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Concurrent assessment of fish and habitat in warmwater streams in Wyoming

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Abstract Fisheries research and management in North America have focused largely on sport fishes, but native non-game fishes have attracted increased attention due to their declines. The Warmwater Stream Assessment (WSA) was developed to evaluate simultaneously both fish and habitat in Wyoming streams by a process that includes three major components: (1) stream-reach selection and accumulation of existing information, (2) fish and habitat sampling and (3) summarisation and evaluation of fish and habitat information. Fish are sampled by electric fishing or seining and habitat is measured at reach and channel-unit (i.e. pool, run, riffle, side channel, or backwater) scales. Fish and habitat data are subsequently summarised using a data-matrix approach. Hierarchical decision trees are used to assess critical habitat requirements for each fish species expected or found in the reach. Combined measurements of available habitat and the ecology of individual species contribute to the evaluation of the observed fish assemblage. The WSA incorporates knowledge of the fish assemblage and habitat features to enable inferences of factors likely influencing both the fish assemblage and their habitat. The WSA was developed for warmwater streams in Wyoming, but its philosophy, process and conceptual basis may be applied to environmental assessments in other geographical areas.

KEYWORDS: conservation, faunal filter, fish assemblage, sampling, warmwater stream.

Introduction

Many native fish species have been locally extirpated or have experienced substantial declines in distribution across North America (Williams, Johnson, Hendrickson, Contreras-Balderas, Williams, Navarro-Mendoza, McAllister & Deacon 1989; Richter, Braun, Mendelson & Master 1997), particularly in the Great Plains and Rocky Mountain regions (Hesse 1987; Pflieger & Grace 1987; Minckley, Marsh, Deacon, Dowling, Hedrick, Matthews & Mueller 2003). For example, Patton, Rahel & Hubert (1998) found that over 50% of the native fish species in the Missouri River drainage of Wyoming have experienced reduced distributions. Similar findings have been reported in other portions of North America (Williams *et al.* 1989; Hesse, Mestl & Robinson 1993; Richter *et al.* 1997; Minckley *et al.* 2003). As a result, management of native fishes and their habitats is becoming an increasingly important responsibility of natural resource agencies.

Fisheries management in the western United States has been dominated by sport fisheries interests with a focus on coldwater salmonids. However, native non-game species have attracted increased attention due to their declines. The Wyoming Game and Fish Department (WGFD) is responsible for the conservation and enhancement of all aquatic wildlife and has identified the need to inventory, evaluate, and enhance habitat for all aquatic wildlife. Thus, the WGFD and other natural resource agencies are charged with conserving both native non-game fishes and their habitats in warmwater stream systems (i.e. streams with maximum summer water temperatures > 20 °C).

Proper management of warmwater stream systems requires methods that integrate both fish and habitat information. Such methods can provide insight on factors influencing individual species, thereby guiding

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management decisions to conserve fish and habitat. The Warmwater Stream Assessment (WSA) was developed to evaluate fish and habitat in warmwater streams (Quist, Hubert & Rahel 2004a). The WSA is a process of accumulating existing information, collecting new fish and habitat information, and evaluating that information to help guide management activities. The WSA uses standardised sampling and evaluation methods for both fish and habitat to provide insight as to how fish communities have been altered and potential mechanisms causing changes. The purpose of this paper is to present the philosophy and rationale, introduce the sampling and evaluation process, and provide examples of the benefits and limitations of the WSA so managers in other geographical areas may consider their adoption.

Current sampling and assessment protocols

Management of native fishes in warmwater streams is hindered by the lack of suitable frameworks for collecting, analysing, and interpreting information on stream systems (Bain, Hughes & Arend 1999; Bain & Stevenson 1999). Adequate techniques are difficult to develop in warmwater streams because of high fish species richness, diverse life histories of fishes, and complex interactions among abiotic and biotic processes (Matthews 1998; Jackson, Peres-Neto & Olden 2001). As a result, few methods have been proposed for concurrently evaluating both fish and habitat. Several methods claim to be evaluation techniques, but in reality, they are sampling protocols with the purpose of acquiring standardised data (e.g. McMahon, Zale & Orth 1996; Hubert & Bergersen 1998; Bain & Stevenson 1999). For example, the American Fisheries Society published a manual titled *Aquatic Habitat Assessment: Common Methods* (Bain & Stevenson 1999), which implies evaluation and interpretation of aquatic habitat; but the manual is a detailed account of how to acquire standardised data. Although such protocols are necessary to provide data that can be used for inventory and trend monitoring, rarely are they tailored to an evaluation process. Nevertheless, a few techniques have been proposed for evaluating either fish or their habitat, most of which incorporate some form of index.

