A patch perspective on summer habitat use by brown trout *Salmo trutta* in a high plains stream in Wyoming, USA

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Abstract – We quantified the use of habitat patches by brown trout, *Salmo trutta*, during summer conditions in a plains stream in the western United States. A Global Positioning System was used to map discrete habitat patches (2–420 m^2) consisting of macrophytes, wood accumulation, or deep water. Habitat use by brown trout was monitored by radio telemetry. Brown trout used habitat in a nonrandom manner with 99% of all daytime observations and 91% of all nighttime observations occurring in patches that consisted of combinations of deep water, wood accumulations or macrophytes even though such patches constituted only 9.8% of the available habitat. Brown trout used deep water almost exclusively during the day but broadened their habitat use at night. Most fish stayed within a large plunge pool created by a low-head dam. This pool supplemented the deep-water habitat that was naturally rare in our study area and illustrates how human modifications can sometimes create habitat patches important for stream fishes.

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Introduction

There is growing interest in examining the distribution of aquatic organisms from a landscape perspective that emphasizes the patchiness of stream habitats (Fausch et al. 2002; Le Pinchon et al. 2006). A patch is a discrete area with a set of characteristics that are important to the organism under study. Determining the characteristics of patches used by various species is critical for managing and conserving stream fishes. For example, imperiled blue shiners, *Cyprinella caerulea*, were seldom found outside of pool habitats in a southeastern United States stream (Johnston 2000). Pirate perch, *Aphredoderus sayanus*, were highly associated with areas of wood accumulations in headwater coastal streams in Louisiana (Monzyk et al. 1997). Sometimes patches can be important at certain time periods or for certain life history stages. Juvenile Coho salmon, *Oncorhynchus kisutch*, in coastal Oregon streams overwinter in pools or side channels with large woody debris and enhancing such habitat increases the production of Coho smolts (Solazzi et al. 2000).

Specific habitat patches needed during certain times of the year or by certain life history stages can be rare within the landscape and thus have a large influence on the local persistence of populations (Fausch et al. 2002). For example, relatively rare groundwater-fed pools that did not freeze in winter were critical for the persistence of Arkansas darter, *Etheostoma cragini,* in an intermittent Colorado plains stream (Labbe & Fausch 2000). Spawning habitat for cutthroat trout, *Oncorhynchus clarkii*, in a large Montana river basin was mainly present within two headwater tributary reaches that contained gravel substrates appropriate for redd construction (Magee et al. 1996).

Brown trout, *Salmo trutta,* tend to be highly associated with features that provide cover in streams such as deep pools, wood, or undercut banks (Clapp et al. 1990; Meyers et al. 1992). In plains streams, wood input is limited and channels tend to consist of long runs with shifting sand substrates (Rahel &

Hubert 1991). Consequently, habitats favored by brown trout such as deep pools or wood accumulations tend to be scarce and, when present, exist as relatively discrete patches surrounded by unsuitable habitat. This suggests that a patch perspective might be a useful way to characterize brown trout habitat in such systems.

We examined habitat patchiness and habitat use by brown trout in the Laramie River, a high plains stream in southeastern Wyoming, USA. Our objectives were to (i) map the distribution of habitat patches within a river segment; (ii) quantify the use of these patches by brown trout and determine preferred patch types; and (iii) compare day versus night use of habitat patches.

Methods

Study area

The study area was a 2.0 km segment of the Laramie River, a 5th–order tributary of the North Platte River in southeastern Wyoming (Fig. 1). A water diversion dam about 1 m tall marked the upstream end of the study reach and inhibited upstream movement by fish during low streamflow conditions in the summer. No other fish movement barriers were present in the study segment.

Most of the river consisted of relatively homogenous substrates of cobble, gravel, and sand with little structural cover in the water column. A small proportion of the river consisted of discrete patches of aquatic macrophytes, wood accumulations, or deep water (>1 m deep). Macrophytes, primarily common water milfoil (*Myriophyllum exalbescens*) and mare's tail (*Hippuris vulgaris*), were present as distinct beds, typically adjacent to the stream bank. Large wood in the form of logs, root wads, overhanging branches, or aggregations of these, were present in the stream channel. Macrophyte beds and wood were usually separated by areas of open water making it possible to delineate discrete patches of fish habitat. Deep water (>1 m in depth) was infrequent in the study area. Daily mean streamflow during the study period was about 2 m^3 s^{-1}, which is typical for the Laramie River in late summer.

