A review of fisheries habitat improvement projects in warmwater streams, with recommendations for Wisconsin. No. 169 1990

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A Review of Fisheries Habitat Improvement Projects in Warmwater Streams, with Recommendations for Wisconsin

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COVER PHOTO: *Electroshocking the North Fork of the Bad Axe River, a typical warmwater stream in southwestern (Vernon County) Wisconsin in summer 1988. Fisheries biologists from left to right are Steve Statz, Greg Rublee, and John Lyons. (Photo by Paul Kanehl.)*

ABSTRACT

We reviewed over 100 publications and unpublished reports, contacted over 30 fisheries biologists from 20 universities and natural resource management agencies, and made on-site observations of projects in Illinois and Missouri to determine what is currently (early 1989) known about physical habitat improvement for fisheries in warmwater streams. Previous improvement work has focused on 3 main objectives: reducing bank erosion and in-stream sedimentation, modifying channel morphology and alignment, and increasing in-stream cover. A wide variety of techniques appear to be useful in achieving these objectives, although few have been adequately evaluated.

Based on our reviews, contacts, and observations, we make the following general recommendations for warmwater stream habitat improvement projects in Wisconsin:

(1) Consider the entire stream ecosystem and watershed when planning projects, and try to address fundamental underlying causes of habitat problems whenever possible.
(2) Before beginning a project, collect quantitative data that demonstrate a need for habitat improvement and indicate probable limiting habitat characteristics.
(3) Use the most cost-effective techniques to improve habitat, and rely on natural objects or simple, easily replaced structures whenever possible.
(4) Use all available data and expertise in determining the proper placement and installation of habitat improvement objects and structures.
(5) Completely and thoroughly evaluate responses of habitat and fish populations to habitat improvement.

For warmwater streams in Wisconsin, we believe that bank revegetation coupled with the judicious use of riprap is the best approach to bank stabilization. Careful placement of boulders, trees, and rock wing dams should be effective in reducing sedimentation and increasing channel depth. Stable banks and deeper channels will improve in-stream cover. If further increases in cover are warranted, the placement of additional rocks and logs or the installation of half-log structures will be beneficial.

Key Words: warmwater, fish, streams, habitat improvement, techniques, erosion, channelization, cover, deposition, sedimentation, limiting habitat.

A REVIEW OF FISHERIES HABITAT IMPROVEMENT PROJECTS IN WARMWATER STREAMS, WITH RECOMMENDATIONS FOR WISCONSIN

by John Lyons and Cheryl C. Courtney

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CONTENTS

INTRODUCTION

Wisconsin contains hundreds of warmwater streams capable of sustaining sport fisheries. Some of these streams do not provide the fishery they could because of poor-quality physical habitat, which Wisconsin managers propose to improve. However, efforts to improve habitat in warmwater streams are hampered by a lack of knowledge; Wisconsin has a long and successful history of trout stream habitat improvement, but essentially no experience in habitat improvement of warmwater streams. Our objective in this report is to foster a better understanding of the most effective methods for improving habitat in Wisconsin warmwater streams. To do this, we summarize the highlights of selected habitat improvement projects on warmwater streams elsewhere in the United States. We then combine this information with what we know about general stream ecology and trout stream habitat improvement, and we develop a set of recommendations for habitat improvement in Wisconsin warmwater streams.

What is a warmwater stream? In Wisconsin, a warmwater stream is a stream that is too warm to support a self-sustaining trout population. Clearly, by this definition, a huge number and variety of streams in Wisconsin are warmwater (Fig. 1). We limit our discussion to those streams that are large enough to support significant populations of gamefish or panfish species, but not so large as to be considered major rivers (such as the Mississippi or the Lower Fox). The streams that we consider have typical daytime summer temperatures greater than 75 F, average widths greater than 20 ft but less than 300 ft, and maximum depths at baseflow (flow in the absence of recent precipitation or runoff) of at least 2 ft. The drainage areas of these streams range from 10-600 $miles^2$, and the typical flow in midsummer ranges from 3.5-350 ft^3/sec.

(a) Jump River in northwestern Wisconsin. High-gradient and rocky. (Photo by Paul Kanehl.)

(b) Mukwanago River in southeastern Wisconsin. Low-gradient and marshy. (Photo by John Lyons.)

FIGURE 1. *Two very different Wisconsin warmwater streams.*

Although we do not discuss habitat improvement methodologies for small warmwater streams or large warm-water rivers, it is clear that habitat improvements in such environments may be very beneficial in the overall management of a watershed. No single publication summarizes habitat improvement methodologies for small warmwater streams, but methodologies that are effective in small trout streams should be useful (White and Brynildson 1967, Payne and Copes 1986, Hunt 1988*b*). Schnick et al. (1982) provide an extensive, detailed review of habitat improvement techniques for large warmwater rivers.

Regardless of stream size, habitat improvement in warmwater streams is a new area in fisheries biology (Fajen 1981, Nelson 1988), and this report is not the final word on the subject. Rather, we hope that this report is a useful starting point for the development of new and innovative approaches to habitat management in Wisconsin warmwater streams.

METHODS

To determine what is currently known about physical habitat improvement for fisheries in warmwater streams, we conducted a literature review, made contacts with fisheries biologists, and made on-site observations of several pertinent ongoing studies. This evaluation included studies completed or nearing completion as of spring 1989. The literature review comprised over 100 publications and unpublished reports. Personal contacts were made with over 30 fisheries biologists from 20 universities and natural resource agencies; data and ideas were provided by most of the persons contacted. (We determined which biologists to contact based on our literature review and on recommendations from other biologists.) On-site observations were also made of ongoing studies in Illinois and Missouri.

After reviewing this database, we made several decisions to prevent our analysis and report from becoming too long and cumbersome. We limit our summary and recommendations to methodologies designed primarily to modify physical habitat in or immediately adjacent to a stream. Thus, we do not consider methodologies for which the primary purpose is to improve water quality rather than physical habitat, although clearly such techniques may indirectly benefit physical habitat. We also do not consider methodologies that focus primarily on modifications in land use away from the riparian zone, although such modifications may also improve in-stream habitat. Finally, we do not present this report as a how-to handbook. We review and recommend certain approaches and techniques, but we do not provide a detailed specific description of how to apply these techniques. For such descriptions, we recommend that readers consult the references we cite in this report, especially White and Brynildson (1967), B. C. Minist. Environ. (1980), Schnick et al. (1982), Helfrich et al. (1985), Seehorn (1985), U. S. Dep. Agric. (1985), Commonw. Pa. (1986), Payne and Copes (1986), and Ohio Dep. Nat. Resour. (1986, 1987). We also provide a list of publications (termed "Other References") that we do not cite, but which we feel provide useful information about the hands-on aspects of stream habitat improvement.

Our report focuses on the major goals and efforts to enhance habitat of warmwater streams for fish. An overview provides links between these goals and basic stream ecology. For each goal, key techniques used to achieve the goal are identified and evaluated. Based on this evaluation, we name what we believe to be the habitat improvement techniques most likely to be effective in Wisconsin warmwater streams. A glossary of commonly used stream improvement techniques is provided in Appendix A.

In Appendix B, we provide short summaries of all of the warmwater stream habitat improvement studies from other states that we were able to find and review. These summaries focus on techniques to stabilize banks; reduce sedimentation; and increase cover, depth, and habitat heterogeneity. To facilitate comparisons, the same features are given for each study: stream(s) and location, year(s), stream characteristics, watershed characteristics, objectives, improvement techniques, results, problems and/or comments, and reference(s). For stream characteristics, a standard checklist of information is given (where known) for each study: mean width, mean depth, stream flow, gradient, substrate composition, and study area length. For all other features, our approach to describing each feature varies because the studies themselves varied. In Appendix B, studies are listed in chronological order by the year in which the study was started. Appendix Figure B.1. shows locations of the study streams cited and provides an alphabetical index to stream names.

Taxonomy of fishes cited in the report follows Robins et al. (1980). Scientific names are given in Appendix C.

WARMWATER STREAM RESTORATION TECHNIQUES

Efforts to rehabilitate or improve physical habitat for fish in warmwater streams have usually had one or more of the following interrelated goals:

(1) Reducing stream bank erosion and in-stream sedimentation,
(2) Modifying channel morphology and alignment, and
(3) Increasing in-stream cover.

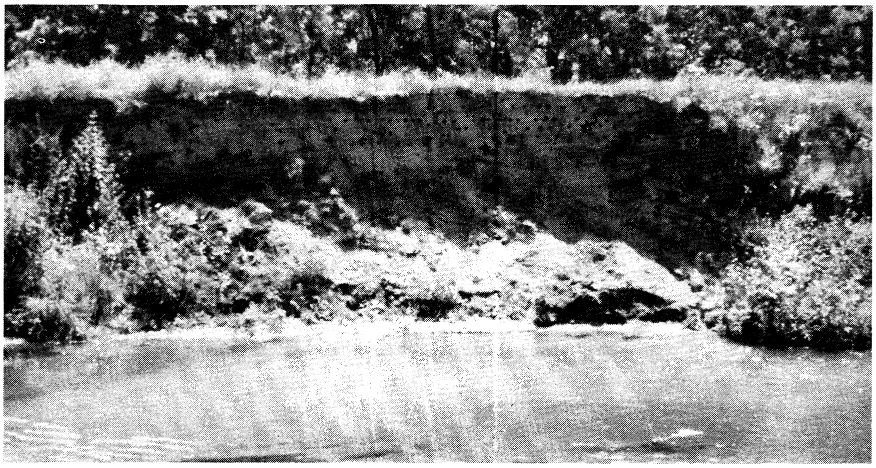
Often techniques designed to attain one of these goals also help to achieve another; thus the distinction between the 3 goals is somewhat artificial.

Stream Bank Erosion and Sedimentation

Overview

Over time, undisturbed streams undergo gradual alterations in their channel geometry as a result of long-term changes in the watershed (Leopold et al. 1964). Within the context of these long-term changes, a cyclical pattern of small-scale streambed and bank degradation (i.e., scouring) and aggradation (i.e., sedimentation) occurs. Human modifications of the watershed tend to accelerate this cycling pattern, and cause major changes in stream channel geometry within a short time period (Nunnally 1978, Hasfurther 1985). Most habitat improvement projects concerned with bank erosion and sedimentation can be thought of as attempts to return the stream to a more natural (i.e., slower and less dramatic) cycle of degradation and aggradation. Thus an understanding of this degradation-aggradation cycle and its role in sediment transport and deposition is essential.

Water discharge, depth of flow, and slope of the stream all affect the



(a) North Fork of the Bad Axe River in west-central Wisconsin. (Photo by Paul Kanehl.)

(b) South Fork of the Flambeau River in north-central Wisconsin. (Photo by John Lyons.)

FIGURE 2. *Severe bank erosion.*

sediment-transport capacity of the stream (Strahler and Strahler 1977, Gore and Bryant 1988). Sediment deposition will occur if the sediment load is greater than the stream can carry. Conversely, if the sediment load is less than the carrying capacity of the flow, then, if available, additional material will be scoured from the streambed and banks.

Deposition of fine sediment particles, particularly silt, has well-known negative impacts on fish habitat and fish populations in warmwater streams (e.g., Berkman and Rabeni 1987). Stream bank erosion (Fig. 2) is a major cause of such sedimentation (Roseboom et al. 1983*a*, 1983*b*, 1985; Roseboom and Russell 1985). Protection of stream banks can thus significantly reduce erosion and the resulting large sediment loads that lead to deposition (Apmann and Otis 1965, Binns 1986).

Undercutting and sloughing are 2 basic mechanisms of bank erosion. Serious undercutting can occur when the lower third or half of the bank consists of small-diameter, non-cohesive material and lacks suitable protection from vegetation or rock. Whereas limited undercutting may be beneficial to fish populations, excessive undercutting will lead to bank collapse, which causes major increases in sediment input into the stream. Sloughing of bank material results when the bank becomes saturated with water and loses its structural integrity. As with undercutting, the bank then collapses. Sloughing can be particularly extensive along low-gradient channels with steep banks (U. S. Dep. Agric. 1985).

Techniques to stabilize banks and reduce erosion usually focus on increasing the resistance of the bank to erosive forces, decreasing the energy of the water at its point of contact with the bank, or both (Gregory and Stokoe 1981). Stream bank stabilization generally entails some combination of the following: sloping the bank to reduce the likelihood of collapse, armoring the bank with rock or other solid materials to protect it from the erosive forces of water, revegetating the bank to increase its cohesiveness and structural integrity, and installing structural devices to deflect high-velocity (i.e., high-energy) water away from the bank (Stern and Stern 1980*a*).

If severely eroding banks are protected, input of fine sediment to a stream should be substantially reduced (Roseboom and Russell 1985, Roseboom et al. 1985). However, sedimentation may remain a problem, either because of continued erosion from other parts of the watershed (Platts and Nelson 1985, Rinne 1988) or because of a large bedload of fine sediments already in the channel (Hansen 1973, Alexander and Hansen 1986, Bassett 1988). In areas with sandy soils, such as central Wisconsin, large bedloads of sand may be a natural condition and may be present even if the stream has never been subject to significant human-induced erosion. Thus, in many streams, stabilizing banks to reduce sediment input cannot by itself eliminate the negative impacts of sedimentation on fish. In these streams, efforts must be made to manage the fine sediment that is already in the channel.

Excessive fine sediment in the channel can degrade fish habitat in a variety of ways (Apmann and Otis 1965; Stern and Stern 1980*a*, 1980*b*; Everest et al. 1987). Fine sediment may cover coarse substrate such as gravel or cobble, reducing the food-producing capability of that substrate and making it unsuitable as spawning habitat for many fish species. Fine sediment may fill pools and holes in the channel, decreasing channel depth and roughness and increasing channel width (Jackson and Beschta 1984). Most warmwater gamefish need deep water, a habitat that streams choked with sediment usually lack. As streams become shallower and wider due to sediment buildup, they often become more likely to flood, leading to bank destabilization, unstable channel morphologies, and damage to the riparian zone.

Techniques to reduce in-stream sediment focus on changing current patterns to flush fine sediment downstream or manually removing (or flushing downstream) the sediment from the channel. Scour structures are designed to change current patterns and increase flushing of the channel.

Other techniques—sediment traps and mechanical substrate cleaning and sediment resuspension—are manual approaches to reducing in-stream sediment.

Sloping

Bank sloping is an effective but expensive way to reduce bank erosion (Hansen 1968; Winger et al. 1976; Keown et al. 1977; Stern and Stern 1980*a*, 1980*b*). Basically, enough of the top of the bank is removed to significantly reduce the angle at which water meets the bank. As a result, water does not strike the bank with the same erosive force that it did previously. Bank sloping also reduces erosion by decreasing the velocity, and hence the energy, of runoff water flowing from the riparian zone into the stream (Helfrich et al. 1985).

Bank sloping is expensive for a variety of reasons and is often not the most efficient way to stabilize banks (Binns 1986). Except in small streams with low banks, bank sloping requires motorized heavy equipment. Accessibility of the eroded banks to this equipment is thus a potential problem. When eroding banks are steep and high, large amounts of adjacent terrestrial habitat must be modified to achieve an acceptable bank slope. The bank material that is removed must then be deposited somewhere away from the stream, often causing further disruption of terrestrial habitats. Finally, the newly sloped bank usually must be armored or revegetated to prevent a resumption of erosion.

Armoring

Another technique to reduce bank erosion that, like sloping, is effective but often expensive is bank armoring (Stern and Stern 1980*a*). Armoring involves covering all or part of the bank with objects that are hard enough to resist erosion, and heavy enough or well-placed enough to not wash away during floods. Placement of such objects prevents high-energy water from directly striking and scouring the underlying bank. Armoring also physically prevents bank collapse.

A variety of materials and structures have been used for armoring, including articulated concrete mattresses, automobile bodies, automobile tire matting, bulkheads, concrete pavement, cribwells, fabric blankets, gabions, jacks, revetments (usually sack, stump, or tree), riprap (loose or grouted), and tetrapods (Engels 1975, Keown et al. 1977, Burroughs 1979, Gregory and Stokoe 1981, Ohio Dep. Nat. Resour. 1987; see Append. A for descriptions). In the upper Midwest, riprap (Fig. 3) has been by far the most commonly used and successful material (Hansen 1968, Bulkley 1975, Witten 1975, Witten and Bulkley 1975), although concrete pavement and articulated concrete mattresses have routinely been used in urban areas and around bridges (Gregory and Stokoe 1981). Several states, including Illinois, Ohio, and Pennsylvania, have recently advocated the use of tree revetments (Roseboom et al. 1985, Commonw. Pa. 1986, Ohio Dep. Nat. Resour. 1986; Ken Fritz, Ohio Dep. Nat. Resour., pers. comm.).

