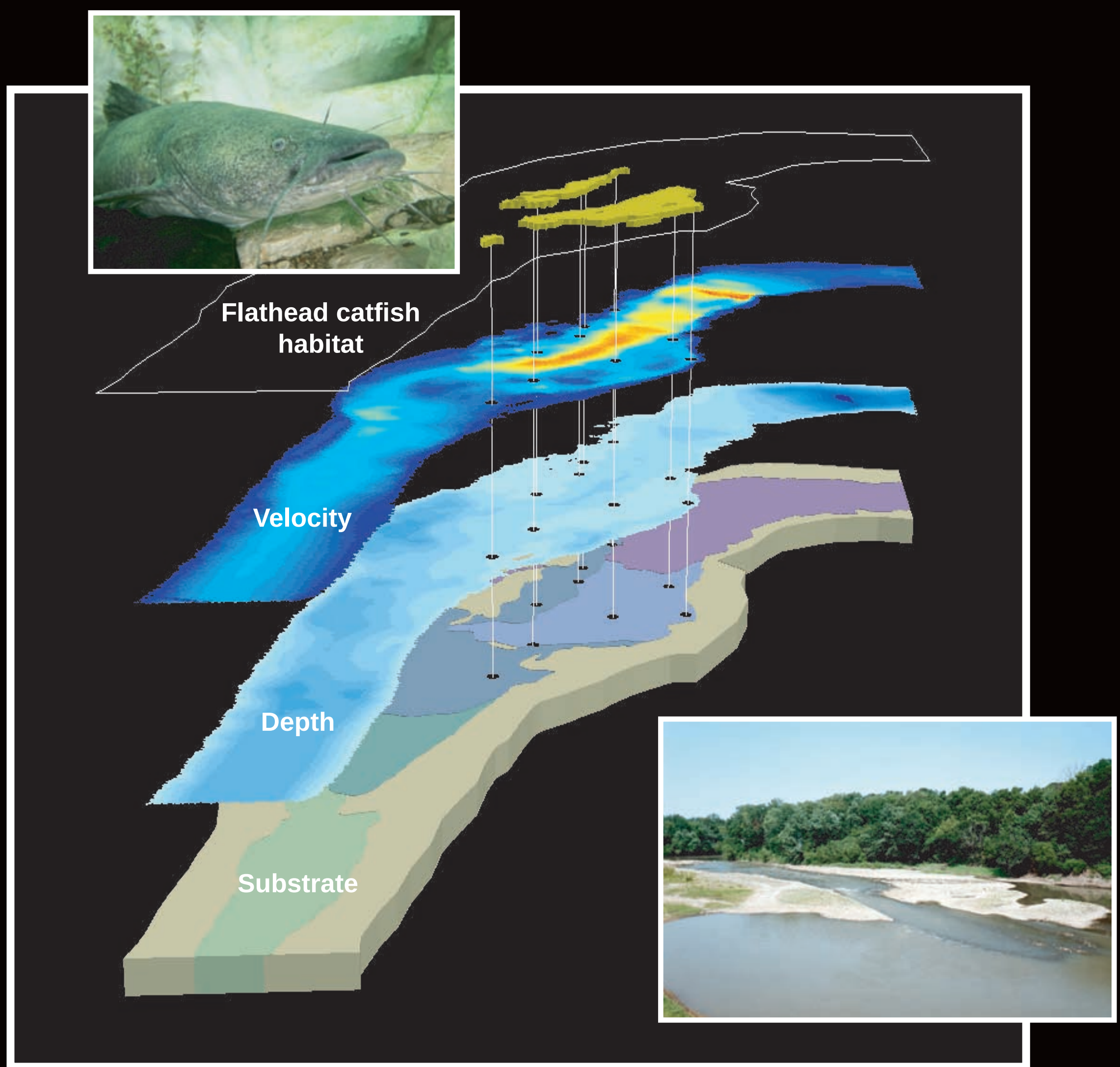
Prepared in cooperation with the Missouri Department of Conservation

Quantification of Fish Habitat in Selected Reaches of the Marmaton and Marais des Cygnes Rivers, Missouri



Scientific Investigations Report 2005–5180

U.S. Department of the Interior
U.S. Geological Survey

Quantification of Fish Habitat in Selected Reaches of the Marmaton and Marais des Cygnes Rivers, Missouri

By David C. Heimann[a], Joseph M. Richards[b], Shannon K. Brewer[c], and Richard D. Norman[a]

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U.S. Department of the Interior
U.S. Geological Survey

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Film

Conversion Factors and Datum

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
Area		
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
Volume		
cubic meter (m^3)	6.290	barrel (petroleum, 1 barrel = 42 gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	0.0002642	million gallons (Mgal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
Flow rate		
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second per square kilometer [$(m^3/s)/km^2$]	91.49	cubic foot per second per square mile [$(ft^3/s)/mi^2$]
cubic meter per day per square kilometer [$(m^3/d)/km^2$]	684.28	gallon per day per square mile [$(gal/d)/mi^2$]
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Quantification of Fish Habitat in Selected Reaches of the Marmaton and Marais des Cygnes Rivers, Missouri

By David C. Heimann[a], Joseph M. Richards[b], Shannon K. Brewer[c], and Richard D. Norman[a]

Abstract

The U.S. Geological Survey, in cooperation with the Missouri Department of Conservation, undertook a study to quantify fish habitat by using relations between streamflow and the spatial and temporal distributions of fish habitat at five sites in the Marmaton and Marais des Cygnes Rivers in western Missouri. Twenty-six fish habitat categories were selected for nine species under varying seasonal (spring, summer, and fall), diel (summer day and night), and life-stage (spawning, juvenile, and adult) conditions. Physical habitat characteristics were determined for each category using depth, velocity, and channel substrate criteria. Continuous streamflow data were then combined with the habitat-streamflow relations to compile a habitat time series for each habitat category at each site.

Fish habitat categories were assessed as to their vulnerability to habitat alteration based on critical life stages (spawning and juvenile rearing periods) and susceptibility to habitat limitations from dewatering or high flows. Species categories representing critical life stages with physical habitat limitations represent likely bottlenecks in fish populations. Categories with potential bottlenecks can serve as indicator categories and aid managers when determining the flows necessary for maintaining these habitats under altered flow regimes.

The relation between the area of each habitat category and streamflow differed greatly between category, season, and stream reach. No single flow maximized selected habitat area for all categories or even for all species/category within a particular season at a site. However, some similarities were noted among habitat characteristics, including the streamflow range for which habitat availability is maximized and the range of streamflows for which a habitat category area is available at the Marmaton River sites.

A monthly habitat time series was created for all 26 habitat categories at two Marmaton River sites. A daily habitat time series was created at three Marais des Cygnes River sites for two periods: 1941 through 1963 (pre-regulation) and 1982 through 2003 (post-regulation). The habitat category with the highest median area in spring was paddlefish (*Polyodon spathula*) with normalized areas of up to 2,000 square meters per 100 meters of stream channel. Flathead catfish (*Pylodictis olivaris*) habitat area generally was the category area most available in summer and fall. Differences in daily selected habitat area time series between pre- and post-regulation time periods varied by species/category and by site. For instance, whereas there was a decline in the distribution of spring spawning habitat for suckermouth minnow (*Phenacobius mirabilis*) and slenderhead darter (*Percina phoxocephala*) from pre- to post-regulation periods at all three sites, the 25 to 75 percentile habitat area substantially increased for paddlefish under post-regulation conditions.

Potential habitat area for most species was maximized at the Marmaton River sites at flows of about 1 to 10 cubic meters per second, whereas median monthly streamflows ranged from less than 1 to 20 cubic meters per second depending on site and season. Paddlefish habitat was available beginning at higher flows than other categories (4 to 7 cubic meters per second) and also maximized at higher flows (greater than 50 to 100 cubic meters per second). Selected potential habitat area was maximized for most species at the Marais des Cygnes River sites at flows of about 1 to 50 cubic meters per second, whereas median monthly streamflows ranged from 4 to 55 cubic meters per second depending on site and season.

The range of streamflows for which selected habitat area was available in summer and fall was substantially less at the channelized Marais des Cygnes River site when compared to the non-channelized sites, and, therefore, the susceptibility of categories to high-flow habitat limitations was greater at this site. The channelized reach was more uniform and had a greater conveyance as a result of the greater slope, and, therefore, category criteria were exceeded at lower flows.

The susceptibility of fish habitat to dewatering varied by species, site, and season, but generally habitats for slenderhead

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darter, stonecat (*Noturus flavus*), and paddlefish were the most susceptible to habitat limitation at flows less than 1 cubic meter per second. Red shiner (*Notropis lutrensis*) and sand shiner (*Notropis stramineus*) habitat areas were the least susceptible to low flows. Habitat was limited for most species, other than paddlefish, at streamflows greater than 20 to 30 cubic meters per second at the Marmaton River sites. At the Marais des Cygnes River sites, the susceptibility of categories to habitat limitations at high streamflows varied greatly from streamflows greater than 100 cubic meters per second at the channelized site to greater than 800 cubic meters per second at an upstream non-channelized site.

INTRODUCTION

Currently (2005), no flow requirements are established for the protection of aquatic life in rivers and streams in Missouri. A useful step in the development of flow requirements is the quantification of the ecological effects associated with changes in streamflow and stage. These ecological considerations will include both instream and flood-plain (riparian) biota requirements. With this information, managers can make informed decisions regarding the effects of flow alterations on aquatic habitat availability. Flow requirement considerations are further complicated for rivers that originate and predominantly lie outside of Missouri as river management priorities may differ greatly between states.

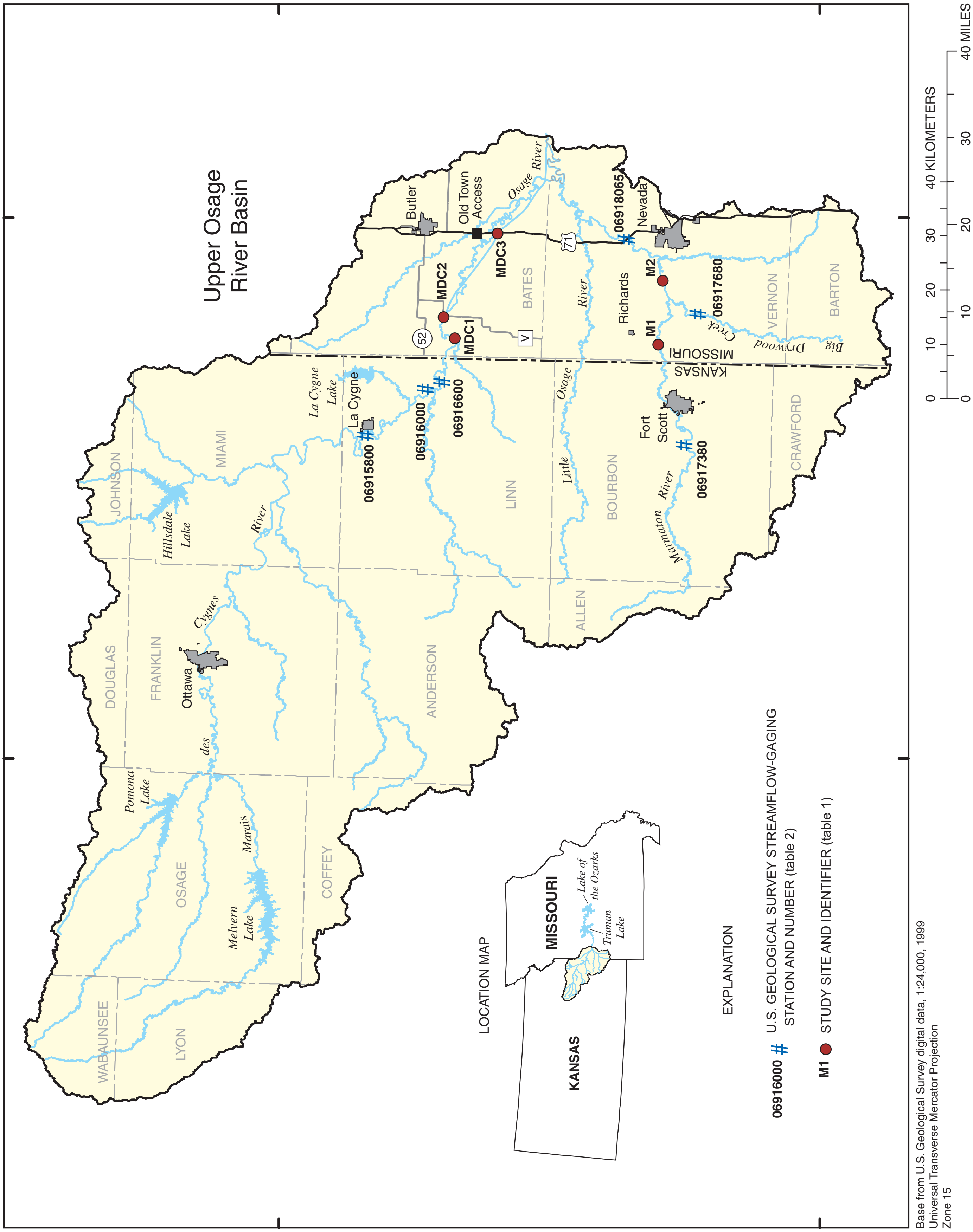
Reservoirs and other impoundments can have substantial effects on flow regimes in the upper Osage River Basin. Currently (2005), 35, 2, and 15 percent of the Marais des Cygnes, Little Osage, and Marmaton River Basins, which compose the upper Osage Basin, are regulated by impoundments upstream from the Missouri-Kansas state line. The U.S. Army Corps of Engineers operates three reservoirs (Pomona, Melvern, and Hillsdale; fig. 1) that control 25 percent of the Marais des Cygnes River Basin in Kansas (Dent and others, 1997). Multiple watershed districts in Kansas have formulated plans to construct 283 additional flood-control impoundments that will further change the hydrology of the upper Osage Basin (Kansas Water Office, 2004). These impoundments, ranging from 1.6 to 360 acres with most being less than 30 acres, are intended to decrease the peak flood flow of a 25-year, 24-hour rainfall event. Construction of planned impoundments eventually will modify basin control to 45, 2, and 59 percent of the Marais des Cygnes, Little Osage, and Marmaton Basins (Kansas Department of Agriculture, written commun., 2004; U.S. Army Corps of Engineers, 2004). Dry-weather flows also may be substantially altered by new impoundments. During rainfall following dry periods when lake levels have decreased because of infiltration and evaporation, little runoff will reach the channel immediately downstream from the dam until the lake level increases and reaches the spillway elevation.

Direct river withdrawals and flood-plain wells in Missouri and Kansas also are concerns for sustaining dry-weather flows in the upper Osage Basin (Dent and others, 1997). Demand on streamflow for irrigation, wetland management, drinking-water supplies, and operation of power plants has increased in recent years. Implementation of proposed water marketing and basin transfers in Kansas and anticipated increases in industrial, power-generation, and municipal uses of water also could decrease dry-weather flows.

While water laws are substantially different in Missouri (Riparian water law) and Kansas (Prior Appropriation water law), existing laws and permits have allowed total (zero flow) and partial depletions of streamflow in both states in recent years. Although the Kansas Water Office (2004) lists the protection of historical minimum desirable streamflow levels for two sites on the Marais des Cygnes River as a primary management issue no such designation was provided for any location on the Marmaton or Little Osage Rivers. For the Marais des Cygnes River, a threshold streamflow of 50 ft^3/s (cubic feet per second) is required to reach the Marais des Cygnes at LaCygne, Kansas, streamflow-gaging station (U.S. Geological Survey streamflow-gaging station number 06915800). A nearby power plant can no longer withdraw directly from the Marais des Cygnes River at flows below this threshold (Bruce Beckman, LaCygne Power Plant, oral commun., 2004), but flow is not required to reach the Missouri-Kansas state line. Harmful effects downstream on mussels and other biota from total depletions have been observed (Ron Dent, Missouri Department of Conservation, oral commun., 2000). Total depletions, and chronic partial depletions, of dry-weather flows degrade aquatic, riparian, and wetland habitats and biotic communities in and along these three streams. Depletions also have direct and indirect effects on riverine recreation.

Streamflows that mimic the timing, frequency, magnitude, rate of change, and duration of natural flows are essential for maintaining streams, rivers, wetlands, bottomland hardwoods, bottomland lakes, and wet prairies (Poff and others, 1997). Because aquatic, riparian, flood-plain, and wetland communities naturally are diverse and have adapted to seasonal and annual variation in dry-weather flows and flooding, different species are favored under different flow conditions. Therefore, a single minimum flow or flood flow is not adequate to protect a stream (Poff and others, 1997). To maintain stream system habitat and community diversity, hydrologic regimes must include flows that maintain the aquatic communities, riparian zones, and flood plains. Streamflow regimes should vary seasonally and annually to mimic natural flow variability.

Information is needed to determine appropriate flow regimes for the upper Osage River Basin and to better understand the specific effects of flow alterations on riverine habitats. The effects of potential flow alterations on the quantity and character of aquatic habitat are not known. Therefore, a study was undertaken by the U.S. Geological Survey (USGS), in cooperation with the Missouri Department of Conservation (MDC), to quantify relations between streamflow and the spatial and temporal distribution of fish habitat in the most susceptible areas—shallow-water habitats—of selected reaches in the Marmaton and Marais des Cygnes Rivers. Results from this



Base from U.S. Geological Survey digital data, 1:24,000, 1999
Universal Transverse Mercator Projection
Zone 15

Figure 1. Location of study sites.

study can be used to identify and mitigate flow alterations that may have adverse effects on fish habitat in Missouri.

Objective

The objective of the study was to determine the spatial and temporal distribution of various in-channel fish habitats and quantify characteristics of these habitats at different flows for selected Marmaton and Marais des Cygnes River reaches. Habitat area was determined for those fish species that use shallow-water habitats in these rivers. Shallow-water habitats are most susceptible to modifications in the flow regime and species that use these habitats are most directly affected by changes in flow.

Description of Study Area

The upper Osage River Basin is in the Osage Plains physiographic province, is adjacent to the Missouri-Kansas border, encompasses 14,000 km^2 (square kilometers), and is drained north to south by the Marais des Cygnes, Little Osage, and Marmaton Rivers (fig. 1). Surface bedrock in these basins usually has low permeability, consisting primarily of Pennsylvanian shales and sandstones with smaller amounts of limestone and coal (Bevans and others, 1984). Consequently, dry-weather flows in these three streams are not well sustained as calculated 7Q10 streamflows (average minimum 7-day flows with a recurrence interval of 10 years) are at or near zero flow at sites on both rivers (Skelton, 1976; Bevans and others, 1984). Surface water is the primary water-supply source in the region because alluvial deposits are relatively thin and the more permeable aquifers at depth are highly saline and hydraulically isolated from streams.

Although the Marmaton and Little Osage Rivers primarily lie in their natural channels, more than 75 percent of the Marais des Cygnes River in Missouri was channelized in the early 1900's. Channelization of the Marais des Cygnes River resulted in the loss of 30 km (kilometers) of river channel and a substantial change in the hydraulic (slope, velocities) and physical habitat characteristics of this section of channel (Dent and others, 1997).

