RIVER RESEARCH AND APPLICATIONS

River. Res. Applic. (2007)

ARENA

USING MESOHABSIM TO DEVELOP REFERENCE HABITAT TEMPLATE AND ECOLOGICAL MANAGEMENT SCENARIOS

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ABSTRACT

An important goal in the development of the MesoHABSIM model is its integration into river management frameworks. Here I explain how the model can be used as a backbone for ecological management planning at the catchment scale, and how it may serve in establishing rehabilitation end-points. Next, I merge the MesoHABSIM model with the target fish community (TFC) approach to develop target habitat conditions and make recommendations for their achievement. By observing the frequency, magnitude and duration of extreme habitat events occurring under natural conditions, one can estimate the critical habitat values and limiting habitat factors leading to environmental stress. This creates a foundation for the developing dynamic flow/habitat augmentation schemes to help prevent human-induced pulse and press disturbance at the intra- and inter-annual scale. The rules are seasonal and use 'habitat' as an ultimate metric rather than flow alone. The final recommendations identify locations with high restoration potential and conservation needs. Copyright © 2007 John Wiley & Sons, Ltd.

KEY WORDS: bioperiod; restoration planning; UCUT-curve; habitat threshold; flow augmentation; dam removals

Received 4 June 2007; Accepted 15 June 2007

INTRODUCTION

Running water ecosystems are among the most endangered and most complex environments on our planet (Karr, 1993; Arthington and Welcome, 1995; Naiman *et al*., 1995), and their temporal and spatial variability is dependant upon both physical and biological dynamics (e.g. Junk *et al*., 1989; Ward and Standford, 1995). Effective management of river and stream ecosystems requires a detailed definition of goals and management endpoints. To specify how conservation or restoration actions might reduce effects of human-induced alterations, it is necessary to understand first how each system functioned without alteration by human activities, and then how different human activities have impacted system dynamics (Petts, 1984; L'vovich and White, 1990; Dynesius and Nilsson, 1994; Naiman *et al*., 1995; Bernhardt *et al*., 2005). Only then can we identify the maximum realizable future condition, or reference, for a river targeted for management action (Karr, 1981).

Many rivers and their catchments are so strongly altered that *in situ* observation of unimpaired conditions is almost impossible. Urbanization and other changes in land use (e.g. deforestation) have not only modified river channels but restricted floodplain habitats and altered river flow regimes, especially at the local scale. Furthermore, the effects of climate change may also modify flow regimes, and references based on present-time observations could be misleading. Historical data usually do not go back far enough to predate impacts, or they lack enough detail to make direct comparisons. This makes establishing a reference very difficult and therefore many conservation efforts are constrained to functional rehabilitation measures of largely unknown improvement potential (Magnuson *et al*., 1980; Kaufman *et al*., 1997).

The combination of physical habitat simulation models, *in situ* observations and historical information can establish a quantitative reference by describing channel shape, substrate, depth of water, flow rate, turbulence, temperature,

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shading, etc. MesoHABSIM (Parasiewicz, 2001) is well-suited for application in this context. In this article, I show the utility of the model in providing general guidelines for restoration, rehabilitation, or conservation at the river scale.

RATIONALE

Native species composition is the result of centuries-long adaptation of biota to the surrounding environment under undisturbed catchment conditions (Kalmijn, 2000), which follows the habitat templates concept described by Poff and Ward (1990). Thus, a native fish community structure, and the habitat requirements of the native fish community, can be designated as the first elements of a reference baseline. A logical consequence of this is to assume that under natural conditions habitat utilization is optimum. Therefore, the physical circumstances that maximize habitat availability for the native (or reference) fish community can be considered a rough estimate of the desired restoration conditions. This concept also applies to the temporal variation of physical circumstances (Poff and Ward, 1989; Poff and Allen, 1995). In other words, we can assume that native fauna are less adapted to, or tolerant of, short-lived habitats and are structured to reflect common conditions (in a temporal, not spatial sense). Therefore, within a specific range of variation, naturally occurring habitats with the highest cumulative duration should provide better conditions for supporting the aquatic fauna present during a specific season. By observing the frequency, magnitude and duration of extreme habitat events occurring under natural conditions, we can estimate the rare events that demarcate critical habitats leading to environmental stress.

