

The Importance of Day Versus Night Fish Sampling for Instream-flow Determinations

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Abstract: Developing and recommending protective flows for stream fishes requires precise information on how fishes use their habitat. Collections to establish fish-habitat relations are typically conducted during daylight hours, but because of diel habitat shifts exhibited by many warmwater stream fishes, we were concerned that determining protective flows only from day collections would result in recommended flows that were not protective. We tested for diel differences in habitat selection by stream fishes and evaluated the effects of these differences on simulated usable habitat area as flows varied. Logistic regression modeling and habitat-selection analyses for five fish species showed substantial differences between day and night habitat relations. A two-dimensional hydrodynamic model that used habitat selection and flow specific habitat-availability data indicated that habitat selection data collected during the day were generally not sufficient to protect adequate habitat throughout the diel period for the majority of species.

Key words: hydrodynamic modeling, fish habitat, stream fish, prairie river

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 59:336–347

Few rivers in the United States escape flow alteration from impoundment, diversion, or withdrawals (Benke 1990). Maintaining fish biodiversity or sport fishery quality in flow-managed systems is now one of the most serious challenges facing fisheries managers. Ideally, managed flows should replicate the natural flow regime (Poff et al. 1997) to preserve maximum ecological values, but in practicality, fisheries biologists can only suggest or achieve minimum flows that provide adequate habitat for critical life stages of a species of interest. The common approach in instream-flow studies is to determine the range of habitat elements that a species uses or selects from the suite of available depths, velocities, and substrates. By assuming that high use or selection of a habitat equates with importance, we suggest flows that provide as much of that habitat as possible at the appropriate time.

The amount of appropriate fish habitat available at different discharges can be quantified by various hydraulic habitat modeling approaches, e.g., PHABSIM (Bovee et al. 1998) or two-dimensional hydrodynamic modeling (Ghanem et al. 1995). With these approaches, fish use or selection of particular ranges of habitat conditions are determined, and the corresponding conditions are quantified for particular stream reaches to produce information on the amount of suitable habitat available at different flows. Although site-specific information on fish-habitat use for instream-flow purposes is almost always obtained during daylight hours, many fish inhabiting warmwater rivers and streams are known to have different diel habitat preferences (Mendelson 1975, Magnan and Fitzgerald 1984, Todd and Rabeni 1989, Matheney and Rabeni 1995, Burr and Stoeckel 1999, Yu and Peters 2002). We hypothesize that models using only day-collected data could be biologically misleading. Our objective was to test for diel differences in habitat selection by stream fishes and evaluate the effects of those differences on simulated usable habitat area as flows varied.

Study Area

The Marais des Cygnes River is a seventh-order river that originates in east-central Kansas and flows 296.1 km before reaching Missouri, where it travels 54.4 km before entering Truman Reservoir. Flow is regulated by three large flood-control reservoirs in Kansas (Hillsdale, Pomona, and Melvern), 47 smaller impoundments, and a power plant located near the Missouri-Kansas state line. Mean discharge was 8 m³/s and mean wetted width was 37 m during the sampling period (June–July). On average, the Marais des Cygnes River exceeds bankfull discharge (493 m³/s at gauging station 06916600 located near the Missouri-Kansas state line) eight times per year.

The river lies within the Osage Plains Ecoregion with the study reach included in the scarped Osage Plains subsection (Nigh and Schroeder 2002), which has a landscape consisting of shale plains separated by limestone scarps decreasing in elevation in a stair-step fashion. Limestone bedrock is regularly exposed within the area. The resulting channel morphology is a series of long deep-water sections separated by what we define as shallow-water habitats. Shallow water habitats were ~200-m long bedrock outcroppings which resulted in a heterogeneous mixture of riffles, pools, runs, and backwaters. Substrate was dominated by cobble, pebble, and bedrock outcroppings. This study is based on data collected from one of these shallow-water habitats in summer 2002.

Methods

Quantifying the amount of fish habitat available under various flow conditions so that day versus night comparisons could be made required a three-step procedure. First, we determined fish-habitat relations and established habitat-selection categories, each encompassing ranges of depth, velocity, and substrate. Second, hydraulic characteristics (depths and velocities) were simulated for different flows at the study

site and dominant substrate was mapped. Finally, the simulated depth and velocity information was combined with substrate information using Geographic Information System (GIS) tools based on biological sampling (habitat categories) results to determine the aerial extent of selected habitat for different fish species under various flow conditions.