One method for evaluating warmwater fish assemblages is the index of biotic integrity (IBI: Karr, Fausch, Angermeier, Yant & Schlosser 1986), and several similar approaches adopted by management agencies (e.g. Simon 1998). The function of the IBI is to summarise fish assemblage data by rating community attributes relative to values expected in the absence of anthropogenic effects. The resulting IBI score provides an index as to the condition of a fish assemblage. The IBI has been modified for a variety of aquatic systems (Simon 1998), but its application is difficult in areas where species richness is naturally low or in areas that lack pristine reference sites for establishing rating criteria (Miller, Leonard, Hughes, Karr, Moyle, Schrader, Thompson, Daniels, Fausch, Fitzhugh, Gammon, Halliwell, Angermeier & Orth 1988; Simon 1998). Also, the IBI does not provide information regarding the status of individual species. In systems with impoverished fish assemblages, a species-by-species approach may provide a more detailed and insightful evaluation.

Index-based systems are also commonly used to assess stream habitat. For example, the fish habitat rating (FHR) system was developed to summarise habitat characteristics in Wisconsin streams by rating measures of habitat relative to undisturbed conditions (Simonson, Lyons & Kanehl 1994). Similar techniques have been used in Missouri (Fajen & Wehnes 1981; Osborne, Dickson, Ebbers, Ford, Lyons, Kline, Rankin, Ross, Sauer, Seelbach, Speas, Stefanavage, Waite & Walker 1991), Ohio (Osborne *et al.* 1991), and Oregon (Parsons, Maxwell & Heller 1981). These methods typically summarise information into a single index that reflects habitat quality; but measurements of individual habitat characteristics used to compute the index are not used in an evaluation (Bain *et al.* 1999). Index-based approaches may conceal important information regarding habitat characteristics. For instance, habitat that results in a high index score may be important for one species, but not other members of the fish assemblage. Regardless, techniques that compute an index (e.g. IBI, FHR) are appealing due to their simplicity and ability to summarise complex data, but they also limit opportunities for the integration of both fish and habitat information.

Warmwater stream assessment philosophy

A central tenet of the WSA is that collection, analysis, and interpretation of fish and habitat data is a synergistic process (Fig. 1). The WSA includes accumulation of existing information and collection of new information on both fish and habitat. Data are summarised to provide an evaluation of factors likely influencing both fish and habitat. The WSA assures that data are evaluated so they can then be used to guide management decisions.

A unique feature of the WSA is application of hierarchical faunal filters (e.g. Tonn, Magnuson, Rask & Toivonen 1990; Poff 1997; Matthews 1998). The

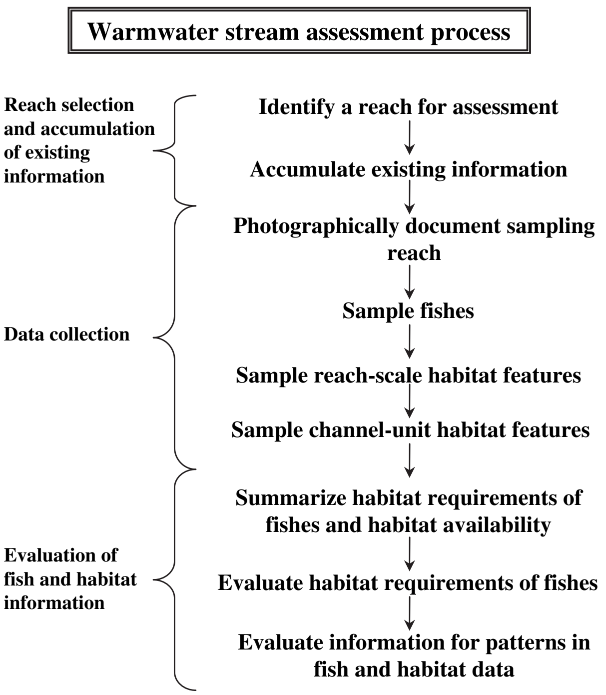

Figure 1. Outline of the Warmwater Stream Assessment (WSA) process used in Wyoming to sample and evaluate warmwater stream systems.

concept of faunal filters can be traced back to Simpson (1953), but Smith & Powell (1971) first applied them to fishes. They suggested that the sequential reduction of species from potential species pools can be conceptualised as the passage of species through progressively finer (i.e. shorter temporal and smaller spatial scales) faunal filters. For instance, if we begin with the global fish fauna, the array of species is reduced by a physiological filter that allows some species to live in freshwater environments while others are confined to marine systems. Next is a series of geographical filters (e.g. glaciation, zoogeography) that result in continental (e.g. North American freshwater fishes) and regional (e.g. Great Plains fishes) fish faunas. Local habitat features and biotic interactions represent the final filters that determine the occurrence of species. Thus, faunal filters reflect the ecology of individual species, provide insight into factors limiting their occurrence and contribute to a framework for evaluating aquatic systems (Quist, Rahel & Hubert 2005).