Stream temperatures were taken several times during each tracking period with a handheld thermometer at the upstream end of the study area. Temperatures ranged from daytime highs of 15–22 °C and nighttime lows of 13–19 °C with diel temperature ranges of about 3 °C.

Mapping habitat patches

We used a Global Positioning System (Trimble Pathfinder Pro XRS GPS receiver) to map the location of stream banks and habitat patches in the Laramie
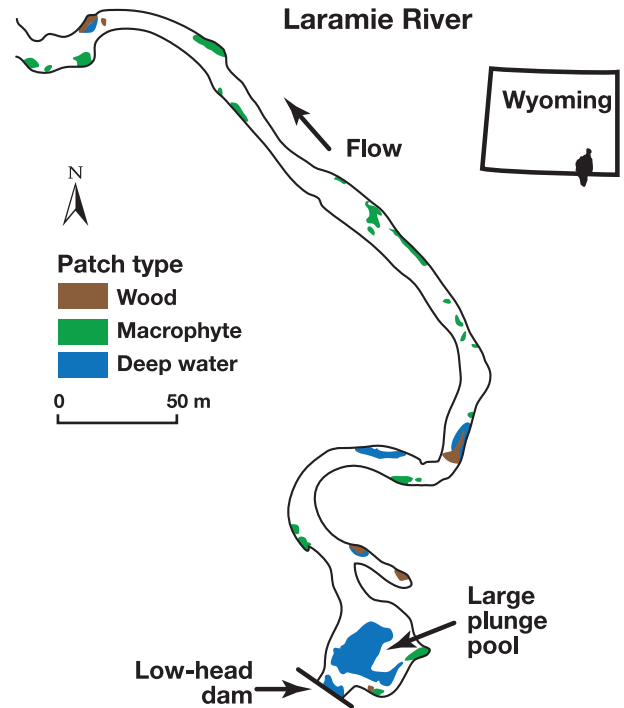

Fig. 1. Habitat patches in a 450 m reach of the Laramie River downstream of a low-head dam used to divert water for irrigation. The study reach was 15 km southwest of Laramie, Wyoming. UTM coordinates at the downstream end of the study reach were 439569.8 E and 4563844.0 N (Zone 13N, NAD27) All transmitter-implanted fish were located within this reach during the course of the study.

River during baseflow conditions from July 22 to 28, 2004. We defined six patch types or combinations of patch types: deep water (>1 m depth), deep water-macrophyte, deep water-wood, macrophyte outside of deep water (macrophyte), wood outside of deep water (wood), and open water. Although open water can be viewed as the background matrix from a landscape ecology perspective, we considered it a type of habitat patch in order to facilitate the analysis of habitat selection. The minimum size threshold used to define a patch was 2 m^2 which was the smallest area that could be reliably mapped using the Global Positioning System.

We mapped the wetted channel by walking the bank and taking a point measurement of 5 vertices every 2 m, unless more points were needed to accurately capture detail. Polygons that delineated a habitat patch were mapped by wading in the stream and taking point measurements of 10 vertices every 0.5 m along the perimeter of the patch, unless more points were necessary to trace the detail of the patch. We used a vertex averaging method to improve the accuracy of our maps. Vertex averaging collects a point position once per second and averages them to approximate the true location (Dauwalter et al. 2006). Spatial data were

differentially corrected using U.S. Geological Survey base station data to ± 0.5 m with 5 vertices per point and ± 0.4 m with 10 vertices per point at 68% precision (GPS Pathfinder Office 2.90, Trimble Navigation Ltd., Sunnyvale, CA, USA). Mapping data were converted to shape files using GPS Pathfinder Office 2.90. Maps were created using ArcGIS version 8.1 (ESRI, Environmental Systems Research Institute, Inc., Redlands, CA, USA).

Fish collection

Adult brown trout (≥250 mm total length) were captured by electrofishing or angling within the study segment between July 30 and August 9, 2004. Fish were anesthetized and surgically implanted with a radio transmitter (1.7 g, Advanced Telemetry Systems) using the shielded needle technique. All fish weights allowed for meeting the 2% body weight guideline suggested by Winter (1983). After recovery from anesthesia, fish were placed into a covered flow-through holding cart set in the river for 30–60 min prior to release at their location of capture.