Study sites were located at the Marmaton (two sites) and Marais des Cygnes (three sites) Rivers near the Missouri-Kansas state line (fig. 1; figs. 2 to 6, on compact disc at the back of this report; table 1). The Marmaton and Marais des Cygnes Rivers will be affected the most through the construction of additional impoundments. Sites were selected at or near locations of previous biological surveys in these rivers (Hoel, 1998; Brewer, 2004) and, in the case of the Marais des Cygnes River sites, included both non-channelized (sites MDC1 and MDC2, figs. 4 to 5) and channelized (site MDC3, fig. 6) reaches. Shallow-water habitat areas (riffles) were selected for the study site because these areas, and the habitat of those species that use these areas, were considered the most susceptible to reproduction or rearing constrictions with changes in streamflow. In choosing a riffle as the index of habitat for the rest of the stream, information derived from the analyses of these critical functioning areas is assumed to satisfy the food production, passage, and spawning requirements of the species analyzed. The remaining selection criterion was that study site reaches be free of structures (for example, low water crossings) that would prevent or limit the results of numerical hydraulic modeling at all desired streamflows.

Table 1. Location and characteristics of study sites.

[ID, identifier; m, meter; km^2, square kilometer; km, kilometer]

Site ID (fig. 1)	Description	Location of center of study reach[a]		Model reach length, in m	Drainage area, in km^2	Distance downstream from Missouri-Kansas state line, in km
		Northing, in m	Easting, in m			
M1[b]	Marmaton River near Richards, Missouri	4191976	360811	344	1,180	8.0
M2	Marmaton River above Nevada, Missouri	4190880	372820	278	2,270	25.0
MDC1	Marais des Cygnes River below State Line, Missouri	4229105	361914	599	8,580	7.1
MDC2	Marais des Cygnes River at Highway V, Missouri	4231404	365674	558	8,710	20.9
MDC3[c]	Marais des Cygnes River at Old Town Access, Missouri	4222155	380616	496	9,010	55.0

[a]Universal Transverse Mercator coordinates Zone 15 N, North American Datum of 1983.

[b]Starting survey benchmark established by U.S. Geological Survey. North west corner of concrete rail of bridge of north south gravel road south of Highway Z and north of Highway 54 a 2.5-inch chiseled square painted white. Northing 4191989.428, easting 360813.759, elevation 239.226 m, Zone 15 N, North American Datum 1983, North American Vertical Datum of 1988.

[c]Starting survey benchmark established by U.S. Geological Survey, Missouri Water Science Center. MDC3—a 2-inch chiseled square at top of boat ramp on downstream curb. Painted white. Northing 4222322.745, easting 380369.262, elevation 229.845 m, Zone 15 N, North American Datum of 1983, North American Vertical Datum of 1988.

Streamflows in the Marmaton and Marais des Cygnes Rivers typically are highest in spring and early summer, and lowest in late summer and winter based on numerous streamflow-gaging station records in the basins (U.S. Geological Survey, 2004a; 2004b). Selected USGS continuous streamflow gages in the Marmaton and Marais des Cygnes Basins and the period of record used in this study are provided in table 2.

Table 2. Selected continuous streamflow-gaging stations in the Marmaton and Marais des Cygnes River Basins and period of record used.

Station name	Station number (fig. 1)	Period of record used
Marmaton River near Marmaton, Kansas	06917380	1971–2003
Big Drywood Creek near Deerfield, Missouri	06917680	2001–2003
Marmaton River near Nevada, Missouri	06918065	2000–2003
Marais des Cygnes River at Trading Post, Kansas	06916000	1944–1957
Marais des Cygnes River near State Line, Kansas	06916600	1958–2003

Purpose and Scope

The purpose of this report is to summarize the quantification of fish habitat using the relation between the spatial extent of selected fish habitat and streamflow determined from the simulation and analyses of hydraulic and substrate data at five selected reaches of the Marmaton and Marais des Cygnes Rivers. Habitat selection criteria and quantified habitat areas were developed for selected fish species based on observed use of shallow-water habitats in the Marais des Cygnes River. Analyses included the development of relations between selected habitat area (SHA) and streamflow by species/season, the spatial distribution for habitat with streamflow, and habitat persistence. Analyses also include the development of time series of selected habitat from 1971 through 2003 for the Marmaton River sites and from 1941 through 1963 (pre-regulation) and 1982 through 2003 (post-regulation) for the Marais des Cygnes River sites.

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METHODS

Hydraulic characteristics of the selected study reaches with incremental changes in flow using numerical simulations were determined along with the spatial distribution of channel substrate material. Previously developed species-specific habitat categories (Brewer, 2004) based on depth, velocity, and channel substrate were used as criteria to quantify fish habitat. The resulting quantified habitat characteristics were used to develop spatial and temporal relations between streamflow and habitat area.

Numerical Simulation of Hydraulic Characteristics

The hydraulic characteristics of the five study reaches were simulated using the numerical hydrodynamic model River2D (River2D version 0.90; Ghanem and others, 1995; 1996) and packaged utilities [River2D is public domain software, and the numerical model, packaged utilities (R2D_Bed, R2D_Mesh), and documentation are described by University of Alberta (2003)]. River2D is a two-dimensional depth-averaged finite-element model based on the streamline upwind Petrov-Galerkin weighted residual formulation and is capable of predicting regions of supercritical flow. The model uses a simplified ground-water flow component to facilitate the determination of wetting and drying boundaries of surface flow. Output consists of horizontal velocity components and depth at each finite-element mesh node. Simulations ranged from no flow to bank-full flows.

Finite-Element Mesh

A finite-element mesh was constructed within defined model boundaries, and streambed elevations at mesh nodes were defined by interpolation of topographic data points onto the constructed mesh. The finite-element mesh was constructed using the software R2D_Mesh. The area within the model boundary was uniformly filled with nodes at 2-m (meter) intervals and a triangular mesh was constructed. The observed riffle area within each reach was then refined to a 1-m nodal density and re-triangulated (figs. 7 to 11, on compact disc at the back of this report). The number of nodes in the model meshes were 8,834 (site M1); 6,511 (site M2); 32,867 (site MDC1); 18,198 (site MDC2); and 26,106 (site MDC3). The number of computational mesh elements (mesh triangles) for each site was 17,076 (M1); 12,463 (M2); 64,569 (MDC1); 35,578 (MDC2); and 51,500 (MDC3). Mesh quality was assessed using the mesh-quality index value computed in the R2D_Mesh utility (Waddle and Steffler, 2002). Mesh-quality index values for the constructed study site meshes ranged from 0.21 to 0.31 and exceeded the recommended minimum value of 0.15.

The bed topography (bed elevation) and bed roughness information were created within the utility R2D_Bed, imported into R2D_Mesh, and combined with the constructed mesh to obtain a River2D input file. Estimated bed roughness height (channel roughness) was specified for each topographic data point based on substrate and vegetation characteristics of the channel (figs. 7 to 11). Starting bed roughness height values were estimated using Manning's *n* and hydraulic radius values (determined empirically from streamflow measurements) in the bed roughness converter provided with R2D_Bed. Estimates of Manning's *n* values also were obtained from guidelines provided in Arcement and Schneider (1989). Each simulated streamflow required the specification of boundary conditions, including an inflow streamflow and corresponding measured downstream end-of-reach water-surface elevation (table 3, on compact disc at the back of this report) and an estimate of the upstream end-of-reach starting water-surface elevation. The default parameter values were used in all River2D simulations unless otherwise specified. These include, but are not limited to, parameters describing eddy viscosity, ground-water transmissivity, and ground-water storativity (Steffler and Blackburn, 2002).

Topography

The accurate determination and representation of streambed 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). Reference marks were established at each site from National Geodetic Survey class "A" horizontal and vertical benchmarks using a Kinematic Global Positioning System (GPS) with vertical accuracy of plus or minus (+/-) 2 cm (centimeters) and horizontal accuracy of 1 mm (millimeter). A Total Station was used to collect all topographic points at the two Marmaton River sites. Most of the topographic data at the Marais des Cygnes River sites were collected by boat at bank-full stage conditions using a survey-quality fathometer (accuracy of 3 cm) in conjunction with a submeter accuracy GPS (for horizontal position). The water depths obtained from the fathometer were subtracted from the surveyed water-surface elevation (surveyed using optical surveying equipment) to obtain bed elevations. Top of bank and toe of bank elevations were collected by MDC surveyors at the Marais des Cygnes River sites using a Total Station. Initial survey data collected at all sites were plotted and interpolated using geographic information system (GIS) software to assess data quality and coverage. Additional "fill in" points were collected as necessary using a Total Station to complete the topographic data sets. A total of 2,246 and 2,214 data points was used to define the topography at Marmaton River sites M1 and M2 (fig. 1). The topography at Marais des Cygnes River sites MDC1, MDC2, and MDC3 (fig. 1) were constructed using data sets of 4,270, 4,260, and 2,990 data points.

Hydrology

Water-surface elevations and stage-streamflow relations were determined for each study site to provide required input boundary conditions for the incremental flow simulations (table 3). Downstream end-of-reach water-surface elevations were obtained for the anticipated range of simulation streamflows using a pressure transducer with recorder. The pressure transducers initially were set and checked periodically (1 to 2 times per month) against a reference gage (staff plate or wire-weight gage; Rantz and others, 1982) or surveyed water-surface elevation at each site. Streamflow measurements were made at each site (from near zero flow to near bank-full flows) to construct a stage-streamflow relation. Measurements at mid- and high streamflows on the Marais des Cygnes River sites were made with an Acoustic Doppler Current Profiler (ADCP) using suggested 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 Marais des Cygnes River sites and all measurements at the Marmaton River sites were made using an AA current meter and wading rod as described in Rantz and others (1982) or a FlowTracker current meter (U.S. Geological Survey, 2005). The locations of measurement stations (soundings) associated with the low-flow streamflow measurements were referenced to a horizontal datum so that these values could be compared to simulated values at the same location during model calibration/validation. The velocity ensembles (vertical composition of velocity measurements 0.25 m apart) collected with the ADCP measurements were depth-averaged, and the corresponding GPS horizontal positions of ensemble locations were used to compare to model output for calibration/validation purposes. The water depths and locations measured using the survey-quality fathometer in conjunction with the ADCP measurements also were used in the calibration/validation of Marais des Cygnes River simulations.

Site specific flow-duration statistics were computed for each study site using monthly or daily streamflow values from nearby continuous streamflow-gaging stations. For the Marmaton River sites, monthly, instead of daily, flow statistics were calculated because the distance and drainage area values between study sites and the nearest continuous streamflow-gaging station [Marmaton River near Marmaton, Kansas, (06917380, fig. 1)] were considered too large for daily correlations of streamflow. Monthly flows were used because errors resulting from time lag and flow routing would be substantially less than for a daily time period. Monthly flow-duration statistics for both the M1 and M2 sites were determined by applying a drainage area adjustment factor to the mean monthly flows from the USGS streamflow-gaging station near Marmaton, Kansas. A regression of mean monthly flow data at the downstream Marmaton River near Nevada, Missouri, streamflow-gaging station (06918065, fig. 1) compared to data from the upstream Marmaton River near Marmaton, Kansas, gage indicated this to be a reasonable approach. Despite the sizable differences in drainage areas, the slope of the regression equation ($y = 3.59x$, $r^2 = 0.95$) was similar to the calculated drainage area adjustment factor of 3.49. For consistency, the drainage area adjustment factor was applied in determining monthly flow data at sites M1 (adjustment factor = 1.56) and M2 (adjustment factor = 3.00).

The Marais des Cygnes River has undergone substantial regulation since 1963; therefore, flow duration statistics were determined for both pre- and post-regulation periods. In 1963, 1.3 percent of the Marais des Cygnes River Basin at the Kansas state line was controlled by impoundments (Kansas Department of Agriculture, Division of Water Resources, written commun., 2004; U.S. Army Corps of Engineers, 2004). In late 1982, following the construction of numerous small impoundments and U.S. Army Corps of Engineers reservoirs Pomona, Melvern, and Hillsdale, the percentage of the regulated drainage area west of the state line increased to 31 percent. A 23-year pre-regulation [1941 through 1963 water years (October 1–September 30)] and a 22-year post-regulation (1982 through 2003 water years) period was chosen for comparative analyses. Precipitation data from the Nevada Sewage Treatment Plant, Missouri, (1941 through 1948) and LaCygne, Kansas, (1949 to 2003; High Plains Regional Climate Center, 2004) indicated that annual precipitation data during water years 1941 through 1963 and 1982 through 2003 were statistically similar (t-test, $p = 0.853$). The 1941 through 1957 daily flows from the Marais des Cygnes River at Trading Post, Kansas, (USGS streamflow-gaging station number 06916000; fig. 1) were adjusted to the Marais des Cygnes near State Line, Kansas, (USGS streamflow-gaging station number 06916600; fig. 1) site using a drainage area adjustment factor of 1.13 (the ratio of drainage area at the Marais des Cygnes River near State Line, Kansas, to the drainage area at Marais des Cygnes River at Trading Post, Kansas). The 1958 to 1963 daily record from the Marais des Cygnes River at State Line, Kansas, gage completed the pre-regulation period and the 1982 through 2003 record from this site was used for the post-development record. The compiled record for Marais des Cygnes River near State Line, Kansas, for the 1941 through 1963 and 1982 through 2003 water years were then adjusted to the MDC1, MDC2, and MDC3 sites using drainage area adjustment factors of 1.02, 1.04, and 1.07, to obtain estimates of historical mean daily flow at the Marais des Cygnes River sites.

A comparison of the pre- and post-regulation period streamflows at the upstream Marais des Cygnes River site MDC1 was conducted using the "Indicators of Hydrologic Alterations" version 7.0 software (The Nature Conservancy, 2005). Analyses included comparison of median monthly flows, flood peaks, flood duration, and flood recession rates for the 1941 through 1963 and 1982 through 2003 water years.

Model Calibration, Validation, and Sensitivity

River2D simulations were calibrated to observed water depths, velocities, and water-surface elevations at selected measured streamflows and validated with additional independent measured water velocities, depths, and water-surface elevations under varying streamflow conditions (table 4). Selected low flows were included in all site calibrations because the sensitivity of the model to changes in bed roughness height and topographic substrate controls is greater at low flows than higher flows as demonstrated at site M2 (fig. 12). Simulated velocities, depths, and water-surface elevations were not as sensitive to changes in eddy viscosity bed shear parameter (fig. 13) as to changes in bed roughness; the default eddy viscosity values (Steffler and Blackburn, 2002) were used in all simulations. At the Marmaton River sites depths, velocities, and water-surface elevations at a middle and/or high flow also were used in the calibration and the remaining measurements used for validation. At the Marais des Cygnes River sites, a low-flow streamflow was used for calibration, and the depths, velocities, and water-surface elevations from remaining streamflow measurements were used for validation because fewer streamflow measurements were available.

Root median square errors for differences in measured and simulated depths generally were less than 0.10 m, and measured and simulated velocity differences were less than 0.20 m/s (meter per second; table 4). Root median square errors in measured and simulated water-surface elevation generally were less than 0.02 m at the Marmaton River sites and less than 0.04 m at Marais des Cygnes River sites (table 4).

Sources of Error

The River2D numerical hydraulic simulations are a simplified representation of complex and dynamic natural systems. Therefore, the simplification of this natural system through mathematical formulas, discrete nodal calculation points, channel roughness estimates, and depth-averaged approximations will result in errors. The cumulative effects of these errors are quantified through calibration and validation and are summarized in table 4. Errors from input data primarily result from the measurement and representation of topographic and hydrologic characteristics.

The error associated with the channel topographic surveys in this study was determined from the independent topographic data sets associated with substrate mapping. An additional 134 to 330 independent topographic data points were collected at each site for the length of the study reaches in conjunction with channel substrate mapping. Comparisons of these independent data points with the interpolated model mesh surface indicated that root median square errors in the mesh bed elevations ranged from 0.06 (site M2) to 0.2 m (site MDC1; table 5). The additional substrate survey data points were later added to the original topography data sets and interpolated into the bed-elevation meshes so the actual differences of the working mesh were less

Table 4. Calibration and validation error results for measured and simulated hydraulic properties at selected scenario streamflows.

[m/s, meter per second; m^3/s, cubic meters per second; m, meter]

Measured and simulated velocity		Measured and simulated water depth			Measured and simulated water-surface elevation	
Root median square error, in m/s	Number of comparison points	Simulated streamflow, in m^3/s	Root median square error, in m	Number of comparison points	Root median square error, in m	Number of comparison points
		Marmaton River site M1				
0.051	21	0.260	0.007	21	0.024	1
.055	26	.970	.023	26	.023	1
.042	27	[a]**1.22**	.033	27	.019	1
.074	21	10.9	.035	21	.002	1
.127	22	21.4	.030	22	.005	1
.073	19	31.1	.169	19	.005	1
.119	27	[a]**61.5**	.043	27	.004	1
.113	18	74.6	.073	18	.014	1
.186	27	[a]**134**	.116	27	.001	1
		Marmaton River site M2				
0.021	28	0.623	0.008	28	0.040	1
.079	18	[a]**2.01**	.038	18	.005	1
.067	18	2.35	.031	18	.015	1
.099	20	[a]**9.74**	.055	20	.009	1
.020	22	27.3	.033	22	.015	1
.029	18	[a]**48.7**	.092	18	.003	1
		Marais des Cygnes River site MDC1				
0.076	23	[a]**6.17**	0.028	23	0.009	17
.200	2,927	753	.074	1,637	.037	16
		Marais des Cygnes River site MDC2				
0.115	23	[a]**5.78**	0.044	23	0.024	26
.194	2,713	776	.068	2,233	.031	18
		Marais des Cygnes River site MDC3				
0.087	22	[a]**6.77**	0.035	22	0.034	30
.211	2,395	685	.061	1,069	.053	19

[a]Streamflow in bold represents calibration streamflow.

