo gairdneri*) eggs and fry in an acid lake through incubation in limestone. Can. J. Fish. Aquat. Sci. 37: 1522-1530.

Gustofson-Marjanen, K.I., and Moring, J.R. 1984. SFA 30(1) Construction of artificial redds for evaluating survival of Atlantic salmon eggs and alevins. Am. J. Fish. Manage. 4(4A):455-461.

Hartig, J.H., Kelso, J.R.M., and Wooley, C., 1996. Are habitat rehabilitation initiatives uncoupled from aquatic resoure management objectives in the Great Lakes? Can. J. Fish. Aquat. Sci. 53(Suppl. 1): 424-431.

Hector, D., and Colman, B. 1995a. Stag Island rehabilitation project, p. 171-175. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Hector, D., and Colman, B. 1995b. Bear Creek wetland creation project, p. 168-170. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Hector, D., and Colman, B. 1995c. MacDonald Park habitat enhancement demonstration project, p. 164-167. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Hector, D., and Tulen, L. 1995a. Ruwe marsh protection project – phase 1, p. 154-157. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Hector, D., and Tulen, L. 1995b. Windsor salt riverfront rehabilitation project, p. 158-163. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

House, R. A. 1996. An evaluation of stream restoration structures in a coastal Oregon stream, 1981-1993. N. Am. J. Fish. Manage. 16:272-281.

House, R.A., and Boehne, P.L. 1985. Evaluation of instream enhancement structures for salmonid spawning and rearing in a coastal Oregon stream. N. Am. J. Fish. Manage. 5: 283-295.

House, R.A., and Boehne, P.L. 1986. Effects of instream structures on salmonid habitat and populations in Tobe Creek, Oregon.. N. Am. J. Fish. Manage. 6: 38-46.

Hunt, R.L. 1974. Annual production by brook trout in Lawrence Creek during eleven successive years. Wis. Dep. Nat. Resour. Tech. Bull. No. 82. Madison, Wis.

Hunt, R.L. 1976. A long term evaluation of trout habitat development and its relation to improving management-related research. Trans. Am. Fish. Soc. 105: 361-364.

Jude, D.J., and DeBoe, S.F. 1996. Possible impact of gobies and other introduced species on habitat restoration efforts. Can. J. Fish. Aquat. Sci. 53(Suppl. 1): 136-141.

Kauffman, J.B., Beschta, R.L. Otting, N., and Lytjen, D. 1997. An ecological perspective of riparian and stream restoration in the western United States. Fisheries. 22: 12-25.

Kelch, D.O., and Reutter, J. 1995. Artificial Reefs in Lake Erie: A habitat enhancement tool, p.243-249. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Kelso, J.R.M., and Wooley, C. 1996. Introduction to the International Workshop on the Science and Management for Habitat Conservation and Restoration Strategies (HabCARES). Can. J. Fish. Aquat. Sci. 53 (Suppl. 1): 1-2.

Knudsen, E.E., and Dilley, S.J. 1987. Effects of riprap bank reinforcement on juvenile salmonids in four western Washington streams. N. Am. J. Fish. Manage. 7:351-356.

Kondolf, G.M., Vick, J.C., and Ramirez, T.M. 1996. Salmon spawning habitat rehabilitation on the Mercid river, California: An evaluation of project planning and performance. Trans. Am. Fish. Soc. 125:899-912.

Lacroix, G.L. 1992. Mitigation of low stream pH and its effect on salmonids. Environ. Pollut. 78:157-164.

Lacroix, G.L. 1995. Mitigation of low pH in salmonid streams, p. 59-63. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Lacroix, G.L. 1996. Long term enhancement of habitat for salmonids in acidified running waters. Can. J. Fish. Aquat. Sci. 53(Suppl. 1):283-294.

Lee, P.F. 1995. Aquatic macrophyte establishment in McKellar River embayments at Thunder Bay, Ontario, p. 179-183. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Lychwick, T.L. 1995. Fox River walleye habitat improvement, p. 272-281. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Manny, B.A. 1995. Ecological effects of rubble-mound breakwater construction and channel dredging at West Harbour, Ohio (Western Lake Erie), p. 263-266. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Mathers, A., and Hartley, K. 1995. Sawquin Creek marsh channel creation project, p. 197-199. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

McAughey, S.C. and Gunn, J.M. 1995. The behavioral response of lake trout to a loss of traditional spawning sites. J. Great Lakes Res. 21 (Suppl.1): 375-383.

McClure, W.V., and White, R.J. 1992. Streambank stabilization with riprap and tree revetment in Deep Creek, Broadwater County, Montana. The Montana Dept. of Nat. Res. And Conserv. Project no. RIT-87-8506.

Milton, G.R., and Towers, J. 1990. Fish habitat improvement structures and the forest industry. St. Mary's River Forestry Wildlife Project, report no. 6.

Moore, K.M.S., and Gregory, S.V. 1988. Response of the young-of-the-year cutthroat trout to manipulation of habitat structure in a small stream. Trans. Am. Fish. Soc. 117:162-170.

Moring, J.R., and Nicolson, P.H. 1994. Evaluation of three types of artificial habitats for fishes in a freshwater pond in Maine, USA. Bull. Mar. Sci. 55: 1149-1159.

Moring, J.R., Negus, M.T., McCullough, R.D., and Herke, S.W. 1989. Large concentrations of submerged pulpwood logs as fish attraction structures in a reservoir. Bull. Mar. Sci. 44: 609-615.

Morrow, J.V. 1995. Early life history of northern pike in artificial wetlands of Consensus Lake, New York, p. 236-238. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Moy, P.B. 1995. Burns Harbour major rehabilitation – submerged breakwater reefs, p.250-254. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Moyer, E.J., Hulon, M.W., Sweatman, J.J., Butler, R.S., Williams, V.P. 1995. Fishery responses to habitat restoration in Lake Tohopekaliga, Florida. N. Am. J. Fish. Manage. 15:591-595.

Newman, L.E. 1995. Creating upwellings as habitat for incubation of eyed stage brook trout (*Salvelinus fontinalis*) eggs, p. 69-72. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Nickelson, T.E., Solazzi, M.F., Johnson, S.L., and Rogers, J.D. 1992. Effectiveness of selected stream improvement techniques to create suitable summer and winter rearing habitat for juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 49: 790-794.

Pardue, G.P. 1973. Production response of the bluegill sunfish, *Lepomis macrochirus* Rafinesque, to added attachment surface for fish food organisms. Trans. Am. Fish. Soc. 3: 622-626.

Prevost, G. 1956. Use of artificial and natural spawning beds by lake trout. Trans. Am. Fish. Soc. 86: 258-260.

Prince, E.D., Maughan, O.E., and Brouha, P. 1985. Summary and update of the Smith Mountain Lake artificial reef project. *Edited by* F. D'Itri. Lewis Publishers, Inc., Chelsea, Mich. Pp. 401-430.

Reutter, J.M. 1995 Big Island wetland, Sandusky Bay, Ohio, p. 291-294. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Ricker, W.E. 1968. Methods for the Assessment of Fish Production in Fresh Waters. International Biological Programme Handbook No. 3. Blackwell Scientific Publications. Oxford. 313 pp.

Riley, S.C., and Fausch, K.D. 1995. Trout population response to habitat enhancement in six northern Colorado streams. Can. J. Fish. Aquat. Sci. 52: 34-53.

Roper, B.B., Dose, J.J., and Williams, J.E. 1997. Stream restoration: Is fisheries biology enough? Fisheries. 22: 6-11.