Habitat use by brown trout

Brown trout were located during seven daytime periods (August 10, 13, 16, 24, 25, 26, 29) and seven nighttime periods (August 11, 14, 17, 24, 25, 27, 29) in 2004. For both time periods, tracking began at the upstream end of the study site. We slowly walked the bank in a downstream direction until all fish were located. Fish were located using an ATS model R2000 (Advanced Telemetry Systems, Isanti, MN, USA) radio receiver and Yagi directional antenna. The transmitter number, time, and location of each fish within the stream (inside or outside of a previously mapped patch) were recorded on a field map showing the locations of the habitat patches that had been previously mapped as described above. Fish locations also were recorded with a handheld GPS unit (Garmin Vista). After locating the farthest downstream fish, we paused for 30 min then walked along the bank upstream and relocated all transmitter-implanted fish. This protocol was repeated twice more so that a total of six passes of the study area were completed.

Daytime tracking was done between 1000 and 1600 h. On August 24 and 25, 2004, only two locations for each fish were documented beginning at approximately 1100 h. Overall, each fish was located a total of 34 times over the seven daytime periods. The large size of the fish being tracked, the high water clarity at baseflow conditions, and the relatively discrete delineation of habitat patches allowed us to locate fish relative to the location of habitat patches during the day. The timbre of the signal broadcast from the receiver changed noticeably when the range to the transmitter became small (<3 m) and the antenna was pointed directly at the transmitter (a percussive "snap" replaced the beeping sound). Once near the fish, we could determine whether it was within a patch of habitat (i.e., wood, deep water, or macrophyte patch) or located in open water. Fish located in cover never spooked when we approached, allowing us to move close to verify their location. On occasions when a fish was using open water, visual identification of the fish was possible. On two occasions fish in open water were disturbed. In these instances, the fish moved to the closest cover, usually <5 m from their original position. One fish returned to open water before the next observation and one fish stayed in cover.

Nighttime tracking was done between 2200 and 0400 h. On August 24 and 25, 2004, only two locations for each fish were documented beginning at approximately 2300 h. Overall, each fish was located a total of 34 times over the seven nighttime periods. At night, we relied on the sound from the transmitter to discern the location of the fish. Although it was more difficult to see fish at night, it was easier to approach without disturbing them. On the last observation of a tracking period, we used a flashlight to spot the fish and verify its location. When we were unsure of a fish's location, we would wade into the river downstream of the fish and approach slowly without any lights on (to avoid spooking the fish). We approached the fish until we were close enough to determine if it was using a habitat patch or open water based on the sound from the receiver which changed when the antenna was pointed directly at the fish.

Analysis of patch selection

One of the challenges in resource selection studies is defining the geographic extent for calculating resource (i.e., patch) availability (Manly et al. 2002). We opted to calculate patch availability only for the portion of the Laramie River occupied by our study organisms. Although brown trout could have moved throughout the 2 km study area, all observations of transmitter-implanted fish occurred within a 450 m reach downstream from the low-head dam that diverted water for irrigation. Therefore, we quantified patch availability within this reach because it included the home range of all 12 brown trout during our period of study. Using a GIS, we calculated the proportional availability of each patch type in the 450 m reach downstream as the sum of the areas of all patches of that type divided by the total area of the reach.

Selection ratio analysis was used to compare the magnitude of habitat type selectivity during day and night observations (Manly et al. 2002). The selection

ratio is the proportional use of a habitat type divided by the proportional availability of that habitat type. Values can range from 0 to infinity with values near 1 indicating no evidence of selection. Values >1 represent evidence of selection for a habitat type and values <1 show evidence of selection against a habitat type. Proportional patch use for each brown trout was calculated by dividing the number of observations of that fish in each habitat patch type by the total number of observations for that fish ($N = 34$ for all fish). Selection ratios for each patch type were calculated by dividing the proportional patch use by the proportional patch availability for each fish. An average selection ratio for each habitat patch type was then calculated by averaging the values across all fish. Confidence intervals for the selection ratios were calculated based on the Bonferroni method whereby $\alpha = 0.05$ was divided by $n-1$ habitat patch types ($N = 6$) to give a more conservative $\alpha = 0.01$. Thus, we calculated 99% confidence intervals and determined whether selection ratios for given patch types were below 1 (indicating selection against a patch type) or above 1 (indicating selection for a patch type).