Two types of stressors that affect aquatic communities may be defined: a pulse stressor and a press disturbance (Niemi *et al*., 1990). A pulse stressor is an instantaneous alteration in fish densities; a press disturbance causes sustained alteration of species composition. Habitat limitation can become a pulse stressor or press disturbance in several ways: (1) the habitat is so limited that it leads to extirpation of species (e.g. the river dries out completely), (2) the habitat availability is very limited over a very long period of time (e.g. for the entire summer), or (3) available habitat is limited most of the time, and occurs over consecutive years. In general, a recovery of the community from a pulse stressor (1 or 2 above) is faster than from a press disturbance (although it is related also to other factors such as life history or the distance to a recolonization source) (Niemi *et al*., 1990). Therefore, to assure ecological integrity, the human-induced press disturbance (HIPD) should be avoided.

To avoid the potential impacts caused by HIPD, a management strategy must secure appropriate intra- and inter-annual cycles that do not allow for any of the scenarios described above. The goal should be to develop augmentation rules that apply to both time scales and do not interfere with the natural flow regime. Consequently, management actions should be limited to preventing lasting damages resulting from human actions only, and rely on natural resilience otherwise. These ‘emergency’ measures are established by following natural hydrological patterns and providing increased habitat at critical moments (i.e. flow releases).

Based on the above rationale, rehabilitation recommendations may be developed by applying the MesoHABSIM model within a framework similar to instream flow incremental methodology (IFIM; Bovee *et al*., 1998), according to the following steps:

1. Selection of target aquatic community
2. Selection of bioperiods, intra-annual seasons with corresponding indicator species and life stages that have the most demanding habitat requirements
3. Computation of the MesoHABSIM model for dominant members of the target fish community (TFC) and other indicator species
4. Elimination of anticipated human impacts in order to maximize community habitat
5. Calculation of ‘pre-development’ flow time series
6. Determination of durations and frequencies of habitat stressors
7. Identification of habitat restoration opportunities and recommended measures

Below I describe the application of these procedures, and incorporate new concepts for future applications.

Selection of target community

The TFC approach, as described in Bain and Meixler (in press), provides a practical approximation of the desired fish community and a biological reference that gives a list of key species composing the modelled community. In

DOI: 10.1002/rra

doing so, it is assumed that the community structure should roughly reflect habitat structure, so the most common species should indicate the most common habitat. According to the habitat template concept (Poff and Ward, 1990), securing habitat for naturally occurring dominant species should thus preserve the most profound characteristics of the ecosystem, providing survival conditions for the majority of the aquatic community. It does not preclude the possibility of incorporating endangered species or species of special concern into the modelled community. In the northeastern US, we frequently select 5–10 species for model development depending on rehabilitation objectives and the condition of existing fauna. For rivers where TFC represents resident native fish, and diadromous species can be expected in some seasons, we include these species as indicators of specific habitat needs during migration times.

Bioperiod development

Bioperiods (flow/habitat seasons) are designated calendar periods during which the management of a river's flow and habitat condition is of particular importance to a targeted species or its particular life stage. Bioperiods are selected by evaluating the seasonal needs of the target, resident (e.g. fallfish, *Semotilus corporalis*; brook trout, *Salvelinus fontinalis*) and anadromous species from the literature (see Parasiewicz in press (b)). Next, the beginning and end dates of the periods over the hydrological time series (median daily means) are superimposed and the length of literature-specified periods is adjusted to coincide with hydrological change. The bioperiods also reflect different life stages of these species. For example, the spawning season is a time where a majority of resident fauna reproduce (frequently the spring and falling limb of the hydrograph). This period is often followed by a rearing and growth time that in the northeastern US coincides with summer and low flows in the river. Anadromous species spawning may correlate with flow increases in the fall or spring (e.g. Atlantic salmon, *Salmo salar*). Consequently, each bioperiod is associated with a different biological template with a specific faunal composition. For times with very limited biological information such as winter and very early spring (flood and storage) we do not use habitat-based criteria to determine the beginning or the end of the season but rather follow hydrological patterns only. For an example of the bioperiods developed for the Quinebaug River see Parasiewicz (in press (a)).

