# Stream Habitat Analysis at Differing Temporal and Spatial Scales: A Study of the Relationship between Human Disturbance and Fish Habitat in Manitoba Escarpment Streams

By
Maureen G. M. Forster

A Thesis Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements for
the Master of Science Degree

Department Of Zoology
University Of Manitoba
Winnipeg, Manitoba

August 2004

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

*****

COPYRIGHT PERMISSION

# Stream Habitat Analysis at Differing Temporal and Spatial Scales: A Study of the Relationship between Human Disturbance and Fish Habitat in Manitoba Escarpment Streams

BY

Maureen G. M. Forster

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of

Manitoba in partial fulfillment of the requirement of the degree

Of

MASTER OF SCIENCE

## ABSTRACT

Stream habitat analysis was conducted on five different stream systems that originate in the Manitoba Escarpment to collect information on the existing fish communities and to explore potential relationships among the chemical, biological and physical habitat features of the streams in relation to differing levels of human disturbance among the watersheds. The study was modelled on an integrated watershed approach to stream habitat analysis that has been undertaken in several regions of the United States. Nine sites were selected to represent three levels of human disturbance at three spatial scales. The disturbance levels were assigned as “minimally”, “moderately” or “highly” disturbed based on an assessment of the amount of human activity (e.g., industry, agriculture, urbanization) in each stream system. The spatial scale categories were defined by drainage area and position within the watershed as “headwater sites” (20-30 $km^2$), “sub-catchment sites” (60-70 $km^2$) and “catchment sites” (200-300 $km^2$). Sample collections of fish, aquatic macroinvertebrates, and stream habitat variables were gathered from each site during the open-water season for a two-year period. Water samples for nutrient and pesticide analyses were collected year-round on a biweekly basis for the same two-year period as the biological and habitat data. The data were examined using summary statistics, cluster analysis and Principal Component Analysis (PCA). Eighteen regionally used pesticides were detected from samples collected during spring, summer, and fall application periods, and in winter samples collected outside of application periods. Low levels of pesticides were detected in streams located within Riding Mountain National Park that are upstream of agricultural activities. The study identified nineteen fish species and provided new locality records for sixteen fish species, some of which may be relict populations from post-glacial recolonizations of southern Manitoba’s waterways. Data analysis indicated higher nutrient concentrations, increased pesticide detections and a higher number of channel alterations or barriers to fish passage in the “moderately” and “highly” disturbed sites in comparison to the “minimally” disturbed sites. Fish species diversity was lowest in the “highly” disturbed sites and highest at the “moderately” disturbed headwater site, “minimally” disturbed sub-catchment site and “minimally” disturbed catchment site. These results suggested that the proximity and presence of human disturbances, particularly activities related to agricultural practices and land-clearing, has affected these stream habitats, but these effects can be ameliorated by the maintenance of perennial flows, fish access to upstream and downstream areas, riparian zone integrity, and instream habitat heterogeneity.

## Table of Contents

## Table of Contents (continued)

List of Tables

List of Figures

List of Appendices

# INTRODUCTION

The study of stream fish and their habitat has expanded from the interpretation of site-specific conditions to include the influences of the surrounding landscape (Frissell et al. 1986; Allan and Johnson 1997; Lammert and Allan 1999). The complex and dynamic interrelationships among stream fish, their habitat, and the neighbouring landscape can be better understood by investigating these factors at differing spatial and temporal scales (Jackson et al. 2001; Hauer et al. 2003; Montgomery and Bolton 2003). Previous investigations into the influence of spatial scale on stream habitat analysis have shown that variability among streams can not be fully interpreted using site-specific data alone (Allan and Johnson; Allan, Erickson and Fay 1997; Lammert and Allan 1999). Local stream conditions are influenced by processes and activities occurring at different spatial scales within the watershed; therefore, the variability among streams is better revealed by assessing the stream characteristics at different scales of measurement and at different points within the watersheds (Allan and Johnson; Allan, Erickson and Fay 1997; Frissell et al. 1997; Lammert and Allan 1999). Spatial analysis includes the examination of the stream environment at site, tributary, and catchment levels. A temporal component is used to account for seasonal and historical changes in the stream ecosystem that result from natural and human-related processes. This multi-dimensional approach functions by drawing on the scientific disciplines of biology, hydrology, geography, and chemistry. The result is an integrated methodology that can be used to identify the state of the local stream environment and of the watershed, and describe the relationships among them.