Rozich, T. 1995. Pere Marquette River Rehabilitation Project, p. 255-258. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Schacht, B. 1995. Urban stream stabilization efforts which increase instream habitat while controlling bank erosion, p. 149-153. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Bull. Fish. Res. Board Can. 184: 966 p.

Slaney, P.A., Rublee, B.O., Perrin, C.J., and Goldberg, H. 1994. Debris structure placements and whole river fertilization for salmonids in a large regulated stream in British Columbia. Bull. Mar. Sci. 55: 1160-1180.

Snucins, E., and Gunn, J. 1995. Rehabilitation of the native aurora trout lakes, p. 17-20. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Spitler, R.J., and Thomas, M. 1995. Lake Orion water quality-habitat improvement project, p. 184-186. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Steck, R., Poole, A., and Wilkinson, M. 1995. Strawberry Island (Niagara River) shoreline habitat restoration and protection project, p. 200-230. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Stonehouse, D. 1995. Lower Don River demonstration wetland habitat, p. 64-68. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Strus, R. 1995. Metro Toronto Waterfront – restoration of natural habitat sructure, p. 55-58. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Thomas, M., Spitler, R., Cozad, D., and Pienkowski, A. 1995. Paint Creek habitat improvement (Southeast Michigan), p. 287-290. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Thomas, P.M., and Bromley, D.D. 1968. Establishment of aquatic vegetation in and around artificial fish shelters in Douglas Lake, Michigan. Am. Midl. Nat. 80: 550-554.

Thomas, P.M., LeGault, R.O., and Carpenter, G.F. 1968. Durability and efficiency of brush shelters installed in 1937 in Douglas Lake, Michigan. J. Wildl. Manage. 32: 515-520.

Tori, G. 1995. Metzger Marsh coastal wetland restoration project, p. 145-148. *In* J.R.M. Kelso and J.H
. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Vincent, J. 1995a. Underwater fish reef creation project within Ashbridge's Bay Park, City of Toronto, p.121-127. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Vincent, J. 1995b. Toronto Islands northern pike spawning habitat, p. 139-144. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Vincent, J. 1995c. Wetland plantings within the Mimico Creek estuary, Humber Bay park, city of Etobicoke, p. 133-138. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Vincent, J. 1995d. Col. Samual Smith waterfront park bass spawning area, p. 128-132. *In* J.R.M. Kelso and J.H. Hartig [*editors*]. Methods of modifying habitat to benefit the Great Lakes ecosystem. CISTI (Can. Inst. Sci. Tech. Inf.) Occas. Pap. No. 1.

Vogele, L.E., and Rainwater, W.C. 1975. Use of brush shelters as cover by spawning blackbasses (*Micropterus*) in Bull Shoals Reservoir. Trans. Am. Fish. Soc. 1975: 264-269.

White, R.J., Riley, C.W. and McClure, W.V. 1992. Log sills to trap trout spawning gravel in Confederate Gulch, Montana. The Montana Department of Natural Resources and Conservation, Project no. RIT-87-8506.

Table 1. Provide structural habitat diversity in lakes

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Above and/or Underwater reef creation – to create and enhance habitat			Reefraft – floating wooden platform with plastic snow fence hanging from the bottom of the platform	Placed near Toronto waterfront in 1993	One reefraft $3 500	Habitat successful for common terns and fish, no production	Visual assessment for terns, and electrofishing on three occasions for fish		Common terns	Lake Ontario	Do not need to remove for ice	Blokpoel and Jarvie 1995
			Artificial Reefs in Lake Erie central basin, using scrap concrete	Placed in nearshore areas 9 – 12 m in depth, reefs were 167 – 243 m in length and 1 – 5 m in height; started project in 1986	$100 000 plus donations and volunteers	Effective fish concentration devices, shallower and larger reefs were more effective, no production	Angler reports and VHS video research	Smallmouth bass and walleye		Lake Erie, Loraine Harbour 1.2 km offshore and Cleveland harbour 0.8 km offshore		Kelch and Reutter 1995
			Submerged breakwater reefs made of armor stone – to reduce wave energy, and increase spawning area available for lake trout	Placed in 13-15 m of water, six segments 114.3 m long by 45.7 m wide and one segment 480 m long; June 1995 to Sept. 1997	$14 million for construction, $8 000 annually for assessment	Assessment incomplete, (at pre-construction stage)	Plan to assess 2 years prior, 3 years during, and 2 years after construction	Lake trout		Burns harbour, Portage, Indiana		Moy 1995

Table 1

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Above and/or underwater reef creation – to create and enhance habitat			Underwater reef creation project made of quarried riprap stone and small outlying rubble piles to increase diversity of fish habitat and enhance productivity	Created in 3.5 m depth, 44 m^3 area created Dec. 1992	$53 537 including 5 years monitoring	Accumulation of fish found around the reef, no production; assessment incomplete	Electrofishing around reef			Ashbridge Bay park, Lake Ontario		Vincent 1995a
	Large increase in primary production through periphyton community on artificial structures over littoral phytoplankton	Increase vulnerability to harvest	Artificial reefs made of scrap tires and Christmas trees to conserve and develop inland fisheries resources	Nine reef sites consisting of 7000 scrap tires 4000 Christmas trees covering 9500m^2 in total; construction 1973, assessment 1974-75	$4998 for 9 sites	Sport fishes more abundant on the reef sites than before reef installation; white catfish spawned directly on and inside tires, used reef areas as a feeding station, localized sig. increase in production of sunfish	Experimental fishing surveys, SCUBA surveys, trapping and netting, speargun radio tagged some fish to track movement	Lake sport fishes include: sunfish, white catfish, centrarchid, basses		Smith Mtn. Lake, Virginia; surface area 8100 ha, z=17m	Still effective after 9 years	Prince et al. 1985

Table 1

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Above and/or underwater reef creation – to create and enhance habitat		Reef infested with zebra mussels	Installation of a rock rubble reef to enhance fish spawning and survival and to improve fishing opportunities in nearshore protected areas	3 628 tonnes of limestone to create 450 m long pile, constructed Aug. 1987	Construction: $40 000 assessment: $35 000 per year	Considered successful for lake trout spawning, 99% mark-recapture surveys show clipped (hatchery) adults, little known about walleye	4 year study, underwater observations with ROV of lake trout prespawning activity, assessment and documentation of fry production performed, egg and fry traps, mark-recapture study (gillnets)	Walleye, lake trout		Tawas Bay, L. Huron, Michigan		Foster and Kennedy 1995

Table 1

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Above and/or underwater reef creation – to create and enhance habitat			Build shallow water rock reefs in Michigan and Minnesota	15 of 19 were placed less than 2 m deep; size ranged from 500 – 4500 m^2	$350 000	Heavily used by spawning walleye (egg density similar nat. and art.), rock bass and juvenile smallmouth bass occur in large numbers around reef; 49% legal sized walleye resulted from reprod. in 2 years following constr. of reef	Fish counted by divers, electrofishing	Walleye and smallmouth bass	Inverts occur in greater numbers around reef	Brevourt Lake 1712 ha, 1.4 m deep, 600 m long, 16 m wide; produced 1.1-4.2 mill. walleye fry annually		Basset 1994