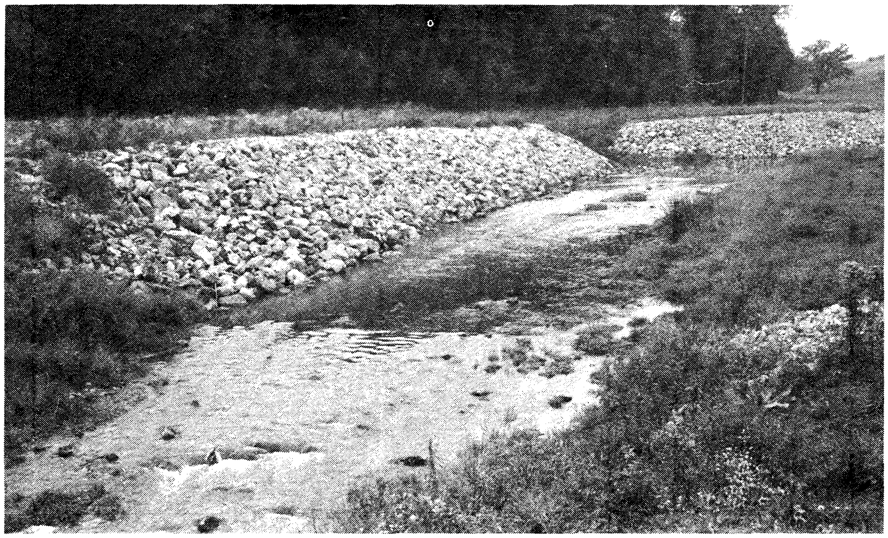


FIGURE 3. *Banks protected by riprap along the Sinsinawa River in southwestern Wisconsin. During higher flows, much of the riprap is underwater and serves as bankside cover for fish. (Photo by Cheryl Courtney.)*

Bank armoring, when properly done, is almost always effective in reducing erosion (Winger et al. 1976, U. S. Dep. Agric. 1985) and, unlike bank sloping, does not usually require modification of large areas of riparian zone (Binns 1986). If riprap is the armoring material used, it has the potential added benefit of directly improving in-stream habitat, particularly if the riprap is submerged at certain times of the year. For instance, riprap added to the lower bank to prevent erosion provided increased spawning habitat for lake sturgeon in the Fox River, Wisconsin (Folz and Meyers 1985).

However, bank armoring has disadvantages. It tends to be expensive, because motorized heavy equipment is usually required and because armoring materials may be costly. Additionally, many armoring materials (e.g., automobile bodies) are aesthetically displeasing; others (e.g., concrete pavement) may reduce the quality of riparian habitat for terrestrial organisms (Binns 1986).

Revegetation

Bank revegetation is an effective and inexpensive approach to bank stabilization (Carlson 1979; Stern and Stern 1980*a*; U. S. Dep. Agric. 1985; Commonw. Pa. 1986; Ohio Dep. Nat. Resour. 1986, 1987). As the name implies, bank revegetation involves planting the bank with seeds, seedlings, or plant cuttings of vegetative materials such as grasses, small non-woody plants, and/or woody vegetation. Vegetation stabilizes banks primarily through the development of a dense matrix of roots that holds together loose soils and reduces their susceptibility to erosion. When vegetation is well developed, it may also act to naturally armor the bank and to physically prevent bank collapse.

Bank revegetation has several advantages over bank armoring or sloping (Helfrich et al. 1985, Commonw. Pa. 1986). The most important one is cost; typically the materials used to revegetate banks cost far less than armoring materials. Also, heavy motorized equipment is not usually required for revegetation, although when used, it often greatly reduces the time and labor involved. Bank revegetation is relatively simple to do, whereas armoring and sloping require trained equipment operators. Additionally, bank revegetation often helps trap eroding soils from the riparian zone before they enter the stream. Sloping

FIGURE 4. *A tree revetment in Court Creek in west-central Illinois, installed using the George Palmiter river restoration techniques. The revetment has been damaged by ice and only partially protects the severely eroded bank. (Photo by John Lyons.)*

and armoring typically do not do this. If bank revegetation leads to well-developed woody vegetation, then it usually provides more in-stream cover along the bank than sloping and armoring do, as well as more habitat for many terrestrial organisms (e.g., insects) that are important food items for fish. Finally, bank revegetation typically enhances the aesthetics and habitat quality of the riparian zone, whereas bank sloping and armoring often do not.

Bank revegetation is not effective by itself in all situations, however. Revegetation often takes several years to complete, and heavy rains, floods, and ice can destroy plantings before they have a chance to become established (Carlson 1979; Don Roseboom, Ill. State Water Surv., pers. comm.). If erosion is severe enough, it may be impossible for vegetation to become established on a bank. Thus efforts to control severe erosion often involve a combination of bank sloping, armoring, or structures, along with revegetation (Fry 1938, Commonw. Pa. 1986). Often these other techniques are used on the lowest part of the bank, where erosion is most severe, and revegetation is employed farther up the bank, where erosion is less. Revegetation of the upper bank can be accelerated by combining limited sloping and terracing with seeding, fertilizing, mulching, sodding, and shrub and tree planting.

An approach to bank protection that incorporates elements of both armoring and revegetation is the so-called George Palmiter River Restoration Plan. This plan has been successfully applied in North Carolina, Ohio, and Tennessee (Willeke and Baldwin 1982, Ohio Dep. Nat. Resour. 1986; Ken Fritz, Ohio Dep. Nat. Resour., pers. comm.), but has seen less success in Court Creek, Illinois, where flood water velocities are particularly high (Append. B, Study No. 18). The basic steps of the Palmiter Plan involve:

(1) Removing log jams and other flow obstructions from the channel,
(2) Protecting eroding banks with trees or other natural materials,
(3) Removing sand and gravel bars that impede flow,
(4) Revegetating the bank for long-term protection, and
(5) Practicing periodic maintenance to keep the channel clear.

With the Palmiter Plan, trees from log jams and from the riparian zone are typically cabled to the stream bank as armoring (Fig. 4). When properly positioned, these trees also act to divert high-velocity water into the center of the channel and away from the bank. When the velocity of water is reduced near the eroding stream bank, sediment deposition occurs and vegetation can become established. Conversion of log jams in the channel into low-cost tree revetments is actually an old Soil Conservation Service technique that has gained additional emphasis as part of the Palmiter Plan (Roseboom et al. 1985). A disadvantage of using the Palmiter Plan to protect stream banks is that although the emphasis on eliminating log jams and other flow obstructions is useful for flood control (a main focus of the Plan), this emphasis may actually reduce the quality of fish habitat (Marzolf 1978, Bisson et al. 1987, Sedell et al. 1988).

Whether or not bank revegetation efforts follow the Palmiter Plan, willows (*Salix* spp.) are one of the most commonly used plants, because they are relatively inexpensive and easy to obtain, take root and grow quickly, and survive regular submersion under water. They are usually planted in the late fall or early spring as dormant "posts" (large-diameter limbless trunks), "stakes" (small-diameter limbless trunks), or "wattles" (bundles of cuttings) (Fig. 5). Willows have been used to stabilize banks in coldwater streams since the 1930s (Fry 1938, U. S. Dep. Agric. 1983). In the Midwest, Illinois and Missouri currently have ongoing evaluations of their effectiveness for bank revegetation along warmwater streams (Append. B., Study Nos. 18 and 20).

In many areas, high densities of beaver, muskrat, or deer might limit the effectiveness of willow plantings as a revegetation technique (Payne and Copes 1986). All 3 species consume willow shoots and leaves, and beaver use the trunks and larger branches to build dams. In some cases, these mammals could prevent willow plantings from succeeding. In such instances, plantings of grasses and other non-woody species would probably be more successful. The U. S. Soil Conservation Service and the Illinois State Water Survey are evaluating different grass mixtures for planting on eroding banks of warmwater streams, but they have not yet completed their studies (Don Roseboom, Ill. State Water Surv., pers. comm.).

On some small streams, establishment of grasses rather than woody vegetation may be beneficial for another reason. Studies of small coldwater streams in Wisconsin suggest that removal of woody vegetation along the banks may benefit trout populations (White and Brynildson 1967; Hunt 1979, 1988*a*). In these streams, woody vegetation may prevent sufficient solar energy from reaching the stream. Resulting shading may inhibit understory plant growth and actually lead to increased erosion and a wider and shallower stream channel. Trout abundance and growth often improve when woody vegetation such as alders (*Alnus* spp.) are replaced by grasses and other smaller plants (Hunt 1979).

We do not know whether replacement of bankside woody vegetation with grasses would benefit warmwater streams, but we suspect that it would not in most instances. The warmwater streams that we considered in this study are much wider than most Wisconsin trout streams, and shading of understory plants by riparian woody vegetation is thus less of a problem. Additionally, bankside woody vegetation is the primary source of large woody debris in the stream channel, and such debris is important cover for warmwater gamefish (Hickman 1975, Angermeier and Karr 1984). In areas with clay banks, such as Wisconsin Lake Superior tributaries, mature trees are more effective than grasses in preventing erosion (Davidson et al. 1989).

Whether woody or grassy plant species are used, fencing to exclude livestock is a critical component of any bank revegetation effort in agricultural areas (Platts 1981). In some instances, fencing may be all that is needed to stabilize banks; natural revegetation in the absence of grazing may be sufficient to stop erosion (e.g., Berry 1980). Conversely, fencing alone may be an inefficient approach to stream habitat improvement, and further bank or instream work may be necessary to significantly increase fish populations (Platts and Wagstaff 1984).

Structures

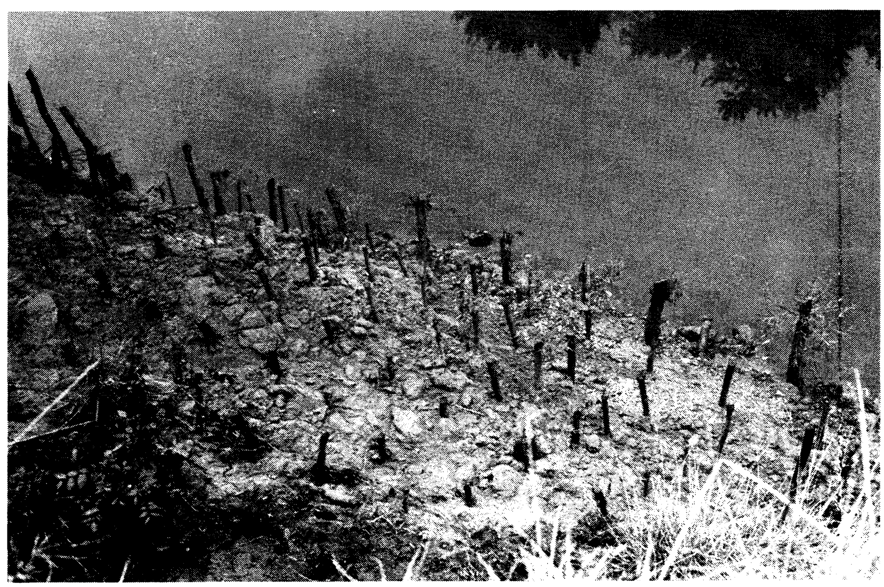
Bank structures are an effective but usually expensive way to stabilize banks (Shields 1983). Bank structures are objects, constructed of wood, stone, concrete, metal, or some combination of these materials, that function to reduce bank erosion and prevent bank collapse. These structures work by deflecting high-velocity water away from the bank, which reduces erosion and increases the likelihood that attempts at bank revegetation will be successful. Structures also often directly armor the bank, and in many cases, the distinction between bank armoring and bank structures is minor (Swales and O'Hara 1980).

A wide variety of structures have been constructed to protect banks, including bank cribs and live cribwells, bulkheads, current deflectors, fence barriers or retards, groins, "lunker" structures, and wing dams or jetties (Hansen 1968, Witten 1975, Witten and Bulkley 1975, Gregory and Stokoe 1981, Helfrich et al. 1985, Seehorn 1985, Wesche 1985, Commonw. Pa. 1986, Ohio Dep. Nat. Resour. 1987, Vetrano 1988; see Append. A for descriptions). All of these structures have proven effective in smaller streams, but on larger rivers, bulkheads and wing dams have been most widely used (Fig. 6).

When correctly installed, bank structures are nearly always effective in reducing bank erosion (Stern and Stern 1980*a*, 1980*b*; Shields 1983). They also typically provide other benefits besides bank protection. By deflecting currents, they often narrow the channel and increase streambed scour. This can result in a reduction in sedimentation and an increase in channel depth, both of which are beneficial to warmwater gamefish. Some types of structures, especially those constructed with large logs or boulders, directly provide cover along the bank.

Bank structures have several disadvantages (Stern and Stern 1980*a*, 1980*b*;

(a) Willow posts planted to protect eroded banks in Court Creek in west-central Illinois. Pictured in March, these posts were planted about 12 months previously; their root system is already well developed and helps stabilize the bank. They will develop small branches and leaves during the coming spring. (Photo by John Lyons.)



(b) Willow stakes planted to protect eroded banks in the Lamine River, central Missouri. These stakes were planted a few months previously; the ones nearest the water have already begun to sprout. A few partially submerged willow posts can be seen in the upper left-hand corner of the picture. (Photo by Cheryl Courtney.)

FIGURE 5. *Using willows to stabilize and revegetate eroded banks.*

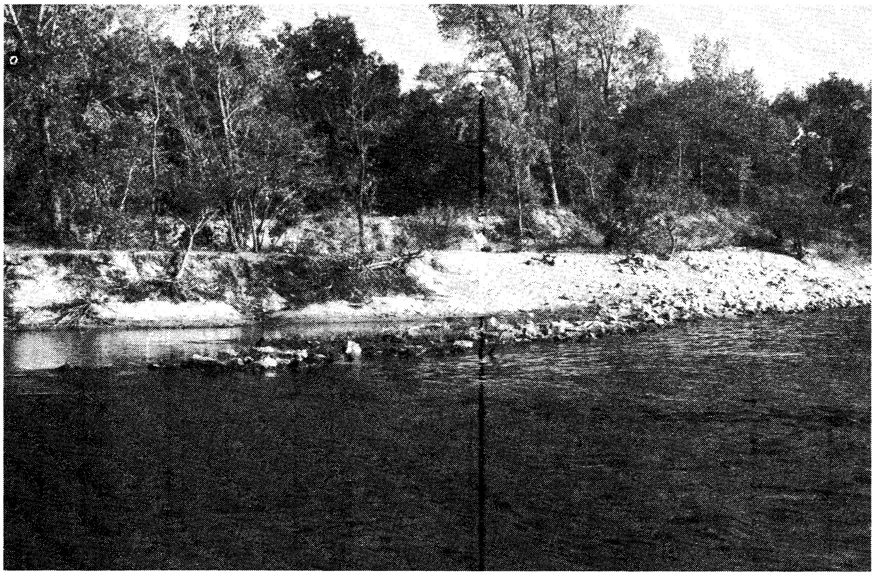


FIGURE 6. *A rock wing dam that has persisted for at least 60 years in the Wisconsin River in southwestern Wisconsin. The water level is very low; normally the wing dam would be covered by water. A very deep hole has formed just below the wing dam, and it is occupied by large gamefish. (Photo by John Lyons.)*

Shields 1983; Commonw. Pa. 1986). In nearly all instances, construction and installation require heavy motorized equipment, intensive labor, or both. To be effective, each structure must be carefully placed in the correct location. Improper placement can lead to destruction of the structure and even more bank erosion. In many cases, use of a structure to deflect water away from one bank necessitates protection of the opposite bank.

Reducing Sedimentation

Several approaches have been used to reduce impacts of sedimentation on fish habitat; the most successful ones are scour structures, sediment traps, and direct removal of fine sediment with addition of coarse substrate. Scour structures are structures constructed and placed to speed up the flow of water and increase water turbulence in a localized area, increasing the rate at which fine sediment is scoured away from the area (Brusven et al. 1974, Winger et al. 1976, Swales and O'Hara 1980, Shields 1983). The change in flow also reduces the amount of new sediment deposition. Greater scour deepens the channel and exposes coarse substrate, which improves fish habitat. Many types of structures and objects have been used to increase scour, including boulders; low-head dams, drop structures, or rock sills; wing dams; and current deflectors (see Append. A for descriptions). If placed correctly, all are effective, but most are expensive to install and some have negative impacts. For instance, low-head dams or drop structures increase scour downstream, but they may also increase deposition upstream and hamper fish movement.