Developing Fish-Habitat Categories

A total of 313 day samples and 120 night samples was collected from 25 June through 31 July 2002. Fishes were quantitatively collected with pre-positioned electrofishing grids that consisted of an electrode frame (2.5 x 0.6 m) powered by a 120 volt, 2300 watt alternating-current generator. Transects, perpendicular to the direction of flow, were spaced every 10 m throughout the 200-m long study reach. Sampling began at the downstream transect. Sample grids were placed at 10-m intervals on each transect across the river. Sampling in this way allowed incorporation of a systematic study design including a random component (Bain and Finn 1991). Each electrofishing grid was sequentially set in place, left undisturbed for approximately 15 minutes, and then energized for 30 seconds. All fishes originating from the sampled area were collected by two netters. Depth (m), velocity (m^3/s), substrate composition (percent coverage of each of six categories), and distance from nearest shoreline (DFNS) were measured at each grid location prior to fish sampling (Brewer 2004).

Habitat Associations

Logistic regression models relating species presence to measured habitat variables were constructed for fish species present in $\geq 25\%$ of samples. Models estimated the probability that a fish would be present given the explanatory variables retained. Models were fit to each species, by diel period, with all potential explanatory variables in the models (SAS 2000). Diagnostic stepwise logistic regression was used to obtain a subset of explanatory variables that explained the presence of a fish species in a particular microhabitat. Each sampling grid was considered a homogeneous environment of depth, current velocity, and substrate conditions. Logistic regression models were considered significant at $\alpha < 0.10$. A Hosmer-Lemeshow (1989) Goodness of Fit test was performed to test for major departures from a logistic response function (Allison 1999). The null hypothesis was rejected at $\alpha < 0.05$ with model fit assumed to be questionable. The predictive capability of each model was assessed by obtaining percent concordant values for each model.

In addition to the logistic regression models that indicated those variables highly associated with the presence of a species, we also used fish abundance and associated microhabitat data from each grid sample to conduct selection analyses (see McHugh and Budy 2004 for a rationale for both analyses). Each habitat variable was divided into intervals (e.g., velocity of 0–0.10 m^3/s , 0.11–0.20 m^3/s , etc.), and the proportional use of the total number of fish in relation to the interval's proportional availability was calculated. An interval of a habitat variable was considered to be selected when habitat use exceeded habitat availability. The selection analyses served

Table 1. Fish-habitat categories used in the determination of selected habitat area for two-dimensional modeling. Asterisks denote hydraulic variables that were significant in logistic regression modeling. Specific substrate categories included were significant in regression models; cases where all substrate categories are listed resulted from a lack of an association between the fish species and a specific substrate variable.

Species	Period	Depth	Velocity	Substrate
Flathead catfish	Day	0.05–0.60	*0.00–0.40	Pebble, cobble, boulder
	Night	0.10–0.40	0.20–0.80	Cobble, boulder
Channel catfish	Day	0.10–0.30	*0.00–0.40	Fines, gravel, pebble, boulder
	Night	0.30–0.50	0.80–1.00	All substrate categories
Stonecat	Day	0.05–0.90	0.20–0.90	Pebble, cobble
	Night	*0.05–0.20	0.2–1.00	Cobble
Red shiner	Day	*0.05–0.20	0.00–0.80	Cobble
	Night	*0.05–0.10	0.00–0.40	All substrate categories
Slenderhead darter	Day	0.20–0.70	*0.40–1.00	Cobble
	Night	0.10–0.30	0.40–1.00	Cobble, boulder

two purposes. First, it helped to better understand the pattern of selection occurring along a habitat gradient for those significant variables from the logistic regression. Secondly, the 2-D modeling of selected habitat under different flows requires complete information on depth, velocity, and substrate. Even though some of these variables were not significant in the logistic models, it was necessary to select appropriate ranges to complete the 2-D modeling. We selected appropriate ranges from the selection analyses. Results from the logistic regression and selection analyses were assembled to develop fish habitat categories—conditions of good fish habitat—which were incorporated into the determination of fish-habitat characteristics with changes in flow (Table 1).