Table 1

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Above and/or underwater reef creation – to create and enhance habitat			Create an artificial reef	Two reefs one pier shaped and one boomerang shaped (later connected) covered an area 1400 m^2 , made of fieldstone, placed in 3 to 3.6 m depth, and covered with sand and pebble sized beach stone; complete Nov. 1980	$4 000 per reef	Greater fish species diversity and abundance around reef than other sampling locations in the reef area, yellow perch larger and more abundant than before reef construction	Gill net sampling once a week, and some seine netting	Yellow perch, rainbow trout, white suckers	invertebrates	Lake Michigan marina	Configuration of the reef changed within 6 months	Binkowski 1985
Shelters	Provide access to sport fisheries, potential for overfishing		Evaluate three types of artificial structures as attractors, brush bundles, cinder blocks, and tire bundles for artificial structures underwater	Placed at depths 3 m or less, brush bundles were 1.2m x 1.2m x 1.2m, tire bundles consisted of four tires placed in "+" pattern; constructed in June 1990		Artificial cover attracted fish, no one type clearly selected by all fish (preferences outlined), recommended further study to assess value of artificial structure and increase productivity	Divers swam along transects recorded species, number and size of fish at different structures	Pumpkin seed, chain pickerel, brown bullhead, common shiner and golden shiner		Lac D'or, 1.4 ha, max 3 m deep, freshwater pond in Maine	Beaver removed branches from brush bundles, cinder blocks most permanent	Moring and Nicolson 1994

Table 1

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
			Observe use of brush shelters by black basses	Placed along alternate 100 m shoreline sections about every 10 m in two coves in avg. depth of 2.5m; made of second growth trees; constructed in April 1972		Spotted preferred shelter, largemouth preferred shelter early in spawning season, smallmouth showed no preference; subsequent shoreline flooding forced bass to move to new cover	SCUBA divers examined underwater for seven weeks during spawning season	Spotted, largemouth, and smallmouth bass		Gunnel Fork, Bull Shoals Reservoir		Vogele and Rainwater 1975
			Place log cribs	2-4 m wide 1-2 m high, green hardwood, placed above thermocline		Use by all species dropped as temperature dropped; concentrated large and smallmouth bass, 3-6 m best success		Largemouth bass, smallmouth bass, pumpkin seeds, and yellow perch			Effected by diameter and species of wood used	Bassett 1994
			Break land ridges into a series of islands, place log structures for fish habitat and nest boxes for waterfowl		$530 000	Assessment incomplete	Electrofishing will be used to monitor fish populations	Walleye spawning areas, cover and spawning for other species		Stag Island		Hector and Colman 1995a

Table 1

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Build dike/breakwater	Creates calm water area/wetland while providing structural habitat		Build dyke to restore and protect coastal marsh on Lake Erie	2 341 m long dyke with 12m opening with control structures; used 239 498 m^3 of embankment and 118 105 m^3; started construction June 1994	Construction: $15000 / m in length	Assessment incomplete	Plan to use biological indicator species			South shore Metzger Marsh, 12 ha coastal marsh along Lake Erie (plan to increase size)		Tori 1995
			Build two breakwaters and dredge channel between them to provide smallcraft entrance to western Lake Erie	Constructed in 0-4 m of water, between Aug. 1981 and Nov. 1982	Assessment study cost $50 000	Breakwater and channel constructions had no detectable adverse effects on macrozoobenthos and fishes, higher diversity of macrobenthos on breakwater than lake bottom	Limnological and fish surveys conducted 1981-1983, additional surveying would have been beneficial			Southwestern Lake Erie along beach shoreline 0-4 m water		Manny 1995

Table 1

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
			Dyke repair and reconstruction	Finger dyke 1 125 m long; new/repaired dyke will protect 366 ha of provincially sig. wetland; expected implementation Jan. 1995	Estimate: $300 000	Assessment incomplete	Electrofishing has been done prior to project reconstruction		Reptiles and amphibians	Ruwe Marsh, class I marsh part of a 580.26 ha wetland complex, Detroit River	Affected by wind, ice and wave action, restoration: $300/m in length	Hector and Tulen 1995a
Log sills/tree drops			Tree drops extended from shore to attract fish for anglers, expected production to increase	>0.3 m diam. near base, leave several feet of trunk on shore		Trees at different depths were utilized by different fish species		Black bass, rock bass, bluegill, and black crappies		various	Species and diameter effect longevity	Bassett 1994
			Placement of half logs to provide overhead cover over existing spawning beds in Michigan and Wisconsin lakes	50 half logs per lake; placed 1985		Increased lakewide reproduction of smallmouth bass 603%-3844%				various		Basset 1994

Table 1

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
			Compare fish distribution between submerged logs left from log drives and non-log areas	Estimated 1 to 3 million cords of spruce and balsam sank during log drives, (1830's), depth of most concentrations 3-15 m, most within 50 m of shore		Females and juveniles were found in greater abundance near submerged logs, seasonal patterns in distribution evident	Fish were sampled with gillnets in 1979 and 1980	Yellow perch		The Kennebec River and Wyman Lake (1 273 ha, max depth 43 m), Maine		Moring et al. 1989
			Create shelter for fish using woody brush and fallen trees	Use hardwood species or cedar, shelter are linear and run parallel to shore; implemented winter 1994/95	Construction of two linear brush shelters $25 000,	Asessment incomplete				Metro Toronto waterfront, Lake Ontario	Expected to last 15-25 years	Strus 1995
Construct embayments	Created quiet water areas and wave susceptible areas		Create seasonally flooded channels to provide habitat at a variety of water depths	Create projections at varying heights, 2.5 – 6 m wide, to provide a variety of depths when flooded; spring 1992	Construction: $40 150	Increase in species richness and biomass 896% higher than before breaching berm; no active spawning observed in 1994	electrofishing	Northern pike	Smallmouth bass and bluegill	Toronto Island lagoon, Lighthouse channel		Vincent 1995b

Table 1

Table 2. Provide structural habitat diversity in streams/rivers

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
	Plan to improve aesthetics		13 stage rehabilitation project; improve aquatic habitat, reintroduce sport fishing and recreational canoeing, create positive water flow, improve island water circulation, improve visual aesthetics, reduce maintenance burden	Started 1992; install and relocate pumps to deliver 37850 l/min., improve circulation, creat emergent wetland and 1.2 ha deep water habitat, connect to Detroit R. to provide spawning, nursery and cover habitat, implement fish stocking program, remove exotic veg. and point and non-point source discharge	$1.2 million estimated	Project in progress, plan to assess	Assessment of biological resources			Belle isle, 398 ha park in the Detroit River	Plan is to reduce maintenance burden	Denison et al. 1995

Table 2

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Log drop structures			Install log drop structures to increased pool volume, decreased current velocity, and increase depth and cover	Placed in 250 m sections of stream; installed in 1988, assessed 1987-90		Significantly increased abundance and biomass of adult and juvenile trout, effects on survival and growth minimal and variable, response different between trout species, evidence for immigration as mechanism of increased abundance and biomass	Electrofishing was used to obtain removal estimates of fish population size	Brown trout, brook trout, and rainbow trout		Six small Rocky Mountain streams; gradient range 1-2.4%,coarse substrate, little cover,baseflow low discharge $<0.1\ m^3 \cdot s^{-2}$	Required only minor repairs during 1988 and 1990	Riley and Fausch 1995