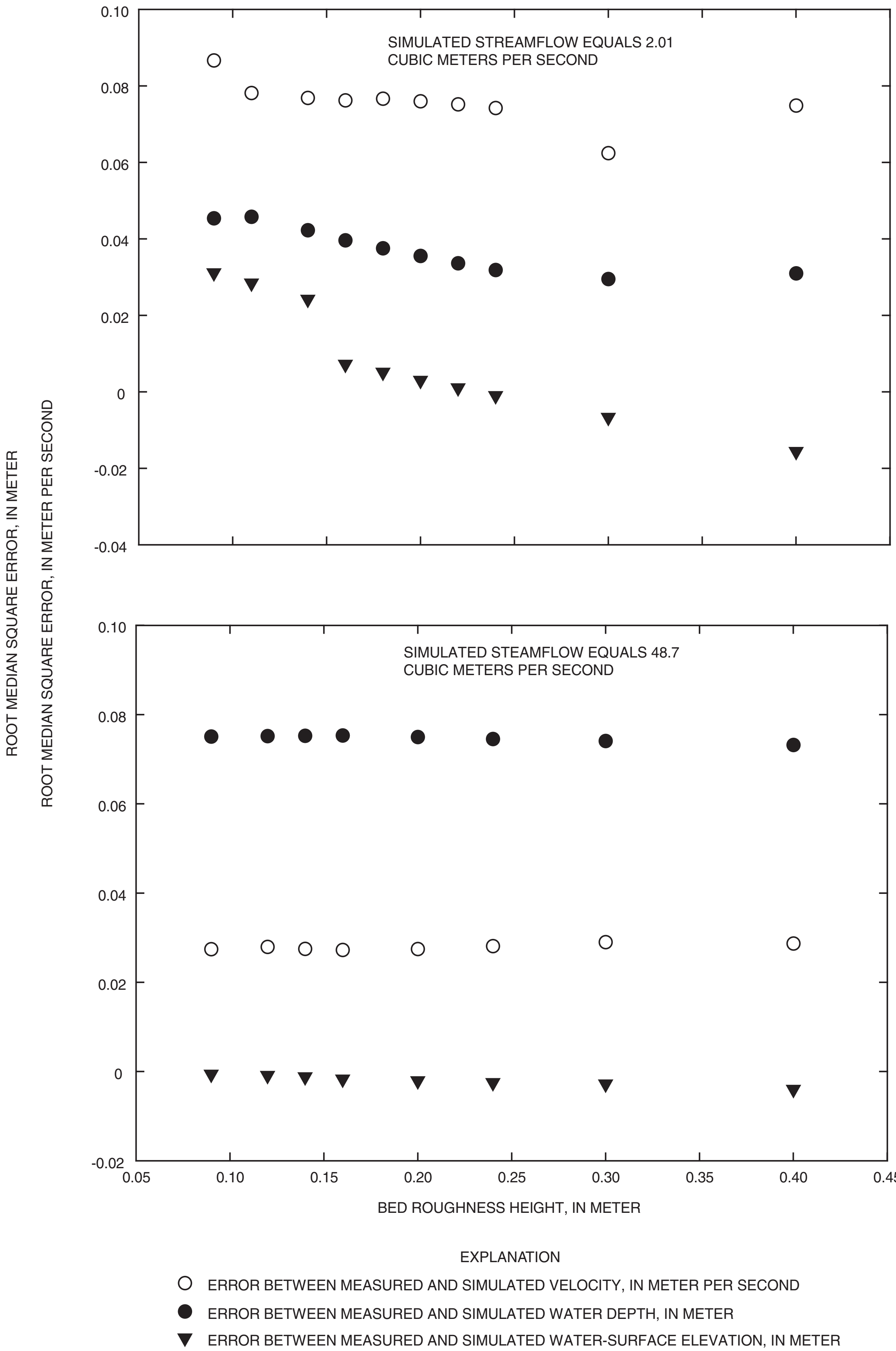

Figure 12. Sensitivity of simulated velocity, depth, and water-surface elevations to changes in bed roughness height at flows of 2.01 and 48.7 cubic meters per second at the Marmaton River site M2.

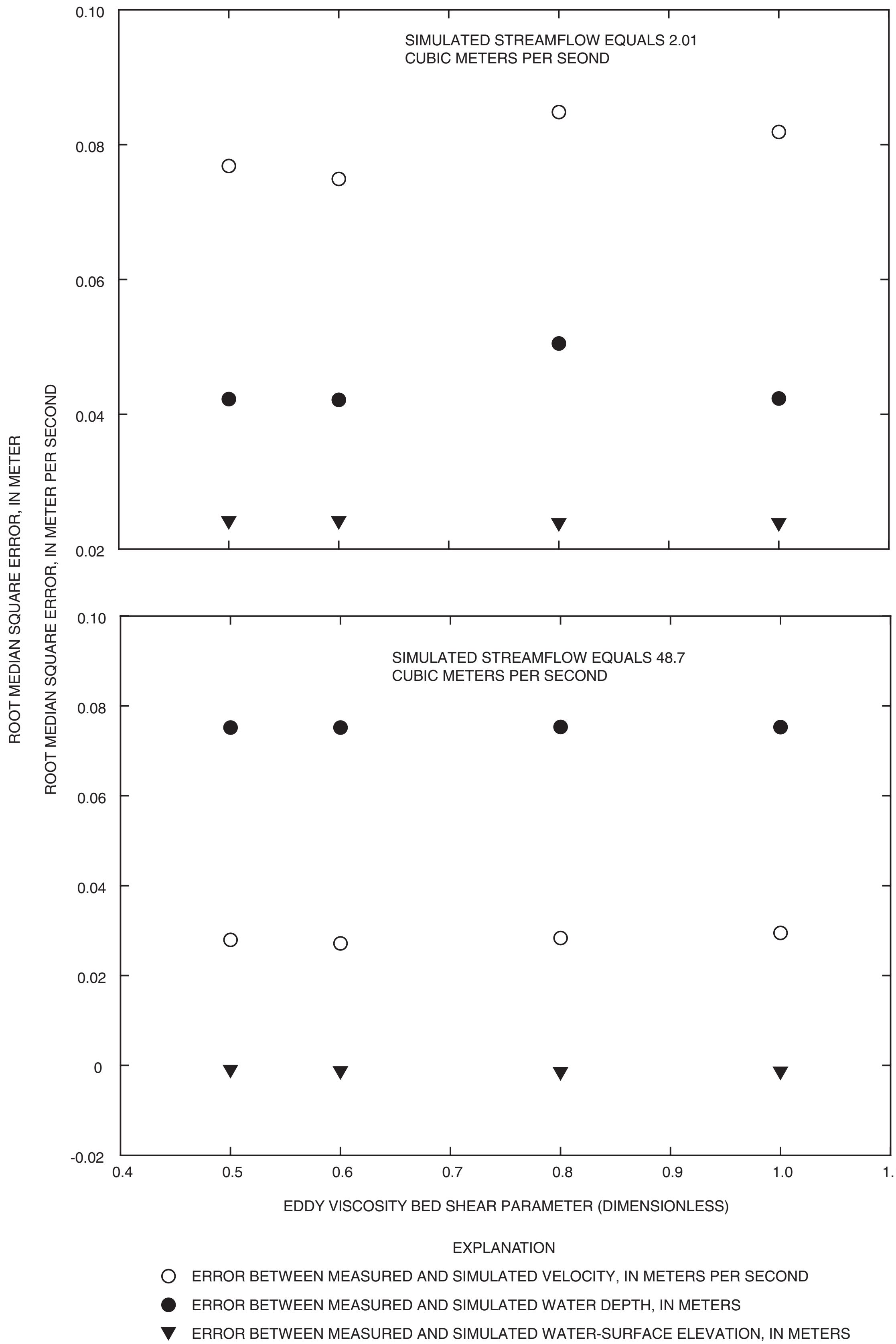

Figure 13. Sensitivity of simulated velocity, depth, and water-surface elevations to changes in eddy viscosity bed shear parameter at flows of 2.01 and 48.7 cubic meters per second at the Marmaton River site M2.

Table 5. Channel-bed elevation errors associated with stream model mesh interpolations at each study site.

[m, meter]

Study site (fig. 1)	Root median square error of interpolated values, in m	Number of independent topographic sample points
M1	0.071	200
M2	.062	134
MDC1	.213	228
MDC2	.181	180
MDC3	.118	330

than those originally calculated. A static topographic and substrate distribution surface is assumed with numerical simulations. The degree of error associated with this assumption would need to be determined by measuring actual changes in the topographic and substrate surfaces with time.

Hydrologic measurements included the collection of streamflow and water-surface elevations used in the construction of elevation-streamflow ratings. Errors associated with these data will contribute to overall simulation errors. Streamflow measurements included errors associated with the measurement of water depth (dependent on flow conditions, but in this study generally was 0.006 m) and velocity (approximately 5 percent). Water-surface elevations were collected with an accuracy of 0.02 m (corresponding to the error of the reference benchmark) and precision of approximately 0.01 m (corresponding to the accuracy and precision of the reference gage or pressure transducer).

Substrate Mapping

Channel substrate was mapped at each site to create a digital surface of the spatial distribution of dominant bottom-material size classes. The first step in creating the substrate maps was to develop a topographic map of each study reach using GIS software and data points from the topographic surveys. A 5-m scaled grid was imposed graphically over the topographic maps to aid in orientation in the field. A Federal Interagency Sedimentation Project (FISP) US SAH-97™ gravelometer was used to classify bottom material into six substrate size categories based on those used by Brewer (2004) and modified from Kinsolving and Bain (1993). These included (1) sand, silt, and clay (fines) [less than (<) 2 mm]; (2) gravel (2–15 mm); (3) pebble [greater than (>) 15–40 mm]; (4) cobble (>40–200 mm); (5) boulder (>200 mm); and (6) bedrock. Each site was inspected to visually define the boundaries of areas with consistent dominant (greater than 50 percent of size class coverage) substrate material on the onsite map. Once the substrate boundaries were approximated on onsite maps, the boundaries were more accurately defined using a Total Station. The substrate boundary survey points were then imported into GIS software and used to develop digital surfaces consisting of polygons of consistent dominant substrate areas.

Fish Habitat Categories

Habitat categories can be defined as combinations of water velocity, water depths, and substrate composition that are considered important to a particular life stage of a fish species during some period. Habitat categories were developed using relations modified from Brewer (2004) between fish species, life stages, and hydraulic and substrate variables for the Marais des Cygnes River study site locations. The reproductive and juvenile life-history stages were targeted in developing these habitat relations. Brewer (2004) defined juveniles as fishes not yet capable of reproduction, spawning adult fishes were identified using an accurate laboratory method (histology), and adult fishes were defined as fishes capable of reproducing, but not in spawning condition. This approach allowed specific spawning chronologies to be identified and then applied to habitat selection during the critical species reproductive season. Information regarding reproduction by a species often is borrowed from the literature, obtained by gross measures (secondary sexual characteristics), or based solely on judgment. Whereas these approaches help identify important life-history phases of fishes, they fail to acknowledge annual variation in spawning conditions, error associated with gross measures, and differences because of locality (latitude) and environmental factors (habitat availability and water temperature). From a biological point of view, determination of specific spawning chronologies provided support for the development of habitat categories because a fitness consequence was associated with the habitats selected by these fishes.

Logistic regression models (Neter and others, 1996) were developed by Brewer (2004) relating the presence of a species with microhabitat variables for fish species present in a minimum of 25 percent of samples by life stage (juvenile, adult, or spawning adult), season (spring, summer, and fall), and diel (summer day and night) periods. Regression models estimated the probability that a species would be present or absent given the explanatory variables (water depth, velocity, substrate composition, distance from bank, and percent attached algae) retained in the model. Diagnostic procedures were conducted on each of the original logistic regression models, including residual plots and influence statistics, to identify extreme observations (Allison, 1999). A Pearson correlation procedure identified explanatory variables that were correlated with one another. Many of the habitat variables were expected to be inter-correlated, and this was a means of excluding variables that were multicollinear. Although there was no strict cutoff, variables with correlation coefficients (r) values of -0.3 were defined as being multicollinear. Graham (2003) considered r equal to -0.6 as strongly multicollinear and <0.4 weakly multicollinear. The variable having the strongest effect on the outcome (determined by calculating standardized coefficients) was retained in the final model (Allison, 1999). Stepwise logistic regression was used to obtain a subset of explanatory variables that explained the presence of a fish species in a particular microhabitat (Neter and others, 1996). Variables continued to be added to the model until they exceeded the predetermined alpha limit [significance level (α) = 0.10] or were statistically insignificant to the model based on the variables already included. A Hosmer-Lemeshow Goodness of Fit test (α <0.05; Hosmer and Lemeshow, 1989) was performed on the final models to check for major departures from a logistic response function.

Water velocity, depth, and substrate composition were retained as explanatory variables in the logistic models and frequency-of-use and availability histograms were constructed for these variables. Fish densities (fish per sample grid) were incorporated into the habitat variable and scaled to 100 percent to determine the use of a habitat element. Habitat availability was considered for all habitats sampled within a season or period and was categorized into discrete velocity, depth, and channel substrate size classes. Velocity categories were divided into 0.20-m increments, depth categories into 0.10-m increments, and substrate into dominant cover size classes. Selection is defined as a process by which an animal chooses a resource disproportionately to the availability of the resource (Johnson, 1980); therefore, the SHA for a category was composed of those histogram sections where habitat use exceeded habitat availability. An example of this is provided for orangespotted sunfish in figure 14. Selected habitat area, as defined, is somewhat similar to "optimum" habitat area as defined by Thomas and Bovee (1993) in that it represents a selective part of the measured usable area, and these selective areas are more highly correlated with measured fish population variables (year class strength, growth rates, and survival) than usable area (Bovee and others, 1994). Habitat elements were incorporated into a habitat matrix by fish species for instream flow modeling. To complete the matrix of depth, velocity, and substrate for every species, frequency-of-use and availability histograms were created for the hydraulic habitat components that were not included in the final logistic regression models. These histograms identified areas of habitat selection by densities of fishes that were not evident by presence-absence models. If no selection was evident in the histograms, habitat-use patterns were used to identify sections of a habitat element that likely were most important to the fish species.

Paddlefish (*Polyodon spathula*) is a sport fishery in Missouri although the natural reproductive capacity has been diminished and the population of this species is maintained through hatchery-raised stock. Depth, velocity, and substrate criteria used in this study for paddlefish habitat were developed and used for similar simulations of paddlefish habitat in the lower Osage River downstream from Lake of the Ozarks (fig. 1; Missouri Department of Conservation, 2004).

A habitat matrix was developed for 26 seasonal, diel, and life-stage habitat categories and used to quantify habitat area and define habitat-streamflow relations for 9 different fish species (table 6). The prioritized vulnerability of the habitat categories to habitat alteration noted in table 6 was based on the life stage and adaptability of the species. The designation of a vulnerability status was for the purpose of this report and was not intended to indicate a fisheries management priority for the sampled species. Whereas the actual importance of a habitat feature to a fish often is not clearly known, two vulnerable periods are spawning and survival of young fishes. Habitat mapping and category development were focused on linking reproduction and nursery periods to specific habitat conditions. The reproductive timing and the general ecology of the fishes were the criteria used to characterize the vulnerability of a species/category to habitat alteration.

Critical spawning-period categories were identified in the seasonal and life-stage habitat categories (table 6) for four species including suckermouth minnow (*Phenacobius mirabilis*), slenderhead darter (*Percina phoxocephala*), paddlefish, and red shiner (*Notropis lutrensis*). In Missouri, populations of the suckermouth minnow have declined (Winston, 2002), and although this species is a multiple spawner, the spawning period (mid-March through early May) is much shorter than for species that spawn throughout the summer months (for example, red shiner). Slenderhead darters are benthic fish that bury their eggs within the substrate (Pflieger, 1997; Simon, 1999), and habitat quality may be deleteriously affected by reduced flows that may prevent the removal of silt from coarse substrate where they deposit their eggs. Paddlefish have restricted spawning periods (April and May), limited spawning habitat as a result of Truman Reservoir (fig. 1) and Lake of the Ozarks, and specific streamflow requirements during the spawning period (Pflieger, 1997) that result in limited natural reproduction. Natural reproduction of paddlefish has been documented in the Marais des Cygnes River, but no natural reproduction takes place downstream from Bagnell Dam at Lake of the Ozarks (Trish Yasger, Missouri Department of Conservation, written commun., 2005). Paddlefish also have used the Marmaton and Little Osage Rivers for spawning, but information on the success of natural reproduction in these rivers is not available (Trish Yasger, written commun., 2005). Alternatively, red shiners are speleophils (fish that lay eggs in crevices, holes, and under rocks for protective cover; Simon, 1999) with adaptive spawning requirements (Pflieger, 1997) and, therefore, are not listed as a category of high or medium vulnerability (table 6). Furthermore, red shiners are one of the most abundant and widely distributed fish species in midwestern prairie streams (Cross, 1967; Pflieger, 1997); a protracted spawning period and early sexual maturity increase the opportunity for reproductive success for this species.

Juvenile abundances are important in determining species richness and composition (Schlosser, 1985); however, few studies have been dedicated to juveniles despite their important role in the maintenance of fish populations. Shallow habitats are critical nursery habitats for young-of-the-year fishes (Humphries and Lake, 2000). Therefore, juvenile Ictalurids [flathead catfish (*Pylodictis olivaris*), channel catfish (*Ictalurus punctatus*), and stonecat (*Noturus flavus*)] categories were identified as having a high level of vulnerability to habitat alteration

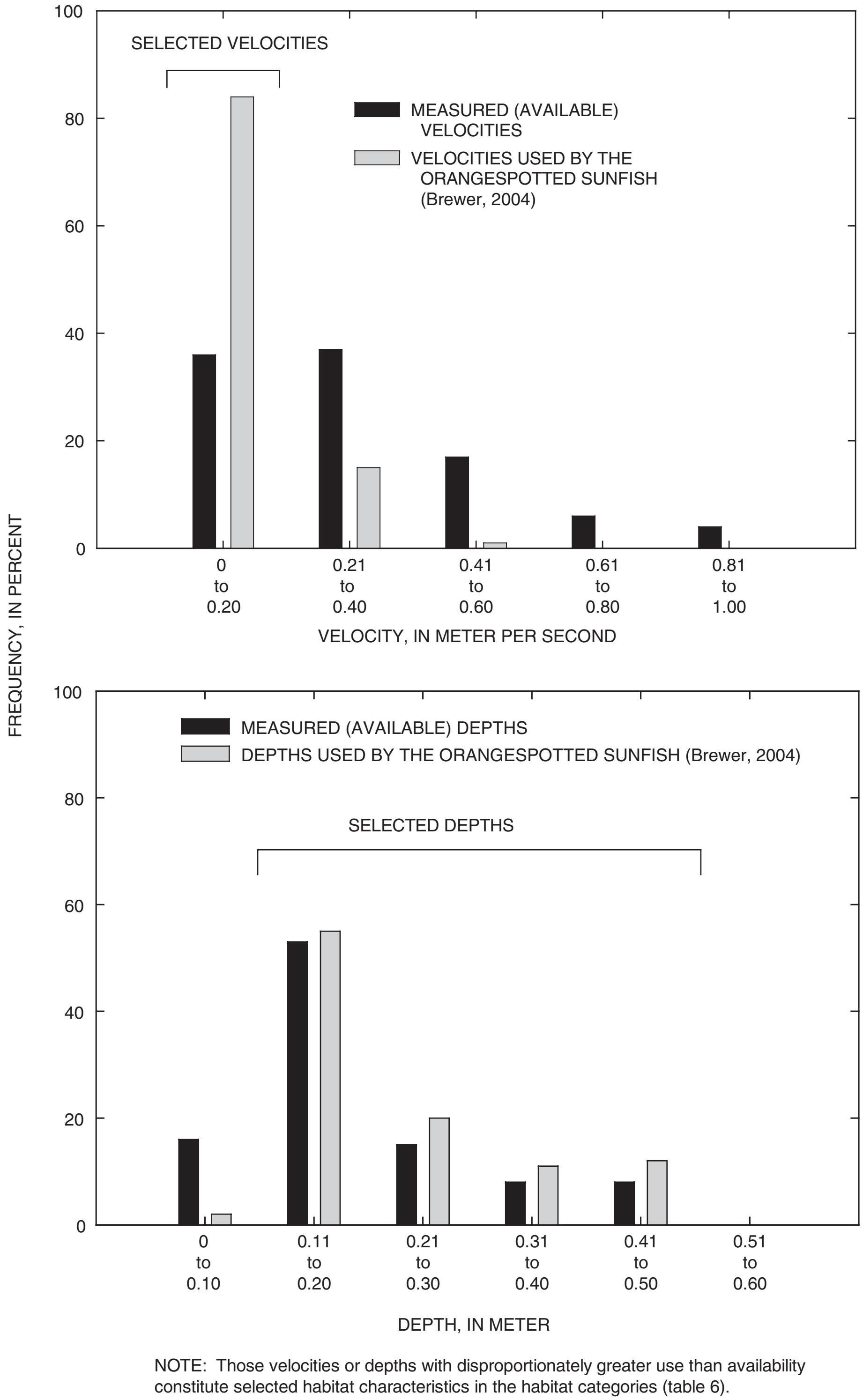

Figure 14. Distribution of measured (available) velocities and depths and those used by the orangespotted sunfish.