The WSA accumulates information on the expected native fish assemblage in a stream reach, facilitates comparison to the current observed assemblage of fishes, and provides insight regarding major natural and anthropogenic factors possibly influencing the presence of individual species. Consequently, the WSA is an integrated process of acquiring and evaluating both fish and habitat data.

Warmwater stream assessment process

The WSA comprises three major components: (1) reach selection and accumulation of existing information, (2) fish and habitat sampling and (3) summarising and evaluation of fish and habitat data (Fig. 1).

Reach selection and accumulation of existing information

Sampling reaches are identified in advance of field sampling to allow biologists to accumulate existing data and identify potential logistical constraints prior to sampling (e.g. access limitations, equipment needs). Disturbances in the watershed are identified prior to sampling, including development of water resources (e.g. impoundments, irrigation diversions), land-use activities (e.g. livestock grazing, urban areas), extraction of natural resources (e.g. oil and gas development, mineral extraction, timber harvest), and natural disturbances (e.g. fire, natural movement barriers) using protocols developed by the WGFD for watershed characterization (Quist & Hubert 2004). These protocols include the accumulation of existing information on the watershed (e.g. grazing management history) and field surveys of terrestrial (e.g. riparian and upland vegetation characteristics, land use) and aquatic resources. The WSA uses historic and recent survey data to identify native fish species that likely occurred in the reach prior to settlement by Europeans and introduced species that may currently occur in the reach (Fig. 2).

Collection of fish and habitat information

Sampling is conducted at the reach scale. Reach length criteria were established to maximise the probability that all species present in the reach are sampled. Based on previous research in Wyoming (Patton, Hubert, Rahel & Gerow 2000), stream reaches for the WSA are at least 200-m long in streams with mean wetted widths up to 11 m at baseflow and 20 times the mean wetted stream width in rivers with wetted widths > 11 m. Because warmwater fishes often have distinct associations with particular habitat types, reaches encompass as many different types of channel units (i.e. pools, riffles, runs, side channels, backwaters) as possible.

Pulsed-DC electric fishing is the primary gear used for sampling fishes (Reynolds 1996). In small streams (e.g. wetted width ≤ 5 m) a backpack electric fishing unit is

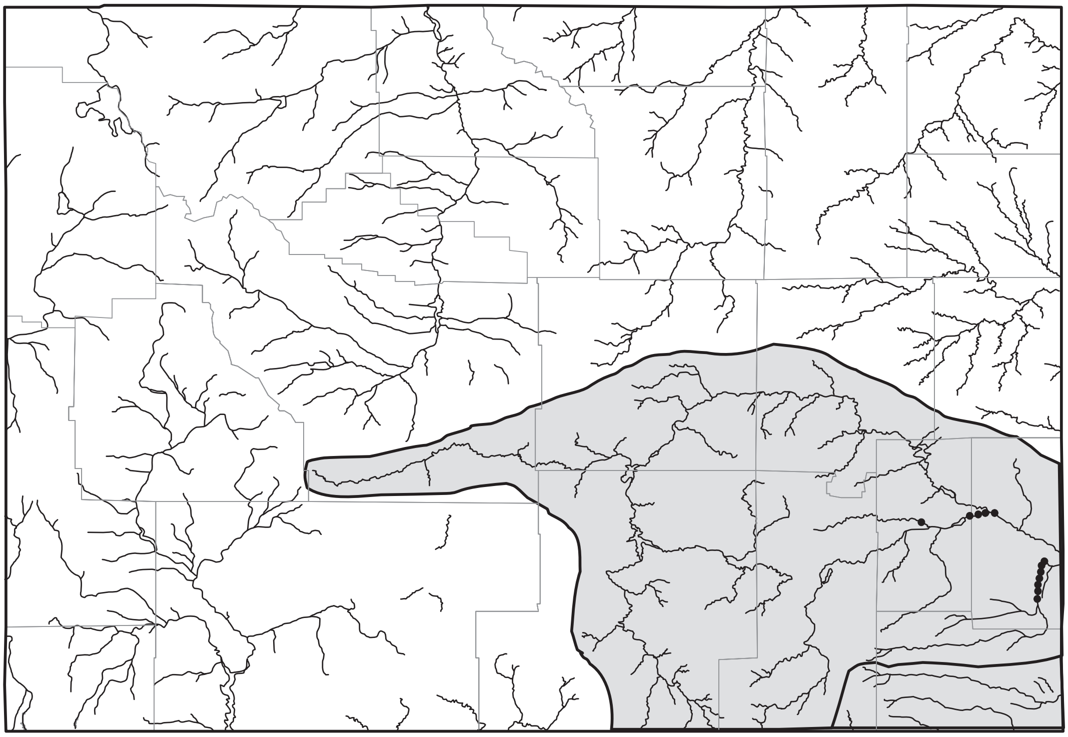

Figure 2. Example of a distribution map for suckermouth minnows in Wyoming used to determine whether a species is expected in a reach. Shaded regions indicate drainages where the species is native and solid circles represent sites where the species has been sampled.