Results

Distribution of habitat patches

Most of the Laramie River was sand/gravel substrate in open water habitat, with macrophyte, wood and deep water patches collectively constituting only 14.2% of the stream area in the 450 m reach where brown trout were located (Table 1). The most common patch type was deep water at 8.4% of the stream area but this mainly occurred as a large plunge pool (420.2 m^2) immediately below the water diversion structure (Fig. 2). There was a single deep water-macrophyte patch (12.5 m^2) that constituted 0.3% of the stream area and which was located
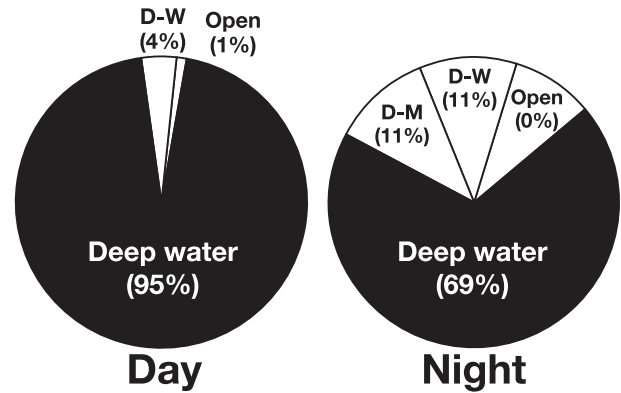

Fig. 2. A comparison of day versus night habitat use by brown trout in the Laramie River, Wyoming. Patch types are deep water, deep water-wood (D-W), deep water-macrophytes (D-M), and open water habitat (Open).

adjacent to the large plunge pool below the water diversion structure. Deep water-wood patches constituted 1.1% of the total area and ranged from 3.2 to 36.6 m^2. Macrophyte patches constituted 3.8% of the total area of the study reach and ranged in size from 2.0 to 45.0 m^2. Wood patches constituted 0.6% of the stream area in the study reach and ranged in size from 5.8 to 17.6 m^2.

Distribution of large brown trout

Large brown trout were highly concentrated in the deep plunge pool downstream of the low-head dam. Despite extensive electrofishing of the 2-km stream segment, we collected only three brown trout ≥250 mm total length outside of this pool. These three fish were captured in wood accumulations in deep water. The other nine brown trout were captured by electrofishing or angling within the plunge pool. Mean total length of the brown trout was 389 mm (SD = 121 mm).

Table 1. Habitat use and habitat selection ratios for day and night habitat patch use by brown trout in the Laramie River. Selection ratios greater than 1 indicate selection for a patch type and selection ratios less than one indicate selection against a patch type.

Patch type	Proportional use	Proportion availability	Selection ratio	SE	99% CI
Day habitat use					
Deep water	0.951	0.084	11.320	0.463	9.881–12.759
Deep water-macrophyte	0	0.003	0	0	–
Deep water-wood	0.042	0.011	3.780	3.547	−7.237–14.797
Macrophyte	0	0.038	0	0	–
Wood	0	0.006	0	0	–
Open	0.007	0.857	0.009	0.006	−0.005–0.023
Night habitat use					
Deep water	0.691	0.084	8.228	1.007	5.099–11.357
Deep water-macrophyte	0.110	0.003	36.750	11.770	0.194–73.306
Deep water-wood	0.105	0.011	9.576	4.767	−5.228–24.380
Macrophyte	0	0.038	0	0	–
Wood	0	0.006	0	0	–
Open	0.091	0.857	0.106	0.035	−0.002–0.215

Habitat use by brown trout

Nine of the 12 fish (fish 1–9) did not leave the vicinity of the plunge pool (deep water patch) formed by the low-head dam that marked the upstream end of the study area (Fig. 1). These fish were always located in the deepest part of the pool (approximately 2.5 m deep) during the day (Table 2). At night, however, these fish often moved to areas near the perimeter of the pool where they utilized macrophyte patches or open water along the bank (Table 2). On several occasions, we observed brown trout feeding on young white suckers, *Catostomus commersonii*, at night in these shallow habitats.

The other three fish (fish 10, 11, and 12) also spent much of the day and night in the plunge pool formed by the low-head dam but occasionally traveled downstream, usually at night. For example, fish 11 was always located within the diversion pool from Aug 10–16 but nighttime observations included deep water-macrophyte, deep water-wood, or open water patches (Table 2). This fish moved approximately 250 m downstream during the night of August 24 where it was observed in open water. It subsequently moved upstream to occupy a deep water-wood patch from August 25 to 27, before moving to a location 450 m downstream of the diversion structure on the night of August 29 where it was observed in open water and in a deep water-wood patch.