Scour structures often are incapable of sufficiently reducing in-stream sediment. In such instances, installation of sediment traps may be valuable. Sediment traps are large holes dug in the channel. Fine sediment moving downstream in the bedload is deposited in the trap, reducing deposition downstream. With reduced deposition downstream, natural scouring increases channel depth and exposes coarse substrate (Hansen 1973; Alexander and Hansen 1982, 1983, 1986, 1988; Hansen et al. 1982, 1983; Bassett 1988). Thus far, sediment traps have only been used to improve spawning habitat in small trout streams, but they may be effective in some larger warmwater streams (Ed Avery and Scot Stewart, Wis. Dep. Nat. Resour., pers. comm.). Potential advantages of sediment traps are that they can be constructed very quickly and easily with the right equipment, and until they fill with sediment, they directly provide an area of deep water for fish. Disadvantages are that they require motorized heavy equipment to construct, they must be regularly cleaned out (sometimes more than once per year), and if improperly placed, they can cause undesirable changes in channel morphology. Additionally, proper disposal of the sediment from the trap may be difficult.

Where scour structures or sediment traps are impractical or inadequate, fine substrate can sometimes be directly removed from an area of stream (Mih 1978, Payne and Copes 1986). Several techniques can be employed to do this, including resuspension of fine sediment with hydraulic jets, so that it is carried out of the area, and mechanical cleaning of coarse substrates with sieves and pumps. These techniques are effective but require specialized, expensive equipment, they often must be repeated at regular intervals, and because they resuspend fine sediment, they cause increased sedimentation downstream.

As well as removing fine sediment, it may be beneficial to add coarse substrate. Addition of coarse substrate has successfully rehabilitated spawning areas in some small trout streams (Payne and Copes 1986) but has not been tried in warmwater streams. Coarse substrate is usually added below scour structures or sediment traps, so that it is not quickly covered by new sediment deposition.

Recommendations

Plans to stabilize banks and reduce impacts of sedimentation on fish populations in warmwater streams should consider the watershed as a whole. Although bank erosion along the stream may be a major source of fine sediment, erosion along tributaries and away from the riparian zone may also be significant. Reduction of erosion in these areas is outside the scope of most in-stream habitat improvement projects but important nonetheless. Fish managers should cooperate and coordinate their efforts with those groups charged with managing these other sources of erosion in the watershed (e.g., government agencies responsible for nonpoint-source pollution, the Soil Conservation Service, local land and water conservation districts, zoning boards, etc.). In the long run, the efforts of these groups may do more to benefit fish habitat than any in-stream habitat improvement project.

We believe that the ultimate goal of bank stabilization should be establishment of a buffer strip of relatively undisturbed riparian and bank vegetation. Buffer strips can reduce erosion, moderate runoff and variations in flow and physical and chemical characteristics of stream water, often provide a source of food and organic matter, enhance aesthetics, and provide logs and other woody debris for in-stream cover (Gregory and Stokoe 1981; Schlosser and Karr 1981*a*, 1981*b*; Barton et al. 1985).

Therefore, we recommend bank revegetation as the primary approach to bank stabilization. Potential impacts of beaver, muskrat, and deer must be considered in choosing plant species for revegetation efforts. In areas with livestock, bankside fencing must be incorporated into revegetation efforts. When bank revegetation alone is not sufficient, we advise use of riprap, tree revetments, current deflectors, or wing dams in combination with revegetation. An advantage of current deflectors and wing dams is that they can double as scour structures if sedimentation is likely to persist as a problem after banks have been stabilized. We advocate use of natural objects or simple structures to reduce in-stream sedimentation in most instances, but under certain conditions sediment traps and addition of coarse substrate may be warranted.

Channel Morphology and Alignment

Overview

A host of factors determine channel morphology and alignment, including stream gradient and discharge patterns, and human impacts, particularly channelization and acceleration of sediment deposition. Undegraded streams usually have a wide variety of depths, widths, and flow patterns within their channels (Funk 1973, Nunnally 1978, Winger 1981). Deeper water tends to occur in areas of scour, such as along the outside of bends or just below areas of high-velocity water (e.g., riffles, channel constrictions). Flow patterns are complex, with areas of both slow- and fast-moving water and both turbulent and smooth flow. Degraded streams, however, have less heterogeneity in channel morphology and alignment (Gorman and Karr 1978, Schlosser 1982), and channel shape and position may be less stable (Muller and Oberlander 1978, Nunnally 1978).

Stream gradient or slope has influences on channel morphology and flow patterns that are particularly important for fish (Backiel 1964, Funk 1973). High-gradient streams tend to have substantial longitudinal variability in water velocity and channel shape (Yang 1971). Within high-gradient streams, some reaches have particularly steep slopes, forming shallow, turbulent riffles, rapids, or, in extreme cases, waterfalls. Reaches with less-steep slopes tend to be deeper, forming pools, while reaches of intermediate slope form runs or glides. These runs provide habitats intermediate in depth with moderate to high water velocity and smooth flow. The deeper the pools and runs are, the better the habitat tends to be for warmwater gamefish (e.g., Schlosser 1982, Probst et al. 1984). Pool-riffle-run sequences usually occur regularly over the length of a stream, on the order of once every 5 to 12 times the channel width (Leopold et al. 1964, Yang 1971, Hasfurther 1985). At baseflow, pools have the slowest-moving waters and are areas of deposition, whereas riffles have the fastest-moving waters and are areas of scour. During floods, the situation is reversed, with riffles becoming areas of deposition, and pools becoming areas of scour (Winger 1981, Jackson and Beschta 1984). Thus, discharge variations have a major impact on channel form in high-gradient streams.

Low-gradient streams, on the other hand, have very different channel characteristics. Typically, streams decrease in gradient as they flow downstream, although exceptions to this pattern are common. As stream gradient decreases, the frequency and length of riffles and rapids also decrease, and the distinction among pools, runs, and riffles becomes less clear-cut (Funk 1973). Stretches of smooth-flowing water become longer, and in low-gradient streams, riffles and other areas of obvious turbulence are absent. In low-gradient streams, stream meander becomes the most obvious source of longitudinal variability in velocity and channel form. Stream meander, also known as lateral migration, is the tendency of the channel to form loops and bends (Muller and Oberlander 1978). Meanders also occur in high-gradient streams and contribute to pool-riffle-run development. Scour and, consequently, deep water tend to be greatest on the outside of bends, whereas deposition occurs on the inside of bends (Hasfurther 1985). Bends typically provide the best habitat for gamefish in low-gradient streams (Funk 1973). Major floods can change the channel alignment, creating new meanders and cutting off old meanders from the main flow of the stream to form oxbows and backwaters, thus substantially influencing fish habitat.

No matter what the gradient, a variety of human impacts—including channelization, removal of in-stream rock and large woody debris, sediment deposition, and bank destabilization—can negatively modify channel morphology and alignment as habitat for fish. In channelization, or channel straightening, stream length is reduced by eliminating meanders (Fig. 7). This increases stream gradient, because the stream does not travel as far to drop a given amount in elevation. Accompanying the loss of meanders is a loss of the deeper water that occurs along the outside of bends.

Once a stream has been straightened, several other changes occur, depending on the condition of the stream bank. If the stream banks are not well protected, channel width tends to increase and depth tends to decrease (Nunnally 1978). The stream immediately begins to attempt to revert to a more natural pattern of meander, usually causing increased stream bank erosion and in-stream sediment deposition. If, however, stream banks are well protected against erosion, then the increase in gradient causes extensive scour of the existing channel and "headcutting," the progressive, rapid erosion of the streambed in an upstream direction. This erosion often leads to increases in the stream's sediment load and deposition downstream (Fajen 1981, Newbury and Gaboury 1987). Headcutting and deposition represent the stream's tendency to return to a more gradual channel slope and may affect areas of the stream well upstream and downstream of the channelized region (Nunnally 1985). Overall, channelization makes channel morphology more homogeneous at any particular point in time but less stable over time, conditions that are not favorable for most gamefish.

In addition to direct modification of channel morphology and alignment, channelization usually entails the removal of all objects in the channel that might impede water flow, including large woody debris and boulders. This further reduces heterogeneity in channel width, depth, and flow patterns, because woody debris and boulders act to alter the direction of stream currents and to create local areas of deposition and scour (Bisson et al. 1987, Andrus et al. 1988, Sedell et al. 1988, Bilby and Ward 1989). Large woody debris and boulders are also important food-producing and cover areas for gamefish (Marzolf 1978, Angermeier and Karr 1984, Probst et al. 1984, McClendon and Rabeni 1987), so even in the absence of channelization their loss is harmful (e.g., Hickman 1975).

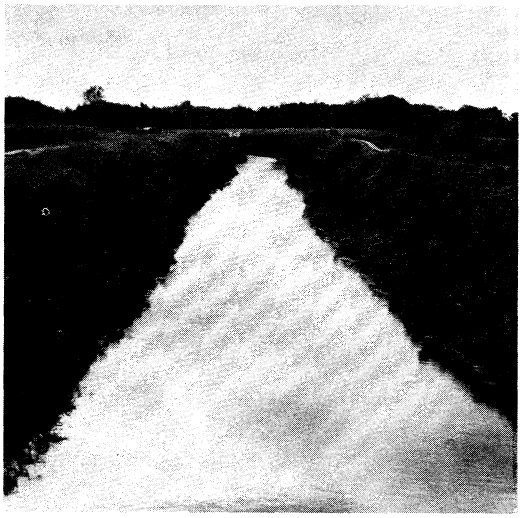


FIGURE 7. *Goose Lake Canal, a channelized stream in southeastern Wisconsin. Note the lack of heterogeneity in flow patterns in the channel and the absence of in-stream and bankside cover. (Photo by Paul Kanehl.)*

Another human impact that directly affects channel morphology and alignment is accelerated sediment deposition. Such deposition occurs when human activities cause greatly increased inputs of sediment into the stream. This sediment fills deep areas in the channel, reducing average depth. To transport the same amount of water through the now-shallower channel, the stream must either increase in width or in water velocity (Nunnally 1985). Sediment deposition creates bars and other blockages to flow, modifying channel alignment and flow patterns. Stream bottoms of fine sediment, such as silt or sand, are easily modified during high flows, so sedimentation usually leads to a less stable channel morphology.

Bank destabilization is a major cause of erosion and increased sedimentation, and thus contributes to modifications in channel morphology and alignment. Additionally, unstable banks are more likely to be breached during floods, which could lead to formation of completely new channels and loss of habitat in old channels.

Efforts to modify channel morphology and alignment to benefit fish usually involve installation of structures or natural objects (e.g., boulders, logs) to change scour and deposition patterns in the channel. Typically, the primary goals are to increase maximum depth or to increase heterogeneity in depth, or both. In some cases, pools or riffles are constructed directly, usually in coordination with installation of structures. In extreme cases, a completely different channel is constructed or restored, and the stream is diverted into it.

Changing Scour and Deposition Patterns

Channel morphology and alignment can often be modified to benefit fish populations through proper installation of natural objects or structures. These objects or structures (described below) are typically installed to increase scour in a particular area in order to increase depth. Most installations have the additional related goals of increasing in-stream cover, stabilizing banks, or removing fine sediment.

Scour increases when water velocity or turbulence increases (Leopold et al. 1964). Thus, to increase depths, structures or natural objects should be installed to increase current speed or turbulence. However, material that is scoured must eventually be deposited, so installations must strive to maximize desired scour while minimizing undesirable deposition.

A variety of natural objects can be used to increase scour. The simplest are logs, stumps, brush, rock piles, or boulders (Shields 1983, Seehorn 1985, Wesche 1985, Payne and Copes 1986). All must be judiciously located either in the channel or along the bank, to remain in place and be effective, but they are otherwise inexpensive and easy to install. More complex installations of natural objects include fallen trees cabled to, or embedded in, the bank to form current deflectors and groups of rock piles or boulders placed to form wing dams or jetties (Witten 1975, Witten and Bulkley 1975) (see Fig. 6).

In addition to natural objects, structures can also be used to increase scour. The distinction between the 2 types of installations is minor, as most structures consist, at least in part, of logs or rocks. Structures effective in increasing depth in small streams include low-head dams or log drop structures (e.g., Hewitt ramps [Fig. 8], gabion dams, rock sills, trash-catcher dams, etc.), channel constrictors, and current deflectors (Robinson and Menendez 1964, Brusven et al. 1974, Ebert and Knight 1981, Shields 1983, Helfrich et al. 1985, Seehorn 1985, Wesche 1985, Payne and Copes 1986; see Append. A for descriptions). These structures can usually be installed without motorized heavy equipment, although installation will be labor-intensive.

Many of the above structures have not been tested and might not work in larger streams or small rivers (> 40-50 ft in width; Shields 1983). The force of flow in larger streams is substantially greater than in small streams, and structures that are effective in small streams, such as single-wing current deflectors and log drop structures, would probably be washed away during the first major flood on larger streams. Additionally, the amount of material and labor necessary to build many types of structures quickly becomes prohibitive on larger streams. For instance, on a small stream, a low-head dam can be constructed merely by dropping a large log or two across the channel. Conversely, on a small river, construction of a low-head dam is a major undertaking, requiring large amounts of material, heavy equipment, and detailed hydrological analyses in the planning of the construction.

The simplest and most inexpensive approach to changing scour and deposition patterns in larger streams is to place natural objects, especially boulders or logs, in the channel. These objects only influence stream flow in a small area, but are nonetheless effective in increasing channel depth in many instances. They may not be effective in increasing depth if stream gradient is very low or if sedimentation rates are very high (Shields 1983). However, even when not effective in increasing depth, addition of boulders or logs increases in-stream cover.

If changes in scour and deposition are required on a large scale, construction of rock jetties or wing dams is the most time- and cost-effective approach. Rock jetties or wing dams are effective in all sizes of rivers (up to and including the Mississippi) and also contribute to in-stream cover (Witten 1975, Witten and Bulkley 1975, Schnick et al. 1982).

Directly Reconstructing the Channel

Sometimes efforts to improve channel morphology and alignment for fish through modification of scour and deposition patterns are ineffective. In such instances, it may be worthwhile to directly reconstruct the channel. This stream improvement technique involves constructing pools or riffles within the channel or, in extreme cases, diverting the stream into a different channel. Such an approach is often expensive and difficult, but it may be the only way to rehabilitate the habitat of the stream, particularly when channelization is extensive (Fajen 1982, Edwards et al. 1984, Newbury and Gaboury 1987, Davis 1988).

Pools can be directly created or deepened by digging out the stream channel. This requires motorized heavy equipment or explosives, but is otherwise quick and straightforward (Payne and Copes 1986). However, maintenance of pools formed in such a manner requires either construction of scour structures upstream to keep the new pool from filling in or regular direct removal of sediments. Directly constructed pools have improved fish populations on salmon and trout streams (Payne and Copes 1986) but, to our knowledge, have rarely been constructed in warmwater streams and have never been thoroughly evaluated there (Append. B, Study No. 19). In warmwater streams, pools have been indirectly created through construction of scour structures such as current deflectors, wing dams, and low-head dams (Shockley 1949; Robinson and Menendez 1964; Hanson 1965; Miles 1969; Witten 1975; Witten and Bulkley 1975; Winger et al. 1976; Carline and Klosiewski 1981, 1985).

Unlike pools, artificial riffles have been directly constructed in warmwater streams. Construction involves adding rocks and gravel to decrease depth and create a faster, more turbulent flow. The artificial riffle itself provides improved habitat for small fish and macroinvertebrates, and the change in flow pattern that it creates often results in deeper water downstream that provides improved habitat for larger fish. In Ohio, artificial riffles were effective in restoring a more natural pool-riffle-run sequence to channelized stretches of a small river (Perry 1974, Edwards 1977, Griswold et al. 1978, Woods and Griswold 1981, Barickman 1984, Edwards et al. 1984). Artificial riffles also proved beneficial in channelized streams in Manitoba (Newbury and Gaboury 1987) and Kentucky (Davis 1988).

In a few cases, a stream must be moved to a completely new channel to create suitable habitat (Fajen 1982). In practice, this has occurred only with channelized streams, and the new channel often incorporates much of what was the original channel before channelization. Habitat is improved because the new channel typically has more meanders, better pool-riffle-run characteristics, or more stable banks. However, moving the stream into a different channel is difficult, even if the new channel is one that the stream formerly occupied. Such a move may also have unexpected impacts on channel morphology and alignment upstream and downstream of the relocated stretch.