MesoHABSIM model

Using the methodology described in Parasiewicz (2007, this volume), MesoHABSIM can be used to define habitat availability for observed conditions at appropriate bioperiods and for behavioural 'modes'. We assume that habitat choice is based on different criteria (e.g. foraging vs. seeking shelter) in different flow conditions. Therefore, suitability indices developed using observations during low flows should not be used for assessment of high flow habitat, even during the same season.

With the exception of over-wintering and spring flood seasons, the habitat model should refer to the habitat used by the actual community present in a bioperiod. Thus, we create flow-habitat rating curves for adult resident, young-of-the-year (YOY) and spawning resident and anadromous fish. Next, we use a 'generic fish' approach to specify habitat available for the entire investigated community, in which we consider every habitat suitable for at least one of the indicator species as suitable for the community (Parasiewicz, 2007, this volume).

Elimination of anticipated human impacts

In order to recreate in general terms the 'natural' settings of physical habitat, we simulate the reversal of human-induced alterations. The flow-habitat rating curve established in the previous step serves as a base for analysis. For example, we could simulate the removal of a small dam by simply replacing the impounded area in the model with the river habitat expected at that section. Technically this happens by increasing the length-proportion of the appropriate section of the river. To select the right section we use the gradient (determined from impoundment length and dam height) and impounded topography (e.g. based on scuba reconnaissance). For larger dams with a considerable amount of sedimentation, more sophisticated modelling techniques may be necessary to assess the future habitat conditions.

The simulation of morphological change is more complex. Based on historical and topographical information, sidearm and backwater locations are selected by delineating now-dry areas that were previously part of the river corridor (as indicated by air-imaged topography typically created by flowing waters) and adding those areas into the current-condition river model. Obviously, adding sidearms and backwaters would increase the wetted area of the

DOI: 10.1002/rra

river corridor and change hydraulic conditions in the main channel, reducing flow in the main channel as water flows through sidearms and backwaters. Nevertheless, we can expect that the measured hydraulic pattern will occur in the main channel at flows which will be greater than those measured. They will be greater by approximately the same amount as the increase of the wetted-area. Therefore, in order to estimate the total amount of restored habitat by adding the observed sidearm and backwater habitat to measured main-channel conditions, the corresponding flows on the rating curve must be increased in proportion to the area. Similarly, we can simulate channel realignments and modification of substrate or cover. Other habitat features such as woody debris can be added to the model by modifying the attributes in the database of each unit (e.g. changing amount of woody debris from absent to abundant). The hydraulic impact of such changes can be estimated and corrected for by modifying the proportions of specific range for depth and velocity.

In this way we create a habitat model that best corresponds with our knowledge and estimate of historical (or future) conditions. Professional judgment and historical and empirical knowledge are primary tools for the selection of simulated measures. As mentioned above we assume that under natural conditions, the habitat is utilized to the highest possible extent. The 'improvements' are simulated with the goal of providing maximum and stable habitat conditions (i.e. high and flat rating curves). The final result of these simulations is a set of seasonal flow-habitat rating curves representing habitat conditions similar to those that shaped the native aquatic community (e.g. Figure 1).

Undisturbed flow time series

The next element necessary to analyse the frequency and duration of natural habitat events is to develop a flow time series that will correspond to simulated conditions and appropriate land use. The historical and topographical information helps in the development of adequate land cover scenarios that would affect hydrology. There are a number of widely available hydrological models that can be used for this purpose.

Duration and frequency of habitat stressors

Finally, habitat augmentation rules must be developed to avoid or mitigate both pulse stressors and press disturbances. The key criteria for these rules are developed by the determination of habitat stressor thresholds (HST) from their occurrence under natural conditions. Intra-annual rules should specify the magnitude of extreme habitat that should always be exceeded, as well as the magnitude and the duration of low-habitat events that are