Table 6. Fish habitat categories used in the determination of selected habitat area for the Maramaton and Marais des Cygnes River study sites.

[ID, identification; m, meter; m/s, meter per second; >, greater than]

Category ID[a]	Species	Life stage	Selected depth, in m	Selected velocity, in m/s	Selected substrate	Vulnerability to habitat alterations
			Spring			
1	Suckermouth minnow (*Phenacobius mirabilis*)	Spawning	0.05–0.30	0.2 –0.8	Sand, silt, clay; gravel; pebble; cobble; boulder; bedrock	High
2	Red shiner (*Notropis lutrensis*)	Juvenile/Adult	.05– .30	.0 – .4	Gravel	Low
3	Sand shiner (*Notropis stramineus*)	Juvenile	.05– .30	.0 – .6	Gravel	Low
4	Slenderhead darter (*Percina phoxocephala*)	Spawning	.20– .80	.6 –1.0	Cobble	High
5	Slenderhead darter (*Percina phoxocephala*)	Spawning	.20– .80	>1.0 –2.0	Cobble	High
6	Stonecat (*Noturus flavus*)	Adult	.10– .40	.2 – .8	Pebble, cobble	Medium
7	Paddlefish (*Polyodon spathula*)	Spawning	>.50	>1.4	Gravel, pebble, cobble	High
			Summer day			
8	Flathead catfish (*Pylodictis olivaris*)	Juvenile	0.05–0.60	0.0 –0.4	Pebble, cobble, boulder	High
9	Red shiner (*Notropis lutrensis*)	Spawning	.05– .20	.0 – .8	Cobble	Low
10	Channel catfish (*Ictalurus punctatus*)	Juvenile	.10– .30	.0 – .4	Sand, silt, clay; gravel; pebble; boulder	High
11	Slenderhead darter (*Percina phoxocephala*)	Adult	.20– .70	.4 –1.0	Cobble	Medium
12	Slenderhead darter (*Percina phoxocephala*)	Adult	.20– .70	>1.0 –2.0	Cobble	Medium
13	Stonecat (*Noturus flavus*)	Juvenile	.05– .90	.2 – .9	Pebble, cobble	High
			Summer night			
14	Flathead catfish (*Pylodictis olivaris*)	Juvenile	0.10–0.40	0.2 –0.8	Cobble, boulder	High
15	Red shiner (*Notropis lutrensis*)	Juvenile/Adult	.05– .10	.0 – .4	Sand, silt, clay; gravel; pebble; cobble; boulder; bedrock	Low
16	Channel catfish (*Ictalurus punctatus*)	Juvenile	.30– .50	.8 –1.0	Sand, silt, clay; gravel; pebble; cobble; boulder; bedrock	High
17	Channel catfish (*Ictalurus punctatus*)	Juvenile	.30– .50	>1.0 –2.0	Sand, silt, clay; gravel; pebble; cobble; boulder; bedrock	High
18	Slenderhead darter (*Percina phoxocephala*)	Adult	.10– .30	.4 –1	Cobble, boulder	Low
19	Stonecat (*Noturus flavus*)	Juvenile	.05– .20	.2 –1	Cobble	High
			Fall			
20	Flathead catfish (*Pylodictis olivaris*)	Juvenile	0.10–0.40	0.2 –0.6	Cobble, boulder	High
21	Red shiner (*Notropis lutrensis*)	Juvenile	.05– .20	.0 – .2	Cobble	Low
22	Channel catfish (*Ictalurus punctatus*)	Juvenile	.20– .40	.2 – .6	Sand, silt, clay; gravel	High
23	Slenderhead darter (*Percina phoxocephala*)	Adult	.30– .50	.2 – .8	Cobble	Low
24	Stonecat (*Noturus flavus*)	Juvenile	.05– .30	.2 –1.0	Sand, silt, clay; gravel; pebble; cobble; boulder	High
25	Stonecat (*Noturus flavus*)	Juvenile	.05– .30	>1.0 –2.0	Sand, silt, clay; gravel; pebble; cobble; boulder	High
26	Orangespotted sunfish (*Lepomis humilis*)	Juvenile	.10– .50	.0 – .2	Boulder	Medium

[a]Modified from Brewer, 2004.

(table 6) during the periods that juveniles were most abundant (summer and fall). The juvenile Ictaluridae species were associated with larger substrate particle sizes and slower velocities, with the exception of stonecat, which selected faster water in the fall. It may be that slower water is more comfortable for small fish and the larger substrate sizes provide abundant microhabitats for resting and abundant microinvertebrates for nutrition. Channel catfish likely was the only species whose selection of a habitat variable, high-current velocity during night, was passive because the selection was likely a dispersal mechanism for young individuals. Day-night differences in habitat associations and densities for flathead catfish and stonecat indicate active movement from one habitat type to another (Brewer, 2004). Other juveniles using shallow habitats during the summer and fall were the red shiner and orangespotted sunfish (*Lepomis humilis*). The orangespotted sunfish was considered to be of medium vulnerability (table 6) because it was present only during the fall and occupied only 25 percent of the samples.

For those species with habitat requirements that included velocities greater than 1 m/s (table 6; category pairs 4, 5; 11, 12; 16, 17; and 24, 25), categories were subdivided into a category less than or equal to 1 m/s and one of greater than 1 to 2 m/s. This was done to compare the part of total habitat that was available at the higher (greater than 1 to 2 m/s) velocities to that available at lower velocities.

Fish Habitat Characteristics

Digital surfaces of depth, velocity, and substrate were combined to quantify SHAs and determine the spatial distribution of the category areas with changes in streamflow. Substrate size was determined at the mesh nodes by intersecting the node locations with the substrate size distribution map for each model reach. The model output of depth and velocity was combined with the substrate material size at each node and evaluated to determine if the node represented selected habitat for a given habitat category definition. If all variables at a node met the requirements of a given selected habitat category, the node 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 SHA were determined by delineating the nodes (1’s) that met the binary criteria for a given habitat category. Statistical characteristics of the SHAs were calculated for each category and each simulated streamflow, including normalized SHA (total SHA per 100 m of channel); the number of SHA patches (polygons of selected nodes); minimum, maximum, and mean patch size; and standard deviation of SHA patches.

QUANTIFICATION OF FISH HABITAT

Hydraulic characteristics (water velocity and depth) were simulated under steady-state conditions for a range of streamflows and combined with substrate characteristics to map and characterize the SHA for 26 fish habitat categories. Resulting products include the area of selected habitat with streamflow, the spatial distribution and persistence of SHA with streamflow, and the temporal characteristics of SHA by category and site.

Simulated Hydraulic Characteristics

Velocities and depth distributions varied greatly with streamflow at the study sites. The spatial distribution and variability of depth and velocity for selected flows at all sites are provided in figures 15 to 19 (on compact disc at the back of this report). The selected streamflows include examples of hydraulic characteristics for three orders of magnitude of streamflow. Simulation results indicate that stages for the lowest represented streamflows are controlled by riffles with velocities in pools near zero, and small areas of substantial velocity restricted to within-riffle areas. As streamflows increase, as represented by the mid- and highest streamflows in figures 15 to 19, areas of substantial velocity greatly expand, and the effects of riffles as the control of stage diminish.

A comparison of hydraulic characteristics between the unchannelized (sites MDC1 and MDC2) and channelized (site MDC3) Marais des Cygnes River sites shows a relative lack of variability in depths and velocities at the channelized site MDC3 (figs. 17 to19, table 7). The depth variability was essentially constant with streamflow at all three sites (table 7). The velocity variability increased substantially with streamflow at all three sites and was lowest at site MDC3 at the highest represented simulated streamflow of 116 m^3/s.

Substrate

Fines (sand, silt, clay) covered more than 66 percent of total substrate coverage at both Marmaton River sites, with cobble being the next largest substrate class (less than 20 percent). Although the remaining four classes covered less than 9 percent each, all six categories were represented at both sites (figs. 20, 21, on compact disc at the back of this report). Generally, finer particles were located along the edges near the river banks in the channel at all sites.

Substrate areas dominated by sand, silt, and clay were less than 47 percent of the total coverage area at the three Marais des Cygnes River sites (figs. 22 to 24, on compact disc at the back of this report), but still were the dominant coverage class at two of the three sites. At the upstream site, MDC1, the second largest cover area class was cobble (42.0 percent). At site MDC2, bedrock was the second largest category at 19.3 percent. At site MDC3 the dominant coverage category was bedrock (34.9 percent) followed by fines (29.7 percent). The channelized site, MDC3, was the only site at which gravel-dominated substrate areas were not observed.

Table 7. Variability in nodal depths and velocities for selected streamflows at the Marais des Cygnes River study sites.

[m, meters; m/s, meters per second; m^3/s, cubic meters per second]

Standard deviation of depths, in m	Standard deviation of velocities, in m/s	Standard deviation of depths, in m	Standard deviation of velocities, in m/s	Standard deviation of depths, in m	Standard deviation of velocities, in m/s
Marais des Cygnes River site MDC1					
Discharge = 1.00 m^3/s		**Discharge = 8.80 m^3/s**		**Discharge = 116 m^3/s**	
3.24	0.058	3.23	0.187	3.24	0.646
Marais des Cygnes River site MDC2					
Discharge = 1.00 m^3/s		**Discharge = 9.90 m^3/s**		**Discharge = 121 m^3/s**	
2.99	0.079	2.99	0.244	3.00	0.664
Marais des Cygnes River site MDC3					
Discharge = 1.00 m^3/s		**Discharge = 10.9 m^3/s**		**Discharge = 116 m^3/s**	
1.83	0.117	2.19	0.303	2.19	0.473

Fish Habitat Characteristics

Habitat Availability

The maximum fish habitat areas in spring (April through June) at Marmaton River site M1 occurred at streamflows between 0.1 and 10 m^3/s for all categories except for paddlefish (fig. 25; table 8, on compact disc at the back of this report) with spring median monthly streamflows of 6 m^3/s (fig. 25). Paddlefish habitat increased with streamflow from 7 to about 50 m^3/s and remained near 1,000 $m^2/100$ m (square meters per 100 meters, normalized area) with subsequent increases in streamflow. Habitat availability for species/categories other than paddlefish occurred for a range of flows from 0 (in pools) to 20 m^3/s. Species most susceptible to complete dewatering in spring at site M1 were suckermouth minnow, slenderhead darter, stonecat, and paddlefish (fig. 25; table 8) as SHA decreased substantially at flows less than 1 m^3/s. These categories have minimum velocity criteria of at least 0.2 m/s (table 6) that are not met at streamflows approaching zero. Suckermouth minnow, slenderhead darter, and paddlefish spawn in the spring and are particularly vulnerable to habitat limitations during this period. Suckermouth minnow and slenderhead darter rely on moving water to prevent siltation and to keep eggs oxygenated. Adult stonecats likely feed in shallow water habitats before moving to deeper water habitat to spawn. Species least vulnerable to loss of spring habitat as a result of dewatering are red shiner and sand shiner (*Notropis stramineus*); as category velocity criteria extend to zero, these species can use pools. Alternatively, all categories other than paddlefish were susceptible to habitat limitations at flows exceeding 20 m^3/s because water depths above this streamflow exceed habitat category criteria.

Backwater effects on habitat quantity in the spring at site M1 for most categories was negligible as backwater conditions occur only at higher flows (near bank full) and selected habitat availability already is limited by excessive water depths. Backwater conditions are a natural and common occurrence on the low-gradient Marmaton River at streamflows near and above bank-full conditions. Paddlefish habitat was available for a greater range of streamflows than other species categories, and habitat area generally was less under simulated backwater conditions than non-backwater conditions (fig. 25) as a result of lower velocities.

Summer (July through September) maximums in SHA (day and night) at site M1 generally occurred between 1 and 10 m^3/s; the summer median monthly streamflow of 0.7 m^3/s (fig. 25) was less than this range of maximum SHAs. Species most susceptible to summer dewatering are slenderhead darter (day and night), stonecat (day and night), flathead catfish (night), and channel catfish (night) because velocity criteria would not be met under these conditions. Slenderhead darter may still be spawning in early summer and would be more susceptible to

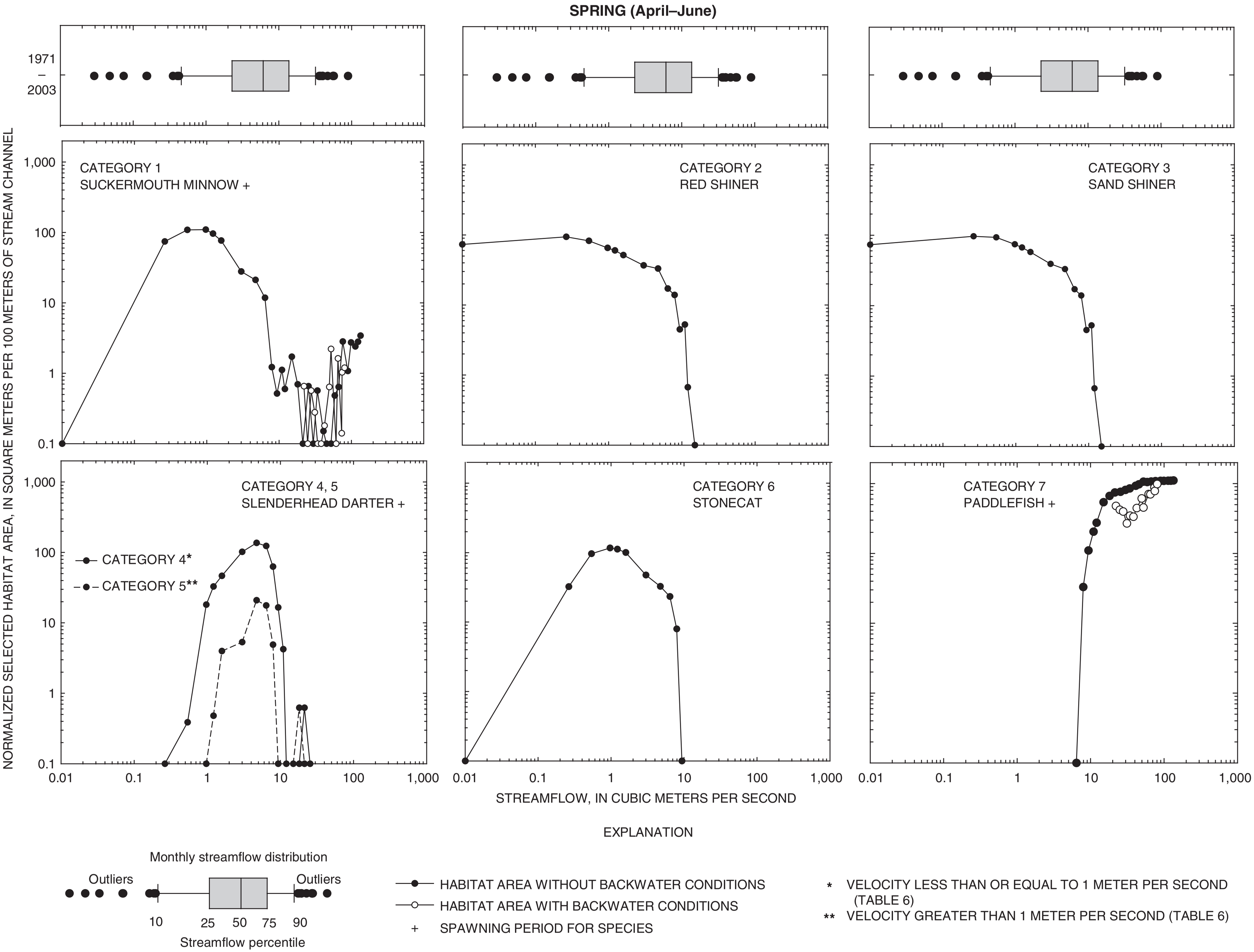

Figure 25. Relation between normalized selected habitat area and monthly streamflow distribution for spring, summer day and night, and fall conditions at the Marmaton River site M1.

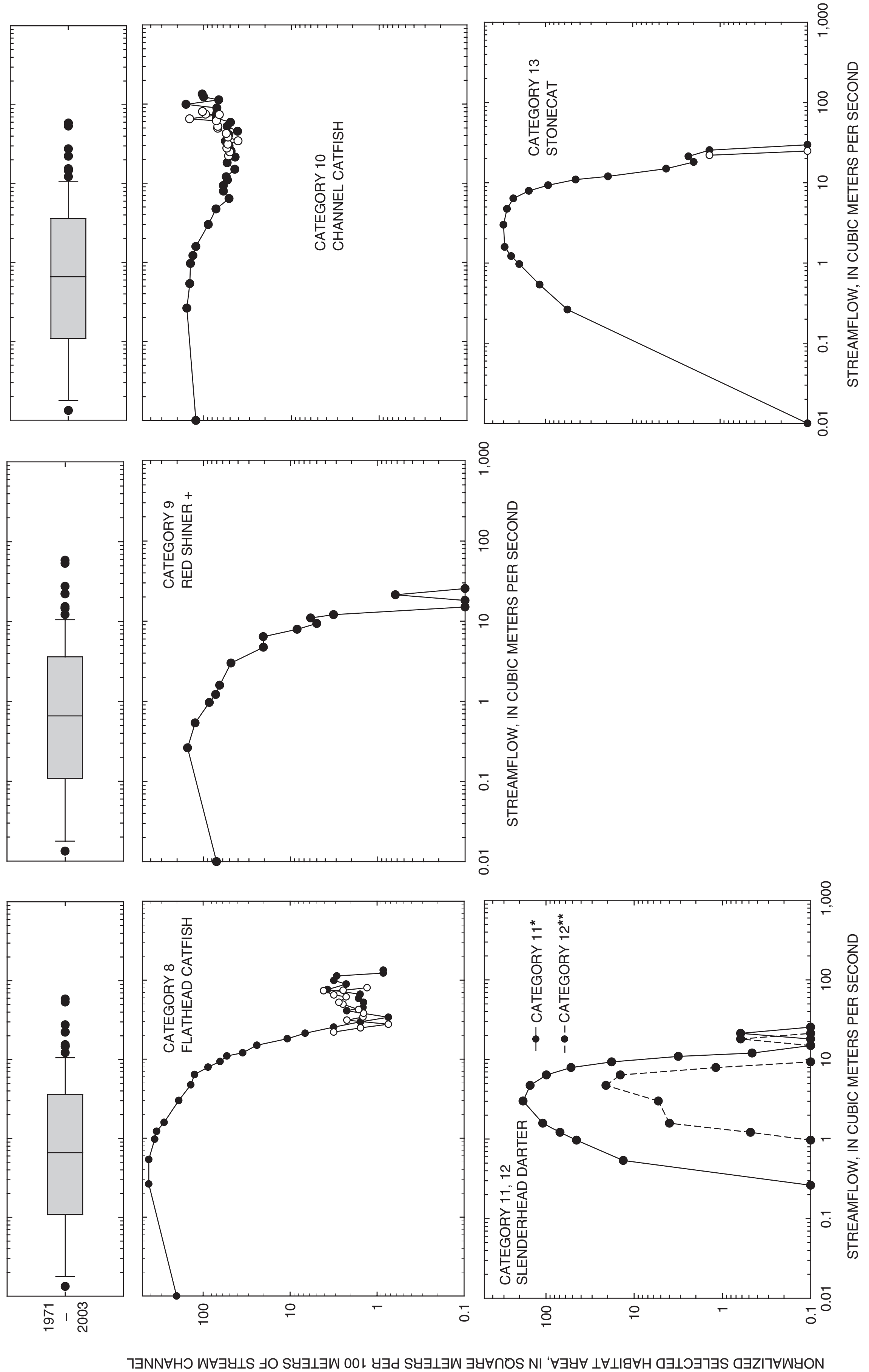

Figure 25. Relation between normalized selected habitat area and monthly streamflow distribution for spring, summer day and night, and fall conditions at the Marmaton River site M1—Continued.