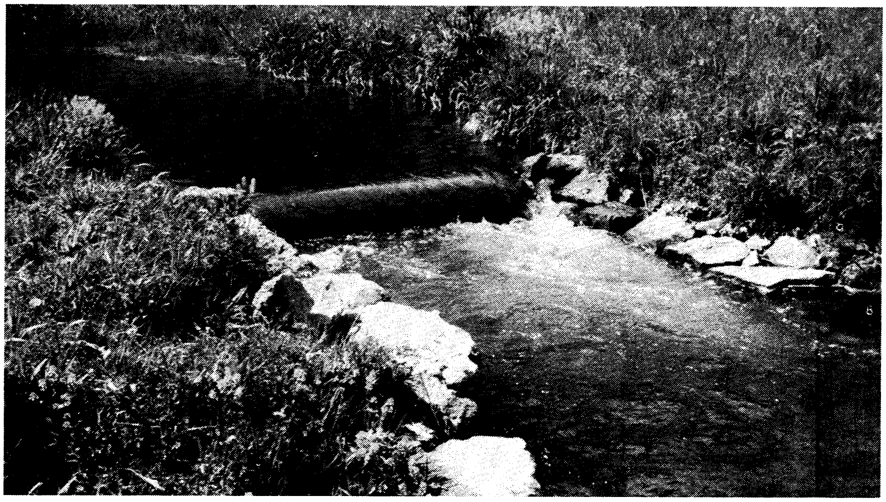


FIGURE 8. *A Hewitt ramp, a type of low-head dam, in Timber Coulee Creek, a small trout stream in west-central Wisconsin. (Photo by Paul Kanehl.)*

Recommendations

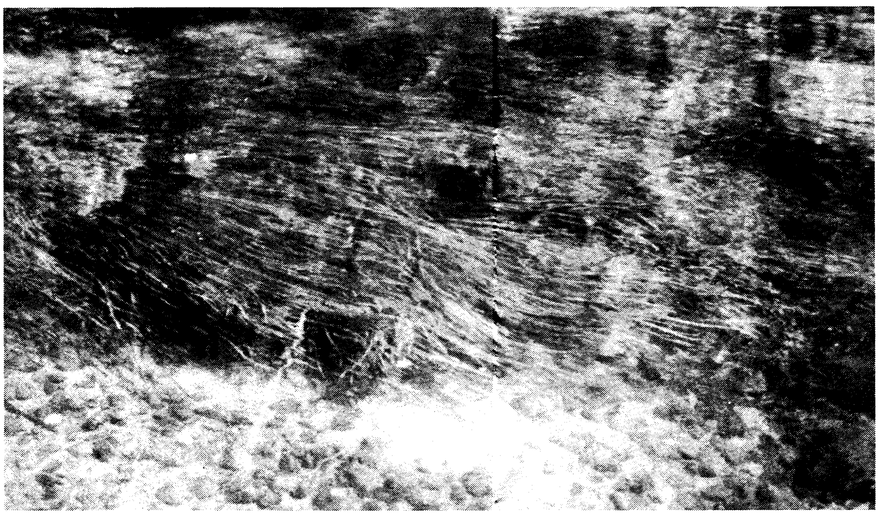
Efforts to change channel morphology or alignment at one location invariably influence channel morphology and alignment at other locations, often well upstream and downstream of the location of modification. Thus, proper placement of structures or natural objects is essential in modifying channel morphology and alignment to improve fish habitat. Improper placement can actually degrade fish habitat or at least neutralize the effectiveness of objects or structures (Winger et al. 1976, Shields 1983, Davis 1988). Conversely, proper placement will often increase protection of banks from erosion and improve in-stream cover for fish, in addition to favorably modifying channel morphology and alignment.

Flow patterns of warmwater streams are complex and highly variable. As a result, the potential for improper placement of objects or structures may be greater in these streams than in the smaller coldwater streams where most habitat improvement structures have been developed and tested. Proper placement of objects or structures requires a quantitative evaluation of stream physical characteristics and dynamics. Although not commonly done in fisheries habitat improvement projects, we recommend that extensive, detailed channel morphology and flow data be collected and analyzed before habitat modification takes place. In particular, the properties and effects of flood flows at the proposed location of channel modification should be simulated using computer hydraulic and geomorphologic models. Most fisheries biologists do not have the training or experience to use these types of models, so water resources scientists and engineers should be brought into the planning process to run and interpret the simulations.

In determining the type and location of efforts to improve channel morphology and alignment, it must be kept in mind that many techniques or structures that are commonly used in small streams are inappropriate in larger, more powerful streams. The amount of force, and consequently the necessary size and strength of channel modification structures, increases exponentially with increasing stream size. A single log cabled to the bank may be an effective current deflector in a small brook, but it will have little influence and probably will be quickly washed away in small river. The best approaches to channel modification in larger streams mimic natural processes and work with, rather than against, the specific flow patterns that are present.

To benefit fish populations, channel modifications should focus on increasing maximum depth and preserving or restoring longitudinal heterogeneity in depth and water velocity. A variety of structures and natural objects will do this in small warmwater streams, but in larger streams, boulder placements or installation of rock jetties or wing dams will be the most cost-effective approaches. Structures constructed of logs or other materials, in addition to

(a) Large woody debris in the Plover River in central Wisconsin.



(b) A macrophyte bed in the Embarrass River in northeastern Wisconsin.

(c) Boulders in the South Fork Flambeau River in central Wisconsin.

FIGURE 9. *Some examples of good in-stream cover. (All photos by Paul Kanehl.)*

rock, may work in larger streams, but will probably be more expensive to construct and maintain.

In-stream Cover

Overview

Cover is a generic term that describes characteristics of or objects in a stream that provide shelter or hiding places for fish (Funk 1973, Wesche 1985). Shelter or hiding places provide protection from water velocity, from light (for nocturnal or crepuscular species), or from predators. In addition, cover can be important spawning habitat for some species, such as catfish and bullheads.

If all life stages of fish species are considered, a tremendous variety of types of cover can be identified. For large gamefish, cover is usually defined as deep water, overhanging banks or vegetation, logs and large woody debris, dense growths of rooted macrophytes, boulders or groups of large rocks, large-sized rubbish (e.g., auto tires, 55-gallon drums, abandoned refrigerators, etc.), and certain types of habitat improvement structures (Platts et al. 1983, Payne and Copes 1986). To be valuable as habitat, cover objects must be big enough and in water deep enough to protect or conceal a fish (Fig. 9). Variation in water levels strongly influences cover availability; objects that provide excellent cover during high flows may be completely out of the water at baseflow and may thus be useless as cover.

The abundance and biomass of warmwater gamefish in a section of stream tend to be positively related to the amount of cover present (Funk 1973, Angermeier and Karr 1984, Probst et al. 1984, Axon and Kornman 1986, Rankin 1986, Sechnick et al. 1986, McLendon and Rabeni 1987). Reduction in cover almost invariably leads to reductions in gamefish populations (Hickman 1975, Edwards 1977, Paragamian 1987).

Many human activities reduce the amount of cover in streams. Channelization and removal of large woody debris for flood control or navigation cause major declines in cover. Sedimentation can bury cover objects and fill in deep holes. Thus, habitat improvements designed to restore a more natural channel morphology and alignment or to stabilize banks and reduce sedimentation often directly or indirectly increase in-stream cover. In particular, certain types of bank structures and scour structures provide excellent cover (Payne and Copes 1986, Gore and Bryant 1988, Hunt 1988*b*).

Cover can also be added directly to a stream, either in the form of natural objects such as rocks, trees and woody debris, and macrophytes, or in the form of constructed cover structures. Such structures include half-logs, leg-type structures, log cribs, metal drums, and trash collectors (Robinson and Menendez 1964, Miles 1969, Wesche 1985; see Append. A for descriptions). In general, all of these structures have proven effective if used in streams with stable channels and substrates (Fajen 1981). They have not been nearly as effective in streams with migrating channels, extensive fine sediment, or large variations in flow (Scott 1962, Miles 1969, Fajen 1981, Shields 1983). The relative effectiveness of natural objects versus structures has not been evaluated in warmwater streams, although installation of structures tends to be more expensive and more labor-intensive (Fajen 1981).

While structures and natural objects are effective in increasing cover, they may have short lifetimes in warmwater streams. Structures that last for many years in small coldwater streams are often damaged or washed away after only a few years in larger, more powerful warmwater streams (Shockley 1949, Robinson and Menendez 1964, Miles 1969, Fajen 1982). Thus, regular maintenance or replacement of them of cover structures and objects may be a necessary part of a warmwater stream habitat improvement program. Use of durable materials and placement of them in areas protected from high flows or shifting substrate should reduce the likelihood of damage to, or washout of, cover installations.

Recommendations

If natural cover is a limiting factor, installation of cover objects or structures should benefit gamefish populations in warmwater streams. In most instances, installations should serve multiple purposes: improving channel morphology and/or bank stability in addition to improving in-stream cover. Proper placement of objects or structures is essential in order to obtain maximum benefits from the installation. Sedimentation or changes in water level can easily reduce or eliminate the value of poorly placed installations.

If increasing in-stream cover is the primary purpose of a habitat improvement project, we recommend the addition of natural objects or simple structures, such as half-logs, rather than more complicated structures such as cribs or leg-type structures. Natural objects and simple structures are less expensive and less labor-intensive to install, probably require less maintenance, and essentially duplicate natural conditions in streams. Cover objects should be matched to the type of stream where they would naturally occur and to the species of interest. For instance, macrophyte plantings or log additions are most appropriate in low-gradient streams with fine substrate, whereas boulder and rock additions are most appropriate in high-gradient streams with coarse substrate. Likewise, boulder additions would probably be more beneficial for smallmouth bass than for northern pike, whereas the opposite would probably be true for macrophyte plantings.

Even when properly placed and well secured to the substrate or bank, cover objects or structures may not persist for long periods in large warmwater streams. Rather than trying to increase the lifetime of structures or objects by making them stronger and more resistant to dislodgment, we suggest letting nature take its course and planning to replace or repair cover installations on a regular basis. For instance, rather than building a concrete and steel crib and bolting it to the streambed (a structure likely to persist for many years, but relatively expensive to construct and install), we recommend adding logs or trees to the stream and planning to replace them every few years as they decompose or are washed away. Such a practice more closely mimics natural conditions and processes in warmwater streams. Natural forms of cover are often short-lived, and their gradual decomposition and loss followed by replacement with new forms is a fundamental cycle that stream organisms have adapted to over their evolutionary history (e.g., Bisson et al. 1987, Sedell et al. 1988).

Lastly, we recommend coordination, when possible, of efforts to increase cover with efforts to improve or protect bank revegetation. If growth of woody vegetation can be promoted along the banks and in the riparian zone, natural recruitment of woody debris to the channel may ultimately eliminate the need to add cover.

CONCLUSIONS

General Considerations

The key to success in any habitat improvement project is to first identify and then improve the characteristics of the habitat that are limiting to the fish populations of interest. A major question, which seems obvious but is all too often ignored in habitat improvement projects, is whether or not physical habitat is the primary limiting factor. Even if physical habitat is highly degraded, habitat improvement will not improve fish populations if other factors, such as water quality, remain unsatisfactory. However, if physical habitat is the limiting factor, then the specific aspect of habitat that is most limiting must be identified and addressed. For instance, although suitable substrate may be scarce in a stream, a lack of deep pools for overwintering may be the main reason that gamefish numbers are low. Identification of specific limiting habitat characteristics is often difficult and invariably requires detailed quantitative data on the physical and biotic characteristics of the stream prior to improvement.

The separation of causes from symptoms is an important part of the process of identifying limiting habitat factors. Whenever possible, habitat improvement projects should try to eliminate the basic causes of poor-quality habitat as well as to improve the habitat itself. An obvious example of this would be the need to stabilize eroding banks before attempting to reduce impacts of in-stream sedimentation. However, treatment of causes often requires long-term approaches, whereas symptoms can be treated in the short-term. For instance, lack of in-stream cover (a symptom) might be remedied by the addition of logs and other large woody debris to the channel. However, the cause of insufficient in-stream cover, which could be the poor condition of bank and riparian vegetation, might be eliminated only through a multi-year program of streamside fencing and bank revegetation. Twenty-five to fifty or more years might elapse before the riparian zone could recover to the point where it could begin contributing significant amounts of large woody debris to the channel (Bisson et al. 1987, Andrus et al. 1988).

In many cases, poor-quality habitat is caused by watershed-wide problems rather than localized in-stream or riparian factors. For this reason, individual stream habitat improvement projects should always be considered in the context of the management of the entire watershed. As fisheries biologists are typically responsible only for the surface-water portion of the watershed, they must coordinate their activities and cooperate with the agencies and organizations that are responsible for the remainder of the watershed. Work done by these groups, normally outside of the purview of fisheries management, may in some cases do more to benefit fish populations than specific fish habitat improvement projects.

In addition to considering the watershed, fisheries biologists should also take into account the possible responses of the entire aquatic and riparian community to habitat modifications. Although relatively little is known about species interactions in warmwater streams (Moyle and Li 1979, Larimore 1981), changes in habitat conditions will likely affect different species or life history stages of individual species in different ways. These differential effects could lead to shifts in community structure and function, resulting in unexpected changes in the populations of primary interest.

Once a habitat problem is identified, and improvement is proposed, an effort should be made to ensure that the potential benefits of the project will exceed the costs. Thus, at least an informal cost-benefit analysis must be carried out before a project is initiated. Habitat improvement on streams that already have fairly good habitat may not be cost-effective, because the resulting improvement in fish populations may be too small to be significant. Priority for projects should be given to streams where habitat quality is poor and where habitat improvement is likely to lead to dramatic and obvious increases in the abundance or biomass of the species of interest.

A factor that should not be ignored in the cost-benefit analyses is the impact of habitat improvement projects on users of the stream other than anglers. Because warmwater streams are usually larger and more heavily used by swimmers, boaters, and hunters, the potential for multiple-use conflicts is much greater in warmwater streams than in coldwater streams. Some habitat improvements, such as stabilizing banks, are likely to benefit most users, but others, such as the construction of low-head dams, may incur a cost to non-angling users. Generally, the large size and multiple use of warmwater streams will make the legal and social issues associated with habitat improvement projects more complex than for coldwater streams.

However, even if the cost-benefit is favorable, the large size of warmwater streams means that habitat improvement must be extensive; thus project costs can quickly become prohibitive. Failures would be expensive. Thus, we recommend using the simplest and most inexpensive techniques that are likely to be effective. In particular, we advise the use of natural materials found near the stream (rocks, trees, etc.) whenever possible.

Whether simple objects or complicated structures are used, the most important consideration in warmwater stream habitat improvement is proper placement and installation of the object or structure. Poor placement or improper installation will lead, at best, to decreased effectiveness and, at worst, to increased habitat degradation. In small streams, the locations for installation of objects or structures can often be picked by eye, with no data on channel and flow characteristics. In larger streams, however, this approach to placement is an invitation to disaster. In such streams, the locations for habitat improvement work should be based on quantitative data on discharge, gradient, channel morphology, water velocity, substrate, and bank and riparian zone characteristics. When possible, these data should be incorporated into geomorphologic and hydraulic models to predict the impact of floods and droughts on the effectiveness of improvement techniques. Engineers and water resources scientists can assist fisheries biologists in the application of these models.

Because warmwater stream habitat improvement is a new field, projects that do not fully accomplish their objectives may at first be the rule rather than the exception. The fastest way to increase the percentage of successful projects will be to carefully evaluate and learn from each project that is undertaken. Thus far, most warmwater stream habitat improvement projects have not been adequately evaluated, and as a result, major questions remain about all of the techniques discussed in this report. Adequate evaluation is a complex undertaking, involving detailed assessment and sampling of habitat and fish from both treatment and reference sections of streams, both before and after habitat improvement is carried out. Some changes that result from habitat improvement may be obvious, but many changes will not be, particularly those connected with fish populations. A proper evaluation may cost more, take longer, and require more labor than the habitat improvement itself. Nonetheless, until a large number of habitat improvement techniques and procedures have been proven effective, a detailed evaluation should be a required part of every warmwater stream habitat improvement project.