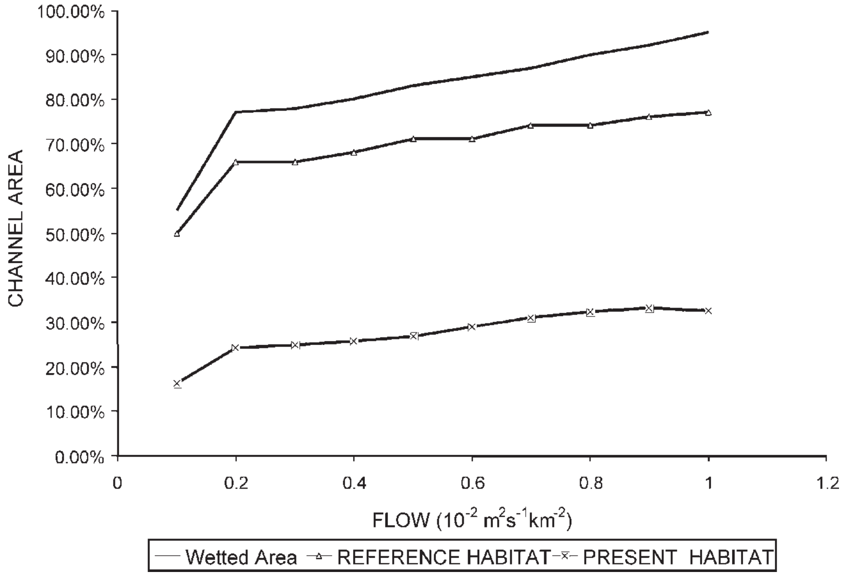

Figure 1. An example of habitat rating curves for generic fish representing close-to-natural (reference) and present conditions. The flows (X-axis) are standardized to the watershed area. The suitable habitat at reference conditions, expressed as a proportion of river channel area (Y-axis), is available across most of the wetted area. Presently less then half of the wetted area is suitable.

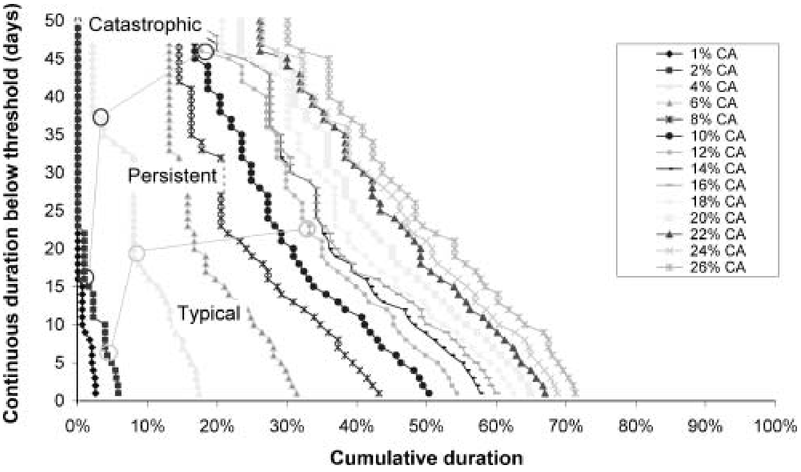

Figure 2. The example of uniform continuous under threshold curves for determination of HST. Each curve on the diagram represents the cumulative duration of events when habitat is lower than a threshold (X-axis) for continuous durations of days depicted on the Y-axis. The reduction in slope as well as increase of spacing between two curves indicate increase in the frequency of under-threshold events. We select the most outstanding curves to identify the rare, critical and common (circle-marked lines) thresholds and their inflection points to demarcate associated persistent and catastrophic durations of events with less habitat than indicated by the threshold. For more detail on construction and interpretation of UCUT curves please see Parasiewicz (in press (b)).

common in an average year. Inter-annual rules should define how frequently uncommonly low and long events could occur. Therefore, we designate two duration types for uncommon events: persistent lows that can happen 2 or 3 years in a row (equivalent to a press disturbance); and catastrophic events that occur on the decadal scale (pulse stressors). All of these rules must be organized by annual bioperiods.