Hydraulic Modeling

Two-dimensional hydrodynamic simulations were used to develop digital surfaces of depth and velocity with changes in discharge from 0 m³/s to approximately bankfull. Hydraulic characteristics of the study reach were simulated with the numerical hydrodynamic model River2D version 0.90 (Ghanem et al. 1995, 1996; University of Alberta 2003) and packaged utilities. River2D is a two-dimensional depth-averaged finite-element model and output consists of horizontal velocity components and depth at each finite-element mesh node. Accurate determination and representation of bed topography is the most critical data requirement of the two-dimensional simulation of flow (U.S. Army Corps of Engineers 1996, Steffler and Blackburn 2002). The majority of topographic data at the site was collected by boat at bankfull conditions with a survey quality fathometer (accuracy of 3 cm) in conjunction with a sub-meter accuracy GPS (for horizontal position). Top of bank and toe of bank elevations were collected by surveyors using a Total Station. Initial survey data collected at all sites were plotted and interpolated with GIS software to assess data quality and coverage.

Water-surface elevations and stage-discharge relations were determined for the study site to provide required input boundary conditions for the incremental flow simulations. Downstream end-of-reach water-surface elevations were obtained for the anticipated range of simulation discharges with a recording pressure transducer. Discharge measurements were made to construct a stage-discharge relation. Measurements at mid and high discharges were made with an Acoustic Doppler Current Profiler (ADCP) according to methods described in USGS Office of Surface Water technical memorandums 2002.01 and 2002.02 (U.S. Geological Survey 2005). Low-flow measurements at the study site were made with an AA current meter and wading rod or by Flow Tracker current meter. River2D simulations were calibrated to observed water depths, velocities, and water-surface elevation observations at selected measured discharges and validated with additional independently measured water depths, velocities, and water-surface elevations under varying streamflow conditions.

Channel substrate was mapped at each site to create a digital surface of the spatial distribution of dominant bottom material size classes. Bottom material was classified into six substrate size categories based on those used by Brewer (2004) and modified from Kinsolving and Bain (1993). Once substrate boundaries were approximated on field maps, boundaries were more accurately defined using a Total Station. Substrate boundary survey points were then imported into GIS software and used to develop digital surfaces consisting of polygons of consistent dominant substrate areas.

Merging Hydraulic Modeling and Fish-Habitat Categories

Digital surfaces of depth, velocity, and substrate were combined to quantify selected habitat areas and determine the spatial distribution of each habitat category (previously determined from the biological sampling) with changes in discharge. Substrate size was determined at the mesh nodes by intersecting node locations with the substrate size distribution map. The model output of depth and velocity surfaces, combined with the substrate material size at each node, was evaluated to determine if the node represented selected habitat for a given habitat category definition. If all three variables at a node met the requirements of a given selected fish-habitat category it was assigned the value "1." If any of the three variables did not represent a selected category it was assigned the value "0." Each node was evaluated in turn, and areas of habitat selected were determined by delineating the nodes (i.e., 1's) that met the binary criteria for a given habitat category. Statistical characteristics of the delineated habitat areas were calculated for each fish-habitat category and each simulated discharge resulting in graphs of normalized selected habitat (total selected area per 100 m of channel) versus discharge. Further details on modeling may be found in Heimann et al. (2005).

Table 2. Logistic regression coefficient estimates and model statistics for fish species included in habitat modeling. Negative values are in parentheses.

Species	Sampling period	Model variables	Coefficient estimate	90% confidence intervals	Coefficient (Pr > Chisq)	Goodness-of-fit (Pr > Chisq)	Percent concordance
Slenderhead darter							
	Day	Velocity	3.1307	2.1678–4.0935	< 0.0001	0.2031	76
		% cobble	0.0212	0.0141–0.0283	< 0.0001		
	Night	% cobble	0.0853	0.0464–0.1243	0.0003	0.7882	95
		DFNS	0.1893	0.0354–0.3432	0.0431		
		% boulder	0.0718	0.0718–0.0297	0.0050		
Stonecat							
	Day	% cobble	0.0256	0.0186–0.0326	< 0.0001	0.1892	73
		DFNS	0.0623	0.0293–0.0953	0.0019		
		% pebble	0.0136	0.0036–0.0236	0.0249		
	Night	% cobble	0.0458	0.0307–0.0609	< 0.0001	0.3944	85
		Depth	(6.3328)	(10.8280–1.8376)	0.0205		
Red shiner							
	Day	Depth	(6.0754)	(8.8111–3.3396)	0.0003	0.6569	86
		% cobble	0.0301	0.0105–0.0496	0.0113		
	Night	Depth	(14.3091)	(19.1072–9.5111)	< 0.0001	0.1963	82
Flathead catfish							
	Day	Velocity	(2.5665)	(3.6758–1.4571)	0.0001	0.1349	77
		% cobble	0.0322	0.0198–0.0446	< 0.0001		
		% boulder	0.0340	0.0172–0.0508	0.0009		
		% pebble	0.0272	0.0079–0.0465	0.0203		
	Night	% boulder	0.0617	0.0266–0.0968	0.0038	0.4852	75
		% cobble	0.0192	0.0075–0.0069	0.0069		
Channel catfish							
	Day	Velocity	(1.0313)	(1.7468–0.3140)	0.0180	0.6795	74
		% cobble	(0.0086)	(0.0149–0.0001)	0.0215		
		% bedrock	(0.0055)	(0.0110–0.0001)	0.0929		