The study of stream fish and their habitat stemmed from a desire to understand the environmental conditions conducive to the proliferation of sport and commercial fish species such as trout and salmon. During the first half of the twentieth century, one of the objectives of North American fisheries biology was to sustain and enhance sport fishing. For example, a report by Gerald P. Cooper to the Maine Department of Inland Fisheries and Game in 1941 cites the aim of their biological survey of the Androscoggin and Kennebec River Drainage in Maine as:

"to obtain information on the physical characteristics of the lakes, the character of the water, the kinds and abundances of different species of fish, and the present status of each of the game species; to determine, from such studies, the types of fishes which are best suited for stocking in each body of water; and to make recommendations which would tend to improve the status of the game fish populations and therefore to improve the fishing"

These types of surveys focused on the water chemistry, basin morphology, fish populations and fish food items within lakes, but paid little attention to the contribution of tributary streams to the maintenance of fish stocks. Stream habitats were recognized as a prerequisite for spawning and the rearing of juvenile fishes, but this requirement could be circumvented with stocking programs. Cooper (1941) stated that "it is biologically unsound to plant trout and salmon fry in lakes and ponds. Fry should be planted only in suitable tributary streams. If the lake has no such streams, the fish should be reared in the hatchery to a length of at least six to eight inches before they are planted in a lake". The role of streams in aquatic environments was not widely investigated during this period. The prevailing perception of the natural environment as an exploitable resource did not promote the need to understand ecological processes.

Over the last few decades, it has become apparent that the view of the aquatic environment as a resource to be developed and manipulated for human purposes has had adverse consequences. Flow regulation, barriers to fish passage, the alteration of stream channels, and inputs of pollution from urbanization, industry, and agriculture can all be identified as causative factors in the diminishment of stream habitat and subsequent losses to fish populations. Overfishing of commercial and sport fish species also contributes to fish population declines. It has been suggested that the decline of walleye (*Stizostedion vitreum*) populations in Dauphin Lake, Manitoba is related to the cumulative effects of the above-mentioned factors within the watershed (Gaboury 1985). Land clearing, wetland drainage, and stream channelization have altered the hydrograph of tributary streams and increased the sediment loading in the watershed (*ibid).* These landuse changes have resulted in the loss of historical spawning grounds for the walleye and other stream spawning species such as the white sucker (*Catostomus commersoni*), quillback (*Carpiodes cyprinus*), shorthead redhorse (*Moxostoma macrolepidotum*), and silver redhorse (*Moxostoma anisurum*) (*ibid*).

Gaboury's 1985 report is but one of numerous publications that acknowledge the relationship between stream habitat degradation and adjacent landuse practices (Resh et al. 1988; Waters 1995; Isenhart, Schultz, and Colletti 1997; Lammert and Allan 1999; Smogor and Angermeier 1999; Stevens and Cummins 1999; Robertson and Rowling 2000). The complex interactions between the terrestrial and aquatic ecosystems were elucidated by Hynes (1975) in his treatise entitled "The Stream and its Valley". The interrelationships between the biological and physical components of the stream environment were then explored by Vannote et al., (1980) in "The River Continuum Concept". The river continuum concept proposed that the structure and function of biological communities in a river system were regulated by fluvial geomorphic processes. Rivers are in a state of "dynamic equilibrium" as the system attempts to both maximize the efficiency of energy utilization and achieve a uniform rate of energy use. This process creates a range of physical factors that dictate the structure and persistence of biological communities. The width, depth, velocity, flow volume, temperature and entropy gain in the system form a continuous gradient from the headwaters to the larger downstream sites (Vannote et al. 1980). The river continuum theory implies that biological communities conform to this gradient of physical conditions and energy dissipation. The community composition of the river alters as the energy inputs to the system shift from the allochthonous inputs of the terrestrial environment to autochthonous within-stream sources. The biological system attempts to maintain a balance between resource partitioning and energy processing, analogous to the physical processes by which the river system moves towards a state of dynamic equilibrium. The theory brought attention to the relationship between the biological and physical processes in riverine systems, and acknowledged the contribution of headwater streams to downstream conditions.