used, but in larger streams a bank or towed electric fishing unit is used. Large rivers may require boat-mounted electric fishing gear. Where electric fishing is ineffective because of high turbidity or conductivity, seining can be substituted (Patton *et al.* 2000). Captured fish are identified to species and counted.

A variety of habitat features are measured at reach and channel-unit scales (Table 1). One component of the WSA that distinguishes it from other methods is collection of information on combinations of habitat features, i.e. the presence of habitat patches (e.g. deep pool habitat with gravel substrate and woody debris), in each channel unit. Most warmwater fishes are dependent on combinations of habitat characteristics, such as the availability of deep pool habitat that also contains woody debris (Baxter & Stone 1995; Pflieger 1997; Gido & Probst 1999).

Summarising and evaluation of fish and habitat information

The next step in the WSA is to summarise and evaluate both fish and habitat data. The WSA provides two methods for the interpretation of fish and habitat data: decision trees and a summary table.

Decision trees follow the logic of hierarchical faunal filters and provide a synoptic account of the zoogeography, reach-scale and channel-unit habitat requirements of species, and sensitivity of individual species to biotic interactions. They also provide a logical framework for evaluating large amounts of information (e.g. Stockwell, Davey, Davis & Noble 1990). Decision trees developed for use in the WSA provide evaluations driven by integration of knowledge of zoogeographical constraints, current stream conditions, and ecology of species (Fig. 3). Suitable ranges for occurrence of individual species for each habitat variable are obtained from the literature and calibrated for application in Wyoming using empirical data (e.g. Quist, Hubert & Rahel 2004b; Quist *et al.* 2005).

The table summarises information on abiotic and biotic features in the reach and the needs of individual species, and may help identify patterns in fish assemblage structure. Species are grouped into one of three categories: (1) expected and present, (2) expected and absent and (3) unexpected or non-native. A 'key' is then used to record the habitat requirements for each species and to identify the habitat characteristics found in the study reach. After the summary table is complete, patterns in the data may be observed. For

Table 1. Reach-scale and channel-unit (e.g. pools, riffles) habitat characteristics measured using the Warmwater Stream Assessment

Habitat variable	Description
Reach-scale habitat	
Elevation	Elevation (metres above sea level) is measured using a global positioning system (GPS) or from topographical maps
Turbidity	Turbidity is characterised as either high or low based on whether the bottom of a 1-m deep pool can be observed. Turbidity is determined for each reach based on whether the reach is generally turbid throughout the year and whether the reach is turbid at the time of sampling
Intermittence	Intermittence is defined as the cessation of water flow. Reaches are categorised as either frequently intermittent (i.e. intermittent at least once every 2 years) or not. Intermittence characteristics are determined for the reach based on whether it typically becomes intermittent over the course of the year and at the time of sampling
Channel morphology	The proportion of the total water surface area of the reach comprised by each channel unit is estimated by measuring the length and width of each channel unit
Maximum depth	Maximum water depth (m) in the reach
Mean width	Mean wetted width (m) is measured of each channel unit at the midpoint of its length. In channel units that are > 50 m long, stream width is measured at 25%, 50% and 75% of the length of the channel unit. Mean width of the reach is estimated using a weighted average (i.e. weighted by the length of the channel unit) of the wetted width measurements
Channel-unit habitat	
Substrate composition	Percentage of the total surface area of the channel unit comprised of silt (Si), sand (Sa), gravel (Gr), cobble (Co), boulder (Bo) and bedrock (Be) substrate
Embeddedness	Percentage of gravel, cobble, or boulder substrate that is covered by fine sediment
Instream cover	Percentage of the total surface area of the channel unit with aquatic vegetation (AV), woody debris (WD), undercut banks (UCB), or overhanging cover (OHC)
Habitat combinations	Combinations of habitat characteristics at 0.5-m depth intervals (e.g. pool with depth of 0.5–1.0 m in combination with gravel substrate and woody debris).

example, species that are absent from the reach may have a cluster of marks that reflect altered habitat characteristics or the presence of non-native species.