To identify HST, we analyse the uniform continuous under-threshold habitat-duration curves (UCUT-curves), modified from Capra *et al*. (1995) (Parasiewicz, in press (b)). The curves evaluate durations and frequency of continuous events with habitat lower than a specified threshold (Figure 2). Using this technique, we identify four habitat quantities that correspond with different types of thresholds in the bioperiods. For low-flow conditions we designate the following levels: extreme, rare, critical and typical. For each of the thresholds, we identified the longest typical durations (zero for extreme), which demarcate the beginning of a persistent low habitat. The shortest of uniquely long durations appearing only every few years are defined as catastrophic durations and are accompanied by their frequency of occurrence. For those bioperiods with unsteady flows (i.e. continuously increasing or decreasing) and lacking biological data (i.e. winter) we may specify only extreme thresholds.

The results of HST analysis are used to develop habitat augmentation strategies (i.e. short-term flow increases) to reduce continuous duration of habitat under HST. Once the allowable duration of habitat under rare or critical levels is exceeded, the strategy calls for release of water that will increase the amount of habitat to critical or typical level, respectively (Figure 3). Such releases should not be confused with flow spates created by hydropeaking, for example, because of the different time steps (several days), magnitudes and objectives involved. Violation of the intra-annual rule triggers a set of inter-annual rules limiting the frequency of catastrophic events (press disturbance or pulse stressor). The violations of inter-annual rules call for more complex solutions involving investment in river-type-specific physical habitat improvements (i.e. that would correspond with natural conditions).

This strategy is then summarized in operational flow charts that can be used for dam operation (Figure 4). The amount of water necessary for augmentation depends on other restoration measures introduced in the catchment. Frequently, the more channel restoration can be accomplished, the less may be the water necessary to provide the required habitat increase. More details and examples can be found in Parasiewicz (in press (b)).

Developing management recommendations

The results of the approach described above provide the basis for developing restoration recommendations. First, we conduct an integrative assessment of the study area in its present status, considering fish density, existing community structure and chemical and thermal parameters. This analysis takes place at various levels of resolution.

DOI: 10.1002/rra

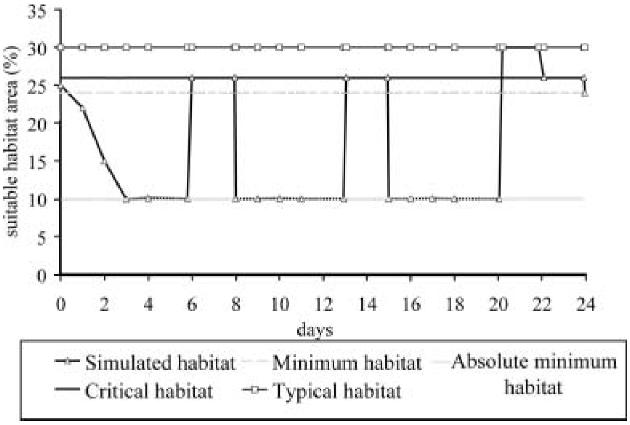

Figure 3. Hypothetical habitat augmentation in rearing and growth bioperiod. The habitat is allowed to decline under the rare threshold for allowable duration (e.g. 5 days). On the third day, the habitat is simulated to reach the extreme level, resulting in the need for augmentation in order to keep the habitat from falling below the extreme threshold. On day 6, a pulse release is necessary to provide some relief to the fauna. The pulse is 2 days long and is followed by 5 days of augmentation to the extreme threshold. Since neither the critical nor the common acute durations are exceeded, the same cycle is repeated after day 13. At the end of the second cycle the allowable duration for the critical threshold is exceeded, and the subsequent pulse must increase the habitat to the common level for 2 days. This is followed by 2 days at the critical habitat level. As long as no catastrophic duration is exceeded, this cycle repeats until the habitat increases naturally for longer than 2 days.