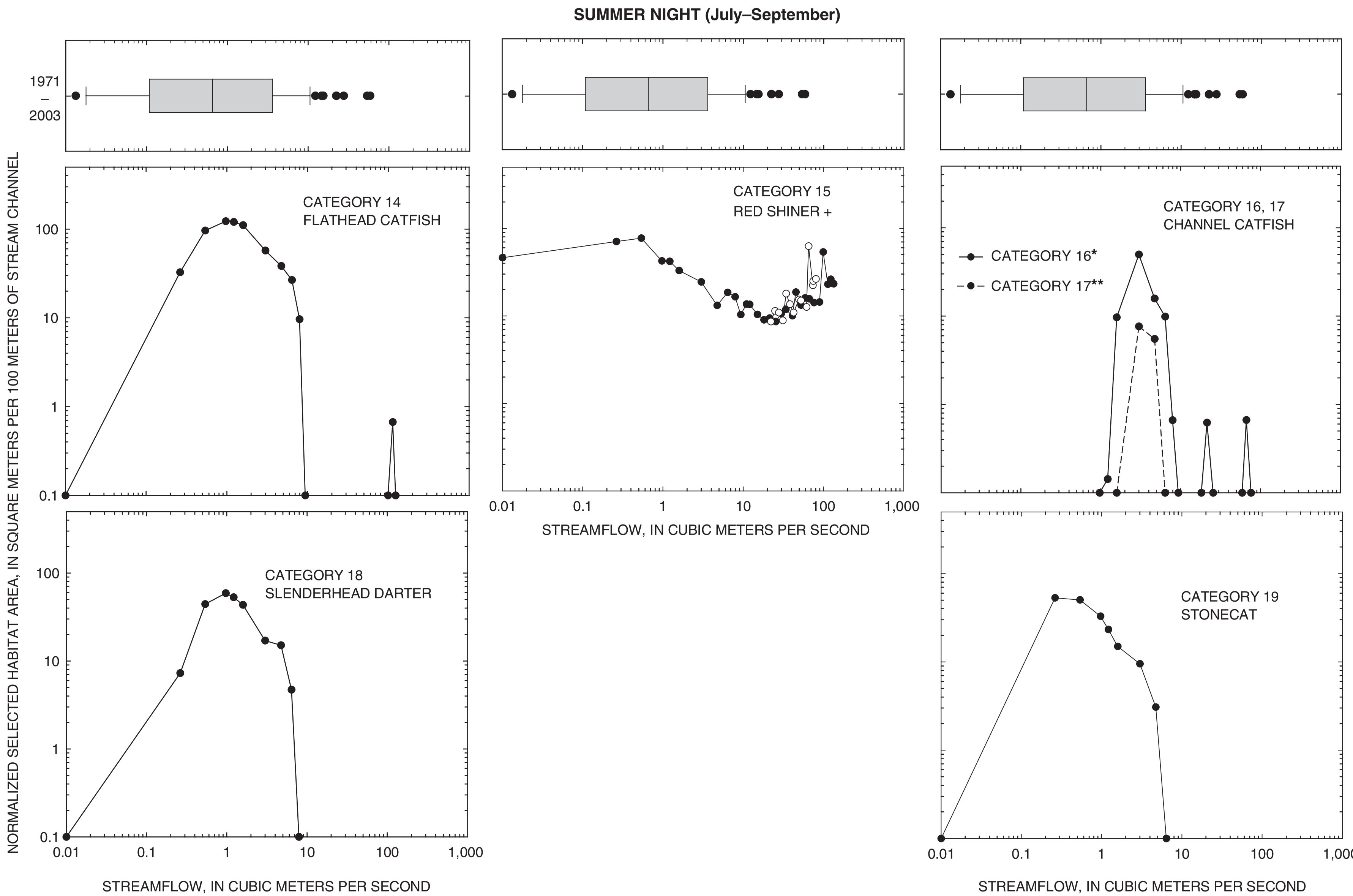

Figure 25. Relation between normalized selected habitat area and monthly streamflow distribution for spring, summer day and night, and fall conditions at the Marmaton River site M1—Continued.

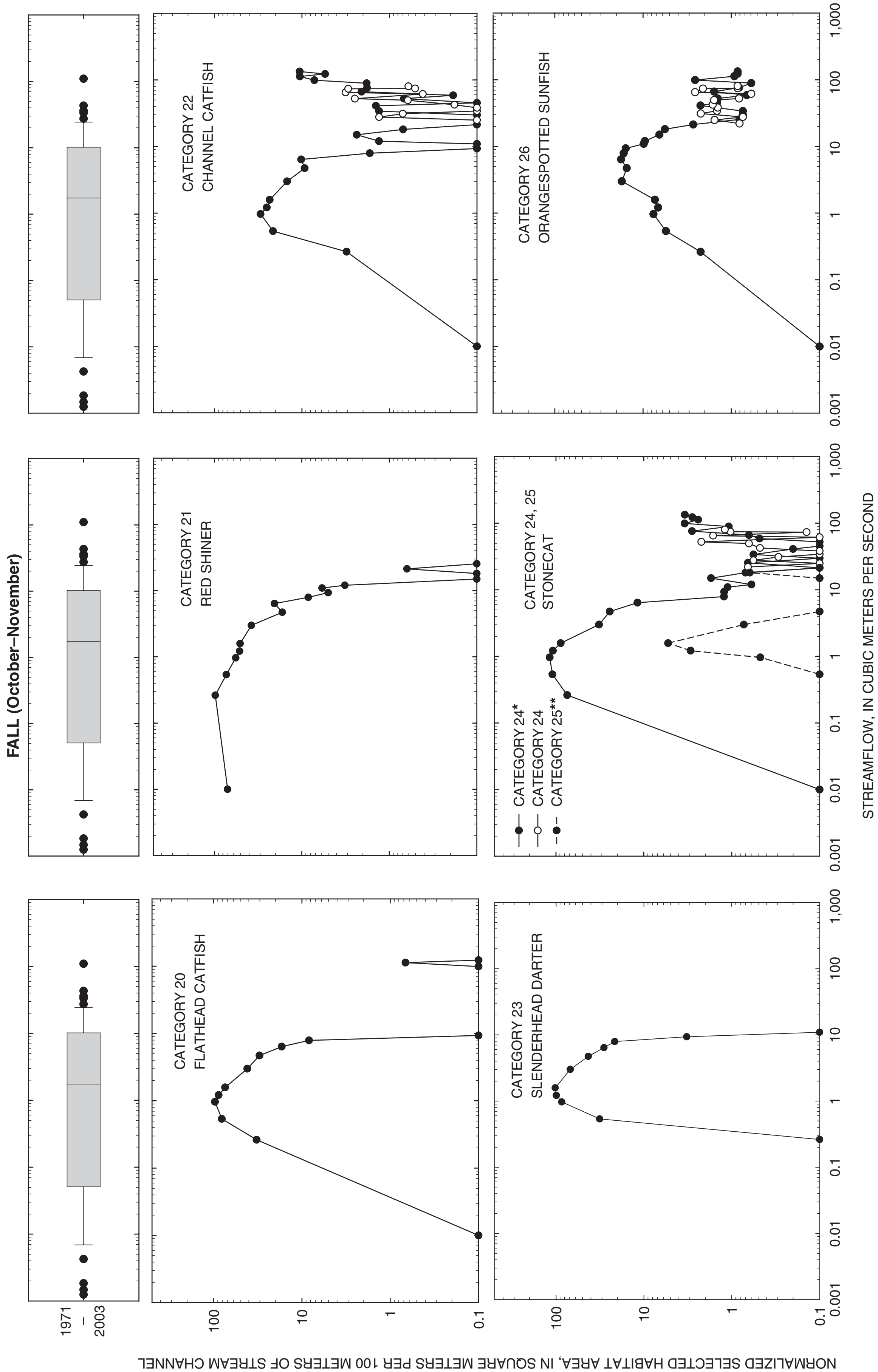

Figure 25. Relation between normalized selected habitat area and monthly streamflow distribution for spring, summer day and night, and fall conditions at the Marmaton River site M1—Continued.

night habitat limitations during this time than non-spawning periods. Later in the summer these fish would use the shallow water habitats to migrate to deeper water habitats. Species that were least susceptible to summer dewatering include flathead catfish (day), red shiner (day and night), and channel catfish (day); all of which have velocity criteria that extend to zero (can utilize pools). Habitat for summer (day) conditions for these species generally was maximized at streamflows of about 1 to 2 m^3/s and SHA occurred for a range of streamflows between 0.01 and 30 m^3/s. Therefore, summer flows greater than 30 m^3/s will result in SHA limitations for all categories because category depth criteria are exceeded. Habitat for all summer night categories generally peaked at streamflows less than 1 m^3/s and occurred for a streamflow range of 0.1 to 10 m^3/s. Therefore, summer night category habitats are limited at flows exceeding 10 m^3/s because depth criteria are again exceeded.

Fall (October through November) maximums in habitat availability at site M1 occurred for streamflows of 0.1 to 10 m^3/s with a corresponding median monthly streamflow of 2 m^3/s (fig. 25). Overall habitat availability in the fall at site M1 also occurred for a range of flows between 0.1 and 10 m^3/s. All species except red shiner were susceptible to dewatering in the fall months, and all fall categories were susceptible to habitat limitations at flows higher than 10 m^3/s.

Selected habitat area for spring categories at the downstream Marmaton River site M2 were maximized at streamflows between 1 and 10 m^3/s for most species (fig. 26; table 9, on compact disc at the back of this report). Site M2 has a long-term (1971 through 2003) spring median streamflow of 20 m^3/s (fig. 26; table 9), which is greater than the range of streamflows for maximum SHAs. Paddlefish habitat area was again the exception with habitat availability beginning at streamflows exceeding 4 m^3/s and peaking at streamflows greater than 100 m^3/s. All spring habitat categories were susceptible to dewatering at site M2, including red shiner and sand shiner, despite having velocity criteria extending to zero (table 6). This is because the gravel substrate selected by these species is exposed at zero streamflow. All categories except paddlefish were susceptible to habitat limitations at flows exceeding 50 m^3/s because category depths were exceeded at this streamflow. Selected habitat area for the spring categories generally was available for the range of streamflows between 0.5 and 50 m^3/s.

Median monthly summer (July through September) streamflows at site M2 are 2 m^3/s, which is within the range of 1 to 10 m^3/s for which SHAs are maximized. The streamflow range was less than 0.1 to 30 m^3/s for day categories and less than 0.1 to 20 m^3/s for night categories for most species (fig. 26). Summer SHA categories susceptible to dewatering and high flows were similar to those at site M1.

The median streamflow for the fall (October through November) 1971 through 2003 months at site M2 was 5 m^3/s, with habitat categories maximized between 1 and 10 m^3/s (fig. 26). Selected habitat was available at streamflows of between 0.5 and 30 m^3/s, although orangespotted sunfish habitat was available even at streamflows exceeding 100 m^3/s. Similar to site M1, red shiner habitat at site M2 was not determined to be susceptible to streamflow depletion in the fall, but remaining categories were susceptible to complete dewatering. Selected habitat area was limited at flows exceeding 30 m^3/s, except for the orangespotted sunfish.

Streamflow analysis of the 1941 through 1963 and 1982 through 2003 water years at site MDC1 indicate that minimum monthly flows were greater for all months from 1982 through 2003, except for April, and the maximum monthly values from 1982 through 2003 typically (9 of 12 months) were less than 1941 through 1963 values (table 10). Also, peak streamflows from 1982 through 2003 were smaller than earlier period peaks, the fall rate of post-regulation floods was slower for the later period, and the duration of small floods was greater for post-regulation floods (table 10).

At site MDC1, the spring SHA for suckermouth minnow, slenderhead darter, and stonecat was available from 1 to 800 m^3/s, from less than 1 to 150 m^3/s for red shiner and sand shiners, and at streamflows greater than 10 m^3/s for paddlefish (fig. 27; table 11, on compact disc at the back of this report). Some categories (suckermouth minnow, slenderhead darter, and stonecat) show secondary habitat availability peaks at site MDC1, and these are associated with the submergence of channel benches at mid-bank streamflows (fig. 4). Similar to Marmaton River sites, SHAs at site MDC1 peaked at streamflows of 1 to 10 m^3/s with the exception of paddlefish habitat, which continued to increase with increasing streamflow.

The median 1982 through 2003 spring streamflow at site MDC1 was 50 m^3/s, whereas the 1941 to 1963 median streamflow was 30 m^3/s. Although the increased flow reduces the likelihood of dewatering, it is further from the range of flow required for maximum SHAs. Spring species/categories most susceptible to complete dewatering at this site were similar to those at the Marmaton River sites and included suckermouth minnow, slenderhead darter, stonecat, and paddlefish. The species/categories least vulnerable to dewatering were red shiner and sand shiners as pool areas with gravel substrate were available. The susceptibility of categories to habitat limitation at higher spring flows is reduced at this site in comparison with Marmaton River sites, because usable flows for all categories other than paddlefish extended from 1 to 800 m^3/s (greater than 80 percentile flows) as opposed to 20 to 50 m^3/s (50 to 80 percentile flows) at site M1 and M2 (fig. 27; table 11). The Marais des Cygnes River sites have greater channel widths and, therefore, depth criteria are still met at higher streamflows.

Median summer streamflow from 1982 through 2003 at Marais des Cygnes River site MDC1 was 5 m^3/s, with SHA category peaks occurring at 1 to 10 m^3/s, as at both Marmaton River study sites (fig. 27). Summer habitat category susceptibility to post-regulation streamflows less than 1 m^3/s was less at site MDC1 (1 m^3/s corresponds to the 25 percentile streamflow) than that at Marmaton River sites M1 (1 m^3/s corresponds to the 60 percentile streamflow) and M2 (1 m^3/s corresponds to the 40 percentile streamflow). The potential habitat was again available for a substantially greater range of streamflows (0.1 to 800 m^3/s rather than 0.1 to 10 m^3/s). Slenderhead darter (day and

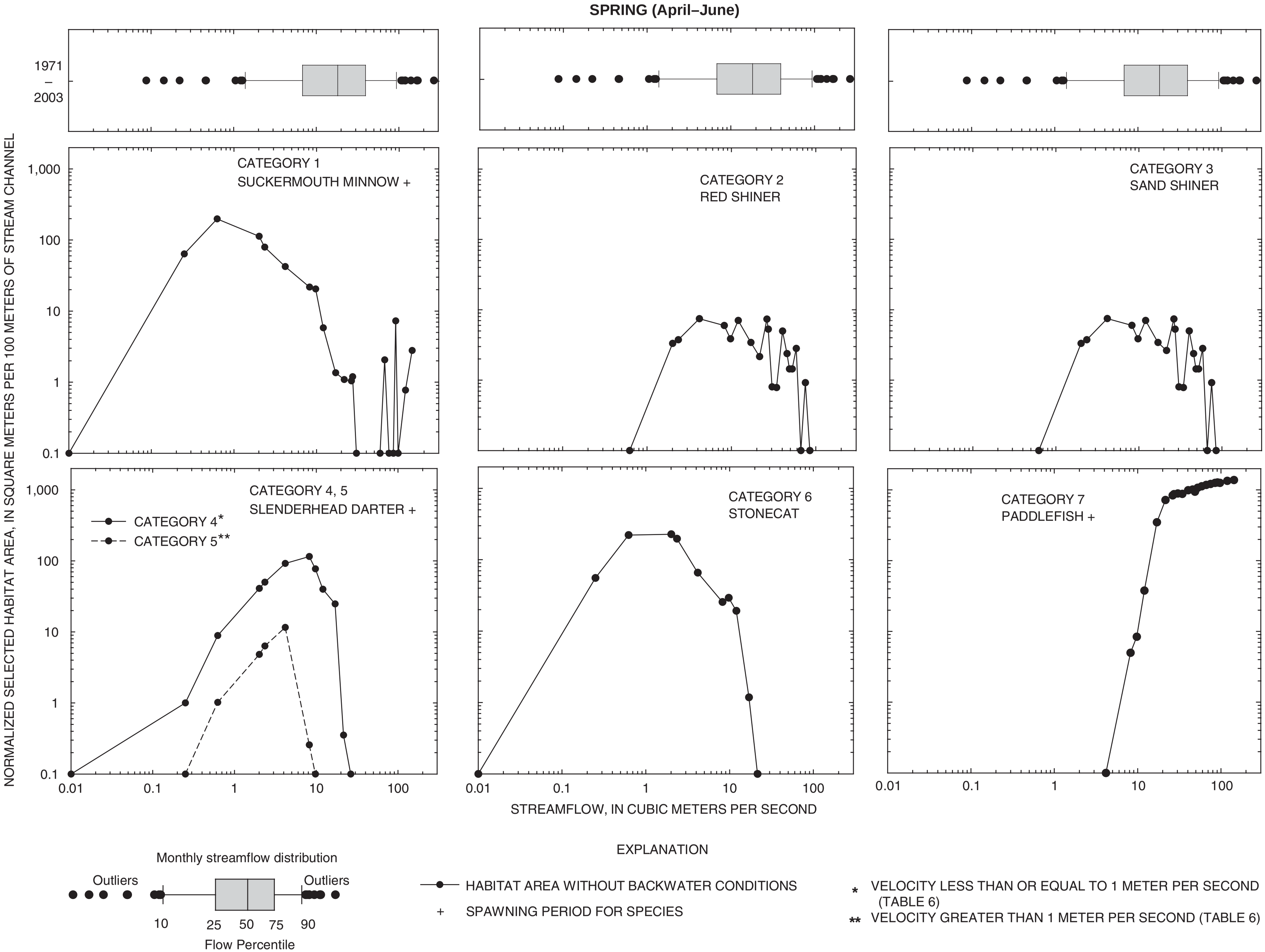

Figure 26. Relation between normalized selected habitat area and monthly streamflow distribution for spring, summer day and night, and fall conditions at the Marmaton River site M2.