Table 2

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Log drop structures	Created quiet water areas		Four embayment structures and eight groupings of log mats, log pilings and boulder pilings were created	Wood piles were rough poplar,4-5 m in length, min. diam. of 300 mm, tops 1 m below surface; boulder pilings were armour stone built to 1 m below surface; implemented 1991	Construction: $109 889	Fish abundance and diversity greater in embayments than unsheltered stretches	Assessed by quantitative seining, electrofishing, midchannel trawling and benthic sampling	Juvenile and spawning salmonids and other sport fish – walleye		1.2 km section of floodway, Neebing/MacIntyre rivers, Thunder Bay		Cullis 1995
Streambank and channel alterations			Evaluate trout response to habitat development	Provide shelter, narrow and deepen channel increase pool depth; 86 bankcovers and current deflectors using 38 000 board feet and 6 000 tonnes of rock; alterations 1964		Section A biomass & production increased after 3 years, max. increase after 5 yrs. Streamwide production remained consistent due to decreases at sections C and D.	Electrofishing to conduct mark recapture estimates over 11 year period (four years pre and seven years post alteration)	Brook trout		5.4 km of Lawrence Creek, (low gradient stream, Wisconsin) divided into 4 sections (A-D), whereas 1.7 km (section A) was modified)		Hunt 1974, 1976

Table 2

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Construct artificial riffle			Construct artificial riffle in previously dredged area	"v" shaped riffle pointed upstream, 23 m wide, used 305 metric tonnes of riprap; constructed Feb. 1992		Relative abundance and similarity indexes of species abundance were close between natural and artificial riffles	Fish were seined along transects across each riffle, similarity indexes of species abundance were compared	Neosho Madtom		Low gradient (0.72 m/km), 4th order stream; Cottonwood River, Chase County, Kansas		Fuselier and Edds 1995
Construct pools			Construct pools using rock gabions, log sills, boulder berms, concrete sills, combined log and boulder berms			Good summer but poor winter habitat, addition of brush bundles increased juveniles in dammed pools but not plunge pools during winter, constructed alcoves were good winter habitat	Mark recapture using seines and electrofishing	Coho salmon		studied coastal Oregon streams		Nickelson et al. 1992

Table 2

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Increase lateral habitat			Form deflectors with cobble and boulders to slow current and create backwater areas; hypothesis: lateral habitat would have a direct effect on age-0 fish abundance	Create currents less than 4 cm·s^{-1} and depth less than 20 cm; experimental manipulation completed May 1983		2.2 times greater density of age 0 cutthroat trout in increased lateral habitat sections/ YOY eliminated in areas with reduced lateral habitat, total production 95% higher than controls and 824% higher than reduced lateral habitat sections	Observations made by snorkeling and electrofishing	Cutthroat trout		Mack creek, Oregons Cascade Mtns., 3rd order stream flowing through 450 year old conifer forest		Moore and Gregory 1988

Table 2

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Increase lateral habitat		Gabions trapped gravel, created shallow gravel bars, increase in the number, size, and quality of pools	Use of gabions and boulder groupings to increase stream diversity, more and deeper pools, side channels, undercut banks and shallow riffle areas	Available spawning area increased from 26 to 296 m^2 in the 0.15 km reach; constructed Aug. 1981, assessment 1981-1983	Aprox. $1200/gabion, $18/linear foot, boulder placement $35/boulder	Increased salmonid spawning and abundance (272% coho) in treated sections over control sections, gabion sites had higher total salmonid densities and biomass than boulder and control sites	24 spawning ground counts were done, adult population estimates were done using two pass removal method (electrofishing)	Coho salmon, winter steelhead, sea run and resident cutthroat trout		East fork Lobster Creek, Oregon stream average annual flow 1.2 m^3 /s,	All gabions remained intact, no bank scouring, 50% log sill structures floated causing downcutting and debris loss	House and Boehne 1985

Table 2

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Increase lateral habitat			Use of gabions and boulder groupings to increase stream diversity, more and deeper pools, side channels, undercut banks, shallow riffle areas and spawning substrate	Installed rock filled gabions 1981, (see House and Boehne 1985); three boulder structures added in 1987, post treatment assessment of fish 1982-1989, habitat 1993		Numbers of coho salmon spawners and juveniles increased significantly for all post treatment years at treated areas, less effect on steelhead and cutthroat trout	30 m station blocked off and electrofished and seined, 189 pools, 55 riffles, and 17 glide habitats were sampled from 1983 to 1989 -spawning ground counts and survey of stream gravel	Coho salmon, cutthroat trout, steelhead		East fork Lobster Creek, Oregon, 1.7 km reach	Habitats created by gabions lasted 10 years before wire mesh started disintegrating, all boulder and wood structures remained in place	House 1996
			Install structures to produce: digging of a downstream pool, undercutting of banks, funneling of water flow and channel deepening, bank stabilization, and provide escape cover	Used log, rock or debris dams, rock or log deflectors, brush tops for cover, and bank stabilizers; 1989	Mean cost and man hours per structure type was assessed and provided in report	Reduced brook trout fry after structure installation, possibly due to mortality and/or movement -small increase in the number BT parr	846 m study reach electrofished twice once before (June 1989) and once after (Aug. 1989) installation of structures			Kelly brook, (St. Marys River) Ontario	Long term permanency not known	Milton and Towers 1990

Table 2

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Increase lateral habitat			Install 200 instream structures, and 11 side channels consisting of pools, glides, and riffles	106 full spanning and 96 partial spanning structures installed, mainly tree boles, boulders and rootwads; restructured 1986-1989. Increase in stream surface area of 74% and in volume by 168% in the treated area.	$110 000 U.S. equipment labour and materials	Coho salmon spawning activity increased 4X in treated sections. Suitable summer and winter habitat for coho increased five fold and six fold respectively in treated reach	Coho salmon were counted weekly on spawning grounds from 1982 to 1992 (before and after restructuring)	Coho salmon		Elk Creek, 5th order stream that drains 26.6 km^2 of recently harvested second growth timberland	Flooding took out some structures, 98% still functioning in 1990	Crispin et al. 1993

Table 2

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Log sills to trap trout spawning gravel		Construction disturbance temporarily caused fish to move to untreated sections	Create streambed structure to cause deposition of gravel during high flows and to create hiding cover for trout	Used two types log sills: oblique sill and "V" sill; 40 sills built in 770 m of stream in August 1988, assessment 1986-90	Assessed in terms of materials and man hours not dollars	Structures were effective in capturing gravel; brook trout spawning sites increased from few to to 298; pool area increased dramatically in sill areas; trout biomass changed little	Gravel measured with range pole; observer counted brook trout redds (couldn't find cutthroat trout redds); electrofished for mark-recapture estimates	Brook trout and cutthroat trout		Gulch canyon Broadwater county, Montana; 3.9 km study area, high angling intensity	Some gravel leakage occurred due to construction flaws; maintenance and minor repairs were required	White et al. 1992
			Use structures to simulate large woody debris	Debris bundles an debris catchers were installed; whole river fertilization was done; constructed 1988 to 1991	range: $1000-$2700 per structure	Debris structure placements were effective as salmonid cover, attracted high prop. of fry, could not assess effect on production	Divers made underwater counts monthly from May to October, mark by electrofishing and seining	Chinook salmon	Rainbow trout, shiners, juv. peamouth chub, young squawfish	Upper Nechanko river in British Columbia, mean annual temp 7 °C, mean annual flow 61 $m^3 \cdot s^{-1}$	Debris catchers (pipe and rail) were the most durable, bundles were displaced, shifted and lost debris	Slaney et al. 1994