Habitat patch selection

Brown trout were highly selective in their use of habitat and habitat use differed between day and night (Table 2). During the day, brown trout used almost exclusively the deep water patch associated with the

low-head dam (Fig. 2). Selectivity analysis indicated strong selection for deep water (selection ratio > 1) and strong avoidance of open water habitat during the day (selection ratio < 1) (Table 1). At night, brown trout broadened their habitat use (Fig. 2). Although fish still spent much of their time in the deep water patch associated with the low-head dam, they also spent time in deep water-macrophyte and deep water-wood patches as well as in open water (Fig. 2). Selectivity analysis again indicated strong selection for deep water and strong avoidance of open water habitat during the night (Table 1). There was a trend for increased selection for deep water-macrophyte and deep water-wood patches but the 99% confidence intervals of the selection ratios included one. The patch types used by brown trout, (deep water, deep water-macrophtye, and deep water-wood), constituted only 9.8% of the available habitat (Table 1).

Discussion

Brown trout used habitat in a nonrandom manner in the Laramie River. Most of the study site consisted of shallow water with open substrates that offered little protection from predators such as great blue herons, *Ardea herodias*, or mink, *Mustela vison*. Refuge from predators existed as relatively discrete patches of habitat associated with deep pools, some of which also contained wood accumulations or macrophytes. Brown trout showed strong selection for such patches. We only assessed habitat use by brown trout during the summer in a single year. However, our results are consistent with other studies that report a strong association of large brown trout in summer with cover in the form of structures (Clapp et al. 1990), pools or undercut banks (Meyers et al. 1992), or deep water

Table 2. Habitat use by 12 brown trout in the Laramie River, Wyoming. The proportion of observations occurring in each habitat type is shown for day and night periods.

					Fish identification number							
	1	2	3	4	5	6	7	8	9	10	11	12
Total length (mm)	570	256	304	555	549	270	318	370	318	307	328	520
Day observations												
Deep water	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.941	0.529	0.941
Deep water-macrophyte	0	0	0	0	0	0	0	0	0	0	0	0
Deep water-wood	0	0	0	0	0	0	0	0	0	0.029	0.470	0
Macrophyte	0	0	0	0	0	0	0	0	0	0	0	0
Wood	0	0	0	0	0	0	0	0	0	0	0	0
Open water	0	0	0	0	0	0	0	0	0	0.029	0	0.059
Night observations												
Deep water	0.647	0.941	0.971	0.912	1.000	0.882	0.647	0.647	0.529	0.794	0.265	0.059
Deep water-macrophyte	0.353	0	0	0.088	0	0	0.118	0.206	0.029	0.059	0.176	0.294
Deep water-wood	0	0	0.029	0	0	0.088	0.029	0	0.176	0.059	0.265	0.618
Macrophyte	0	0	0	0	0	0	0	0	0	0	0	0
Wood	0	0	0	0	0	0	0	0	0	0	0	0
Open water	0	0.059	0	0	0	0.029	0.206	0.147	0.265	0.088	0.265	0.029

(Rincón & Lobón-Ceriá 1993). Lobón-Ceriá (2008) noted that water depth acts as a proxy for space availability for large brown trout and that self-thinning coefficients for such trout declined at sites with the greatest mean water depth.

It is common for riverine brown trout to display little daytime movement during the summer (Burrell et al. 2000; Diana et al. 2004). This is consistent with the behavior of brown trout in our study where fish were located almost exclusively in the plunge pool created by the irrigation diversion dam (deep water patch) and rarely moved among habitat patches during the day. By contrast, brown trout were more active at night and most fish broadened their habitat use by moving into macrophyte beds or wood accumulations that were in deep water. However, most of the fish returned to the deep plunge pool to spend the day. Young (1995, 1999) also found that adult brown trout in several Rocky Mountain streams moved among foraging sites during the night but typically returned to the same resting site each morning and were relatively inactive during the day. A similar pattern was reported for large brown trout (>400 mm total length) in a Michigan stream (Clapp et al. 1990). We observed that brown trout avoided open water areas in the Laramie River even at night, a finding consistent with the behavior of this species in the Rio Grande River of Colorado (Shuler et al. 1994). The nocturnal activity of large brown trout appears to reflect a tendency for these fish to be piscivorous (Clapp et al. 1990).

We examined habitat use by large brown trout in the summer and it is likely that the types of habitat patches important to brown trout will vary seasonally. Although we did not monitor habitat use during winter, the plunge pool below the diversion dam is likely to provide the deep water, slow current habitat important for trout in winter (Meyers et al. 1992). Our observations indicate that within our study area, brown trout spawn in patches of riffles containing small gravel. Such patches are of obvious importance for persistence of the brown trout population but are used for only a few weeks each autumn. Although we did not quantify habitat use by small brown trout, our observations indicate that young fish were generally found in shallow water habitats, a finding reported elsewhere (Heggenes 1996).