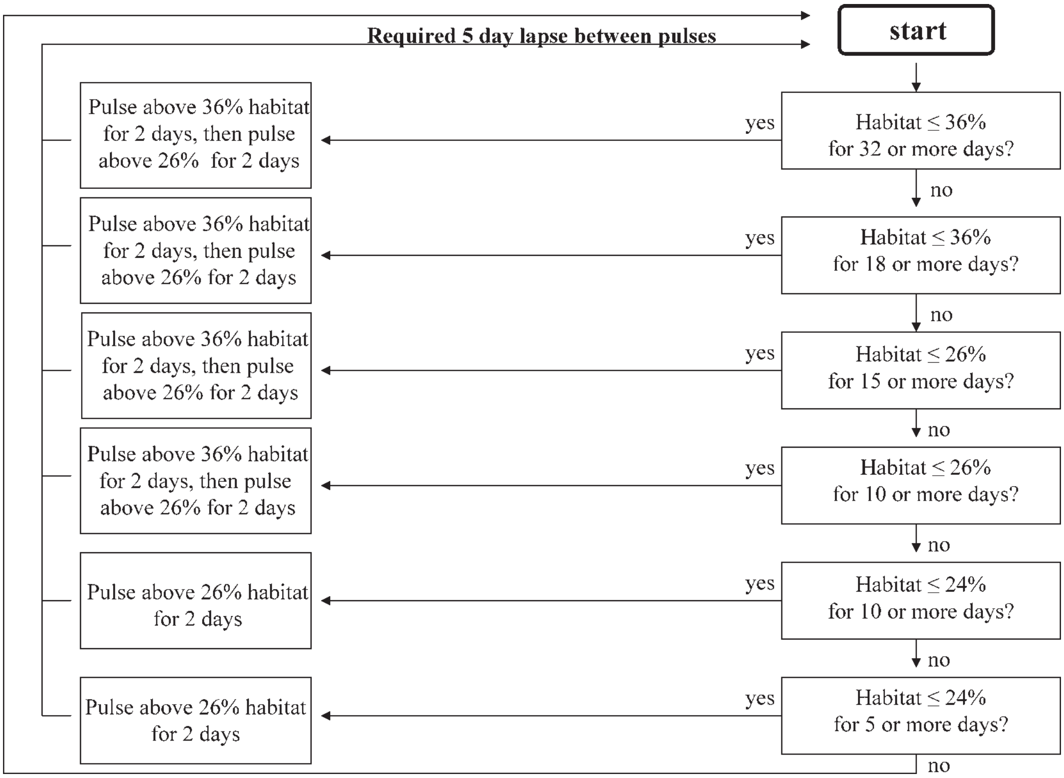

Figure 4. An example of a decision-making tree for flow releases depending on habitat level.

DOI: 10.1002/rra

To determine the overall status of the fish fauna in the entire river, the TFC is compared with the existing fish fauna. The fish data are collected in representative sites along the river by electrofishing or snorkelling (Murphy and Willis, 1996), and all observed species and their length (total length) are recorded. To separate adult from young fish, the maximum length of YOY is determined for each species based on the obtained length frequency diagrams and literature information. Cumulative abundance is assessed as an average of fish observed per unit area and that value is then compared with other rivers in the region. Finally, we compute proportions of the species in the river community. For this purpose, the densities of fish collected at different sites in the river are transformed into an estimate of the existing fish community (XFC) using TFC algorithms (Bain and Meixler, in press). This is necessary to alleviate the coincidence and 'snap-shot' character of the fish survey. Next, the structure of existing and target communities is compared with an affinity index model (Bain and Meixler, in press). The under- and overrepresentation of species is interpreted and the underrepresented species receive special attention in the recommendations.

Another step is comparing habitat structure with target and XFC structure. For this purpose, relative abundance of available habitat in the entire river for each individual species may be compared with the TFC and XFC. This can answer several questions about how well the present habitat supports the TFC and which species show clear habitat deficits that may be reflected in their underrepresentation in the XFC. Comparison with the existing community will document how much of a driving force physical habitat is in shaping the fish community (i.e. if a large amount of habitat is available and community abundances and species proportions are low, the populations are limited by factors other than habitat).

In this context, we also consider existing information on pollution, temperature and biological water quality based on macroinvertebrate surveys, as well as data about geomorphologic impairments (entrenchment, overwidening, connectivity, etc.) and compare it all with the status of the fauna.

The conclusions of these analyses help to develop a diagnosis of the ecological status of the stream and a series of improvement recommendations (such as species to be supported and measures necessary in order to provide such support). For example, if identified key species prefer woody debris in riffle habitats, rehabilitation/conservation should focus on practical ways to increase the number of these structures. We would then identify more specifically the spatial location of targeted measures by locating public lands and areas with obvious opportunities for rehabilitation or specific protection needs. We would then produce a scorecard showing relevance and importance of addressing various issues for river restoration at different sections of the river.