Table 3. Modify littoral zone morphology

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Restore/stabilize banks			Stabilize banks with riprap and planting trees and shrubs to reduce erosion and improve water quality	23 km of river fenced from livestock, 100 ha retired, 38 000 trees and shrubs planted; five year plan initiated 1991	$250 000 yearly for 5 years	Water quality has been improved, reduced phosphorus load, revegetation has been successful	Fish biomass monitoring		Swallows, bluebirds, and wrens utilized nesting boxes	Rehabilitate six rivers flowing into Severn Sound	Tree survival: 65-95%	Craig 1995
			Restore bank and channel from blown out bank, provide additional habitat and restore spawning areas	Stabilize banks with trunks, logs and fieldstone; construction Aug. 1986	$8 350	Salmonids were found utilizing the restored site and were successfully spawning; project considered a success	Mark recapture estimates using electroshocker	Salmonids especially brook trout		Sand Creek, southwest Michigan; third order stream, avg. discharge 0.14 $m^3 \cdot s^{-1}$, 2.7 m wide, and 10 cm deep	Some slumping of the stabilized bank did occur by 1991	Dexter 1995

Table 3

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Restore/stabilize banks			Stabilize streambank with riprap and tree revetment	Installed rip rap (limestone) and juniper tree (5-10 m long, 15-20 cm but diam.) revetments in April and May 1988	Cost assessed in terms of amounts of materials and labour	Evaluation of trout response weak, treatments were effective against erosion, study area effected by drought dewatered (2.5 months) in 1988	Double run electrofishing mark recapture method and multiple removal method to estimate trout populations	Rainbow and brown trout, mountain whitefish longnose dace, sculpin		Deep Creek, Broadwater County, Montana; study area 1400 m of creek		McClure and White 1992
			Restore bank and creek bed after erosion	Plant trees (600 mixed conifers), seed embankment, and use gabion mats, replace creek bed substrate; completed Dec. 1992-94	Construction: $215 000 Assessment: $6100	Chinook salmon have been observed spawning, smelt continue to use the lower creek for spawning	Visual observation, plan to monitor by seining at creek mouth	Walleye, rainbow trout and smelt		120 m along lower McVicar creek where overpass was constructed		Geiling 1995b

Table 3

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Restore/stabilize banks			Soil bioengineering to reduce sediment loading from Black Ash Creek into Collingwood Harbour	Stabilize eroding streambanks using vegetation and cribwall, create instream habitat, enhance riparian zone; construction 1992-94	$6 397	Vegetation was successfully re-established and bank remained stable, YOY rainbow trout increased; erosion reduced to insignificant	Biomass surveys were conducted at two sites			Black Ash Creek, Collingwood Harbour, 2nd or 3rd order stream characteristics		Grillmayer 1995a
Restore/stabilize banks		Negative short term effects on juvenile coho and YOY cutthroat trout increased with severity of habitat alteration and decreased with increase in stream size and fish size	Bank reinforcement with riprap and streambed alterations	Objective: common flood control practices relative to carrying capacity for juvenile salmon; 1979		Yearling steelhead and cutthroat trout biomass increased in the large streams but decreased in the small streams. Coho and trout biomass decreased in all small stream reaches after construction	Sampling was done by electrofishing and seining, Peterson and removal methods used for population estimates. Total biomass and standing stock (per stream reach) were also calculated	Juvenile salmonids		Four tributaries flowing through mixed coniferous and hardwood stands in western Washington		Knudsen and Dilley 1987

Table 3

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Restore/stabilize banks		Structures may provide exotics advantages over natural species	Comparison of fish species abundance in three habitat types	Comparison of three habitat types: sand, riprap and macrophytes; studied 1994		Riprap areas generally had highest species diversity and had significantly higher numbers of gobies, species specific preferences apparent	Seined sample areas of sand, riprap, and macrophytes		Exotic species (gobies) utilized habitat	St. Clair River, Michigan		Jude and Deboe 1996
		Rock visually overwhelming until covered by vegetation (2-3 yrs. post installation)	Stabilize eroding banks with fieldstone riprap and lunker structures and remove sediment, goal to provide salmonid spawning habitat, increase food and refuge habitat	132 erosion sites (7 724 m) stabilized with 15 208 m^3 of fieldstone riprap and lunker structures, conifer restoration along tributary streams; implementation: 1987-1994	$1,312,744 ($170/m of bank)	YOY of brown trout increased; data not shown, units not given	Mark recapture by electrofishing, and visual observations	Brown trout		Pere Marquette River, river used for log drives		Rozich 1995

Table 3

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
			Stabilize banks and establish vegetation, demonstration projects, to increase instream habitat and control bank erosion	Use lunker structures and A-jacks to provide habitat and bank stability; implementation 1992-93	$197 per meter of bank	300% increase in smallmouth bass fry survival and 50% increase in large bass residence, reduced erosion	Fish surveys, no detail given			Sections of the Waukegan River in urban parks (Illinois)		Schacht 1995
			Shoreline habitat restoration and stabilization using geo-fabric foundation blanket riprap and vegetation	Beach repair 38 m long by 12-15 m wide; lagoon beach riprap 30 m long by 0-6 m wide; beach strengthening 27 m long by 6 m wide; revegetation 24 m long by 6 m wide; implemented Dec. 1993, reveg. May 1994	Estimated about $60 000 U.S.	Successful in restoring shoreline and preventing erosion	Visual inspection	Protection of musky, pike, walleye, large and smallmouth bass		Strawberry Island, largest littoral habitat in the Niagara River		Steck et al. 1995
			Lunker structures to stabilize shoreline	Provide 61 m of 15-30 cm deep cover	$115 per 2.5 meter section	Successful in stabilizing bank and decreasing erosion	Visual assessment	Brown and brook trout		Trout stream (Paint Creek)	Affected by ice and high flows	Thomas et al. 1995

Table 3

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Restore/stabilize banks		Some devices were esthetically displeasing; increased cover, stabilized banks	Use artificial devices: wooden deflectors, dams, channel blocks, bank overhangs, streambank vegetation, woody debris, plunges, overpour ramps to concentrate low flows and riprap to stabilize banks	111 habitat improvement devices and 2 150 ft of riprap; project 1973-1977	$27 400	Density of brook trout >6 in. increased 1814% and <6 in. increased 1462% after 7 years. Mean length and weight decreased slightly over same time period. Biomass dropped after extended drought, still better than before treatment; proper construction and location are vital to success	450 ft study station established. Electrofishing and block nets (by the 3-pass removal system) were used for fish estimates. Trout were also measured and weighed.	Brook trout		2nd order stream, base flow <1 $ft^3 \cdot s^{-1}$, 13 mi^2 watershed, gradient 1-1.2%, sinuosity 1.7, Beaver Creek, northeast Wyoming	90% remained functional after 18 years, all types of structures were evaluated for durability and effectiveness	Binns 1994

Table 3

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Excavate to create more littoral zone and create wetland habitat			Excavation of shallow embayments	Three wetland pockets < 1 m deep designed to improve water quality; excavation March/April 1994	pre-construction $50 630, construction: $607 800 assessment $74 830	Water quality improved in 1st year, new habitat colonized by a variety of organisms, assessment continuing	Water, benthos and fish were sampled, using netting and electrofishing		Herptiles and birds	Kaministiquia river delta, north shore of Lake Superior		Bray 1995
Remove contaminated soil			Remove salt contaminated soil; create wetland and fish habitat; rehabilitate and protect shoreline	Create series of offshore islands< 0.05 ha, 100 m apart, slope 4:1; remove salt contaminated soil; expected implementation 1995/96	Construction of islands estimated $140 000, soil removal cost unknown	Project in progress	Pre assessment electrofishing done			Embayment in the Detroit river near Windsor Salt docking, shallow area with hardened banks		Hector and Tulen 1995b
Alter slope of shoreline			Enhance landscape demonstration project	Alter slope of canal to 3:1 and create spawning channel with depth 0.9 to 1.2 m; create wetland area,; excavate ponds; create shoals; expected implementation winter 1994/95	Estimated: $50 000	Project in progress	Electrofishing will be done			Canals in MacDonald Park, Chatham; 100 m long, 30 m wide and 2.5 m deep; agricultural field adjacent		Hector and Colman 1995c