Traditional aquatic habitat features (e.g., depth, current velocity, substrate type) that are measured along transects summarize habitat conditions at the reach scale (Rahel & Hubert 1991; Bain & Stevenson 1999). However, average values of a suite of habitat metrics do little to illuminate where the best fish habitat exists within the reach (Fausch et al. 2002). Additionally, it is often a combination of features that provides important habitat for fishes (Young 1995; Quist et al. 2006). For instance, brown trout in a Michigan stream used a combination of deep water with log cover (Clapp et al. 1990). Similarly, in the Laramie River wood accumulations or macrophyte beds were not used by brown trout unless these features were in relatively deep water (>1 m).

In addition to brown trout, creek chubs, *Semotilus atromaculatus,* are also highly associated with discrete habitat patches in the Laramie River. Belica & Rahel (2008) reported that 79% of 245 creek chubs captured in a segment of the river that overlapped our study site were collected within wood or aquatic macrophyte patches that constituted only 15% of the channel area. In a Michigan stream, brown trout were highly associated with cover provided by logs, even though such cover constituted only about 20% of the available habitat (Clapp et al. 1990). Other examples of stream fish using relatively discrete habitat patches include the association of pirate perch, *A. sayanus,* with wood accumulations (Monzyk et al. 1997), the use of cold groundwater seeps by trout during summer (Ebersole et al. 2003), and the association of some tropical stream fishes with rocky patches (Arrington et al. 2005). Sometimes critical habitat patches are determined by biological characteristics. For example, the endangered Oregon Chub, *Oregonichthys crameri*, is associated with off-channel habitats in the Willamette River but only if such habitats lack nonnative predatory fish species (Scheerer 2002).

In many cases, the occurrence of a species may depend on relatively rare or unique habitats (Burr et al. 2001; Magoulick & Kobza 2003). The large plunge pool below the irrigation diversion dam at the upstream end of the study area appears to be such a habitat for brown trout in the Laramie River. This single pool constituted only about 7% of the study area but accounted for 95% of all day time and 69% of all night time observations of brown trout during the telemetry study. Also, 9 of the 12 fish that we were able to collect for implantation with radio transmitters were captured from this pool despite extensive efforts to collect trout throughout the 2 km segment of the river. The pool was the largest and deepest in the study segment with a maximum depth of 2.5 m and an area where water depth was ≥1 m depth of 420 m^2. The pool was not thermally stratified and thus was not likely providing a thermal refuge for brown trout, especially since water temperatures throughout the study remained below those stressful to brown trout (>24 °C; MacCrimmon & Marshall 1968). Rather, the pool likely served as a refuge from predators. The pool was adjacent to a bed of macrophytes that harbored an abundance of small fishes, especially young white suckers. On several occasions, brown trout were observed feeding on these fishes at night along the periphery of the pool.

The large plunge pool used by brown trout in the Laramie River is an artificial habitat. Similarly, critical habitat for the European bullhead, *Cottus gobia*, in a regulated river in Belgium was provided by patches of artificial stones added to strengthen bridge abutments (Knaepkens et al. 2002). Bunt et al. (1998) found that greenside darters, *Etheostoma blennioides*, a species of conservation concern, used rare riffle habitats formed by high discharge below a fish weir in the Grand River, Ontario. In some circumstances, reliance on human-created habitats may prove useful in controlling invasive species. Introduced brown trout can decimate populations of native fishes (Townsend 1996), and our results suggest that efforts to control brown trout populations in small streams should target the rare, deep-water areas. In regulated streams, such areas are often associated with pools created by water diversion structures offering an opportunity to reduce highly preferred and artificial habitat.

Many species of stream fish use relatively discrete habitat types such as pools, riffles, or wood accumulations that exist as patches in a matrix of largely unsuitable habitat (Johnston 2000; Belica & Rahel 2008). For these species, a patch perspective is a useful way of characterizing habitat use (Le Pinchon et al. 2006). As stream fish ecology moves toward a riverscape perspective, it will become increasingly important to identify the patch characteristics necessary for the survival of various fish species. Sometimes, important patches may be the result of human activities, such as the large plunge pool that supplemented the naturally rare, deep-water habitat in our study stream.

Acknowledgements

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