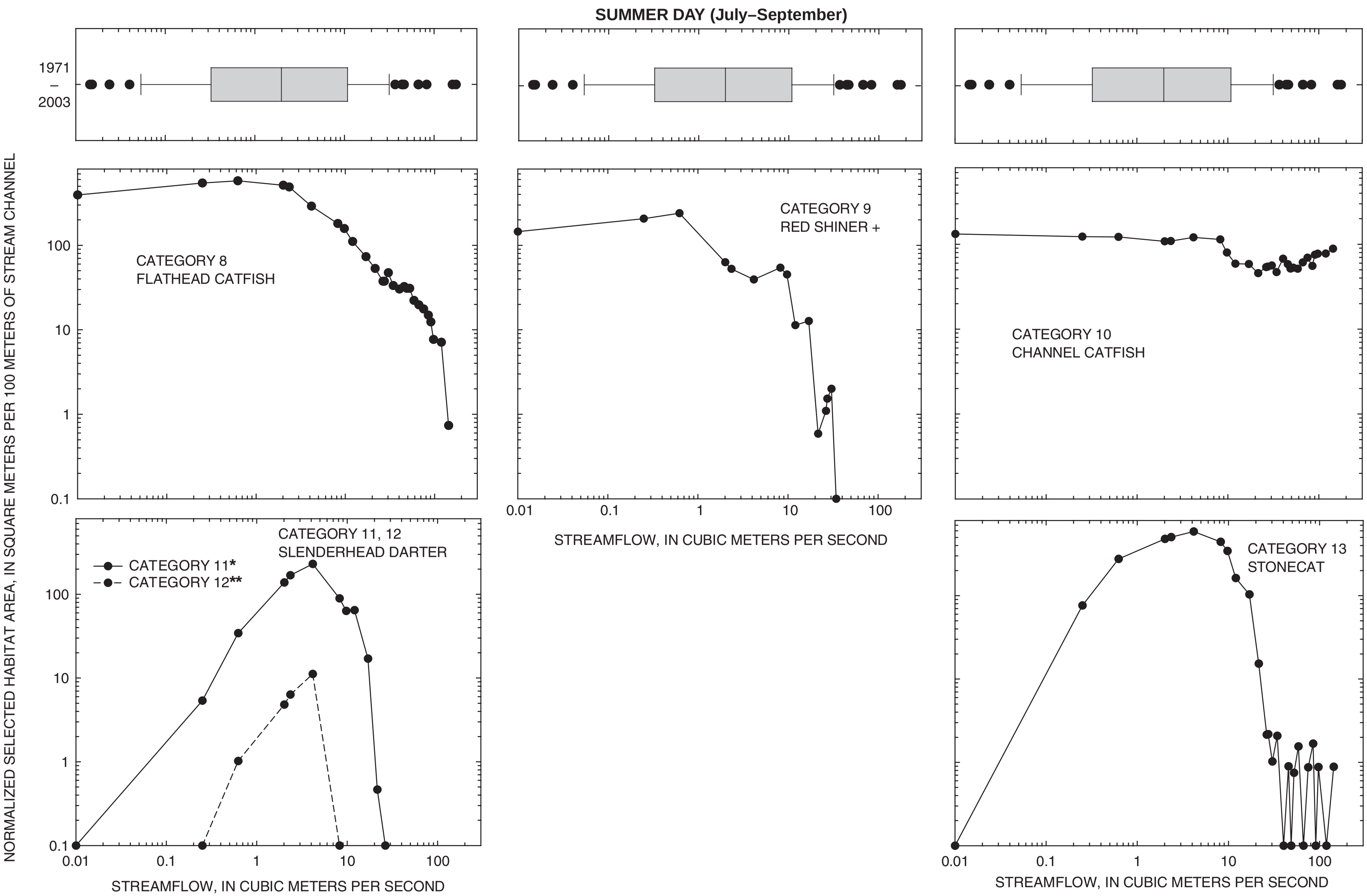

Figure 26. Relation between normalized selected habitat area and monthly streamflow distribution for spring, summer day and night, and fall conditions at the Marmaton River site M2—Continued.

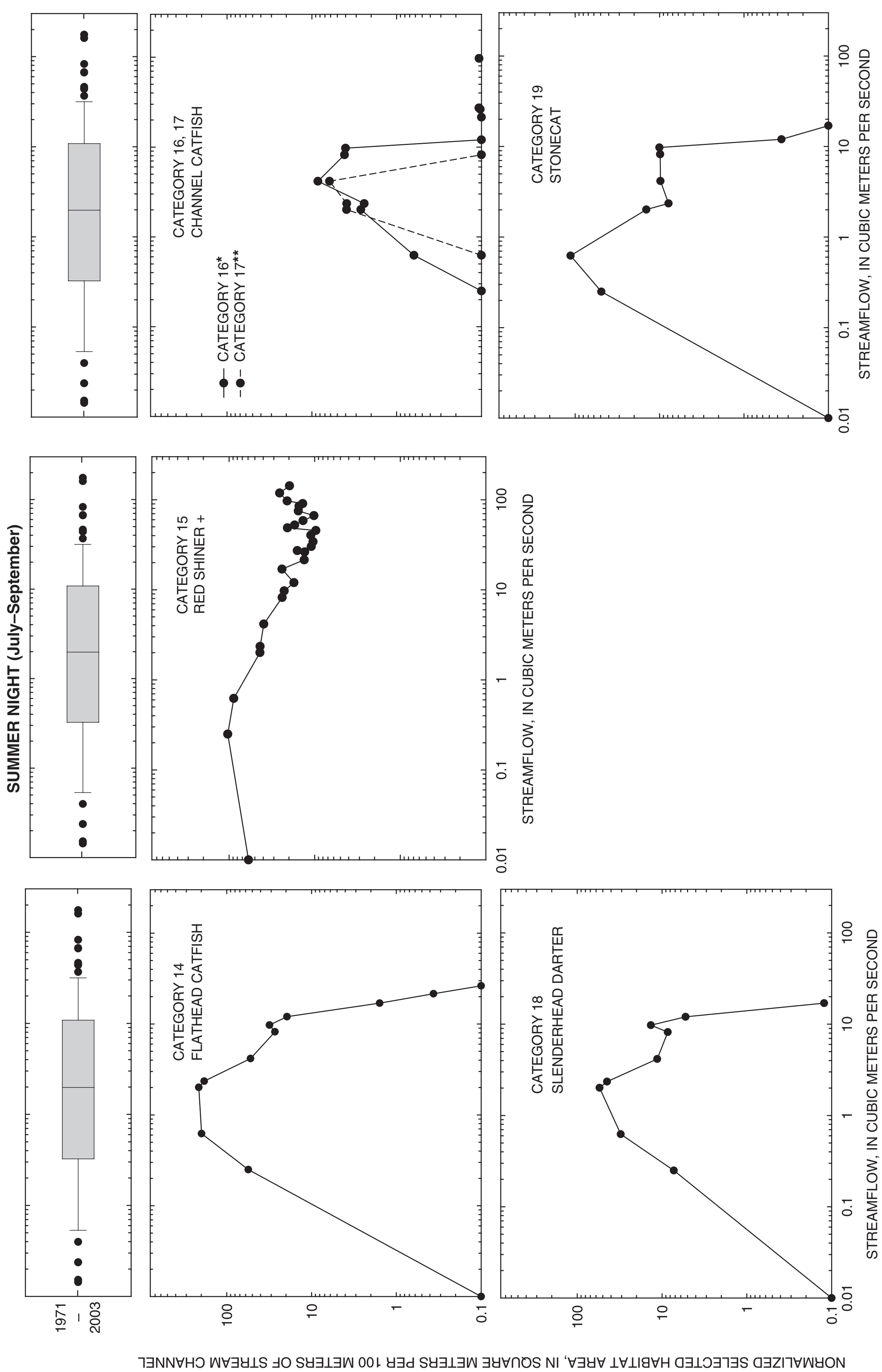

Figure 26. Relation between normalized selected habitat area and monthly streamflow distribution for spring, summer day and night, and fall conditions at the Marmaton River site M2—Continued.

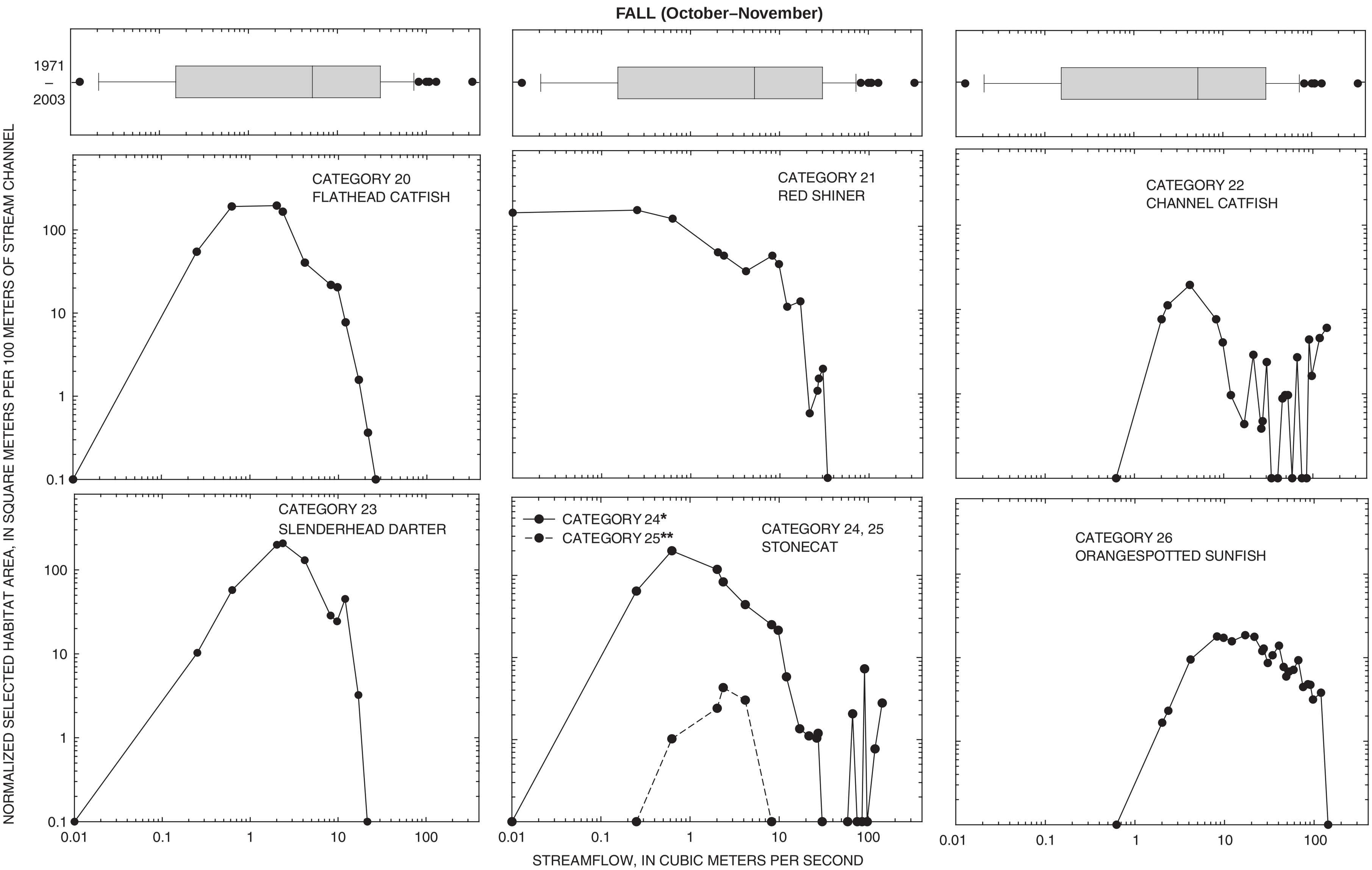

Figure 26. Relation between normalized selected habitat area and monthly streamflow distribution for spring, summer day and night, and fall conditions at the Marmaton River site M2—Continued.

Table 10. Comparison of 1941 through 1963 and 1982 through 2003 streamflow statistics at the Marais des Cygnes River site MDC1.

[m^3/s, cubic meters per second; $m^3/s/d$, cubic meters per second per day]

Summary statistics

	October	November	December	January	February	March	April	May	June	July	August	September
1941–1963 Median monthly value (Pre-regulation)												
Minimum	0	0	0.09	0.09	0.09	0.08	0.81	3.13	0.73	0.03	0.06	0.01
25 Percentile	1.80	1.27	1.66	2.25	4.51	10.91	12.67	9.12	8.34	3.78	.94	.27
Median	5.05	4.05	5.23	14.04	15.92	31.59	28.59	26.25	27.18	8.53	3.32	2.03
75 Percentile	19.87	21.36	16.87	28.88	20.14	70.67	67.41	50.15	58.29	25.56	7.91	12.73
Maximum	511.26	292.86	59.92	210.64	188.55	191.48	420.08	245.5	327.27	547.08	223.07	229.23
1982–2003 Median monthly value (Post-regulation)												
Minimum	0.52	0.62	0.96	0.90	1.19	1.45	0.78	4.21	1.7	1.45	0.29	0.38
25 Percentile	1.57	1.71	2.71	3.91	6.09	14.24	11.29	14.75	19.92	5.72	1.42	1.86
Median	2.95	5.91	23.94	12.01	19.38	38.93	37.70	55.49	52.88	15.66	5.17	4.27
75 Percentile	7.01	55.31	61.74	34.5	42.56	78.01	115.96	175.7	137.53	40.31	12.27	6.17
Maximum	238.24	228.79	151.66	142.65	106.19	218.48	303.61	342.83	316.68	256.83	106.63	84.54

Flood characteristics

	1941–1963	1982–2003
Small flood peak[a], in m^3/s	906.18	903.56
Small flood duration, in days	31	49
Small flood rise rate, in $m^3/s/d$	101.11	85.46
Small flood fall rate, in $m^3/s/d$	-69.14	-20.57
Large flood peak[a], in m^3/s	3,162.02	1,783.87
Large flood duration, in days	68.5	60.0
Large flood rise rate, in $m^3/s/d$	80.87	148.16
Large flood fall rate, in $m^3/s/d$	-119.02	-35.73

[a]As defined by the Indicators of Hydrologic Alteration (The Nature Conservancy, 2005).

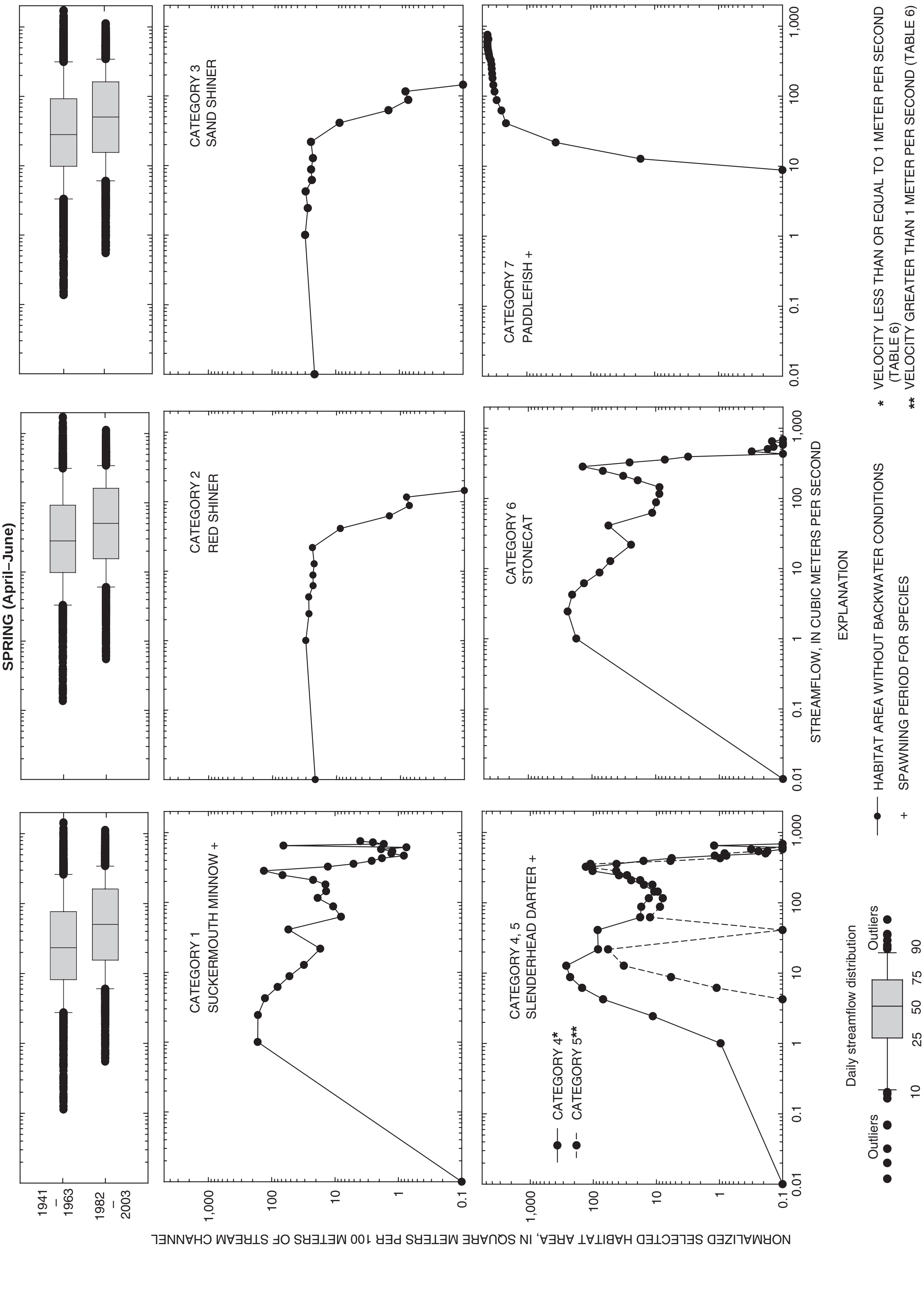

Figure 27. Relation between normalized selected habitat area and daily streamflow distribution for spring, summer day and night, and fall conditions at the Marais des Cygnes River site MDC1.

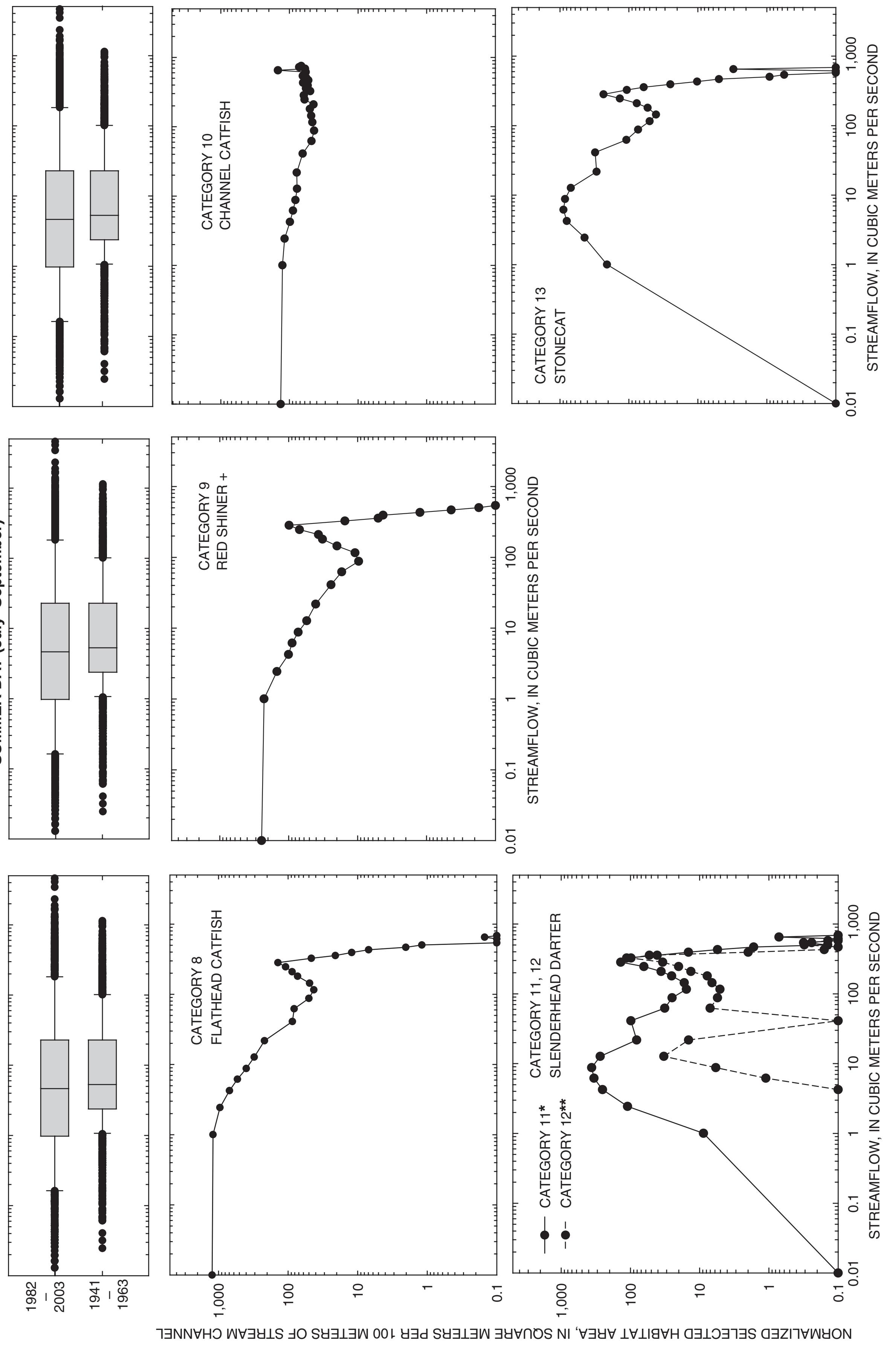

Figure 27. Relation between normalized selected habitat area and daily streamflow distribution for spring, summer day and night, and fall conditions at the Marais des Cygnes River site MDC1—Continued.