The physical, chemical, and biological state of headwater streams influences the flow conditions, sediment load, water chemistry, and organic content of the downstream sections (Rabeni 1992). Small first-order and second-order streams can make up as much as two-thirds of the total stream distance in a watershed (Leopold et al. 1964). Although typically low in biodiversity, headwater streams provide essential spawning, nursery, and feeding habitats for resident and migrant fish species. Natural headwater habitats can harbour many species and serve as a source of colonists to downstream areas (Frissell 1997). Headwater streams are subject to wide seasonal and annual variations in their flow regimes, which creates an unstable environment for stream fishes. The amount of available habitat, water temperatures, and flow velocities fluctuate in response to the changes in discharge. This variability creates a series of habitat patches that are connected through a network of downstream channels. Some species may require these headwater refugia for long-term persistence (Reiman and McIntyre 1995). It has been postulated that many riverine organisms have maintained their historical distributions by a dynamic balance of local extinctions and recolonizations (Frissell 1997). Natural disturbances such as episodic floods and drought can extirpate headwater populations. A local extinction can be reversed if a similar population of the species persists in a nearby refuge, providing a source of migrants to recolonize the disturbed habitat as it recovers (Frissell 1997). This process is exemplified in the headwater streams of the Manitoba Escarpment, where populations of several fish species endure despite dramatic fluctuations in water flows and constant changes to habitat availability.

This study was performed in conjunction with a research project initiated in 1995 by the Department of Fisheries and Oceans under the Toxic Chemicals Program (TCP) that sought to identify the sources, transport, and potential effects of nutrient and pesticide loading in the Red River drainage basin. The TCP projects included the collection and analyses of samples from the atmosphere, precipitation, surface waters, and sediments in the Red River drainage basin. Several streams that are headwaters to the Red River originate from the Manitoba Escarpment in southwestern Manitoba (Figure 1). The focus of this thesis was a stream habitat study, which commenced in June of 1998. The stream habitat study was conducted to collect chemical, biological and physical habitat information on the fish communities and fish habitat within streams of the Manitoba Escarpment, and to examine the relationship among differences in the level of human disturbance within the watersheds based on analysis of the collected data. For the purposes of this investigation, disturbance was defined as the relative amount of human development and human activity among the watersheds and does not refer to variability among the watersheds as a result of natural stochastic or deterministic processes. These streams had not been investigated previously in an ecological framework and there are limited data on the chemical, biological and physical features of these watercourses. Therefore, the study was carried out as an exploratory analysis to:

- provide information on the existing fish communities and fish habitat of Manitoba Escarpment streams;
- examine the similarities and/or dissimilarities in chemical, biological or physical parameters among highly disturbed, moderately disturbed, and minimally disturbed watersheds in the Manitoba Escarpment; and
- identify possible trends or relationships among the chemical, biological and physical parameters collected from Manitoba Escarpment streams.

It was proposed to be analyzed the collected information using multivariate methods that would allow for the simultaneous analysis of several types of variables measured at different scales.

## STUDY AREA

The study area encompassed five stream systems that originate in the southern portion of the Manitoba Escarpment. Figure 1 provides an illustration of the study area and the location of the sampling sites. These streams are the headwaters of several river systems in southern Manitoba, including the Boyne River, the Morris River, the Turtle River and the Ochre River. The Manitoba Escarpment is ridge of Cretaceous shales overlain by glacial till that extends from the centre of western Manitoba to the United States. In Manitoba, the ridge is comprised of the areas known as the Turtle Mountains, Pembina Hills, Riding Mountains, Duck Mountains, and Porcupine Mountains. These hills formed the shoreline of glacial Lake Agassiz following the retreat of the Wisconsinan glacier approximately 9500 years ago (ya) (Crossman and McAllister 1986). Lake Agassiz gradually receded, leaving behind lacustrine deposits of clay and exposing the present-day lakes and large river systems of southern Manitoba. Over time, channels of water cut their way through the landscape toward the lower elevations of the lakes and rivers. These channels eventually formed the streams and rivers that course down from the southern portion of the Manitoba Escarpment to the Red River, Lake Winnipeg, Lake Manitoba, and Lake Dauphin (Figure 1).