The last step in the WSA is to determine the abiotic and biotic features that are likely to have been altered by natural or anthropogenic disturbances, and how and why conditions have changed. For example, if a manager expects a reach to contain deep pools with little fine sediment (e.g. based on historical information or the ecology of expected species) and the reach is dominated by shallow, silt-bottomed habitats, then the manager may ask whether an upstream reservoir has reduced the frequency of flushing flows or whether grazing has increased fine sediment input to the stream. Information accumulated prior to sampling becomes valuable in this process because knowledge of watershed features can provide insight on potential factors influencing fish and habitat. The absence of a species does not necessarily confirm that there is an impact from disturbance. Rather, a species may be absent because of insufficient sampling (Reynolds 1996), upstream or downstream barriers to movement (Luttrell, Echelle, Fisher & Eisenhour 1999), or its rarity (Sheldon 1988). These considerations are not intended to undermine the utility of the WSA, but are provided to suggest that some level of professional judgment, as with other evaluation techniques (e.g. IBI), must be used to determine the historic condition of the reach and potential effects of different disturbances.

Case studies

Horse creek

Horse Creek originates in the Laramie Mountains of south-eastern Wyoming and meets the North Platte River near Lyman, Nebraska. Headwater reaches of Horse Creek are typical of mountain streams with narrow, high-gradient channels, large substrate, and fish assemblages dominated by introduced brown trout *Salmo trutta* L. and brook trout *Salvelinus fontinalis* (Mitchill). As the stream flows onto the plains, it becomes wider with smaller substrate and warmer water temperatures. Fish assemblages in downstream reaches typically consist of cyprinids and catostomids (Rahel & Hubert 1991). A reach on Horse Creek 50 km south of Torrington, Wyoming, was assessed.

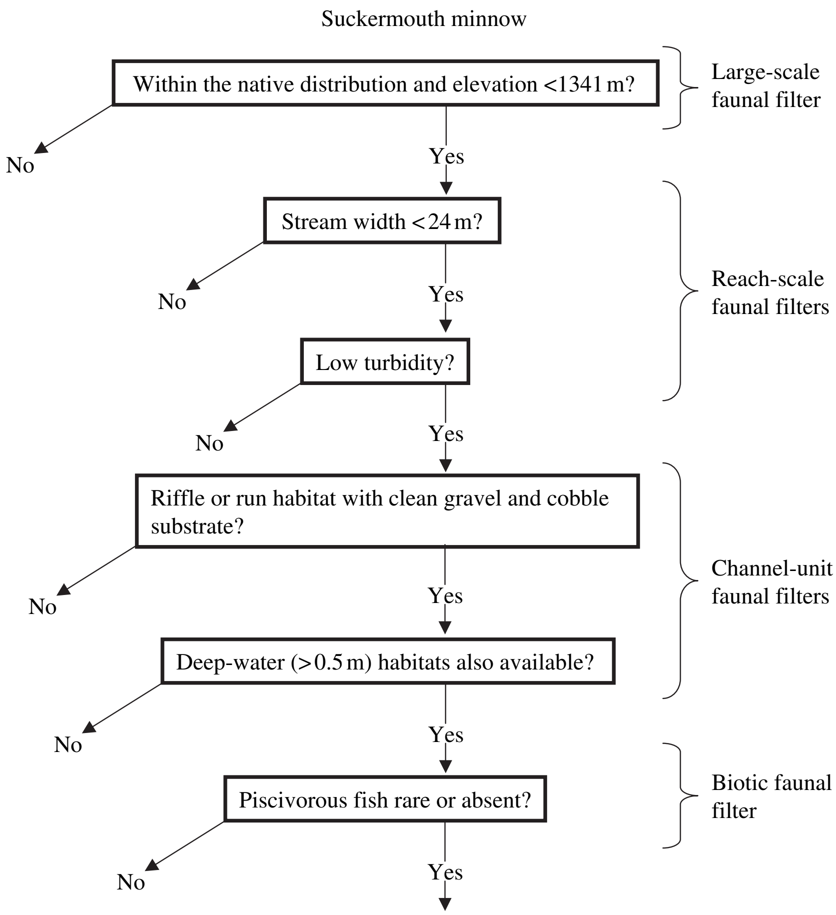

Figure 3. Example of a decision tree for suckermouth minnows in Wyoming that is used as one component of the Warmwater Stream Assessment (WSA) process. Decision trees are hierarchical and vary from large- to small-scale and require information on abiotic and biotic characteristics of the sampling reach. A 'yes' answer to all questions or branches in the decision tree indicates the species has a high probability of occurrence in the reach.

The first step was to accumulate existing information on the stream and its watershed. Livestock grazing was common throughout the drainage and discharge in the reach was influenced by agricultural irrigation withdrawals and return flows (Quist, Hubert & Rahel 2003). Based on knowledge of the system and communication with local landowners, the reach did not experience frequent intermittence and was not turbid except during high discharge events. However, upstream and downstream areas were often intermittent or completely dewatered during summer due to diversion of water for irrigation. Sixteen native species were expected to occur in the reach (Table 2).