Results

Fish-Habitat Associations

Five fish species were present in ≥25% of collections and were collected during both day and night and included in the analyses. The most common fish species collected during the study was red shiner (*Cyprinella lutrensis*). Ictalurids included juvenile flathead catfish (*Pylodictis olivaris*), juvenile channel catfish (*Ictalurus punctatus*), and juvenile stonecat (*Noturus flavus*); channel catfish was the most common Ictalurid collected. The only Percidae collected in sufficient numbers was slenderhead darter (*Percina phoxocephala*).

Flathead Catfish.—Diurnal logistic regression models revealed velocity (negative significance) as the dominant variable for flathead catfish (Table 2), and selection occurred at low-moderate velocities (Table 3). Flathead catfish presence was also positively correlated with coarse substrates (Table 2). The nocturnal logistic

Table 3. Selection values for velocity (m³/s) included in two-dimensional flow modeling; a value of zero indicates no selection, positive values indicate selection, and negative values indicate avoidance.

Species	Diel period	Velocity increments				
		0-0.20	0.21-0.40	0.41-0.60	0.61-0.80	0.81-1.00
Slenderhead darter	Day	-23	-11	9	14	11
	Night	-27	-3	4	11	15
Red shiner	Day	1	-2	0	1	0
	Night	24	16	-15	-14	-11
Stonecat	Day	-3	3	1	0	-1
	Night	-2	0	1	1	0
Channel catfish	Day	0	20	-1	-9	-10
	Night	-4	-5	-6	-7	22
Flathead catfish	Day	0	9	-2	-4	-3
	Night	-2	9	1	-1	-9

Table 4. Selection values for depth (m) included in two-dimensional flow modeling; a value of zero indicates no selection, positive values indicate selection, and negative values indicate avoidance.

Species	Diel period	Depth increments									
		0.05-0.10	0.11-0.20	0.21-0.30	0.31-0.40	0.41-0.50	0.51-0.60	0.61-0.70	0.71-0.80	0.81-0.90	0.91-1.00
Slenderhead darter	Day	-18	1	3	2	10	8	2	0	0	0
	Night	-10	16	1	-4	-3	0	-1	0	0	0
Red shiner	Day	12	7	-2	-3	-4	-3	-3	-2	-1	-1
	Night	55	-19	-15	-15	-3	-3	-1	0	0	0
Stonecat	Day	1	0	0	1	2	1	0	1	1	0
	Night	13	8	-12	-6	-3	0	-1	0	0	0
Channel catfish	Day	0	4	1	-4	-1	0	-1	0	0	0
	Night	-4	-8	5	13	4	0	-1	0	0	0
Flathead catfish	Day	2	4	1	0	1	0	-2	-3	0	0
	Night	-6	2	0	7	0	-3	-1	0	0	0

model retained the same substrate correlations (Table 2), but velocity was no longer correlated with presence. Additionally, selection analyses revealed that flathead catfish selected a range of depths during the night (0.10-0.40 m) that was included in the range selected during the day (0.05-0.60 m; Table 4). Selection analyses revealed minimal differences in selection of day-night habitats, with only a small increase in selection of velocity and a decrease in the range of selected depths.

Channel Catfish.—Diurnal logistic regression models revealed velocity (neg-

ative significance) as the dominant variable (Table 2), with selection occurring at low-moderate velocities (Table 3). Channel catfish presence was negatively correlated with coarse substrate variables, evident by selection values for low percentages of percent cobble. Because of the high abundance of this species in night samples (present in >90% of samples), logistic regression modeling was not possible for this period. Selection analyses, however, indicated a strong shift from shallow (0.05–0.30 m), low-moderate velocity habitats during the day to deeper (0.21–0.50 m), higher-velocity habitats at night (Table 3 and Table 4).

Stonecat.—Stonecat presence was positively related to coarse substrates (percent cobble and pebble) and DFNS (Table 2). Stonecat were present in all depths up to 0.90 m (Table 4), and selected a wide range of velocities, avoiding only those $\leq 0.20 \text{ m}^3/\text{s}$ and $\geq 0.81 \text{ m}^3/\text{s}$ (Table 3).