Table 3

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Beach nourishment			Restore beach sediments	Remove beach sediments from upcurrent side of harbour to sediment starved beaches on down current side (8.4 km segment); implemented Oct. 1980		Area was restored	Physical and biological data collected, no detail given			Small craft harbour, shoreline of Lake Huron, Lexington Michigan		Edsall 1995

Table 4. Create wetland or plant macrophytes

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Create wetland exposure pod	Increase shoreline diversity; vegetated areas have higher fish densities and greater species richness		Wetland exposure pods	Pods are 4.8 m long by 4.8 m wide; composed of galvanized chicken wire; placed in water from 0.5 to 1.0 m; macrophytes were planted in pods	Two pods: $6976.27	Will be considered successful if plants survive without pods and increase observed in juvenile fish and number of spawning adults	Netting, trawling, smallmouth bass spawning surveys and electrofishing	Northern pike, smallmouth bass	Waterfowl, invertebrates	Collingwood harbour		Grillmayer 1995b
Transplant macrophytes	Vegetated areas have higher fish densities and greater species richness	Growth restricted by sediments	Re-establish macrophytes	Crib, fibre pot, free plantings placed in cedar cribs to protect from carp; area of new habitat 402 m^2; implemented 1991	$43 000	Material showed increased propagation after two years			Invertebrates	Mimico creek estuary, Lake Ontario	Affected by carp, water level fluctuations	Vincent 1995c
			Transplanting aquatic macrophytes in new embayment	Plant 0.19 ha with native plant species	$25 800	Embayment is more vegetated than non-transplanted site	Compared percent cover of the embayments		Amphibians, waterfowl, and fish	Embayment in McKellar river, Lake Superior		Lee 1995

Table 4

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Create wetland		Loss of terrestrial habitat	Re-establish lost wetlands, mitigation for airport expansion	Wetland mitigation project completed on 326 ha of land; construction 1993/94	$4.2 million	Plant community establishment successful after 1st year, assessment incomplete	Five year monitoring program	Establish warm water fishery	Waterfowl, invertebrates, muskrats			Braun and Tilton 1995
			Assessment of northern pike in artificial wetland	Wetlands constructed 1990/91		Larval northern pike found, details not given	Measured number of pike larvae produced	Northern pike		Adjacent land to Conesus Inlet Creek		Morrow 1995
			Create a viable wetland habitat by creating ponds and planting native wetland species	Wetland area 2.88 ha; construction begins March 1995	$360 000	Assessment incomplete	Have baseline inventory and will continue to monitor	Northern pike	Wood duck, bull frog,red tail hawks, salamanders, wood frogs	Lower Don River, metro Toronto		Stonehouse 1995
Create wetland			Create wetland by installing water control structure and excavate “prairie pothole” ponds	Wetland 30-60 cm deep, ideally 50% vegetation and 50% open water, “prairie potholes” 60-90 cm deep; expected implementation 1995/96		Not implemented at time of report				Floodway between Sydenham and St. Clair rivers, Ontario		Hector and Colman 1995

Table 4

Habitat Manipulation	**Indirect effects**	**Side effects**	**Description of Project**	**Project Details**	**Cost (approx.)**	**Success**	**Method of Assessment**	**Target Species (fish)**	**Other species affected**	**System characteristics**	**Durability**	**Reference**
			Mitigate a lost wetland	Reconstruct 38 ha wetland to pre-1950 conditions, constructed 1983/84	Estimates as high as $2.7 million	Fishing from the dykes into the bay is excellent, project considered a success	No surveys done, some flora studies done for masters projects		Bald eagles, muskrats, terns	Sandusky Bay, Lake Erie, Ohio		Reutter 1995
Island creation	Protects shore habitat from wave action, increases edge effect and adds diversity	Heavy equipment disturbance during construction	Artificial island to protect shoreline from wave action and foster the growth of historic wetland	Island was 30 m offshore and water depth 1.5 to 2.8 m, composed of quarry stone; completed 1993	$380 000 (205 m in length)	Increased macrophytes in early assessment; assessment incomplete	Fish will be monitored by seining and electrofishing, inverts will be sampled using a petite Ponar dredge	Rainbow trout, smelt, centrarchids, and yellow perch	Macrophytes, macroinvertebrates, waterfowl, reptiles, amphibians	McVicar creek mouth, Thunder Bay Harbour		Geiling 1995a
Create wetland			Dyke and flood farm field to create wetland	Propose to construct a dyke to maintain 30 – 60 cm water levels within wetland		Assessment incomplete	Will use electrofishing and wetland evaluations		Macrophytes, macroinvertebrates, waterfowl, reptiles, amphibians	Chanel Ecarte, tributary to St. Claire River, 100 ha of farm fields with 10 ha of wetland		Hector and Colman 1995b

Table 4

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Restore wetland			Relocate county drain ditch and plug original ditch to restore 14 ha drained wetland	Establish permanent water depth avg. 30-60 cm, combination of forested, scrub, shrub, and emergent wetland implementation Feb. 1994	$7 150	Considered successful, wetland was restored and drainage was maintained, waterfowl use increased	No fish surveys, visual observations of waterfowl		Waterfowl (wood ducks, mallards, blue-winged teal, pintail and black duck)	32 ha parcel on Section 1 of Watertown township, Clinton County, Michigan	Some erosion on ditch banks	Eitniear 1995

Table 5. Provide spawning habitat

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Create artificial shoals			Increase desirable substrate for spawning. Three project areas; 1)111m^2 of spawning habitat, 1989; 2) 3 066 m^2 along 401 m of stream bank, 1990; 3) 2 973 m^2 of spawning habitat, 1992	Water depths < 1.8 m, 3:1 slope, use silt free dolomite limestone (5-15 cm), composed of 1.8 m material laid to depth of at least 20 cm; started 1989	Construction: $30 000	There was an increase in walleye spawning in some sites. Site 1 not producing walleye; Site 2 has 100 to 1000 times greater fingerling walleye; site 3 spawning density increased	Mark recapture spawning age using fyke net surveys, rel. abundance through late fall electrofishing surveys, egg traps	walleye		Fox River, a major tributary to Green Bay		Lychwick 1995
			Create smallmouth bass spawning area	Three spawning shoals 3 m^3 in size; constructed Nov. 1993, fish access June 1994	$3 600	Area colonized by smallmouth bass, adult, juvenile and YOY	Fish seining inventories	Smallmouth bass	Northern pike, sunfish, and minnows	Toronto waterfront, Etobicoke		Vincent 1995d