Specific Recommendations for Wisconsin

Based on our review of projects carried out on warmwater streams in other states, and keeping in mind the above considerations, we recommend the following specific techniques for habitat improvement of warmwater streams in Wisconsin:

(1) *To Stabilize Eroding Banks.* Revegetate banks and try to establish a buffer zone of woody vegetation along the bank and in the adjacent riparian zone. Consider potential impacts of beaver, muskrat, and deer in choosing types of vegetation to plant, and use bank fencing if livestock are present. If erosion is severe, supplement revegetation with riprap or tree revetments.

(2) *To Reduce In-stream Sedimentation.* First, stabilize eroding banks. Then use natural objects, such as boulders or trees cabled to the bank, or simple structures, such as rock wing dams or jetties, to increase scour and expose coarse substrate. Experiment with sediment traps if sand bedload in the stream channel is high, if motorized heavy equipment has easy access to the stream, and if money is available

for regular trap clean-out. Add coarse substrate only in areas of scour (including below scour objects and structures and below sediment traps) and then only if scour processes are insufficient to expose natural coarse substrate. Coordinate activities with efforts to reduce erosion throughout the entire watershed.

(3) *To Modify Channel Morphology and Alignment.* Use boulder and log placements, or construct rock wing dams or jetties, to scour out deeper pools. Collect extensive habitat and hydrological data and, where possible, incorporate them into computer simulation models to assure proper placement of objects or structures. If practical, use explosives or motorized heavy equipment to dig deeper pools, but only do this below scour objects or structures so that the new pool will not quickly fill in. Preserve riffles and meanders in the channel during habitat modifications. In channelized streams, consider constructing artificial riffles in addition to scour structures. Physically move the stream to a new channel only if the current channel is highly degraded, if other habitat modifications fail to sufficiently improve habitat in the current channel, and if a better channel exists or can be constructed.

(4) *To Increase In-stream Cover.* To stabilize banks, reduce sedimentation, or modify channel morphology, use techniques that also increase cover. Use natural objects or simple structures instead of complex structures when possible. Depending on stream characteristics and the species of interest, add rocks and boulders, dead trees and logs, macrophyte plantings, or half-log structures. Carefully place such objects or structures to maximize their effectiveness, and be prepared to replace them on a regular basis when they are washed away or destroyed. Protect or improve woody vegetation along the banks.

APPENDIXES

APPENDIX A. *Glossary of stream habitat improvement structures cited.**

Structure	Description	Purpose (s)
Articulated concrete mattress	A collection of concrete slabs wired together to form a large mattress and placed on the bank.	Protect the bank.
Artificial riffle	A segment of stream where rocks are added to create a shallow area with turbulent flow. Often associated with sills or current deflectors to increase turbulence.	Add hetereogeneity to current and depth patterns of stream. Aid in formation of pools.
Automobile tire mat	A mat of tires wired together and placed on the bank.	Protect the bank. Increase bankside cover.
Broken-sidewalk-slab cover device	A concrete sidewalk slab, broken in half but not separated into 2 pieces, in which the broken region of the slab is propped up off the stream bottom to form an upside-down "V."	Increase in-stream cover.
Bulkhead	A wall of wood, metal, rock, or concrete that shores up a slumping bank.	Protect the bank.
Channel constrictor	A type of structure, such as a notched drop structure or a double-wing current deflector, that forces the main flow of water through a narrow gap.	Increase scour and deepen the channel. Create a downstream pool.
Check dam	Same as low-head dam.	
Crib	A cubical structure constructed of logs, metal posts, concrete blocks, or boulders; filled with rocks; and placed in the channel or along the bank.	Increase in-stream cover. Change scour and deposition patterns.
Cribwell	A crib of logs that is anchored to the bank. Usually filled with rocks or with dirt planted with willows (live cribwells).	Protect the bank. Increase bankside cover.
Current deflector	A structure such as a a log, wing dam, or jetty that is used to force the current in a different direction. Can be a single wing (one side of channel only), or a double wing (both sides of channel with a narrow opening in between). Constructed of rocks, logs, or gabions. Also known as wing deflector.	Change scour and deposition patterns. Create a downstream pool. Protect the bank.
Digger log	A type of current deflector used in small streams, consisting of a log anchored to the bank that juts into the stream at an angle to the flow of water.	Change scour and deposition patterns. Increase depth.
Drop structure	Same as low-head dam.	

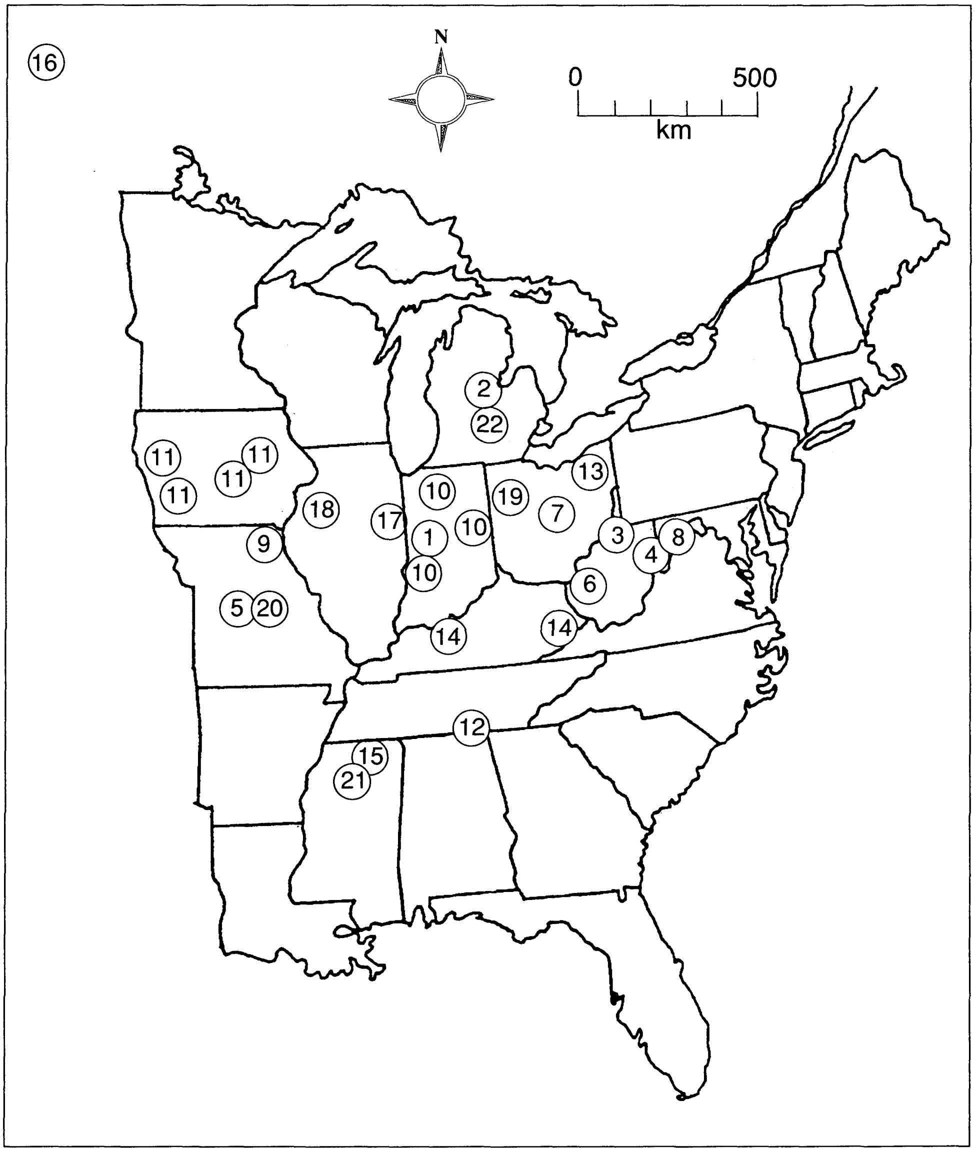
Structure	Description	Purpose (s)
Fabric blanket	A flexible, mesh-like material (usually synthetic) that reduces erosion and through which vegetation can grow. Sometimes used underneath riprap.	Protect the bank.
Fence barrier	A fence-like arrangement of log pilings, sheet metal, gabions, or boulders that is placed along the bank. Also known as a retard.	Protect the bank.
Gabion	A wire cage or basket filled with rocks.	Protect the bank. Provide a material for building other structures.
Grade stabilization structure	Same as low-head dam.	
Groin	A triangular structure, usually built from rock or concrete, that is placed so that the apex juts out from the bank.	Protect the bank. Deflect current to change scour and deposition patterns.
Half-log	A log split lengthwise and anchored (split side down) to the substrate so that there is a narrow gap between the log and the substrate.	Increase in-stream cover.
Hewitt ramp	A type of low-head dam used on small streams that is formed of logs, wood planks, and/or rocks. Rocks or planks are used to create a gradual incline or ramp to the lip of the dam on the upstream side.	Change scour and deposition patterns. Create a downstream pool. Stablize stream gradient and reduce headcutting.
Jack	A structure made from 3 pieces of angle iron bolted or welded together to form a pyramid-like structure. Placed on the bank or in the channel.	Protect the bank. Change scour and deposition patterns.
Jetty	Same as wing dam.	
Leg-type structure	A concrete slab, supported by either 2 legs along one side (parallel-leg or legs-at-one-end), 4 legs at the corners (four-leg), or a "+" of concrete in the middle (cross-leg). Placed in the channel.	Increase in-stream cover.
Low-head dam	A structure that completely spans the channel and causes a sudden drop in channel elevation of less than 5 ft. Built of logs, rock, gabions, concrete, or sheet metal (sheet-pile). May be notched to concentrate flow. Also known as sill, check dam, roller dam, drop structure, or grade stabilization structure.	Change scour and deposition patterns. Create a downstream pool. Stabilize stream gradient and reduce headcutting.
"Lunker" structure	A plank and log, free-standing, box-like structure with open sides that is installed just below the water at the toe of the bank, and is covered with riprap.	Protect the bank. Increase instream cover.

Structure	Description	Purpose (s)
Metal drum	A flattened 55-gallon drum with one end open. Placed in the channel.	Increase in-stream cover.
Retard	Same as fence barrier.	
Revetment	A layer of earth-filled sacks, trees, logs, stumps, gabions, or rocks placed on the bank in such a way as to deflect current from the bank.	Protect the bank. Deflect current to change scour and deposition patterns. Increase bankside cover.
Riprap	A collection of large rocks (or small rocks cemented or grouted together) placed on the bank.	Protect the bank. Increase coarse substrate and bankside cover.
Roller dam	Same as low-head dam.	
Scour structure	A generic term for a variety of materials placed in the channel to increase depth. These include structures, such as channel constrictors, current deflectors, low-head dams, and wing dams, and natural objects, such as boulders, brush, logs, rock piles, and stumps.	Change scour and deposition patterns.
Sediment trap	A large hole dug in the channel to catch fine sediment as it moves downstream.	Change scour and deposition patterns.
Sill	Same as low-head dam.	
Tetrapod	A structure made from 4 legs of pre-cast concrete joined at a central block, all at angles of 109.5° to each other. Placed on the bank or in the channel; similar to a jack.	Protect the bank. Change scour and deposition patterns.
Trash catcher or collector	A structure made from fence posts driven into the channel with wire strung between them. Used to catch debris as it drifts downstream and to create a cover area for fish. In extreme cases, may act like a low-head dam.	Increase in-stream cover. Change scour and deposition patterns.
Wing dam	A structure consisting of narrow piles of rock, rows of log pilings or steel posts (sometimes covered with wire mesh), or a barrier of sheet metal that projects part way across the channel at a sharp (sometimes perpendicular) angle to the current. Can be either permeable or impermeable to flow. Anchored to the bank. Also known as jetty.	Change scour and deposition patterns. Create a downstream pool. Increase in-stream cover. Protect the bank.
Wing deflector	Same as current deflector.	

* See Seehorn (1985), Wesche (1985), and Payne and Copes (1986) for further descriptions of these and other structures.

APPENDIX B. *Summaries of warmwater stream habitat improvement studies cited.*

Stream	Study No.
Big Buffalo Creek	5
Buck Creek	10
Caney Creek	14
Chippewa Creek	13
Court Creek	18
Crow Creek	12
East Nishnabota River	11
Indian Creek	3
Iowa River	11
Jordan Creek	17
Lamine River	20
Little Tallahatchie River system streams	15
Long Creek	21
Maple River	11
Middle Fabius River	9
Mill Creek	8
Mink Creek (Manitoba)	16
Mud River	6
North Creek	18
North Fork of Fishing Creek	3
North River	8
Olentangy River	7
Patterson Creek	8
Pine River	2
Poor Fork Cumberland River	14
Prairie Creek	10
Red Cedar River	22
Right Fork Beaver Creek	14
River Styx	13
Rock Creek	10
Saline Creek	20
Skunk River	11
Soldier River	11
South Branch River (south fork)	4
Sugar Creek	1
Tillatoba Creek	21
Tippah River system streams	15
Town Creek	19
West Nishnabota River	11
Wheeling Creek	3
Wilson Creek	16
Wolf River system streams	15



APPENDIX FIGURE B.1. *Locations of study streams cited in Appendix B and an index to stream names.*

Study No. 1

STREAM(S) AND LOCATION: Sugar Creek, central Indiana.

YEAR(S): 1941-47.

STREAM CHARACTERISTICS: Mean width unknown; mean depth of upper study area 3 ft; stream flows 6-8 ft^3/sec; gradient unknown; substrate composed of coarse gravel covered with a thin layer of sandy silt in the quieter stretches; study area length 0.5 mile.

WATERSHED CHARACTERISTICS: Farmland and wooded areas; most of the uncultivated regions were pasture land.

OBJECTIVES: To create deeper pools for fish and to enhance bass fishing by improving fish habitat.

IMPROVEMENT TECHNIQUES: Twenty-two improvement structures were installed, including a rock bulkhead placed along the bank to prevent erosion, current deflectors to force the current back into the main channel and protect eroding banks, and low-head dams or drop structures to create or deepen pools.

RESULTS: Deepening occurred around some of the devices, and moderate scouring occurred around others.

PROBLEMS AND/OR COMMENTS: Problems encountered were flooding, resulting in one drop structure being washed away, and thick growths of herbaceous *Dianthera*, reducing the effectiveness of another drop structure. Bank erosion occurred behind one current deflector. Information given on improvement devices lacked details on construction materials and techniques. The evaluation of the project was neither detailed nor thorough.

REFERENCE(S): Shockley 1949.

Study No. 2

STREAM(S) AND LOCATION: Pine River, south-central Michigan (lower peninsula).

YEAR(S): 1959-61.

STREAM CHARACTERISTICS: Mean width, mean depth, stream flow, and gradient unknown; substrate composed of shifting sand with a heavy silt load; study area length 2 miles.

WATERSHED CHARACTERISTICS: Some agricultural land use. No other information given in report.

OBJECTIVES: To develop techniques that could be used to improve habitat for gamefish and panfish, particularly smallmouth bass, in warmwater streams in the southern half of the lower peninsula of Michigan. Desired habitat improvements included increased in-stream cover and deeper holes.

IMPROVEMENT TECHNIQUES: Current deflectors were installed, and tree stumps and logs were added.

RESULTS: Northern pike occupied some of the holes formed.

PROBLEMS AND/OR COMMENTS: Three problems encountered were: (1) permits for installing structures were not easily obtained in intensively farmed areas, (2) silt and sand sedimentation reduced the effectiveness of structures, and (3) the effect of these structures on smallmouth bass populations could not be assessed because of a high rate of mortality in the bass population. No data were available on construction of or placement of structures, or on the depth of the holes that were created. The evaluation of the project was neither detailed nor thorough.

REFERENCE(S): Scott 1962.

Study No. 3

STREAM(S) AND LOCATION: Wheeling Creek, North Fork of Fishing Creek, and Indian Creek, northwestern West Virginia.

YEAR(S): 1959-63.

STREAM CHARACTERISTICS:

Wheeling Creek. Mean width approximately 100 ft; maximum depth 2 ft; stream flow 322 ft^3/sec; gradient unknown; substrate composed mostly of ledge rock in some areas, silt in others; length of 4 study areas 250-750 ft each.

North Fork of Fishing Creek. Mean width unknown; mean depth 2 ft; stream flow 40 ft^3/sec; gradient unknown; substrate composed primarily of gravel and sand; length of the 2 study areas 400 ft and 2,100 ft.

Indian Creek. Mean width and maximum depth unknown; stream flow 40 ft^3/sec; gradient and substrate composition unknown; study area length 800 ft.