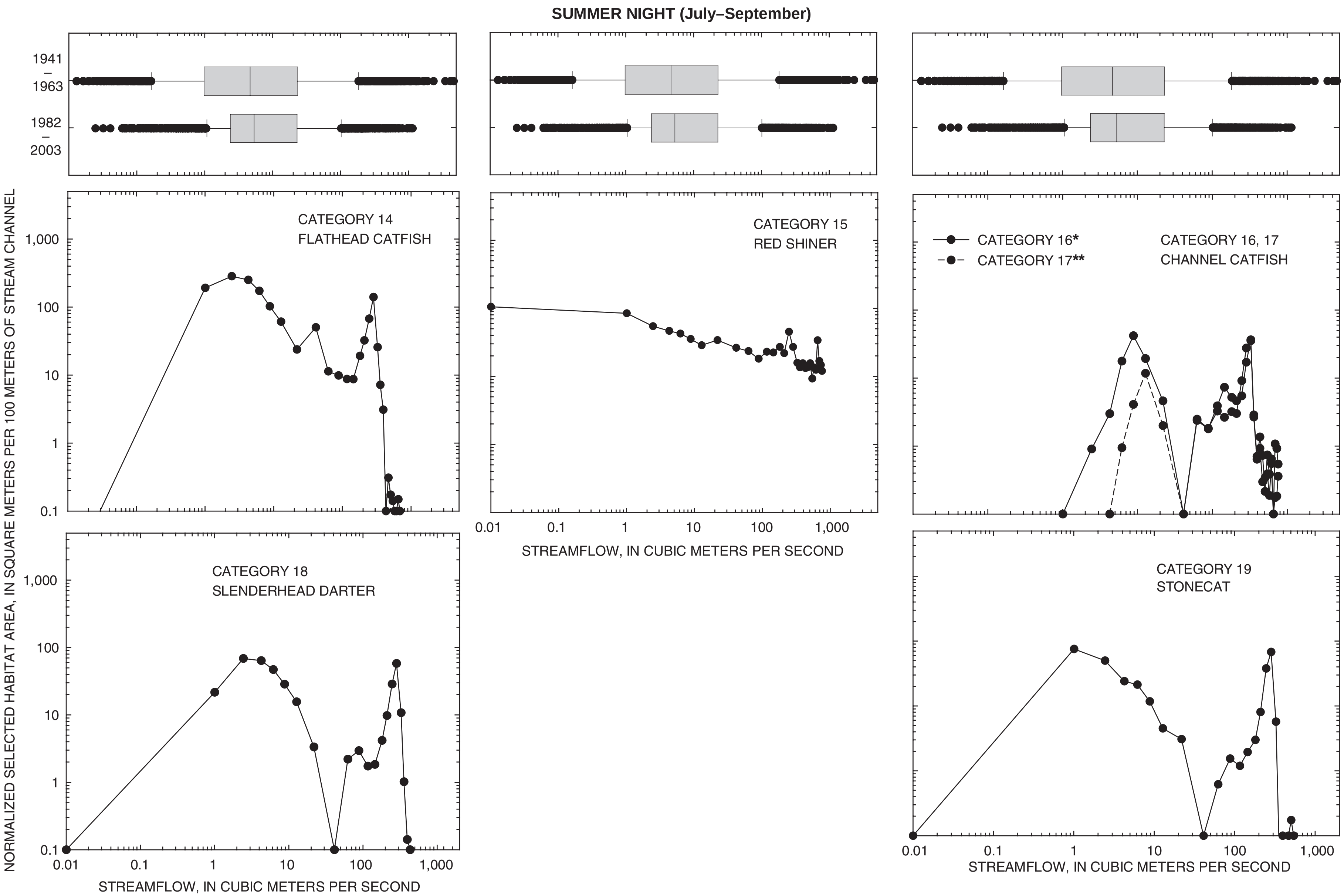

Figure 27. Relation between normalized selected habitat area and daily streamflow distribution for spring, summer day and night, and fall conditions at the Marais des Cygnes River site MDC1–Continued.

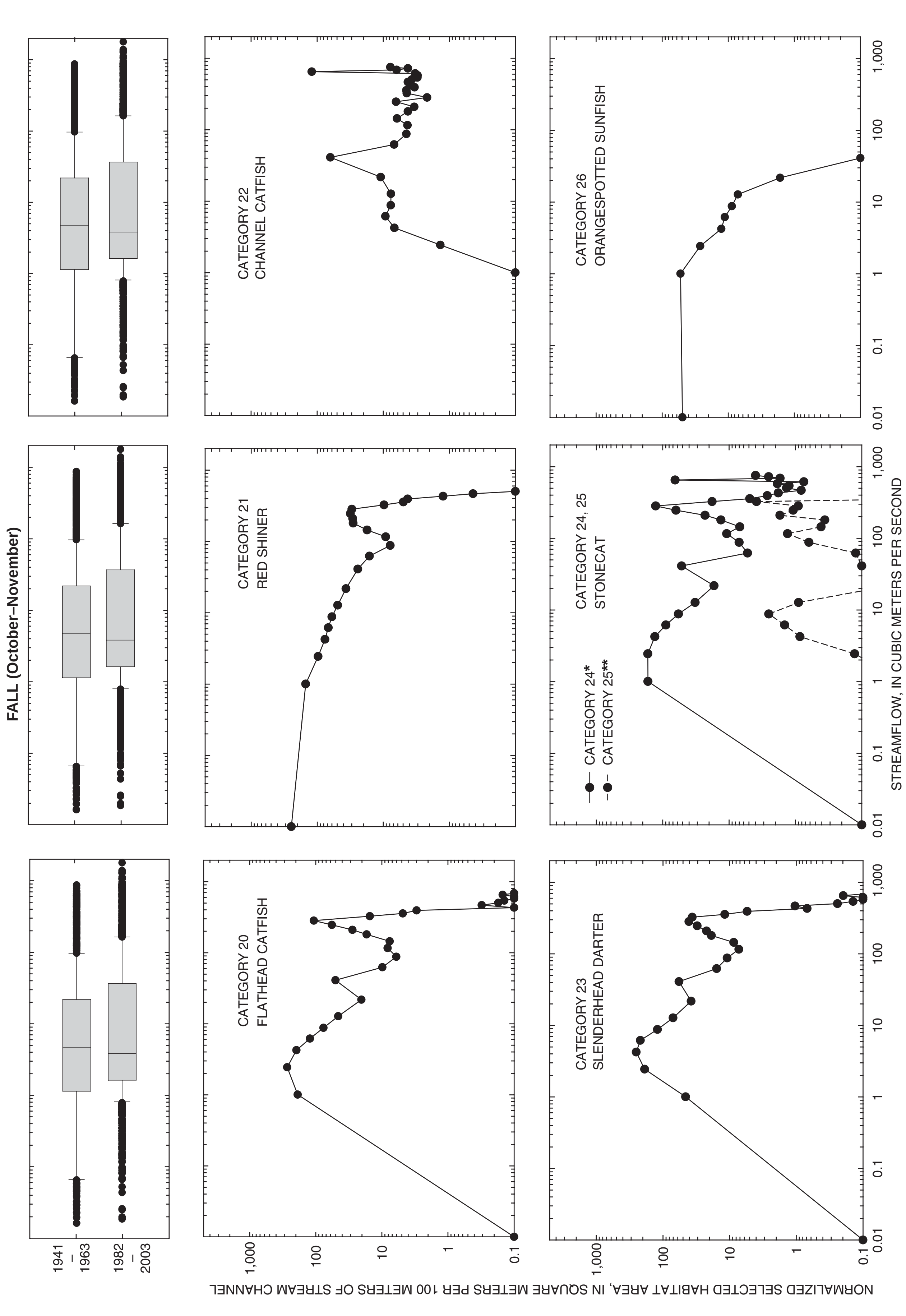

Figure 27. Relation between normalized selected habitat area and daily streamflow distribution for spring, summer day and night, and fall conditions at the Marais des Cygnes River site MDC1—Continued.

night conditions), stonecat (day and night), channel catfish (night), and flathead catfish (night) were the species most susceptible to dewatering with flathead catfish (day), red shiner, and channel catfish (day) the least susceptible. All summer categories had SHAs available at flows as large as 800 m^3/s with channel catfish (summer day) habitat showing no apparent limitations at flows exceeding 800 m^3/s. The extended streamflow range of habitat availability for channel catfish was because this species selected all substrate types, including fines. The depth and velocity criteria are still met at higher flows for this species because fines extend to the top of the channel bank (fig. 22).

The fall SHA peaks at site MDC1 were similar to those for all sites and with other seasonal periods generally occurred for streamflows of 1 to 10 m^3/s for most categories, except for channel catfish (with peaks at 30 m^3/s and 700 m^3/s; fig. 27). Median 1982 through 2003 daily streamflows during October and November was 4 m^3/s, which is within the streamflow range of maximum SHAs. All fall SHAs were available for flows of 0.1 to 800 m^3/s. Species most susceptible to fall dewatering include flathead catfish, channel catfish, slenderhead darter, stonecat, and orangespotted sunfish. The least susceptible habitat category to dewatering was red shiner. The species most susceptible to habitat limitations at high flow (greater than 40 m^3/s) was orangespotted sunfish. This was because the selected boulder substrate was limited (fig. 22), and the depth criterion was exceeded at streamflows exceeding 40 m^3/s.

The range of post-regulation spring streamflows for which category habitats were available was substantially different and more variable at site MDC2 (fig. 28; table 12, on compact disc at the back of this report) than at site MDC1 (fig. 27; table 11). The range of flows for which selected habitat was available at site MDC1 was greater because of the in-channel benches, which extended the range of suitable hydraulic characteristics. Whereas suckermouth minnow habitat was determined to be available for streamflows of 1 to 800 m^3/s at both sites, red shiner and sand shiner were available at streamflows less than 20 m^3/s at site MDC2 (1 to 200 m^3/s at site MDC1), and slenderhead darter and stonecat at streamflows less than 200 m^3/s (1 to 800 m^3/s at site MDC1). Peak habitat availability was more variable between species at this site than at other sites because maximums occurred between 1 and 50 m^3/s (excluding paddlefish) with the comparable range being 1 to 10 m^3/s at other sites.

Median daily 1982 through 2003 spring streamflow at site MDC2 was 55 m^3/s (exceeding the range of streamflow associated with peak SHA), which was an increase of 25 m^3/s from the pre-regulation median. Higher median streamflows will affect red shiner and sand shiner habitat the most because SHA availability for these species occurred at streamflows less than 20 m^3/s (fig. 28). Species most susceptible to dewatering in spring at site MDC2 were similar to those at other sites and included suckermouth minnow, slenderhead darter, stonecat, and paddlefish. Species susceptible to habitat limitations at high spring flows included red shiner and sand shiner (greater than 10 m^3/s), followed by slenderhead darter and stonecat (flows greater than 200 m^3/s) as the depth criteria over the selected substrate types were exceeded.

The 1982 through 2003 summer daily median streamflow at site MDC2 was about 5 m^3/s (fig. 28), which is less than the 10 to 30 m^3/s range of streamflow for which summer SHA peaks occurred for all categories. Susceptibility of habitat categories to dewatering during summer streamflows at site MDC2 was similar to that at sites MDC1, M1, and M2. Slenderhead darter (day and night), stonecat (day and night), channel catfish (night), and flathead catfish (night) were the species most susceptible to dewatering. Flathead catfish (day), red shiner, and channel catfish (day) were the least susceptible because selected areas for these species included pools. Habitat availability at streamflows exceeding 200 m^3/s was limited for all species categories except channel catfish (day) and red shiner (night); these species select substrates that include fines, which extend up the channel bank and allow velocity and depth criteria to be met at higher flows.

Fall habitat availability at site MDC2 occurred for most categories at streamflows between 0.01 and 200 m^3/s, whereas the median 1982 through 2003 fall streamflow at site MDC2 was about 4 m^3/s (fig. 28). Red shiner and orangespotted sunfish were not susceptible to dewatering because these species use pools. Channel catfish and stonecat were again the least susceptible to habitat limitations at high (greater than 200 m^3/s) streamflows because selected substrate included sand, silt, and clay along the channel bank that were initially inundated even at higher streamflows.

The SHA for most spring categories was maximized at site MDC3 (fig. 29) at flows of about 1 to 30 m^3/s except for paddlefish, for which habitat area was first available at a flow of 10 m^3/s, and continued to increase at streamflows approaching 1,000 m^3/s. Selected red shiner and sand shiner habitat was not shown to be available during the spring at site MDC3 because of a lack of the required category substrate (gravel) (fig. 24; table 13, on compact disc at the back of this report). The median streamflow for the spring 1982 through 2003 at site MDC3 was 55 m^3/s, which is greater than the range of streamflows for maximum SHAs. However, SHAs generally were available at streamflows of 1 to 200 m^3/s for suckermouth minnow, slenderhead darter, and stonecat, and, similar to other sites, paddlefish at streamflows greater than 10 m^3/s.

Summer median streamflow at site MDC3 from 1982 through 2003 was about 6 m^3/s (fig. 29), which is within the range of 1 to 30 m^3/s for which SHAs were maximized. The SHA generally was available for all categories at streamflows of 1 to 100 m^3/s. The range of streamflows for which SHA was available in summer was substantially less at site MDC3 than at other Marais des Cygnes River sites (MDC1, 0.1 to 800 m^3/s; MDC2, 0.1 to 200 m^3/s) and, therefore, the susceptibility of categories to high-flow habitat limitations was greater at this site. This can be attributed to the greater proportion of area in which velocities and depths exceeded category limits and a lower variability in velocity and depth distributions at site MDC3 than at other Marais des Cygnes River sites (figs. 17 to 19, table 7). The channelized reach was more uniform and had a greater conveyance as a result of the greater slope of this reach. The susceptibility of SHAs to dewatering conditions in the summer at site

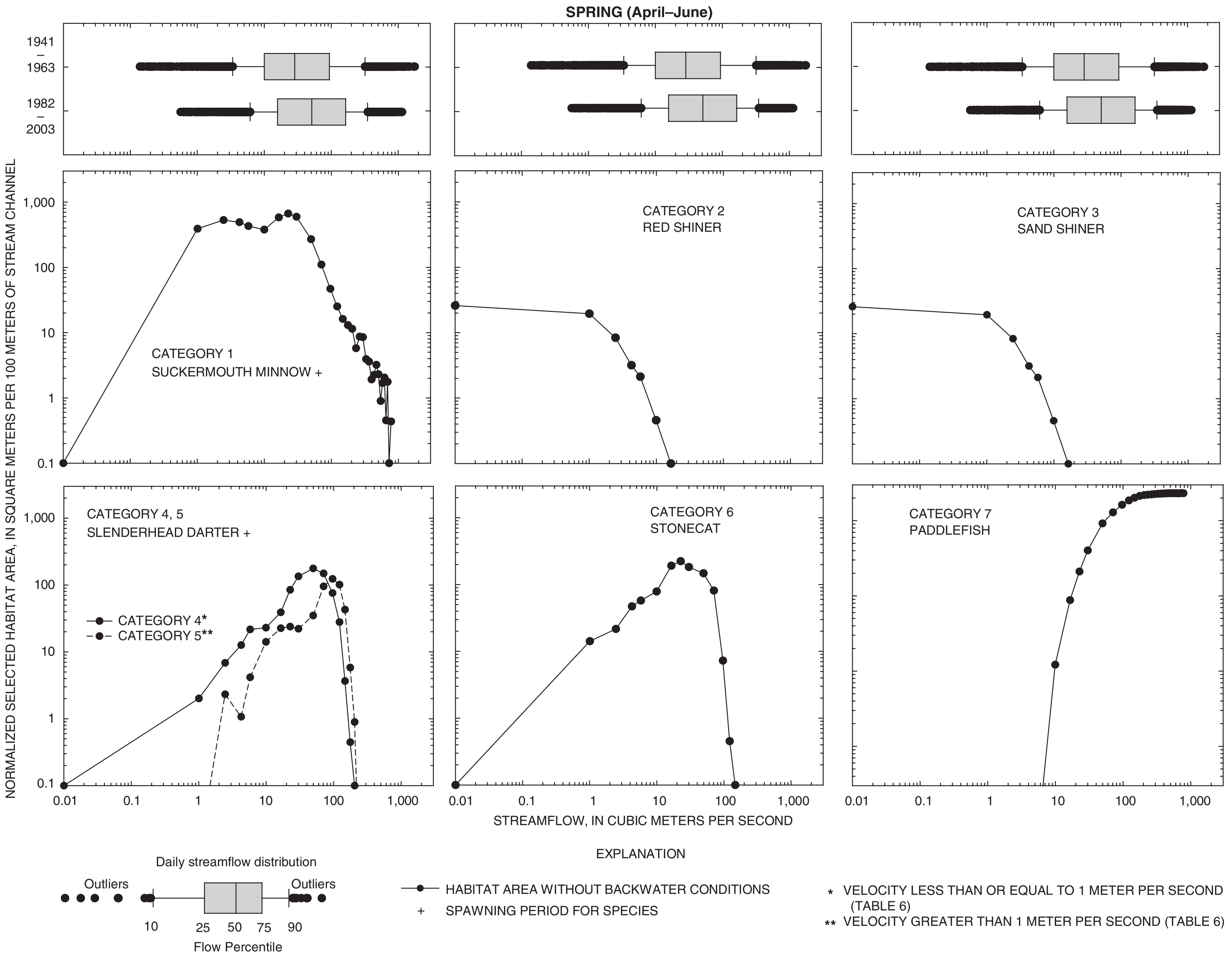

Figure 28. Relation between normalized selected habitat area and daily streamflow distribution for spring, summer day and night, and fall conditions at the Marais des Cygnes River site MDC2.