The reach was sampled by electric fishing and all expected species, except longnose sucker (scientific names are provided in Table 2), were collected. Common carp was the only non-native species sampled. The reach was heterogeneous with regard to channel morphology and included pool, riffle, run, and side channel habitats (Table 3). Maximum depth of the reach was 1.0 m, the substratum was dominated by silt and gravel, and aquatic vegetation was the most abundant form of cover.

Decision trees provided insight on the presence or absence of individual fish species. For example, suckermouth minnow was present and its decision tree (see Fig. 3) illustrates how habitat features were probably suitable for the species. The first couplet asks whether the reach was within their native distribution (i.e. native to the drainage) and the answer was 'yes'. Suckermouth minnows occur at elevations < 1341 m in Wyoming and the reach was at 1319 m. Further, the stream reach was < 24-m wide, generally had low turbidity, and riffle and run habitats with gravel and cobble substrate were present along with deep-water habitats. Lastly, piscivorous fish were absent. A negative response to one of the questions would provide insight as to a potential limiting factor and may explain why a species was absent.

Table 2. Common name, scientific name, species abbreviation and presence (*X*) or absence (–) of fish species sampled from Horse Creek and the Laramie River, Wyoming. Expected species represent those species that were expected to occur in the reach based on their historic distribution and elevational and stream width thresholds in Wyoming. Non-native species represent non-native species sampled in the reach

Common name	Scientific name	Abbreviation	Stream	
			Horse Creek	Laramie River
Expected species				
Bigmouth shiner	*Notropis dorsalis* (Agassiz)	BMS	*X*	*X*
Brassy minnow	*Hybognathus hankinsoni* Hubbs	BMN	*X*	–
Central stoneroller	*Campostoma anomalum* (Rafinesque)	STR	*X*	–
Creek chub	*Semotilus atromaculatus* (Mitchill)	CKC	*X*	*X*
Common shiner	*Luxilus cornutus* (Mitchill)	CMS	*X*	*X*
Fathead minnow	*Pimephales promelas* Rafinesque	FHM	*X*	*X*
Hornyhead chub	*Nocomis biguttatus* (Kirtland)	HHC	*	–
Iowa darter	*Etheostoma exile* (Girard)	IDT	*	*X*
Johnny darter	*Etheostoma nigrum* Rafinesque	JDT	*X*	*X*
Longnose dace	*Rhinichthys cataractae* (Valenciennes)	LND	*X*	–
Longnose sucker	*Catostomus catostomus* (Forster)	LNS	–	*X*
Plains killifish	*Fundulus zebrinus* Jordan and Gilbert	PKF	*X*	–
Plains topminnow	*Fundulus sciadicus* Cope	PTM	*X*	–
Quillback	*Carpiodes cyprinus* (Lesueur)	QBK	*	*X*
Red shiner	*Cyprinella lutrensis* (Baird and Girard)	RDS	*X*	*X*
Sand shiner	*Notropis stramineus* (Cope)	SDS	*X*	*X*
Shorthead redhorse	*Moxostoma macrolepidotum* (Lesueur)	SRH	*	*X*
Stonecat	*Noturus flavus* Rafinesque	STC	*X*	–
Suckermouth minnow	*Phenacobius mirabilis* (Girard)	SMM	*X*	–
White sucker	*Catostomus commersoni* (Lacepède)	WHS	*X*	*X*
Non-native species				
Common carp	*Cyprinus carpio* L.	CRP	*X*	*X*
Green sunfish	*Lepomis cyanellus* Rafinesque	GSF	–	*X*
Smallmouth bass	*Micropterus dolomieu* Lacepède	SMB	–	*X*
Yellow perch	*Perca flavescens* (Mitchill)	YEP	–	*X*

*Species not expected to occur in the sampling reach.

The summary table also provides a second evaluation tool that allows broad patterns in the fish assemblage to be observed and combinations of habitat characteristics to be assessed (Table 3). Specifically, the column denoted as 'reach' is a record of which habitats were available in the sampling reach. Deep pools (> 0.5-m deep) were present with all substrate types, but combinations of substrate and cover were only observed for deep pools with silt, sand, gravel, or cobble substrate and aquatic vegetation. For all species, one or more of the required habitat characteristics were present. In addition to providing an evaluation for individual species, the summary table helped identify patterns. For example, white sucker, suckermouth minnows and longnose dace were all present in the reach and all three species are generally associated with run and riffle habitats; whereas, brassy minnows, creek chubs, common shiners and fathead minnows are typically found in pools with instream cover.