The advance and retreat of the Wisconsinan glacier sculpted the landscape and altered the environmental conditions for Manitoba's biota. The present-day distributions of most Manitoba fish species are largely attributable to the effects of the Wisconsinan glaciation. As the glacier advanced over the landscape, the fish populations that inhabited the waters of Manitoba took refuge in the Mississippi, Missouri and Atlantic refugia to the south, southwest and southeast of the maximum extent of the glacier (Crossman and McAllister 1986). The entire Hudson Bay drainage was ice-covered prior to c.15 000 ya, with the possible exception of the Cypress Hills in Saskatchewan and an area in the Jasper-Banff region of Alberta. The glacier first retreated northward from the western plains, which allowed fishes in the Missourian Refugium to move north before the fishes from the Mississippian Refugium (Crossman and McAllister 1986). The formation of glacial Lake Agassiz c.12 900 ya provided a link to the Mississippian Refugium and enabled the redispersal of fishes to the waters of the north. Lake Agassiz was connected also to the developing Great Lakes, and to glacial Lake Ojibway-Barlow. This pathway allowed the redistribution of fishes from the Atlantic and Mississippian Refugia. Crossman and McAllister (1986) cited the number of fish species native to the Hudson Bay drainage basin as 119.

Appendix 1 lists the refugia and post-glacial pathways for the 19 fish species collected in this study (Crossman and McAllister 1986).

Humans recolonized the Manitoba Escarpment area during the period of inundation by glacial Lake Agassiz, as well (Hayes 2002). Settlement of the area by Europeans began in the early 1800's (Hayes 2002). Appendix 2 provides a figure that depicts the Manitoba Escarpment area from the United States border to the confluence of the Red and Assiniboine Rivers as it appeared on the original Dominion Land Survey (DLS) Township maps from 1872-1906 (Irene Hanuta, University of Manitoba, personal communication). Extensive areas of wetland and marsh covered the landscape, prompting the construction of drainage canals and flow control structures throughout the region. Today the district accommodates a variety of landuse activities including small urban centers (e.g. the towns of Miami, Carman, and Morden), multi-use recreational areas (e.g. Lake Minnewasta, Stephenfield Provincial Park, Snow Valley), agriculture (e.g. rowcrops, hog and dairy production, PMU farms), and Riding Mountain National Park. Many of the regional waterways have been channelized, dammed or re-routed in order to regulate streamflow, alleviate flooding, and provide water for irrigation. Riding Mountain National Park was designated as a Biological Reserve under UNESCO's Man and the Biosphere (MAB) program in 1986 and contains an expanse of undisturbed forests, streams, and lakes within its borders (MABnet 2000).

# METHODS AND MATERIALS

## Study Design

The study objective of exploring the relationships among the chemical, biological and physical features of the watercourses of interest required the use of methods that would allow for the simultaneous analysis of several types of variables measured at different scales. Therefore, methods of stream habitat analysis currently and previously used by other researchers were reviewed to facilitate the development of a study design and sampling protocol. The study was designed to incorporate a disturbance component, a spatial component, and a temporal component. The disturbance component was included by selecting sites from stream systems within the Manitoba Escarpment that were within areas of differing amounts of human interference (e.g. roads, dams, industrial, recreational and agricultural activities). Nine sites were selected from five stream systems within the Manitoba Escarpment to represent three levels of human disturbance ("minimally", "moderately" and "highly" disturbed) at three spatial scales. The South Tobacco Creek watershed was designated in this study as "highly disturbed" as it contains several flow control structures that obstruct fish passage, and over 80% of the available land in the watershed is engaged in agriculture (Ross 1999). The Roseisle Creek watershed has been cultivated and altered in its uppermost and lower stream sites, but contains large tracts of undisturbed mixed-wood forest and riparian zone vegetation through the middle stream segments and Snow Valley area. The Roseisle Creek watershed was therefore designated in this study as the "moderately disturbed" watershed. The "minimally disturbed" sites were chosen from streams located within the boundary of Riding Mountain National Park, and provided an opportunity to examine waterways that were virtually unaffected by human activities.