WATERSHED CHARACTERISTICS: No information given in report.

OBJECTIVES: To evaluate the effectiveness of various stream improvement techniques for providing in-stream cover and creating deeper pools.

IMPROVEMENT TECHNIQUES:

Wheeling Creek. Two hundred leg-type cover devices, 6 current deflectors (built of logs), 5 groins, and 2 low-head dams (built of gabions and logs) were installed. Leg-type cover devices were of 3 types: parallel-leg, cross-leg, and four-leg.

Fishing Creek. Current deflectors (some built of logs, others built of gabions), digger logs, low-head dams constructed of logs or gabions and logs, and more than 200 leg-type cover structures were installed.

Indian Creek. Six broken-sidewalk-slab cover devices and 5 collapsed, open-end metal drums were installed.

RESULTS: Both leg-type structures and broken-sidewalk slabs were effective in providing cover. Simple current deflectors made from logs narrowed the channel and created holes 2-3 ft deep at the ends of the devices. One low-head dam made from gabions and logs created a hole 5-6 ft deep that extended downstream about 60 ft. Low-head dams made from logs also formed pools; however, these were not as permanent as pools created by low-head dams made from gabions and logs. Both types of dams caused scouring, with the former being much sturdier and easier to construct.

A marked increase in the number, weight, and relative abundance of gamefish was seen. In Indian Creek, relative biomass of smallmouth bass and spotted bass increased from 6.4-19.5% seven months after installation of cover devices. One year after the installation of stream improvement devices in the North Fork of Fishing Creek, smallmouth bass increased in number from 1-22 fish, and rock bass from 0-7 fish. The authors concluded that their improvement structures were both effective and economically feasible in warmwater streams having gravel, boulder, and ledge-rock type bottoms.

PROBLEMS AND/OR COMMENTS: The most successful and least expensive cover device was the legs-at-one-end type structure. This structure remained in place to a greater extent than other cover devices and did not flip over during periods of high flow or in areas of current. Cross-leg-type structures were costly and were extremely heavy and hard to handle. Parallel-leg-type structures were costly but useful in relatively still or protected areas. Four-leg-type structures were less costly and easier to handle, but they had a tendency to silt in and flip over during high-water stages.

No information was provided on the effectiveness of groins, current deflectors built from gabions, digger logs, and metal drums.

REFERENCE(S): Robinson and Menendez 1964.

Study No. 4

STREAM(S) AND LOCATION: South Branch River (south fork), northeastern West Virginia.

YEAR(S): 1961-64.

STREAM CHARACTERISTICS: Mean width 108 ft, ranging from 51-165 ft; mean depth 0.5 ft, with maximum depth 3 ft; stream flow and gradient unknown; substrate composed of rubble; study area length 1,320 ft. Entire area mostly riffle.

WATERSHED CHARACTERISTICS: No information given in report.

OBJECTIVES: To increase gamefish populations by utilizing several stream improvement devices to increase in-stream cover and produce deeper pools.

IMPROVEMENT TECHNIQUES: Seven current deflectors (built of gabions), 1 groin, 1 low-head dam, and various cover devices (not specified) were installed in the summer of 1961. The entire cost of the project was $8,650.96.

RESULTS: During normal stream flow in June 1962, mean and maximum channel depth increased to 2 ft and 5 ft, respectively. Maximum stream width did not change, but minimum and mean width declined to 42 ft and 100 ft, respectively. In June 1964, during below-normal flow conditions, mean stream depth was 2.3 ft and maximum depth was 6.4 ft. Minimum and mean widths were the same as in 1962.

In September 1962 smallmouth bass constituted 8.2% of the total sample biomass, and rock bass and sunfish together constituted 24.5%. Almost 1 year later, smallmouth bass comprised 4.4% of the biomass, whereas sunfish made up 27.7% of the total weight. A total of 11.0 lb of fish were captured in 1962, and 13.9 lb in 1963. The increased biomass percentage for sunfish in 1963 was probably due to the decline in the numbers of smallmouth bass, rather than an increase in the number of sunfish. Rough fish constituted at least 67% of the total sample by weight in both years.

PROBLEMS AND/OR COMMENTS: None.

REFERENCE(S): Hanson 1965.

Study No. 5

STREAM(S) AND LOCATION: Big Buffalo Creek, west-central Missouri.

YEAR(S): 1963-76.

STREAM CHARACTERISTICS: Mean width unkown; maximum pool depths 0.9-6.0 ft; stream flow unknown; gradient 23 ft/mile; substrate composed of gravel and rubble; study area length unknown. A portion of the creek had been channelized to reduce bank erosion and minimize flooding of croplands. This channelization produced long shallow stretches that were devoid of cover.

WATERSHED CHARACTERISTICS: Most of the watershed was forested; floodplains were either in pasture or row crops. A fourth order stream (at the study area), draining 21 miles^2.

OBJECTIVES: To provide more cover and deeper pools for fish through use of in-stream structures and relocation of the channel.

IMPROVEMENT TECHNIQUES: Between 1964 and 1965, in-stream and bank devices were installed (current deflectors, gabions, and trash catchers). In 1965, the channelized stretch was eliminated by diverting the creek into a new channel. Berms were constructed to aid in the rerouting. A log and gabion revetment was installed to stabilize the bank and to provide cover for fish.

RESULTS: Realignment of the creek produced deep pools, 6 ft or deeper in 1969-70. However, as the channel began to widen, pool depth decreased.

Standing crops of fish more than doubled between 1966 and 1972, and smallmouth bass standing crops increased by a factor of more than 4. A further increase was evident after a natural pool-riffle-run sequence formed. The revetment attracted fish, especially smallmouth bass, from 1967 to 1976. The standing crops of fish in the section containing this structure more than tripled between 1966 and 1972. Increases in smallmouth bass were related to greater stream depths and additional cover, along with increased productivity of the stream.

PROBLEMS AND/OR COMMENTS: Current deflectors, gabions, and trash catchers installed in the channelized reach failed due to heavy flows that caused channel migration, displacement of devices by undercutting, and gravel deposition.

REFERENCE(S): Fajen 1970, 1974, 1975, 1981, 1982.

Study No. 6

STREAM(S) AND LOCATION: Mud River, southwestern West Virginia.

YEAR(S): 1965-68.

STREAM CHARACTERISTICS: Mean width 60 ft; maximum depths 1-4 ft; stream flow 269 ft^3/sec; gradient 2.2 ft/mile; substrate composed of sand, silt, and mud, with some rocks and boulders; study area length 1,050 ft. Stream is meandering and slow flowing.

WATERSHED CHARACTERISTICS: No information given in report.

OBJECTIVES: To determine the usefulness of log cribs as in-stream cover for gamefish.

IMPROVEMENT TECHNIQUES: A total of 19 log cribs were placed randomly throughout the study area at depths of 1-3 ft. Large rocks were placed inside the cribs. Each crib cost $219 in labor and materials and took 5.7 hours to construct.

RESULTS: Deep pockets of water formed on either side of some of the structures that did not silt over.

Fish species composition changed very little after installation of the cribs. Game species, primarily largemouth bass, spotted bass, and white crappie, increased from 5.7% of the total biomass in 1965 to 8.4% in 1966. However, in 1967 gamefish biomass decreased to 3.3%, with no white crappie captured. Young-of-the-year and yearling bass and sunfish were captured in large numbers from around the cribs.

PROBLEMS AND/OR COMMENTS: Cribs were easy to install and were relatively sturdy. However, of the 19 log cribs installed, 3 that were located at the head of a pool silted in in 1966. The wire holding the logs together in 2 other structures broke and had to be replaced. Rocks inside the cribs settled, and additional rock had to be added. By 1967, 12 of the 19 cribs had completely silted in as a result of heavy flows. The authors recommended that log cribs only be used in streams with a gravel and rubble bed.

REFERENCE(S): Miles 1969.

Study No. 7

STREAM(S) AND LOCATION: Olentangy River, central Ohio.

YEAR(S): 1970-75.

STREAM CHARACTERISTICS: Study area consisted of 2 untreated (reference) sections and 1 treated section:

Section 1 (untreated natural area). Mean width 82 ft; mean depth 2.6 ft, with maximum depth 5.9 ft; stream flows 33-80 ft^3/sec; gradient unknown; substrate composed of sand, gravel, cobble, boulders, and limestone bedrock; study area length 0.6 mile. Banks were slightly to moderately steep.

Section 2 (treated channelized area). Channelized in 1970. Mean width and depth unknown; stream flows 33-80 ft^3/sec; gradient and substrate composition unknown; study area length 0.8 mile. At low flow, the western bank was separated from the current of the river by a flat, 23-ft-wide area of marshy ground.

Section 3 (untreated channelized area). Channelized in 1970. Mean width 1.4 ft; mean depth unknown, but maximum depth 2.6 ft; stream flows 33-80 ft^3/sec; gradient unknown; substrate composed of silt; study area length 0.5 mile. Entire area a shallow pool with steep banks.

WATERSHED CHARACTERISTICS: Row-crop agriculture was the predominant land use, with mixed hardwood stands found in the floodplain. Watershed area was 536 $miles^2$.

OBJECTIVES: To evaluate the use of artificial structures to restore the pool-riffle-run sequence in a channelized stream and thus enhance macroinvertebrate and fish communities.

IMPROVEMENT TECHNIQUES: A total of 5 equally spaced artificial riffles, each 20 ft long, were installed in Section 2. Artificial riffles were composed of large boulders layered over a graded earthen framework. To prevent erosion from destroying riffles, improvements at Section 2 included riprap along the entire eastern bank, using 2- to 3-ft-diameter boulders, and grass plantings on the western bank.

RESULTS: The improvement techniques utilized in this study successfully enhanced habitat for both fish and macroinvertebrates. Artificial riffles persisted, and pools were created between riffles. These pools had maximum depths of 8.2 ft.

After 5 years, the number of families and individuals and the biomass of benthic invertebrates in Section 1 (untreated natural area) and Section 2 (treated channelized area) were greater than in Section 3 (untreated channelized area). Benthic diversity was highest in Section 1 and lowest in Section 3.

Rock bass, bluegill, longear sunfish, smallmouth bass, white crappie and black crappie were the primary gamefish species in the study sections. Fish abundance in Section 1 was greater than in Section 2, but fish biomass was greater in Section 2 than Section 3. Weight per unit length was lowest for common carp, yellow bullhead, green sunfish, bluegill, and longear sunfish in Section 3, and highest in Section 1. Weight per unit length was greater in Section 2 than in Section 3 for smallmouth bass. Generally, gamefish were found in significantly greater numbers in the treated channelized area than in the untreated channelized area. Catostomids and cyprinids predominated in the latter area.

PROBLEMS AND/OR COMMENTS: None.

REFERENCE(S): Perry 1974, Edwards 1977, Griswold et al. 1978, Woods and Griswold 1981, Edwards et al. 1984.

Study No. 8

STREAM(S) AND LOCATION: Mill Creek, Patterson Creek, and North River, northeastern West Virginia.

YEAR(S): 1972 to present.

STREAM CHARACTERISTICS:

Mill Creek. Mean width 20 ft; mean depth unknown; stream flow 14 ft^3/sec; gradient 16.6 ft/mile; substrate composition unknown; study area length 530 ft.

Patterson Creek. Mean width 45 ft; mean depth unknown; stream flow 140 ft^3/sec; gradient 7.2 ft/mile; substrate composition unknown; study area length 1,050 ft.

North River. Mean width and depth unknown; stream flow 140 ft^3/sec; gradient 10 ft/mile; substrate composition unknown; study area length 1,050 ft.

WATERSHED CHARACTERISTICS: Mill Creek drained 36 $miles^2$, Patterson Creek drained 144 $miles^2$, and North River drained 106 $miles^2$. No other information given in report.

OBJECTIVES: To stabilize eroding stream banks.

IMPROVEMENT TECHNIQUES: Automobile tire mats were installed on the banks of all streams. Willow cuttings were planted in every tire along the lower slope. Approximate cost of the tire mat installation on all 3 streams was $10,000, and maintenance cost for 1 year was $3,600.

RESULTS: Tires and willows, once established, along the toe of the bank appeared to provide excellent cover for fish.

PROBLEMS AND/OR COMMENTS: Usually, it took 3 years for the willows to attain a size that added stability to the tire mat. Evaluations of the automobile tire mats in the 3 streams will be completed in the next few years. The final evaluation report will contain installation and maintenance costs, an assessment of the degree of success of the project, and suggested ways to improve effectiveness of tire mats.

REFERENCE(S): Lewis 1978; Gerald Lewis, W. Va. Dep. Nat. Resour., pers. comm.

Study No. 9

STREAM(S) AND LOCATION: Middle Fabius River, northeastern Missouri.

YEAR(S): 1973.

STREAM CHARACTERISTICS: Five sections were established. Mean width, mean depth, and stream flow unknown but similar for all sections; gradient unknown; substrate composed mostly of clay and some gravel, with rock, sand bars, and rock ledges also present; study area length unknown. In-stream cover consisted of deep holes, log jams, root wads, fallen trees, large rock ledges, and aquatic vegetation.

WATERSHED CHARACTERISTICS: Agriculture was the main land use.

OBJECTIVES: To determine the effect of woody debris on fish abundance and its usefulness as in-stream cover for fish.

IMPROVEMENT TECHNIQUES: In 2 of the 5 sections, woody debris and other obstructions to stream flow were removed from the main channel.

RESULTS: Estimated standing crop of fish was 25% greater in those sections containing cover. The population of catchable-sized fish was 51% lower in sections where woody debris had been removed.

PROBLEMS AND/OR COMMENTS: No quantitative information was given on basic stream charateristics. The 2 sections from which woody debris were removed had higher water velocities.

REFERENCE(S): Hickman 1975.

Study No. 10

STREAM(S) AND LOCATION: Rock Creek, northwestern Indiana; Prairie Creek, west-central Indiana; and Buck Creek, east-central Indiana.

YEAR(S): 1973-78.

STREAM CHARACTERISTICS:

Rock Creek. Mean width unknown, but greater than 30 ft; mean depth, stream flow, and gradient unknown; substrate composed mainly of gravel, rock, and solid limestone; study area length unknown.

Prairie Creek. Mean width unknown, but greater than 30 ft; mean depth, stream flow, and gradient unknown; substrate composed mainly of sand, silt, and gravel; study area length unknown.

Buck Creek. Mean width unknown, but smaller than the other 2 streams; mean depth, stream flow, and gradient unknown; substrate composed mainly of sand, silt, and gravel; study area length unknown.

None of these streams had high gradients, but all carried substantial flows during storm events. All 3 creeks had been channelized to reduce flood damage to croplands.

WATERSHED CHARACTERISTICS: Wet woodland adjacent to Prairie Creek; farmland adjacent to Buck Creek; no information given on Rock Creek.

OBJECTIVES: To restore fish habitat in channelized streams by re-establishing the pool-riffle-run sequence and by revegetating the banks.

IMPROVEMENT TECHNIQUES: A "fishway" of pools and riffles was established in all 3 creeks. (Fishway was defined by the authors as an area where channel morphology and alignment is modified to improve fish habitat. This differs from the more common definition of fishway—a channel constructed to allow fish passage around a barrier such as a dam.) Both the Indiana Department of Natural Resources and the Soil Conservation Service were involved in the design of these fishways. Current deflectors composed of riprap or riprap with logs were used to construct the fishways in Rock and Prairie Creek, whereas log and rock check dams were used in Buck Creek. Banks were revegetated to prevent sedimentation from degrading the fishways.

RESULTS: Constructed fish pools were self-maintaining and supported populations of gamefish in all 3 creeks. In Prairie Creek, current deflectors dug holes 4 ft deep. In Rock Creek, pools created were 2.5-4.0 ft deep, and riffles were 0.5 ft deep.

One year after completion of the fishway in Rock Creek, 23 species of fish were found in the treated area compared to 16 species in the natural channel upstream of the fishway. Game species using the fishway included smallmouth bass and rock bass.

PROBLEMS AND/OR COMMENTS: After the fishway was constructed in Buck Creek, a pollution problem from a livestock feedlot was discovered. This problem was solved by fencing the feedlot and by constructing a watering access for cattle. This procedure resulted in re-establishment of good bank vegetation and in improved water quality. To prevent farmers from using revegetated areas, markers (2-inch galvanized steel pipes anchored in concrete) were placed between the revegetated area and the row crops.

No information was given on the installation or effectiveness of the log and rock check dams in Buck Creek, nor was information available on the response of the fish community to habitat improvement in Prairie Creek.