While Horse Creek has experienced extensive water development for irrigation, the sampled reach did not appear to be highly affected by anthropogenic disturbances because nearly all of the expected species and their required habitats were present. Longnose sucker was the only species that was expected and absent, even though its habitat was available. However, upstream reaches of Horse Creek are frequently dewatered because of water diversion for agriculture. Because longnose suckers are typically associated with higher-elevation streams (Baxter & Stone 1995), they may have been unable to access downstream reaches in Horse Creek.

Laramie river

A segment of the Laramie River 5 km downstream from Grayrocks Reservoir illustrates the effects of a large-scale disturbance (i.e. impoundment) on fish and habitat. Livestock grazing and diversion of water for irrigation and municipal water supplies were common in the watershed, but the greatest anthropogenic disturbance was the construction of Grayrocks Reservoir in 1980. Because of the upstream reservoir, the reach is

Table 3. Summary table of habitat characteristics of the reach and habitat requirements of fishes (species abbreviations are provided in Table 2 and habitat abbreviations are provided in Table 1) sampled from Horse Creek, Wyoming. An '*X*' represents the presence of a particular habitat characteristic in the reach or the requirements of a species

		Expected and present														Non-native	Expected and absent
	Reach	BMS	BMN	STR	CKC	CMS	FHM	JDT	LND	PKF	PTM	RDS	SDS	STC	SMM	WHS	CRP	LNS
Intermittence																		
Frequent										*X*	*X*							
Turbidity																		
Low	*X*		*X*	*X*	*X*	*X*		*X*	*X*						*X*			*X*
High		*X*											*X*					
Deep pools (> 0.5-m deep) with																		
Si	*X*																*X*	
Sa	*X*	*X*								*X*								
Gr	*X*	*X*														*X*		*X*
Co	*X*															*X*		*X*
Bo	*X*															*X*		*X*
AV	*X*											*X*						
WD	*X*											*X*						
Deep pools (> 0.5-m deep) with																		
Si + AV	*X*						*X*				*X*							
Si + WD							*X*											
Sa + AV	*X*		*X*				*X*											
Sa + WD			*X*				*X*											
Gr + AV	*X*		*X*		*X*	*X*												
Gr + WD			*X*		*X*	*X*												
Co + AV	*X*		*X*		*X*	*X*												
Co + WD			*X*		*X*	*X*												
Bo + AV			*X*			*X*												
Bo + WD			*X*			*X*												
Riffles with																		
Gr	*X*	*X*		*X*					*X*						*X*	*X*		*X*
Co	*X*			*X*					*X*					*X*	*X*	*X*		*X*
Bo	*X*								*X*					*X*		*X*		*X*
Runs with																		
Gr	*X*			*X*				*X*	*X*						*X*	*X*		*X*
Co	*X*			*X*				*X*	*X*						*X*	*X*		*X*
Bo	*X*							*X*	*X*							*X*		*X*
Backwaters or side channels																		
Present	*X*									*X*		*X*	*X*					
With AV	*X*										*X*							
Predators																		
Absent	*X*	*X*	*X*	*X*	*X*	*X*				*X*	*X*		*X*		*X*			

Table 4. Summary table of habitat characteristics of the reach and habitat requirements of fishes (species abbreviations are provided in Table 2 and habitat abbreviations are provided in Table 1) sampled from the Laramie River, Wyoming. An '*X*' represents the presence of a particular habitat characteristic in the reach or the requirements of a species

		Expected and present												Non-native			
	Reach	BMS	LNS	WHS	SRH	RDS	CSH	FHM	CKC	IDT	JDT	SDS	QBK	CRP	SMB	GSF	YEP
Intermittence																	
Frequent						*X*		*X*				*X*					
Turbidity																	
Low	*X*		*X*				*X*		*X*	*X*	*X*				*X*		*X*
High		*X*										*X*					
Deep pools (> 0.5-m deep) with																	
Si	*X*													*X*			
Sa	*X*	*X*											*X*				*X*
Gr	*X*	*X*	*X*	*X*	*X*								*X*		*X*		*X*
Co			*X*	*X*	*X*								*X*		*X*		*X*
Bo			*X*	*X*	*X*												
AV																	
WD	*X*					*X*											
Deep pools (> 0.5-m deep) with																	
Si + AV								*X*								*X*	
Si + WD	*X*							*X*								*X*	
Sa + AV								*X*									
Sa + WD	*X*							*X*									
Gr + AV							*X*		*X*								
Gr + WD	*X*						*X*		*X*								
Co + AV							*X*		*X*								
Co + WD							*X*		*X*								
Bo + AV							*X*										
Bo + WD							*X*										
Riffles with																	
Gr																	
Co																	
Bo																	
Runs with																	
Gr			*X*	*X*	*X*					*X*	*X*						
Co			*X*	*X*	*X*					*X*	*X*						
Bo			*X*	*X*	*X*												
Backwaters or side channels																	
Present																	
With AV								*X*									
Predators																	
Absent		*X*					*X*		*X*			*X*					