Table 5

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Create artificial shoals			Create three new walleye spawning sites as compensation for habitat lost by dredging	Increased area from 143 to 711 m^2 water depth 0-2.0 m, mean water over the gravel-cobble substrate was 20-29 cm; completed Dec. 1991	$22.06/m construction $37500 plus $42000 assessment	Eggs were found on shoals but no evidence of increase in number of eggs or adults	Schumaker multiple mark recapture, catch per unit effort were compared, scuba survey of egg distribution	Walleye		Current river estuary, Thunder Bay		Geiling, et al. 1996; Geiling 1995c
			Assessment of lake trout spawning on artificial spawning grounds of sharp rocks	Compared spawning on round and sharp substrate		More eggs were found among sharp rocks than round boulders	Observation by SCUBA divers	Lake trout		Lake Tremblant and Lake Superior		Prevost 1956
			Assess the influence of cobble shoals on growth and diets, comparison between natural cobble/rubble reefs vs. sand	Caught perch (yellow and white) at 3.3 m and 7.0 m depths, April-Nov. 1981		Growth rate was significantly greater for both species over the cobble shoals than sand areas	Sampled using gillnets, scale and stomach sample taken from each fish	Yellow perch and white perch		Mexico Bay, Lake Ontario		Danehy et al. 1991

Table 5

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Create artificial redds			Construct artificial redds and develop egg implanting technique to imitate natural redds	Placed eggs on artificial redds using 60 cm long, 2.5 cm diam. standpipe, followed by 10 cm cushion of gravel		Survival from eyed stage to emergence (avg. 5.2%) comparable to natural redds (avg. 6.1%)	Used bag nets to catch eggs washed free	Atlantic salmon		Water 30-60 cm deep, velocity $53 cm \cdot s^{-1}$, permeability 1 271 to 1472 $cm \cdot hr^{-1}$		Gustafson-Marjanen and Moring 1984
Create upwelling			Construct artificial redds and create upwelling. Jan. 1992/94	Three areas: 1)Near shore shoal area in Lake Superior where groundwater seepage occurred just above waterline, 2)stream at its groundwater source, 3) stream with no groundwater source nearby; Formed redds in 0.4 m depth, 1 m wide and 0.2 m deep, in a lake, and two streams; implanted eggs using PVC pipe	$200	84-93% survival to fry stage, with or without upwelling	Evaluated the hatch rate in egg incubators with known number of eggs, assessment ongoing	Coaster brook trout		Lake Superior and Grand Portage streams		Newman 1995

Table 5

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Create upwelling			Construct self-cleaning spawning substrate	Propose to construct upwelling through man-made spawning bed	$13 280	Not actually constructed						Geiling 1995d
Remove sediment			Remove fine organic sediment berm to expose harder substrate	Removed 165 000 m^3 of built up sediment from 19 km littoral zone, 0.6-1.2 m deep; implemented 1987	$3 285/ha total: $446 705	Initial increase in numbers of sport fish and forage fish	Electrofishing catch per unit effort, and used a Wegener ring in shallow areas	Largemouth bass		Lake Tohopekaliga, Florida	After three years overtaken with vegetation	Moyer et. al. 1995
			Use sediment traps to reduce sand bed load construct gravel riffles downstream of sediment traps	79 m long sediment trap excavated 340 m^3 of sediment (excavated Nov. 1985), a 67 m long trap exc. Feb. 1986) with capacity of 200 m^3, 66 m long sediment trap (exc. Feb. 1987). Gravel riffles constructed downstream from traps		Stream channel morphology improved but no significant increase in age 0 trout	Redds counted, single pass mark recapture electrofishing surveys conducted in August for 5 to 6 years after construction	Brown trout, brook trout, and rainbow trout		1.3 to 1.9 km segments of three Wisconsin trout streams 4.5 – 5 m wide	Lasted the length of the study, some traps required continuous sediment removal	Avery 1996

Table 5

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Remove sediment			Excavate a sediment basin	1 mile control section and 1 mile treated section; 1975-1980		Reduced sandy bedload by 86%, small trout increased 40%, trout production increased 28%, increased survival and abundance	Trout captured using electrofishing gear and population estimated using Peterson mark recapture methods	Brown trout and rainbow trout		Michigan trout stream	Maintained with 2-3 excavations per year	Alexander and Hansen 1983
Create riffle			Reconstruct a riffle to be suitable for salmon spawning	Excavate to a depth of 0.6 m and backfilling with gravel preferred by chinook salmon; constructed 1990, reevaluated 1994	$136 000, including $50 000 for maintenance	Gravel was scoured and transported, project not successful	Escapement and redd surveys	Chinook salmon		Project site is 25 km downstream from a 350 x 10^6 m^3 capacity dam; San Joaquin River system, California	The constructed channel was unstable because geomorphic processes were not considered	Kondolf et al. 1996

Table 5

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Create channels			Dredging through dense mono culture of cattails to create spawning and nursery habitat for n. pike and other species	1 140 m^3 of cattails converted to submergent marsh, interconnecting channels 3 m wide, 0.75-1.0 m deep, total 380 m or 2320 m^3 improved wetland area Aug. 1992	$0.88·$m^{-2}$ of habitat, $5.37·$m^{-1}$ of channel	Increased species richness, used as nursery habitat by northern pike, largemouth bass, and other species	Windemere traps, catch per unit effort and species richness were calculated	Northern pike and largemouth bass	Waterfowl and amphibians	Sawquin Creek marsh, Bay of Quinte, 1956 ha class 1 wetland	Will need maintenance	Mathers and Hartley 1995

Table 6. Improve water quality

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Improve water quality	Salmon dug most reds in limed section	Increased emigration and mortality evident following acidic episodes	Add limestone to increase pH	Spread 200 tonnes of crushed 4 cm grade limestone IN September 1987, replenished in some areas in 1991	$45/ tonne	Increased survival of Atlantic salmon and brook trout; Atlantic salmon dug 3 times more reds in limed section, fry were more abundant in limed section, juvenile salmon and brook trout increased, and the density of brook trout increased	Electrofished enclosed sections of stream two years before liming through to 1994 (twice annually) Annual redd counts 1987-1994	Atlantic salmon and brook trout		Fifteen mile brook, southwest coast of Nova Scotia, acidic stream avg. pH 5.0	Partial replenish after 4 years Maintenance at 2-3 year intervals (raking to re-distribute and remove organic cover)	Lacroix 1996, 1995, 1992

Table 6

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Improve water quality			Increase pH of lakes	Add powered calcite, mean diam 5 µm, 96% $CaCO_3$; pH inc. to 6.5 and alkalinity to 2.0-3.5 $mg \cdot l^{-1}$; treated 1989, introduced adult and juv. aurora trout in 1990	$700/tonne, assessment $2500/year	Successful reproduction of introduced aurora brook trout	Schnabel mark recapture estimates during fall spawning season	Aurora brook trout		Whitepine and Whirligig Lake, 100 km N of Sudbury, Ontario	Whirligig was re-acidified in 1993	Snucins, and Gunn 1995
		Lowered inorganic aluminum on artificial limestone shoals	Add limestone to rock spawning shoals increase interstitial water pH	Johnnie lake: 16 m^3 of limestone, diam. 3 to 20 cm, 10-40 cm thick constructed along shoreline, approx. 2 m wide x 3 m long, in water 10 to 150 cm deep, August 1987, project 1985-87	Depend on availability of limestone and lake location and characteristics	Did not effect spawning, but increased embryo survival and survival to the hatched fry stage	Buried incubators in mesh bags containing 50 eggs each	Lake trout		Johnnie Lake: 395 ha, pH 5.2; Miskeway Lake 237 ha, and Laundrie Lake 375 ha	Were not able to assess the length of time the shoals remained beneficial	Booth et al. 1993