The final result is a list of restoration recommendations that include the flow augmentation rules described above. As presented in Parasiewicz (in press (b)), these rules create the foundation for a hydrological decision support system which determines if the appropriate amounts of water necessary for flow augmentation are available, and specifies the sources of augmentation (i.e. impoundments).

DISCUSSION

The central goal of this article is to address the need for a comprehensive view of riverine ecosystems when planning restoration measures. It is a core philosophy of the MesoHABSIM approach, and I have demonstrated that the model can be a central assessment and planning tool. The greatest achievement of this technique is closing the scale gap between physical habitat simulation and synthesis of qualitative impact assessment protocols, allowing professionals to incorporate a wide array of issues into river restoration planning. This approach merges numerous concepts and techniques created independently, while allowing opportunity for more innovation.

The other important feature of this work is that it embraces the reference river concept (Karr, 1981) and the use of quantitative techniques to develop key building blocks of such a reference system (fish community structure, hydrograph and habitat structure). The ability to create such a quantitative baseline with relative ease is also one of the strengths of MesoHABSIM.

Recognition of the importance of biological variation (e.g. Poff and Ward, 1989) is reflected in the development of the bioperiod concept, which is driven by biological processes and uses natural flow patterns as a guide, rather than calendar seasons. Flow and consequent habitat time series analysis (Milhous *et al*., 1990) becomes an approach for quantification of inter- and intra-annual variability as postulated by the Natural Flow Paradigm (Poff

DOI: 10.1002/rra

et al., 1997). The UCUT-curve technique serves as a tool for the determination of HST metrics that helps to create an approach for dynamic flow augmentation schemes as an alternative to steady minimum flow releases. The operational procedures developed under these approaches provide tangible rules for management.

An important postulate of this concept is the recognition of the joint contribution of river morphology and flow to the quality of fish habitat and use habitat, rather than flow or morphology alone as an ultimate metric of restoration needs and success. The habitat area creates a numerical value for validation of restoration measures and, consequently, goals for adaptive management. This approach was developed and applied during the Quinebaug River project and provided a list of recommendations that will be incorporated in a detailed planning and implementation phase in the near future. For more details see Parasiewicz (in press (a)).

Up until now my emphasis has been on creating a procedural framework by combining and adapting existing techniques. The area of habitat dynamics is in an early stage of development and has a high improvement potential. From a management perspective, the approach presently falls short in addressing and predicting fish population size and growth. Because of high biological variability and the complexity of ecological processes, creating direct links between habitat availability and population size is a very difficult task requiring large amounts of long-term biological data.

ACKNOWLEDGEMENTS

The Millennium Power Partners, LP, the New England Water Pollution Control Commission, The Nature Conservancy and the US Geological Survey provided original funding support for this development. The method testing and continuous development were conducted within projects funded by the New York City Department of Environmental Protection, the Greene County Soil and Water Conservation District in New York State, the New York State Department of Environmental Conservation, the Massachusetts Executive Office of Environmental Affairs, the Massachusetts Department of Environmental Protection, the Connecticut Department of Environmental Protection, the Pomperaug River Watershed Coalition and UMass Extension at the University of Massachusetts, Amherst. My then-mentor Mark Bain of Cornell University made great intellectual contributions to the development of this method and provided crucial support. I am very thankful for that. The following individuals made reviews, suggestions and ideas: Ralph Abele of the US Environmental Protection Agency, Richard A. Jacobson of the Connecticut Department of Environmental Protection, Mark Vian of the New York City Department of Environmental Protection, David Armstrong of the US Geological Survey, Todd Richards of the Massachusetts Division of Fisheries and Wildlife, Neil M. Fennessey of Hydrologic Services, Inc. (HYSR), Scott D. Jackson of UMass Extension and many other collaborators and friends. The other members of our team participated in data preparation: Hollie Kitson, Jeffrey D. Walker, Jeffrey J. Fountain, Lisa Snopkoski, Marshall P. Thomas and Ethan R. Sobo. Jessie Gunnard and Jessica Dodge provided great editorial help. A special thank you to Craig Elliott and Laura Wildman for thoughtful review of the manuscript and great suggestions.

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