		Expected and absent							
	Reach	STR	SMM	HHC	PTM	PKF	BMN	LND	STC
Intermittence									
Frequent					*X*	*X*			
Turbidity									
Low	*X*	*X*	*X*				*X*		
High									
Deep pools (> 0.5 m deep) with									
Si	*X*								
Sa	*X*					*X*			
Gr	*X*		*X*						
Co			*X*						
Bo									

Table 4. Continued

	Reach	Expected and absent							
		STR	SMM	HHC	PTM	PKF	BMN	LND	STC
AV									
WD									
Deep pools (> 0.5 m deep) with									
Si + AV					*X*				
Si + WD	*X*								
Sa + AV							*X*		
Sa + WD	*X*						*X*		
Gr + AV				*X*			*X*		
Gr + WD	*X*						*X*		
Co + AV									
Co + WD									
Bo + AV									
Bo + WD									
Riffles with									
Gr		*X*	*X*					*X*	
Co		*X*	*X*					*X*	*X*
Bo								*X*	*X*
Runs with									
Gr		*X*	*X*					*X*	
Co		*X*	*X*					*X*	
Bo								*X*	
Backwaters or side channels									
Present						*X*			
With AV					*X*				
Predators									
Absent		*X*	*X*	*X*	*X*	*X*	*X*		

not turbid during most of the year and does not become intermittent. The expected native fish assemblage included 20 species (Table 2).

The sampled reach was entirely pool habitat (Table 4). Other channel-unit types were present upstream and downstream of the sampled reach, but these areas were not accessible for sampling. Fish were sampled by electric fishing and seining. Several non-native species were collected and several expected native species were absent. Decision trees and the summary table provide a comprehensive view of the fish assemblage and factors likely affecting the presence or absence of species. The presence of silt, sand and gravel and their combination with woody debris likely explain the presence of several native cyprinids and catostomids. Run habitat upstream and downstream of the reach (obtained from field notes and photographs) accounts for the presence of Iowa darters and johnny darters. The summary table shows that some groups of native species were absent, including those dependent on riffle and backwater habitats and those sensitive to non-native piscivores.

The Laramie River provides an example of how abiotic and biotic characteristics can be altered by anthropogenic activities. The reason for loss of riffle, backwater and side channel habitat was channel changes due to the presence and operation of Grayrocks Reservoir (Patton & Hubert 1993). The other factor that appears to be causing the absence of expected species from the reach was the presence of non-native piscivores. The non-native piscivores found in the sampling reach were historically absent from streams and rivers in Wyoming because of the dynamic flow regimes and unstable substrate that created poor habitat for nest-building centrarchids (Baxter & Stone 1995; Fausch & Bestgen 1997), but non-native piscivores were introduced to Grayrocks Reservoir to establish sport fisheries. The presence of non-native piscivores and altered habitat characteristics likely explain the absence of several species in the Laramie River downstream from Grayrocks Reservoir.

Conclusions and management applications

The WSA was developed for warmwater stream systems in Wyoming, but the approach may be applicable to stream systems across a wide geographical range. However, this approach may be of limited utility in systems with high species richness. In such systems, distribution maps and decision trees may be too cumbersome and overly time consuming to use. The WSA process may also be limited when the ecology of individual species is unknown, but the process may provide insight on the habitat needs of individual species if they are repeatedly sampled in specific habitat-unit types with certain habitat features.

The WSA philosophy is that acquiring and evaluating information is an integrated process. Current sampling protocols used by many natural resource agencies often focus almost entirely on collecting data. Consequently, managers often become trapped in the activity of acquiring data (Hubert & Bergersen 1998) and never interpret or evaluate the data. The WSA is cumulative (i.e. every component builds upon the previous) and culminates with an evaluation process that provides insight into the structure and function of stream systems and facilitates informed decisions.

The conceptual basis of hierarchical faunal filters and inclusion of decision trees in the WSA provides a logical approach for evaluation of fish and habitat information. Hierarchical decision trees focus on the ecology of individual species and integrate both abiotic and biotic characteristics of the stream. Although hierarchical faunal filters have largely been discussed in the context of ecological theory, and almost solely with regard to aquatic systems, it is believed that the conceptual framework of faunal filters and decision trees has the potential to be of great value in natural resource management. The WSA is one component of a larger framework used to assess natural resources holistically in Wyoming (e.g. Binns & Eiserman 1979; Quist & Hubert 2004). The WSA provides an example of a structured, logical framework for evaluation. Such approaches are necessary to increase our knowledge of fish and habitat in lotic systems and to provide managers with information necessary for making well-informed decisions.

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