Table 6

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Improve water quality	Atlantic salmon increased while brown trout decreased due to improved water quality, biotic interactions effect fish community after liming		Add limestone to increase pH	Lake liming, doser liming, and wetland liming; monitored streams at stations 5.1 m wide and 0.28 m deep; two limings started 1974-75, 15 in 1977-84, and five in 1985-87		Overall abundance of fish increased, increase in Atlantic salmon after liming, decrease in brown trout with increase in Atlantic salmon	Electrofishing in August-September each year, 447 electrofishing occasions at 78 stations	Atlantic salmon and brown trout	Crayfish increased after liming	22 limed streams and seven unlimed in Sweden		Degerman and Appelberg 1992

Table 6

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Improve water quality	Poor hatching success in exposed limestone filled hatching boxes due to wind - driven acidic pulse of lake water		Use of limestone hatching boxes to increase rainbow trout survival	Used twenty hatching boxes 10 with limestone and 10 with gravel; 1979		Egg and fry survival rates increased in sheltered calcareous incubation boxes (interstitial water mean pH 6.6) mortality of hatched alevins was high after transfer to holding pens in lake proper (pH 5.3)	Alevins were captured from hatching boxes with dip nets	Rainbow trout		George Lake, pH 5.3; 56 km southwest of Sudbury, Ont.		Gunn and Keller 1980

Table 7. Miscellaneous studies

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Controlled laboratory experiment – manipulate habitat availability			Add food organism attachment boards and fertilizer to quantify the relationship between known amounts of surface and production of inverts and fish	Study in 40 plastic pools 3m diam x 76 cm deep, yellow pine boards placed in 36 pools		Significant linear increase in production of bluegill with increase in attachment areas, production higher in fertilized pools	Pools were drained and standing crops were obtained at end of study	Bluegill sunfish	High correlation between production of macroinverts and production of bluegill	Plastic pools		Pardue 1973
Remove habitat			Monitor the response of lake trout to loss of historic spawning sites	Cover spawning area with large plastic tarpaulins and mesh fence; 1st year (1992) covered 15%, 2nd year (1993) covered 50% existing spawning area		When spawning sites were blocked lake trout found alternate sites to spawn	Index netting and mark recapture Schnabel method, nightly observations of spawning activity and egg collecting funnels	Lake trout		Whitepine Lake 90 km NE of Sudbury, 67 ha lake, max depth 22 m, 328 ha forested watershed		McAughey and Gunn 1995

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Comparative studies	Large woody debris caused development of secondary channels, meanders, pools, and undercut banks		Assess effects of removing large woody debris	Chose 11, 45 to 70 m stream sections, some previously cleaned of LWD; mapped sections June 1990		5 times the standing crop was lost in 332 m simple reach due to debris removal	Sections were blocked and electrofished to obtain population estimates	Coho salmon and cutthroat trout		Musquem-Cutthroat Creek, small coastal British Columbia stream with 730 ha watershed		Fausch and Northcote 1992
			Comparison of reaches logged (no woody debris) and not logged (contains large woody debris)	Studied in 1982/83		Positive correlation between coho salmon numbers and the presence of large woody debris	Sampled area by blocking with net and electrofishing, population estimates made by two pass removal method	Coho salmon, winter steelheadsea run and resident cutthroat trout		Tobe Creek, Oregon. Stream with average annual flow of 0.74 $m^3 \cdot s^{-1}$		House and Boehne 1986

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
			Assessment of aquatic vegetation around fish shelters	Installed 1937, were 3.1 x 3.1 x 0.46 m, now piles of brush		Gradient in mean vegetation (stem) density from 12.22·m^{-2} on shelters to 0.79·m^{-2}, 4.5 m from the edge of the shelters	Stems·m^{-2} were measured in quadrants by SCUBA divers on and around shelters	See Thomas et al. 1968		Douglas Lake, Michigan	The shelters collapsed but were still effective	Thomas and Bromley 1968
Comparative studies			Assessing the durability of brush shelters	10 shelters were installed in 1937, one made of four wire baskets filled with stones, the rest of tree branches approx. 10ft by 10ft by 18 in		Still effective as fish concentrating devices after collapse of brush shelter- mostly by rock bass (new shelters) and yellow perch (old shelters)	Fish were counted by SCUBA divers	Rock bass, pumpkinseed, bluegill, longear sunfish, smallmouth bass, yellow perch	Enhanced establishment of aquatic vegetation in and near shelter, see also Thomas and Bromley 1968	Douglas Lake, Michigan	After 30 years collapsed, all smaller branches decomposed, binding wire in pieces	Thomas et al. 1968

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
		Reefs below photic zone, occasionally low oxygen conditions	Assessment of fish use of artificial reefs 1985-86	Compared area around six 1.0 m high reef, 1.5 m high reefs, and no reefs; all 12 m deep; constructed in 1984		No preference shown for reefs over control areas	Controlled angling, vertical gillnets, fathometer transects; 1985 and 1986	Yellow perch, freshwater drum, walleye		Lake Erie, central basin	Further evaluation needed regarding placement of artificial reefs in Great lakes	Gerber et al. 1989 abstract only
Comparative studies			Artificial reefs	Review of lake trout spawning on artificial structures vs. natural spawning areas		Some reefs were used for spawning and some were not, higher abundance of egg, fry, YOY associated with man made structures than natural		Lake trout		Great Lakes		Fitzsimons 1996

Habitat Manipulation	Indirect effects	Side effects	Description of Project	Project Details	Cost (approx.)	Success	Method of Assessment	Target Species (fish)	Other species affected	System characteristics	Durability	Reference
Modify flow			Use a control structure to discharge bottom draw flows of cool water, sustain temp. below 21 °C	Use a 46 cm diam. tube, 226 m long, to tap cold water from 19 m deep and transport to base of the dam and provide 5 km of new trout habitat; implemented 1991	$ 62 000 and $5 000 assessment	Brown trout survived in cooler water temperatures		Brown trout, planted immediately below dam 1992	Blackflies, stoneflies and caddisflies	Paint Creek, warm water pool below dam, SE Michigan	Routine maintenance required	Spilter and Thomas 1995

Table 8. Proportional assessment of habitat rehabilitation projects

Habitat alteration (# of studies)	Assessed cost	Number incomplete	Achieved habitat target	Evidence of increased production	Evidence of increased density or biomass	Evidence of redistribution	Considered durability (deterioration)	Considered aesthetics	Considered side effects	Considered failure
Structural habitat diversity in lakes (20)	14 70%	5 25%	15 75%	1 5%	5 25%	6 30%	8 (4) 40% (20%)	0	5 25%	0
Structural habitat diversity in streams/rivers (13)	7 54%	1 8%	12 92%	2 15%	7 54%	0	8 (6) 62% (46%)	1 8%	3 23%	0
Littoral zone morphology (16)	13 81%	2 13%	14 88%	0	4 25%	4 25%	4 (4) 25% (25%)	2 13%	2 13%	0
Create wetlands or transplant macrophytes (11)	8 73%	3 27%	8 73%	0	0	1 9%	2 (2) 18% (18%)	0	4 36%	0
Create spawning habitat (13)	8 62%	1 8%	11 85%	1 8%	2 15%	2 15%	5 (5) 38% (38%)	0	0	1 8%
Improve water quality (5)	3 60%	0	5 100%	0	3 60%	0	3 (2) 60% (40%)	0	4 80%	0
Overall (78)	53 68%	12 15%	65 83%	4 5%	21 27%	13 17%	30 (23) 38% (29%)	3 4%	19 24%	1 1%