REFERENCE(S): Knox and McCall 1979; Robin Knox, Col. Div. Wildl., pers. comm.

Study No. 11

STREAM(S) AND LOCATION: East and West Nishnabota rivers, southwestern Iowa; Soldier and Maple rivers, west-central Iowa; Iowa River, central Iowa; and Skunk River, northeastern Iowa.

YEAR(S): 1974.

STREAM CHARACTERISTICS: Mean widths, mean depths, and gradients unknown; for stream flow, see "Improvement Techniques" below; substrate composition unknown except for East Nishnabota River (see "Improvement Techniques"); study area length unknown. All of the structures except the Iowa River impermeable jetties were located in channelized sections of the streams.

WATERSHED CHARACTERISTICS: Presumably, intensive agriculture was the predominant land use. No information other than drainage area (see "Improvement Techniques") was given in reports.

OBJECTIVES: To assess the influence of bank stabilization structures on stream depth. Bank stabilization was carried out as part of highway or bridge construction, not for the specific purpose of improving fish habitat.

IMPROVEMENT TECHNIQUES:

East Nishnabota River. This river had a shifting sand bottom and a long history of flooding. In many stretches, the stream banks were almost vertical and 20 ft high. The following structures were evaluated:

One Rock Revetment. Composed of 1.6-ft-diameter rock covering 490 ft of the bank; at this site, the river drained 894 miles^2 and had a stream flow of 367 ft^3/sec.

One Retard. Placed along 590 ft of the bank; at this site, the river drained 236 miles^2 and had a stream flow of 106 ft^3/sec.

Four Permeable Steel Jetties. Each 98 ft long; at this site, the river drained 238 miles^2 and had a stream flow of 106 ft^3/sec.

Two Impermeable Rock Jetties. Composed of 0.5-ft-diameter limestone rock, each jetty extended 10 ft into the river; at this site, the river drained 878 miles^2 and had a stream flow of 353 ft^3/sec.

West Nishnabota River. The following structures were evaluated:

One Retard. Placed along 246 ft of the bank; at this site, the river drained 224 miles^2 and had a stream flow of 102 ft^3/sec.

One Impermeable Rock Jetty. Included a single jetty 10 ft long and a revetment that extended 66 ft downstream of the jetty; at this site, the river drained 164 miles^2 and had a stream flow of 71 ft^3/sec.

Soldier River. This river possessed deeply cut, almost vertical stream banks. The following structures were evaluated:

Eight Permeable Steel Jetties. Two study sections. At each section, there were 4 jetties, each 98 ft long and composed of steel pilings and wire fabric. At these sections, the river drained 286 miles^2 and had a stream flow of 88 ft^3/sec.

Maple River. The following structure was evaluated:

One Rock Revetment. Placed along 262 ft of the bank; at this site, the river drained 3,365 miles^2 and had a stream flow of 124 ft^3/sec.

Iowa River. The following structures were evaluated:

One Rock Revetment. Placed along 66 ft of the bank; at this site, the river drained 1,564 miles^2 and had a stream flow of 759 ft^3/sec.

Three Impermeable Rock Jetties. Composed of rock, each jetty 10-13 ft wide, extending 7-10 ft into the river; at this site, the river drained 641 miles^2 and had a stream flow of 318 ft^3/sec.

Skunk River. This river had a heavy sediment load in its lower stretches. The following structure was evaluated:

One Retard. Placed along 656 ft of the bank; at this site, the river drained 556 miles^2 and had a stream flow of 268 ft^3/sec.

RESULTS: Permeable jetties and retards deepened the channel in their vicinity, with maximum depths at or near the structure 7-110% greater than the maximum depth in control reaches. Older permeable jetties had had a greater effect on depth than newer ones. In the Iowa River, impermeable jetty sites were deeper and had faster currents than control sites. Impermeable jetty sites at other locations apparently caused no significant increases in depth or current. Likewise, rock revetments had no apparent effect on stream morphology. Revetments did, however, lead to increased abundance of benthic invertebrates.

For all rivers, mean size and abundance of channel catfish, black bullheads, and green sunfish were not different between sections with and without structures. However, this may have been because sampling did not occur during low flows, when fish would be more likely to concentrate in the deeper water near structures.

PROBLEMS AND/OR COMMENTS: The authors felt that jetties probably would have been more effective in improving stream habitat for gamefish if the structures had extended into the channel at least one third of the stream width. Longer jetties would have caused the formation of larger holes and backwaters, which in turn would have increased habitat diversity.

REFERENCE(S): Witten 1975, Witten and Bulkley 1975.

Study No. 12

STREAM(S) AND LOCATION: Crow Creek, northeastern Alabama and south-central Tennessee.

YEAR(S): 1974-76.

STREAM CHARACTERISTICS: Study area length totaled 3 miles and consisted of 12 treatment sections and 1 reference section, each 1,230 ft long. For the treatment sections: mean widths 35-63 ft; mean depths unknown; stream flows 0.10-0.82 ft^3/sec; gradient unknown; substrate composed mainly of sand. For the reference section: mean width 33 ft; mean depth, stream flow, and gradient unknown; substrate composed of gravel and sand.

All sections but the reference section had been channelized. The unchannelized section had well-developed pool-riffle-run characteristics and stable, well-vegetated banks. In the treatment sections, riffles were less common, and banks were steep, unvegetated, and highly unstable. Oxbows were also present adjacent to 2 sections.

WATERSHED CHARACTERISTICS: Land use was primarily agricultural, with some forests along the stream.

OBJECTIVES: To mitigate negative impacts of channelization, particularly increased bank erosion and siltation of pools and riffles.

IMPROVEMENT TECHNIQUES: Sheet-pile grade stabilization devices and double-wing current deflectors were installed to reduce sedimentation and deepen pools. Riprap was added to protect structures and banks from erosion. Some sections had woody debris cleared from the channel, but no structures installed.

RESULTS: Riprap reduced bank erosion and protected all structures from bank collapse. All structures created deeper pools and increased heterogeneity in channel depth.

Fish species diversity and number was highest in the vicinity of the structures. Gamefish were most common in deep water and in areas with extensive in-stream cover.

PROBLEMS AND/OR COMMENTS: In several sections, structures were placed too close together, causing excessive pooling and reducing the effectiveness of structures. No fish data were collected before the installation of structures, which prevented a proper evaluation of the effectiveness of habitat improvements for increasing fish populations.

REFERENCE(S): Winger et al. 1976; Parley Winger, U. S. Fish and Wildl. Serv., Athens, Ga., pers. comm.

Study No. 13

STREAM(S) AND LOCATION: Chippewa Creek and River Styx, northeastern Ohio.

YEAR(S): 1977-80.

STREAM CHARACTERISTICS:

Chippewa Creek. Mean widths 39-75 ft; mean depth unknown, but maximum depths 8-16 ft in treatment sections and much less elsewhere in the study area; stream flow unknown; gradient 3.7 ft/mile; substrate composed of silt or sand and gravel; study area length totaled 1 mile. Study area consisted of 4 treatment and 4 reference sections. Most of the channel was riprapped with 6- to-9-inch-diameter rock.

River Styx. Mean widths 10-33 ft; mean depths 0.8-1.6 ft; stream flow unknown; gradient 6.9 ft/mile; substrate composition and study area length unknown. Study area consisted of 3 treatment and 2 reference sections. All sections except one had been channelized.

WATERSHED CHARACTERISTICS:

Chippewa Creek. Land use mainly row crops, with a small proportion of the land in pasture and woodlots. Silty loam was the dominant soil type.

River Styx. Cultivated and pastured land.

OBJECTIVES: To create deeper pools and re-establish the meandering flow pattern of the streams.

IMPROVEMENT TECHNIQUES:

Chippewa Creek. Two double-wing and 7 single-wing current deflectors were installed.

River Styx. Seven double-wing current deflectors, 15 single-wing current deflectors, and 85 rock sills were installed.

All current deflectors were constructed from rocks and boulders.

RESULTS:

Chippewa Creek. Current deflectors created pools (3-4 ft deep in the summer), re-established a more natural meandering flow pattern, and concentrated fish.

Mean catch rates of common carp, common shiner, creek chub, white sucker, green sunfish, pumpkinseed, bluegill, largemouth bass, and white crappie were significantly higher in sections with deflectors than in sections without them.

River Styx. Both types of current deflectors created deep pockets of water. These pockets concentrated fish, particularly common carp, white sucker, and centrarchids. Higher fish densities were found in sections with deflectors than in sections without them, but differences were not significant. The installation of deflectors did not increase the abundance of catchable-sized gamefish.

PROBLEMS AND/OR COMMENTS: Rock sills exhibited only minimal effectiveness due to structural damage by ice. They failed to create a pool-riffle-run sequence. No data were given in the source documents on the effectiveness of current deflectors installed in River Styx in re-establishing meander.

REFERENCE(S): Carline and Klosiewski 1981, 1985.

Study No. 14

STREAMS(S) AND LOCATION: Poor Fork Cumberland River and Right Fork Beaver Creek, eastern Kentucky; Caney Creek, western Kentucky.

YEAR(S): 1977-86.

STREAM CHARACTERISTICS:

Poor Fork Cumberland River. Mean widths 48-80 ft; mean depths 1.20-1.28 ft; stream flow unknown; gradient 11.2 ft/mile; substrate composition and study area length unknown. Channelized between 1974 and 1978; mitigative structures installed during the same period.

Right Fork Beaver Creek. Mean widths 30-46 ft; mean depths 0.96-1.39 ft; stream flow unknown; gradient 4.8 ft/mile; substrate composition and study area length unknown. Channelized between 1978 and 1981; mitigative structures installed during the same period.

Caney Creek. Mean widths 25-92 ft; mean depths 0.57-2.46 ft; stream flow unknown; gradient 1.6 ft/mile; substrate composition and study area length unknown. Channelized between 1971 and 1981; mitigative structure installed toward the end of this period.

WATERSHED CHARACTERISTICS: All 3 streams are fourth order streams (at the study area) in watersheds with extensive coal mining, and all have suffered from mine pollution. In addition, the Caney Creek watershed has extensive agriculture and resultant nonpoint pollution, and the Right Fork Beaver Creek is heavily impacted by sedimentation from upstream road construction.

OBJECTIVES: To determine the effectiveness of several structures to mitigate negative impact of channelization on fish populations. Desired habitat improvements included increased in-stream cover, increased depth heterogeneity, and restored pool-riffle sequences.

IMPROVEMENT TECHNIQUES: On all 3 streams, artificial riffles, randomly placed boulders, low-head dams (built of gabions), and current deflectors (built of gabions or loose stones) were installed in channelized areas. During the evaluation, untreated natural areas without structures (in all 3 streams) and untreated channelized areas without structures (in Caney Creek and Right Fork Beaver Creek) were also sampled for comparison.

RESULTS: In Caney Creek and Right Fork Beaver Creek, natural areas had significantly higher standing crops of fish than untreated channelized areas. Treated channelized areas were intermediate in standing crops. Thus the addition of structures appeared to only partially offset the negative impacts of channelization on fish populations in these 2 rivers. In Poor Fork Cumberland River, standing crops of fish in natural and treated channelized areas were not significantly different from each other (untreated channelized areas were not sampled), suggesting that mitigation may have been more successful in this river.

Diversity and equitability values for fish standing crops did not differ among the different types of areas in the 3 rivers. However, in Caney Creek the dominant species differed among the 3 types of areas. Untreated channelized areas were dominated by gizzard shad and longnose gar, whereas natural and treated areas tended to have more "food" and "pan" fishes (not defined in report).

PROBLEMS AND/OR COMMENTS: No data were presented on the physical response of treated areas to habitat improvement. The author did note that in Right Fork Beaver Creek, improper placement caused some artificial riffles to function as dams and caused others to be inundated by several feet of water, thus reducing their benefits to fish.

REFERENCE(S): Davis 1988.

Study No. 15

STREAM(S) AND LOCATION: Small streams in the Tippah, Little Tallahatchie, and Wolf River systems, north-central Mississippi.

YEAR(S): 1978-79.

STREAM CHARACTERISTICS: Study involves a total of 38 streams. Specific information on the physical characteristics of each channel was not given. Most streams were shallow, with substrates of sand or clay.

WATERSHED CHARACTERISTICS: All streams were first and second order streams (at the study area) in the Holly Springs National Forest.

OBJECTIVES: To maintain and enhance fish habitat.

IMPROVEMENT TECHNIQUES: Some form of habitat improvement was carried out in each study stream. Current deflectors were installed to divert flow away from eroding banks, and log and rock low-head dams were installed to create pools.

RESULTS: Current deflectors produced riffle and pool areas where darters and madtoms were common. Low-head dams created pools where both largemouth and spotted bass were common.

PROBLEMS AND/OR COMMENTS: No quantitative information was given on basic stream characteristics. No data were available on fish populations before structures were installed. None of the streams or structures were evaluated thoroughly.

REFERENCE(S): Ebert and Knight 1981.

Study No. 16

STREAM(S) AND LOCATION: Wilson Creek and Mink Creek, southwestern Manitoba.

YEAR(S): 1978-86.

STREAM CHARACTERISTICS:

Wilson Creek. Width approximately 50 ft; mean depth and stream flow unknown; gradient high at 100 ft/mile; substrate composition unknown but covered by excessive deposits of fine shale sediment; study area length unknown. Headcutting and bank erosion extensive.

Mink Creek. Width approximately 40 ft; mean depth and stream flow unknown; gradient 12 ft/mile; substrate composition and study area length unknown. Completely channelized in 1951. Little in-stream cover or habitat heterogeneity.

WATERSHED CHARACTERISTICS:

Wilson Creek. Adjacent areas and many small tributaries heavily channelized. Located in alluvial fan at base of steep escarpment. Top of escarpment and upper slopes heavily forested; alluvial fan and downstream areas heavily used for agriculture.

Mink Creek. In former lakebed of glacial Lake Agassiz; tributary to Lake Dauphin. All drainage networks in vicinity heavily channelized. Intensive agriculture is primary land use.

OBJECTIVES: To reduce headcutting and bank erosion on Wilson Creek and to improve walleye spawning habitat on Mink Creek through restoration of more natural pool-riffle sequences in channelized areas.

IMPROVEMENT TECHNIQUES: Two grade stabilization structures (termed by the authors gradient-control dams), each 5 ft high with long sloping trailraces, were installed in a 1.4-mile stretch of Wilson Creek during 1980. These dams were made of large-sized (8- to 12-inch) fieldstone and together cost $23,500 (Canadian). Annual maintenance costs were $1,000.

During 1985 and 1986, artificial riffles were constructed in 3 stretches of Mink Creek. Each stretch had 7 riffles spaced 330 ft apart. In a fourth reach, pairs of riffles, 65-160 ft apart, were installed. Riffles were constructed to create an upstream pool, but not to block upstream fish movement. Each artificial riffle cost $800 (Canadian) and was constructed of boulders and cobbles collected during initial clearing of nearby farm fields.

RESULTS: The 2 gradient-control dams on Wilson Creek worked well, eliminating headcutting and reducing erosion of upstream banks. This resulted in less sediment delivery to downstream areas.

The artificial riffles on Mink Creek created a pool-riffle sequence that persisted through several major floods. Eddies created below the riffles provided improved walleye spawning areas, particularly in the paired riffles. The paired riffles had higher walleye egg deposition and larval production than the other artificial riffles. During high flows, drift (and presumably loss) of walleye eggs was less in stretches with artificial riffles than in nearby untreated channelized stretches.

PROBLEMS AND/OR COMMENTS: On Wilson Creek, biological responses to the gradient-control dams were not evaluated; however, the dams are likely to be barriers to upstream fish movement. Over time, the pools above these dams will fill in with fine sediment, diminishing their value as fish habitat, but not their hydraulic value.

REFERENCE(S): Newbury and Gaboury 1987.

Study No. 17

STREAM(S) AND LOCATION: Jordan Creek, east-central Illinois.

YEAR(S): 1979-82.

STREAM CHARACTERISTICS: Mean widths 10-16 ft; mean depth and stream flow unknown; gradient 3.7 ft/mile; substrate composed mainly of silt and sand; study area length unknown. Bordered on both sides by 16-33 ft of woody vegetation. Pool-riffle-run sequence poorly developed.

WATERSHED CHARACTERISTICS: Row-crop agriculture.

OBJECTIVES: To assess the effect of woody debris on fish and invertebrate and fish populations.