For the nocturnal model, substrate associations (i.e., percent cobble) generally remained unchanged when compared to the day model; however, DFNS was not included in the night model and depth became negatively correlated with stonecat presence (Table 2). Stonecats substantially decreased the range of depths selected at night, while selection of velocity increments remained relatively unchanged (Table 3 and Table 4).

Red shiner.—There was a negative correlation between red shiner presence and depth during both diel periods; however, the parameter coefficient was much greater in the nocturnal model (Table 2). This was also reflected in selection values where very shallow habitat selection was most evident at night (Table 4). Percent cobble was the only substrate variable correlated with red shiner presence, and only in the day model (Table 2). Selection within this variable was minor and occurred in habitats with $\geq 20\%$ cobble. Selection analyses also showed minimal selection over a wide range of velocities during the day, and increased selection of lower-velocity habitats at night (Table 3).

Slenderhead darter.—During the day, velocity (positive correlation) was the most important variable predicting fish presence (Table 2). Percent cobble was also positively correlated with fish presence, and was the most important predictor of fish presence during the night period when velocity was not a significant variable. Additionally, DFNS and percent boulder were significantly positively correlated with fish presence at night. During the day, darters selected high-velocity habitats (Table 3) with $\geq 20\%$ cobble. At night, selection of percent cobble was truncated to $\geq 60\%$ which was similar to selection of percent boulder, with selection greatest in mid-channel habitats. Additional selection analyses showed that, during the day, darters used a broad range of depths, marginally selecting depths from 0.11 to 0.7 m, and selected depths over a smaller range during the night period (Table 4). Selection of velocity at night mirrored the day pattern (Table 3).

Quantification of Fish Habitat

In the majority of examples, the total selected habitat available (Normalized Selected Area or NSA) over the full range of flows was greater during the day than at night, and there was considerable overlap in day and night curves (Fig. 1). Chan-

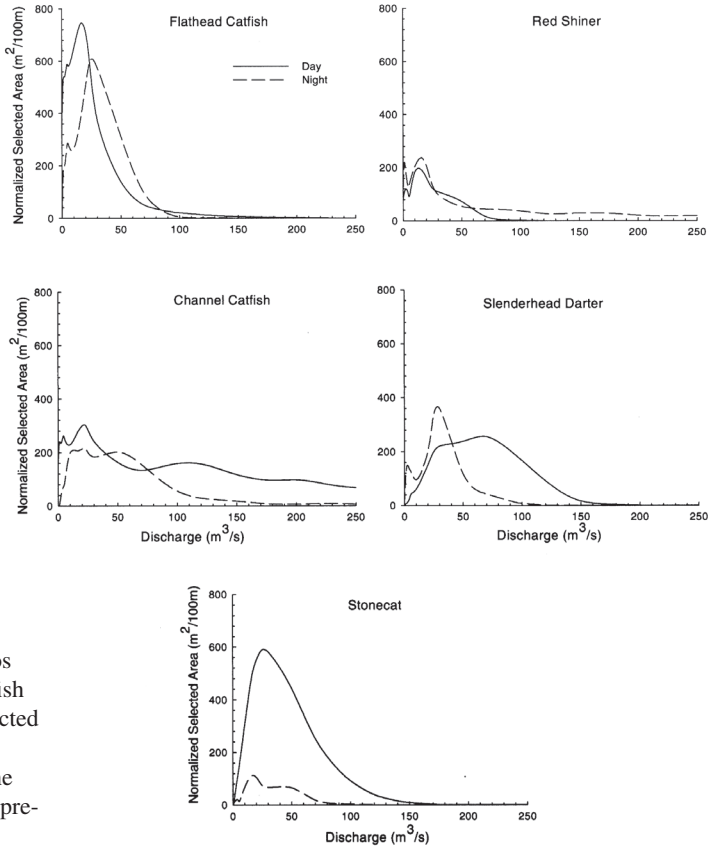


Figure 1. Normalized selected area (m²/100 m) available over a range of discharge (m³/s) scenarios (0 to bankfull) for each fish species. Normalized selected area for the day period is represented by a solid line and the night period is represented by a broken line.

nel catfish exhibited some of the most distinct diel habitat shifts by selecting deeper and faster habitats at night. This resulted in the NSA for channel catfish during the day to be substantially greater at very low flows and very high flows (Fig. 1). In contrast, the substantially greater day NSA at all flows for stonecat were primarily attributed to a narrower selection of depths during the day. This resulted in similar ranges of NSA available; however, the quantity of selected area was greatly reduced based on nocturnal habitat-selection patterns (Fig. 1).