The spatial scale categories were defined by drainage area and location as "headwater sites" (20-30 km$^2$), "sub-catchment sites" (60-70 km$^2$) and "catchment sites" (200-300 km$^2$). The headwater sites were located at the southern branch of S. Tobacco Creek near Opawaka Hill (S. Tobacco Ck-1), a headwater creek of the Roseisle Creek watershed known as Lyle Creek, and Wilson Creek near the Riding Mountain National Park boundary. The sub-catchment sites were located at S. Tobacco Creek near the town of Miami (S. Tobacco Ck-2), Roseisle Creek in the Snow Valley (Roseisle Ck-1), and Henderson Creek near the Riding Mountain National Park boundary. The catchment sites were located at S. Tobacco Creek near the confluence of S. Tobacco Creek with the Little Morris River (S. Tobacco Ck-3), Roseisle Creek near the confluence of Roseisle Creek with the Boyne River (Roseisle Ck-2), and the Ochre River near the Riding Mountain National Park boundary. Figure 1 provides an illustration of the study area and the location of the sampling sites. Table 1 provides a list of the nine sampling sites by number and geographical information for each site.

Sample collections of fish, aquatic macroinvertebrates, and stream habitat variables were gathered during the open-water season, i.e. spring, summer, and fall, over a two-year period. Water samples for nutrient and pesticide analyses were collected year-round over the same two-year period on a biweekly basis. This sampling regime provided a seasonal and annual temporal component to the study. Each site was examined in terms of the quality and availability of aquatic habitat, the presence and type of fish species present, and riparian zone integrity. The sampling methods at each site included the collection of water samples for pesticide, nutrient, and chemical analysis; the collection of benthic macroinvertebrate samples via a kick net; the collection of fish via seining and electroshocking; the measurement of stream habitat variables; and a riparian zone assessment.

## Field Sampling

### *Water and Pesticide Samples*

Surface water samples for nutrient and chemical analysis were collected from flowing water in clear plastic Nalgene PE 500 millilitre (ml) containers. Samples were taken by submersing the bottle directly into the stream. Ambient air temperature, water temperature, site photographs, and general flow conditions were recorded for each site at each sample collection period. As all samples were to be collected from running waters, dissolved oxygen levels were not included in the sampling regime. Water samples for pesticide analysis were collected in clean brown glass bottles that had been baked at 250°C for 12 hours to remove any organic residues. The volumes gathered for pesticide analysis varied from 1 to 4 litres. Samples were taken from flowing water by submersing the bottle directly into the stream, or by transferring the water from a clean pan to the glass bottle. Holes were chopped through surface ice during winter sampling as required. The collected samples were placed in an ice-filled cooler for transport back to the laboratory.

### *Fish Communities*

Potential study sites were identified from the examination of the latest edition of Energy, Mines, and Resources Canada 1:50 000 topographic maps prior to field excursions. The sites were selected based on geographic location, drainage area, position within the watershed, and ease of access. Reconnaissance surveys were conducted to ground-truth the potential sites and to choose appropriate stream sites for sampling. Each sampling site was spatially delineated as a section of stream, i.e. a stream reach, which encompassed a full meander and included pool, riffle, and run areas as defined by Hawkins et al. 1993. This criterion was inapplicable to the S. Tobacco Creek catchment site as the area was highly channelized. Nine permanent sampling sites were selected as per the sampling design. The beginning and end of the sampling sites were marked by tying pieces of flagging tape to streamside trees or vegetation that were positioned above the high water level.

The sampling sites were surveyed in the summer and fall of 1998, and in the spring, summer, and fall of 1999. Two additional sites on the Ochre River representing a headwater site and a sub-catchment site for the watershed were sampled in the summer of 1999. These sites are referred to as Ochre River-Elk Ck and Ochre River–park site 2, respectively. The two sites were surveyed only once as considerable time and resources were required to enter the area. The sites were located in the wildlife reserve area of the park and were accessible only by an All Terrain Vehicle trail. The data for these sites are included in the discussion and appendices, but were not included in any cumulative or multivariate analyses among the sites as they provide only a single data point. The survey was conducted to examine the fish community composition and habitat of the headwater and sub-catchment areas of the Ochre River, and thus provided a "snapshot" of the existing conditions for an entire minimally disturbed watershed for the summer of 1999.