IMPROVEMENT TECHNIQUES:

Split-Stream Experiment. A 100-ft-long stretch was divided in half (lengthwise) with hardware cloth, and woody debris (branches, stumps, logs) were removed from one side.

Multiple-Reach Experiment. In 1980, ten 115-ft-long treated sections, separated by no more than 66 ft, were established, and all woody debris were removed from them. These sections were cleared weekly to remove any new debris that collected. Three 115-ft-long reference sections, where woody debris were not removed, were established less than 500 ft downstream of the treated sections. Artificial woody debris structures (2 pine boards nailed together to form an "+" and then anchored 5 inches off the substrate with steel rods) were installed in 4 of the treated sections, with 2 receiving 8 debris structures each and the other 2 receiving 16 debris structures each. In 1981, 7 more sections (4 treated, 3 reference) were established downstream from the 1980 sites. Two of the new treated sections received 12 artificial debris structures each.

RESULTS: Split-Stream Experiment. In the 2 months of the study, the number of fish species, fish abundance, and maximum size of fish were greater on the side of the stream containing debris. However, only 1 fish species, the bluntnose minnow, exhibited a statistically significant preference for 1 side of the stream, and this species preferred the debris-free side. Invertebrates were more abundant on the debris side at the end of both months.

Multiple-Reach Experiment. Stream depth profiles were similar in reference and treated sections at the beginning of the first experiments in June 1980. By October 1980, treated sections were shallower than reference sections. Treated sections were deeper than reference sections for the second set of experiments in June 1981, but by October 1981 treated sections were again shallower. In June 1982, treated sections were again deeper than reference sections. Thus, reference sections had more stable depth profiles. In the first set of experiments, current velocities were greater in sections with structures than in sections without them, and they remained greater through June 1981. When additional structures were added in 1981 for the second experiment, current velocities were higher in sections without structures. However, by June 1982 the velocity was similar for the 2 types of sections. A greater proportion of sand was found in treated sections compared with reference sections in 1981 and 1982. Occurrences of organic litter were usually reduced in treated sections.

Distributions of at least 1 age-class of the following fish species were examined in 1980 and 1981: grass pickerel, hornyhead chub, striped shiner, bluntnose minnow, creek chub, blackstripe topminnow, rock bass, bluegill, longear sunfish, and johnny darter. Generally, larger and older fish tended to prefer reference sections or treated sections with structures rather than treated sections without structures. Age 0+ grass pickerel and age I johnny darters preferred treated sections without structures. Flow conditions in the creek appeared to influence preferences.

Woody debris provided a colonizable substrate for many aquatic invertebrates (especially dipteran larvae and trichopteran and ephemeropteran nymphs). Although total invertebrate densities were similar between debris structures and the substrate, trichopteran and ephemeropteran nymphs were much more abundant on the structures.

PROBLEMS AND/OR COMMENTS: The authors believed that woody debris may have been functioning more to provide camouflage than to increase food availability or provide safety from strong currents.

REFERENCE(S): Angermeier and Karr 1984.

Study No. 18

STREAM(S) AND LOCATION: Court Creek and North Creek, west-central Illinois.

YEAR(S): 1980 to present.

STREAM CHARACTERISTICS:

Court Creek. Mean widths 20-30 ft; mean depth unknown; stream flow 5 ft^3/sec; gradient 8 ft/mile; substrate composed predominantly of shifting sand, but coarse materials in some locations; study area length unknown. Most of the study area had unstable banks and little in-stream cover, but a few locations had extensive in-stream cover.

North Creek. Mean width 16 ft; mean depth and stream flow unknown; gradient 10 ft/mile; substrate composed primarily of shifting sand, with coarse material in riffles; study area length unknown. A tributary to Court Creek. Banks were unstable, but some in-stream cover was present.

Both creeks had many short stretches that had been channelized, and these stretches had severe erosion problems. Water level fluctuations were substantial in both creeks.

WATERSHED CHARACTERISTICS: Total watershed area (Court Creek plus North Creek) of 98 miles^2, with intensive agricultural practices predominating in most areas. Row crops often extended to the edge of the streams.

OBJECTIVES: To determine the usefulness of low-cost bank stabilization techniques in improving habitat.

IMPROVEMENT TECHNIQUES:

Court Creek. Tree revetments were installed along 2 miles of the creek between fall 1986 and spring 1987. Stretches 0.5 mile in length at the upstream and downstream edges of the treatment area were used as controls. Revetments were installed using the George Palmiter river restoration techniques. Trees along the bank or in the channel that had the potential to obstruct flow were removed and cabled to the bank at the midpoint of the trunk. Their bases were angled upstream over the toe of the bank. Rocks were added where further stabilization seemed necessary. After the tree revetments were in place, willows were planted in the banks. Total cost was about $30,000.

In late 1988, "lunker" structures were installed along a badly eroded bank to stabilize the bank and to provide bankside cover for fish.

North Creek. Dormant willows were used to revegetate eroding banks. In spring 1987, 620 willow posts were planted at points of severe bank erosion over a 4-mile stretch, and an additional 125 posts were planted in a small area farther downstream. Posts were planted below scour holes in the channel. Posts were 12 ft long, 4-6 inches in diameter, and planted 4-6 ft deep into the bank. The cost of planting willow posts was approximately $300 per 100 ft of bank.

RESULTS: Tree revetments and willow plantings resisted flooding and reduced erosion during the summer.

"Lunker" structures stabilized the bank while creating undercut bank cover.

Evaluation of the response of fish populations is still in progress, and results are incomplete. However, in-stream habitat appears to have improved in treatment areas, and channel catfish and smallmouth bass populations have increased, although extreme low flows have confounded results.

PROBLEMS AND/OR COMMENTS: Floods and ice severely damaged tree revetments during the winter and greatly reduced their effectiveness. Willow plantings suffered less damage during the winter and remained effective at reducing erosion.

Unlike many studies reviewed here, extensive pretreatment data were collected on physical, chemical, and biological conditons in the Court Creek watershed before habitat improvement was initiated. As a consequence, results and conclusions from this study will be more comprehensive and complete than those for most other studies.

REFERENCE(S): Roseboom and Russell 1985; Roseboom et al. 1983*a*, 1983*b*; Roseboom et al. 1985; Vetrano 1988; Donald Roseboom, Ill. State Water Surv., and Randy Sauer, Ill. Dep. Conserv., pers. comm.

Study No. 19

STREAM(S) AND LOCATION: Town Creek, northwestern Ohio.

YEAR(S): 1981-83.

STREAM CHARACTERISTICS: Mean widths 18-36 ft; maximum depths at low flow 1-2 ft; stream flow unknown; gradient low to moderate at 3.2 ft/mile; substrate composition and study area length unknown. Pool-riffle-run sequences approximately every 1,300 ft. The creek has been heavily channelized for flood control. At low flow, most of the water in the creek comes from a secondary treatment sewage plant, and water quality is generally low during the summer.

WATERSHED CHARACTERISTICS: Agriculture is probably the dominant land use at present. The stream is part of the Little Auglaize River watershed and drains into Lake Erie. The watershed lies in the region of the historic Great Black Swamp and Glacial Lake Maumee. No other information given in the report.

OBJECTIVES: To mitigate damage to fish resources caused by channelization.

IMPROVEMENT TECHNIQUES: The following structures were installed, 4 per mile, in the creek:

Double-wing Current Deflector with Sill. Two wings of 18-inch rock, 1.5 ft above stream bottom, protruding into the creek from the bank (one wing on each bank) at a 45° angle. A rock sill, 0.5 ft high and 6 ft wide, connects the ends of the 2 wings.

Double-wing Current Deflector with Pool. Two wings, with an excavated pool (approximately 100 ft long and 2 ft deeper than the normal channel) constructed directly below the structure.

Rock Sill. A 15-ft-long artificial riffle made of 18-inch rock that spans the entire channel. The upstream end of the riffle is 1.5 ft above the normal channel bottom.

RESULTS: Structures apparently increased stream depth and cover and habitat heterogeneity, but physical effects were not quantified.

During a single summer sampling period, the number of fish species was higher in the vicinity of structures than in areas without structures. Few gamefish were captured, but of these the largest ones (black bullheads and green sunfish) were taken near structures.

PROBLEMS AND/OR COMMENTS: Few fish data were available from before habitat improvement for comparison, and physical habitat data were not collected. The evaluation was neither detailed nor thorough. Water quality problems probably limited the potential for physical habitat improvement to increase fish populations.

REFERENCE(S): Barickman 1984.

Study No. 20

STREAM(S) AND LOCATION: Lamine River and Saline Creek, central Missouri.

YEAR(S): 1984 to present.

STREAM CHARACTERISTICS:

Lamine River. Mean widths 60-70 ft; maximum depth 12 ft; stream flow unknown; gradient medium; substrate composition and study area length unknown. Stream has banks varying in height from 10-25 ft.

Saline Creek. Two different sections:

Upper section. Mean widths 20-30 ft; maximum pool depths 2-4 ft; stream flow unknown; gradient 20 ft/mile; substrate composition and study area length unknown. Stream has banks varying in height from 6-10 ft.

Lower section. Channel characteristics similar to upper section, except that mean gradient was less than 5 ft/ mile.

WATERSHED CHARACTERISTICS:

Lamine River. A transitional stream in that one of its major tributaries originated in the prairie region, and another major tributary originated in the Ozark Mountain region; a wildlife area lined about 11 miles of the river.

Saline Creek. Flowed through wildlife area; lower section located within a floodplain of an adjoining river.

OBJECTIVES: To stabilize eroding stream banks on the Lamine River and lower Saline Creek, and to increase habitat diversity in upper reaches of Saline Creek through channel relocation.

IMPROVEMENT TECHNIQUES:

Lamine River. In March 1987, a bank stabilization project began along a 600-ft section of the river. A total of 315 willow posts (6 ft long and 3-5 inches in diameter) were planted in a fence revetment along the toe of the bank. Willow wattles, which consisted of willow strips and sprouts tied in a bundle, were positioned vertically on the bank above the posts to catch soil that washed down from above. To complete the revetment, 1,500 willow stakes (1-2 inches in diameter) were placed in rows behind the posts. Only 2 types of trees, willows and cottonwoods (*Populus deltoides*), were suitable for use in the revetment. Willows were chosen because they tolerate wet conditions better.

Saline Creek. In the upper section, a stretch 1,320 ft long was diverted into a former channel by construction of an earth and gravel dam. In the lower section, dead trees were placed on a sharp bend to reduce bank erosion.

RESULTS:

Lamine River. Over 95% of the willow stakes, but only 25% of the willow posts, survived. Many of the posts caught and held slumps of earth. This installation has been effective in revegetating the bank.

Saline Creek. Rerouting of the channel in the upper section improved habitat diversity, creating deeper pools and increasing woody debris cover. Fish abundance appears to have increased. The trees installed on the lower section have stayed in position even during high water periods and overbank flows.

PROBLEMS AND/OR COMMENTS: In the Lamine River, an infestation of leaf beetles resulted in defoliation of willow posts during the first growing season. The impact on willow stakes and wattles was much less. Flood-caused erosion was severe on the Lamine River and resulted in the loss of many willow posts. Although willow plantings could not stabilize the toe of the bank, they were still useful as a revegetation technique.

REFERENCE(S): U. S. Dep. Agric. 1985; William Turner, Steve Gough, and Otto Fajen, Mo. Dep. Conserv., pers. comm.

Study No. 21

STREAM(S) AND LOCATION: Tillatoba Creek and Long Creek, north-central Mississippi.

YEAR(S): 1985.

STREAM CHARACTERISTICS: Mean widths unknown, but streams small; mean depths unknown, but maximum depths up to 10 ft, usually much less; stream flows and gradients unknown; substrates composed of sand and gravel over clay; study area lengths unknown. Banks steep and eroded in many places.

WATERSHED CHARACTERISTICS: No information given in report.

OBJECTIVES: To compare fish populations in pools created by drop structures with populations in natural scour holes in the channel. Structures were installed to reduce channel erosion and headcutting, not to improve fish habitat.

IMPROVEMENT TECHNIQUES: Four sheet-pile drop structures were installed in the early 1970s at several points in both streams. Riprap was added to the adjacent banks and channel to protect the structures. The drop structures were compared with 4 natural scour holes.

RESULTS: Drop structures created stable deep pools, and riprap added cover and habitat for invertebrates and small fishes. Natural scour holes were similar in depth to pools created by drop structures, but were less stable over time and lacked coarse substrate.

River carpsucker and channel catfish dominated both types of pools. Spotted bass and bullheads were more abundant in scour holes, whereas largemouth bass and sunfish dominated in pools created by drop structures. Species richness was higher in scour holes, but size and age structure of gamefish were better in pools created by drop structures.

PROBLEMS AND/OR COMMENTS: No data were available on habitat or fish populations before installation of drop structures.

REFERENCE(S): Cooper and Knight 1987.

Study No. 22

STREAM(S) AND LOCATION: Red Cedar River, south-central Michigan (lower peninsula).

YEAR(S): 1986-88.

STREAM CHARACTERISTICS: Mean width 65 ft; maximum depths ≤ 4 ft; stream flow unknown; gradient low to moderate; substrate composed of silt, sand, and gravel, with some cobble; study area length 3,040 ft. Four sections made up the study area. Each section was 760 ft long and consisted of a 130-ft-long treatment area separated by 500 ft from a 130-ft-long reference area.

WATERSHED CHARACTERISTICS: Agriculture was the dominant land use, and most areas lacked riparian buffer strips of woody vegetation.

OBJECTIVES: To assess the use of half-logs to increase in-stream cover for smallmouth bass.

IMPROVEMENT TECHNIQUES: Half-logs (10 ft long, anchored 6 inches off the bottom) were placed in pairs (6.5 ft apart) in the 4 treatment areas. Enough half-logs were added to each treatment area to increase the surface area of in-stream cover by 20%. This required 20-33 half-logs per area.

RESULTS: After 1 year, abundance of northern pike, cyprinid species, rock bass, and smallmouth bass increased. The increase in predators may have been caused by the increase in cyprinids. Increases in abundance appeared to be due to improved survival and recruitment, rather than movement of fish into the treatment areas.

After 2 years, the overall increase in abundance was 12% for smallmouth bass and 47% for rock bass. Increases were highest in treatment areas that had half-logs for the longest time. Growth rates of smallmouth bass declined in treatment areas.

PROBLEMS AND/OR COMMENTS: The abundance of smallmouth bass and rock bass varied substantially from month to month. Highest abundances were in August and September. Smallmouth bass moved little during the summer, but left the study area in the fall and returned in the spring, possibly displaying homing. The amount of cover that was added to treatment areas was large, the increases observed in smallmouth bass abundance were generally modest, and bass growth rates declined, suggesting that additions of half-logs may not be cost-effective in some streams.

REFERENCE(S): Jill DuFour and William Taylor, Mich. State Univ., pers. comm.

APPENDIX C. *Scientific names of fishes cited.*

Common Name	Scientific Name
Lake sturgeon	*Acipenser fulvescens*
Longnose gar	*Lepisosteus osseus*
Gizzard shad	*Dorosoma cepedianum*
Grass pickerel	*Esox americanus vermiculatus*
Northern pike	*Esox lucius*
Common carp	*Cyprinus carpio*
Hornyhead chub	*Nocomis biguttatus*
Striped shiner	*Notropis chrysocephalus*
Common shiner	*Notropis cornutus*
Bluntnose minnow	*Pimephales notatus*
Creek chub	*Semotilus atromaculatus*
River carpsucker	*Carpiodes carpio*
White sucker	*Catostomus commersoni*
Black bullhead	*Ictalurus melas*
Yellow bullhead	*Ictalurus natalis*
Channel catfish	*Ictalurus punctatus*
Madtoms	*Noturus* species
Blackstripe topminnow	*Fundulus notatus*
Rock bass	*Ambloplites rupestris*
Sunfish	*Lepomis* species
Green sunfish	*Lepomis cyanellus*
Pumpkinseed	*Lepomis gibbosus*
Bluegill	*Lepomis macrochirus*
Longear sunfish	*Lepomis megalotis*
Bass	*Micropterus* species
Smallmouth bass	*Micropterus dolomieui*
Spotted bass	*Micropterus punctulatus*
Largemouth bass	*Micropterus salmoides*
White crappie	*Pomoxis annularis*
Black crappie	*Pomoxis nigromaculatus*
Darters	*Ammocrypta, Etheostoma,* and *Percina* species
Johnny darter	*Etheostoma nigrum*
Walleye	*Stizostedion vitreum vitreum*

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