The NSA curves for flathead catfish were similar to those of channel catfish except for a shift of the night curve to greater discharges (Fig. 1). This is likely due to flathead catfish selecting a broader range of depths and velocities at night.

The red shiner shift to extremely shallow habitats during the night period resulted in the NSA for both periods to be similar up to flows of 80 m³/s, when NSA was absent during the day but persisted in small quantities at night over the full range of flows modeled. In contrast, the resulting 2-D model for slenderhead darter indicates the NSA is greatly reduced at night at discharges >50 m³/s, but is more abundant at very low flows (Fig. 1). Stonecat exhibited the greatest difference be-

tween the total area available between day and night. The much reduced habitat area at night was accompanied by a much narrower range of flows where suitable habitat was available.

Discussion

The amount of appropriate fish habitat present under different flow conditions relates directly to the categories of habitat variables deemed important to particular species. We chose to evaluate habitat choice in two ways: using logistic regression to determine the strength of a variable in predicting probability of the species presence, and examining the use of habitat elements by the population in relation to availability. Although the two approaches give somewhat different information, results were usually complementary. However, to complete the matrix for habitat-category development, it was necessary to supplement the selection analyses completed for the significant logistic regression parameters with selected ranges of variables from parameters that were not significant in the regression models. Although this may introduce some uncertainty into the process, any biases would be equal in both day and night analyses and would not impact our conclusions.

We hypothesized that modeling results could differ substantially if only day-collected data on habitat selection were used because of diel shifts in habitat use that have been shown by many warmwater stream species including creek chubs (*Semotilus atromaculatus*; Magnan and Fitzgerald 1984), emerald shiners (*Notropis atherinoides*; Mendelson 1975), and madtoms (*Noturus* spp.; Burr and Stoeckel 1999). Red shiners in the lower Platte River, Nebraska, exhibited the same shift to shallow water as was found in this study (Yu and Peters 2002). Irwin et al. (1999) found no difference in diel use of habitats by juvenile flathead catfish, but their sample was small ($N = 5$). In contrast to our study, Irwin et al. (1999) found channel catfish to shift to shallower, slower velocities at night. Our result of much faster velocities being selected at night may be related to the drift dispersal of smaller individuals. But even if active selection was not involved, the ecological importance of fast currents during this time period is not diminished. Diel shifts by slenderhead darters may indicate larger-scale movements out of the study area; the significance of DFNS may indicate fish were using mid-channel habitats as movement corridors migrating to and from deeper-water habitats.

The question of whether instream flow recommendations from day-collected data would be sufficient to protect substantial night habitat cannot be answered consistently for every species (Fig. 1). For flathead catfish, 0–50 m³/s during the day would likely protect the majority of night habitat. Similarly, for red shiner, a 0–50 m³/s recommendation from the day curve would protect substantial night habitat. The red shiner has some appropriate night habitat available at high flows that is not encompassed by the day model, but it is highly unlikely that this extremely prolific and adaptable species (Matthews 1985) would be harmed if only day habitat flows were used for instream-flow analysis. However, for channel catfish, a reasonable recommendation of protective flows 0–250 m³/s from the day model would include

very little night habitat once discharge exceeded 100 m³/s. For the slenderhead darter, reasonable protective flow recommendations from the day curve of ~ 30–120 m³/s would leave substantial night habitat unavailable at both low flows and high flows. Similarly, the stonecat night habitat would not be protected by either end of the day curve. This would be especially significant for this species because of the dearth of night habitat.

It is difficult to generalize our conclusion to other species in other rivers, or even the same species in other rivers. The amount of available normalized selected habitat area under a range of discharge scenarios (0 to bankfull) is a function of how the three habitat variables are used by each species and the spatial distribution and relative abundance of habitats within the river. The heterogeneous nature of the channel morphology of our river was such that increasing discharges were not necessarily linearly related to depths, velocities, or substrate conditions. More information on day versus night habitat-use patterns is necessary before concluding that day sampling is sufficient to provide adequate instream flow assessments.

Acknowledgments

This is a contribution from the Missouri Cooperative Fish and Wildlife Research Unit (U.S. Geological Survey, Missouri Department of Conservation, University of Missouri, and Wildlife Management Institute cooperating).

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