Fishing surveys were conducted using a modified version of Zippin's removal method, also called the depletion method (Lockwood and Schneider 2000), to obtain quantifiable measures of the resident fish populations (Seber 1973). Immigration and emigration of fish to and from the site during sampling were prevented by placing barrier nets at each end of the sampling site. Each site was electro-fished in three upstream passes. Additional passes were done if there was less than a 33% decline in the number of fish in successive catch efforts. The passes were conducted at intervals of approximately twenty minutes to allow missed fish to recover. Each pass was conducted at equal intervals and for equal periods of time in order to maintain a uniform catch-per-unit-effort (CPUE). Electrofishing was accomplished using a Smith-Root Inc. Model 12-A Programmable Output Waveforms (POW) backpack electrofisher. Electrofishing was usually effective with the electrofishing unit set to emit a standard pulse of 400 volts in the F5 (30 HZ at 6ms) mode setting. On sampling surveys where electrofishing appeared to be less effective, the settings were modified until the normally observed level of fish capture efficiency was obtained. At the catchment site of S. Tobacco Ck, seine hauls were used as a capture method after electrofishing attempts yielded a zero fish capture rate.

The survey teams consisted of one person equipped with the electrofishing unit, and one or two persons walking alongside with dipnets to capture the stunned fish. The seine hauls were conducted by two people. One person held each end of the seine net and dragged it through the water column in an upstream pass. The captured fish were placed in a bucket of stream water, then separated by species, enumerated, and weighed on a Mettler PJ4000 scale at the end of each sampling pass. Fish collected that were less than 20 mm in length were not counted as their capture rate was highly inconsistent; several slipped through the mesh of the net during sampling. The omission of fish less than 20 mm in length from electrofishing surveys has been suggested by other researchers because of inconsistent capture rates and the difficulty in identifying larval fishes (Plafkin et al. 1989). Fish found caught in the barrier nets at the end of each sampling survey were not counted as part of the catch. The barrier net had to remain in place throughout the entire survey; therefore, it could not be determined from which sampling pass the caught fish would have been trapped. Some of the fall fish collections were kept in their entirety and brought back to the laboratory for later identification and analysis. This method was used to reduce the time required at each sampling site as the amount of available daylight decreased during the fall collection periods. Specimens that could not be identified in the field were sacrificed and placed in a 10% formalin solution for later identification. Specimens kept for later analysis were placed on ice and transported back to the laboratory. The collection of water samples, habitat variables, and benthic macroinvertebrate samples was done at the end of each fish sampling survey. All data were recorded in field notebooks and transcribed into Microsoft ® Excel spreadsheets.

### *Habitat Data*

The following habitat measurements were collected during each sampling survey:

- the length of each sampling site in meters;

- the wetted width of the stream channel in meters;
- the depth in centimetres and velocity in centimetres per second (cm/s) in the middle of the channel at 2 m intervals for the length of each sampling site;
- a sketch done in planform view of each site that showed the layout of the site and identified the substrate types, location of pools, riffles, runs, instream cover, overhanging cover and riparian zone vegetation;
- measurement of the stream channel slope in centimetres/meter (cm/m);
- measurement of channel sinuosity;
- documentation of the substrate composition and sources of instream cover throughout the length of the sampling site;
- collection of a benthic macroinvertebrate sample;
- photographs of each site to document channel, bank, flow, and riparian zone conditions; and
- a riparian zone assessment conducted as per Petersen 1992.

Width and depth measurements were collected with a measuring tape and a meter stick. The velocity measurements were taken with a Global Flowprobe(TM) velocity meter set to display the mean velocity as recorded over a 30 second time period. The slope measurements were collected using a surveyor's rod and level. The slope of the stream channel was calculated as the difference in the height of the water surface at the beginning and end of each sampling site in centimetres per meter of channel length. Sinuosity was measured as the length of the stream channel site, divided by the length of the stream valley within the site (USDA Federal Interagency Stream Restoration Working Group 1998).

The initial surveys conducted in the summer of 1998 included the documentation of the percent pool: riffle: run and general substrate composition at all of the sampling sites. A more detailed analysis of the substrate composition and sources of instream cover was conducted during subsequent surveys in the fall of 1999. The substrate composition and sources of instream cover were recorded by dividing the site into ten cross-sections and listing the numbers of each type of substrate and instream cover across the stream channel at each cross-section. The categories for the substrate and instream cover types were determined based on information in Hawkins et al. (1993), Hauer and Lamberti (1998) and USDA Federal Interagency Stream Restoration Working Group (1998).