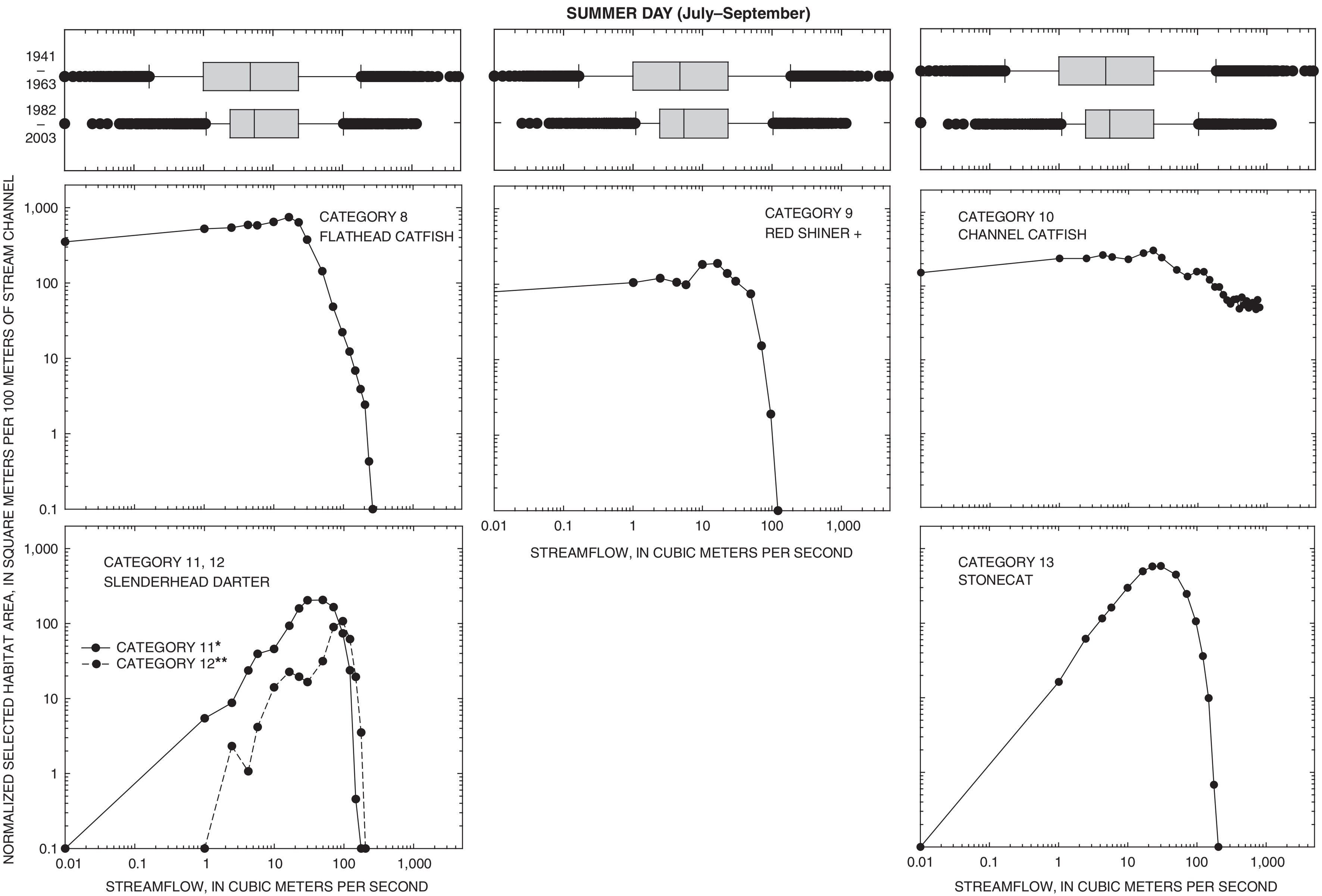

Figure 28. Relation between normalized selected habitat area and daily streamflow distribution for spring, summer day and night, and fall conditions at the Marais des Cygnes River site MDC2—Continued.

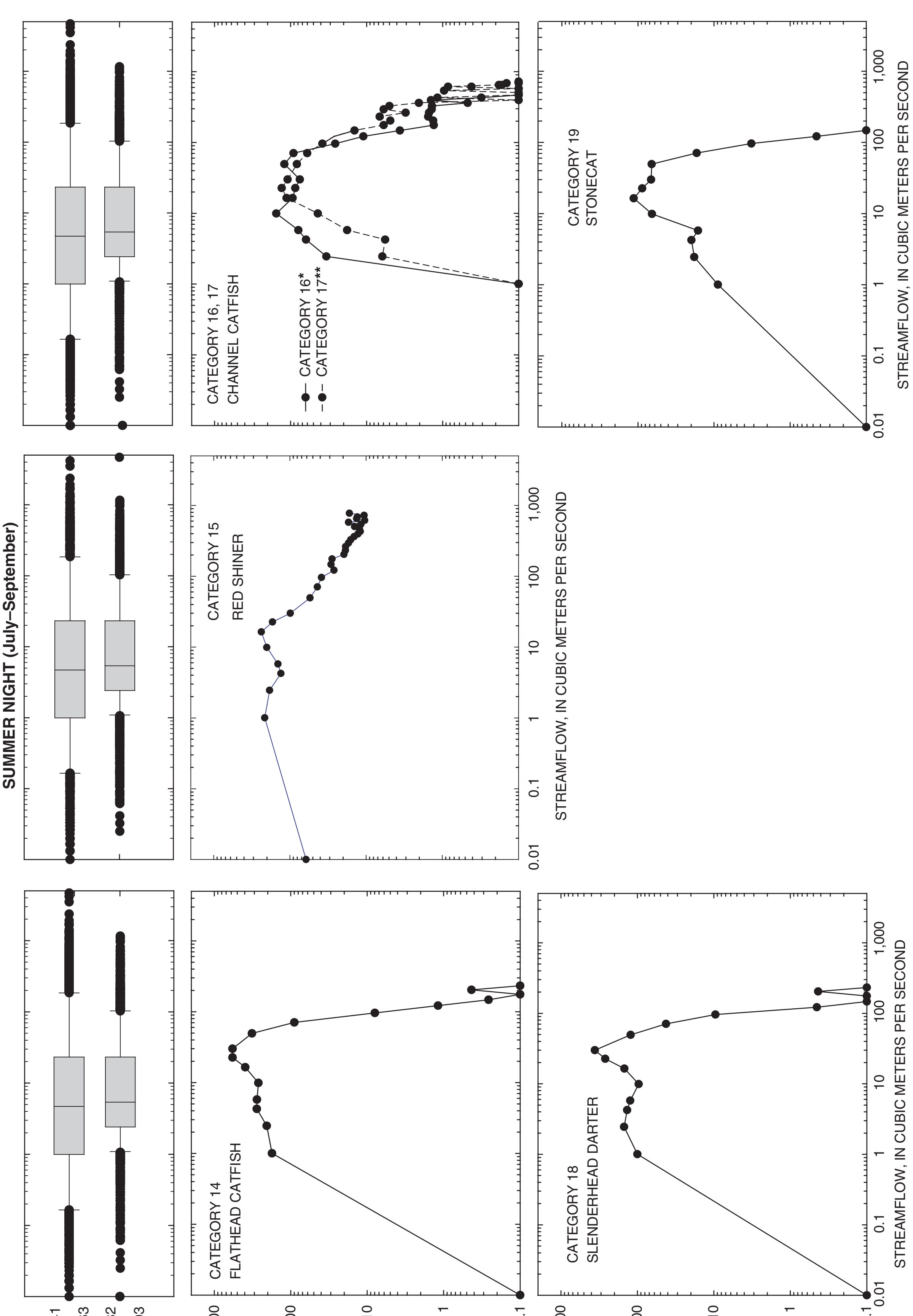

Figure 28. Relation between normalized selected habitat area and daily streamflow distribution for spring, summer day and night, and fall conditions at the Marais des Cygnes River site MDC2—Continued.

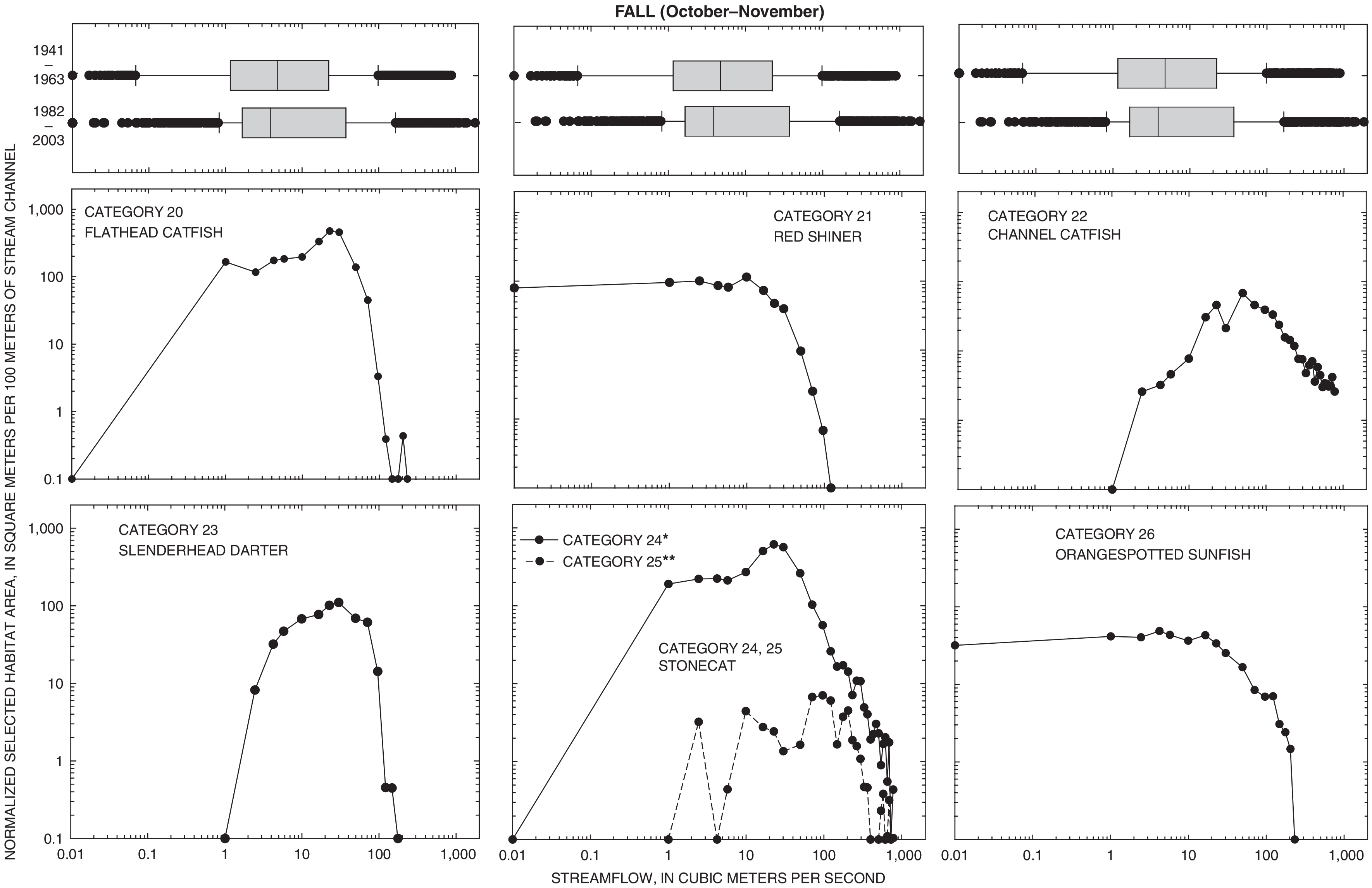

Figure 28. Relation between normalized selected habitat area and daily streamflow distribution for spring, summer day and night, and fall conditions at the Marais des Cygnes River site MDC2—Continued.

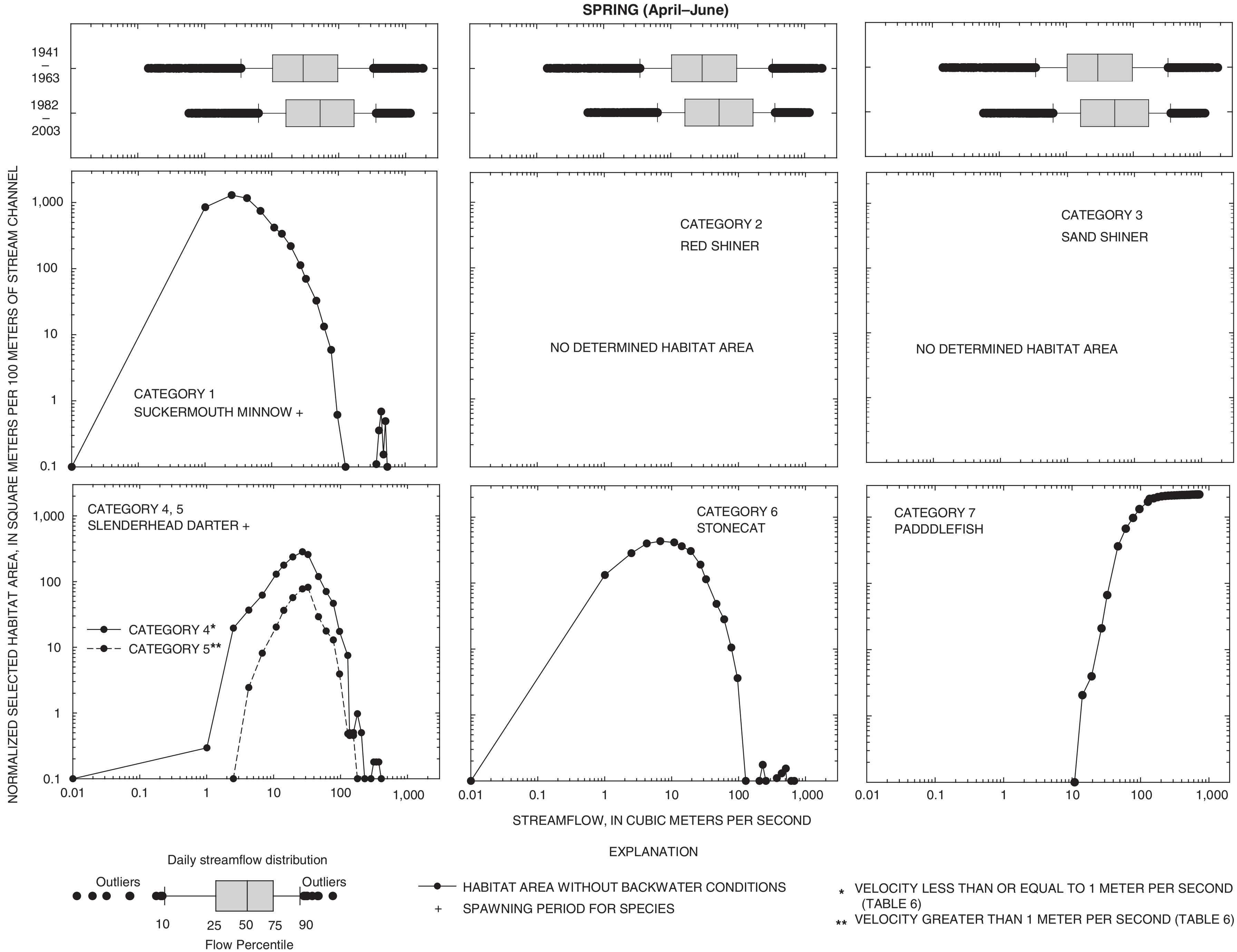

Figure 29. Relation between normalized selected habitat area and daily streamflow distribution for spring, summer day and night, and fall conditions at the Marais des Cygnes River site MDC3.

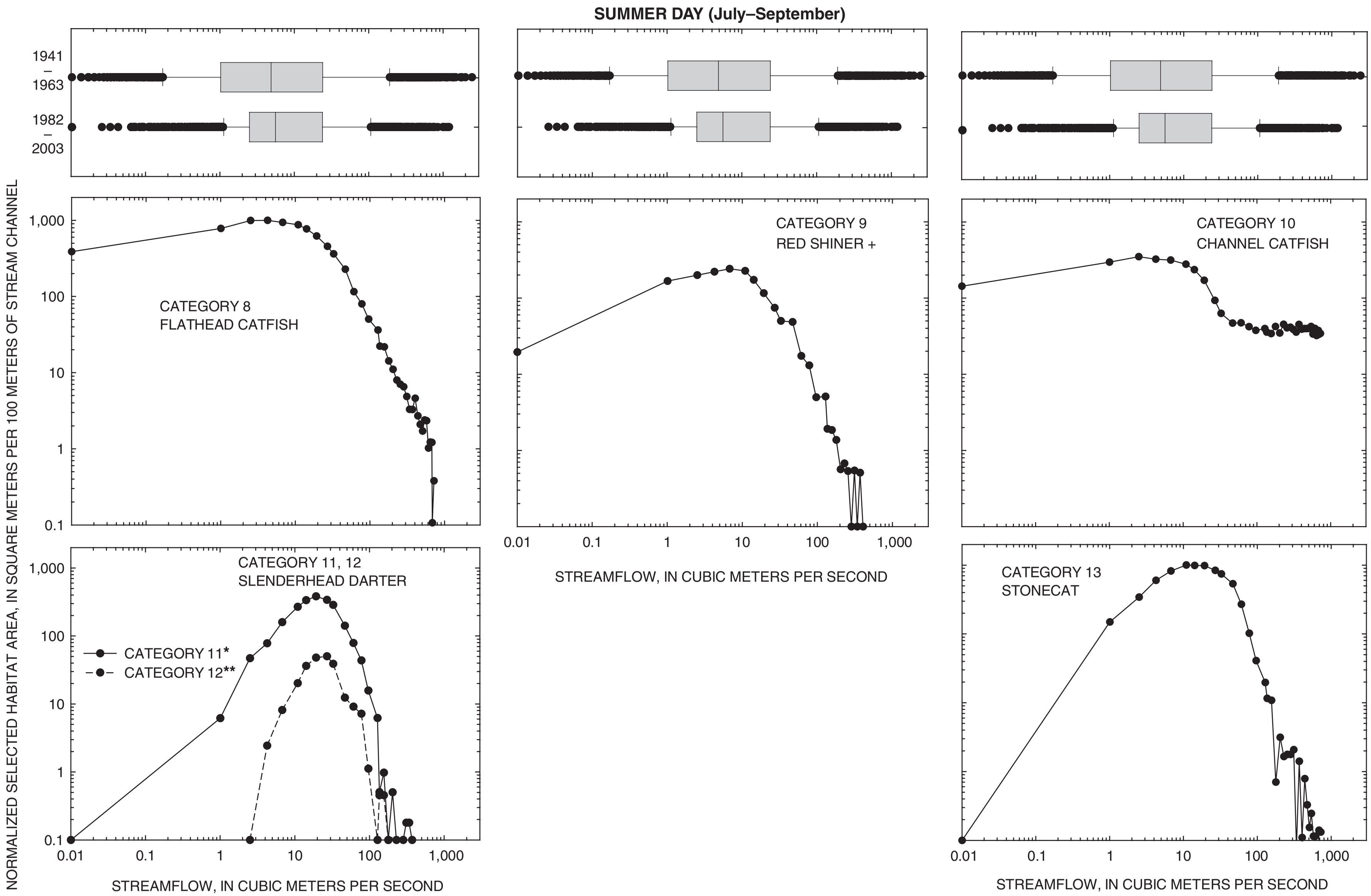

Figure 29. Relation between normalized selected habitat area and daily streamflow distribution for spring, summer day and night, and fall conditions at the Marais des Cygnes River site MDC3—Continued.

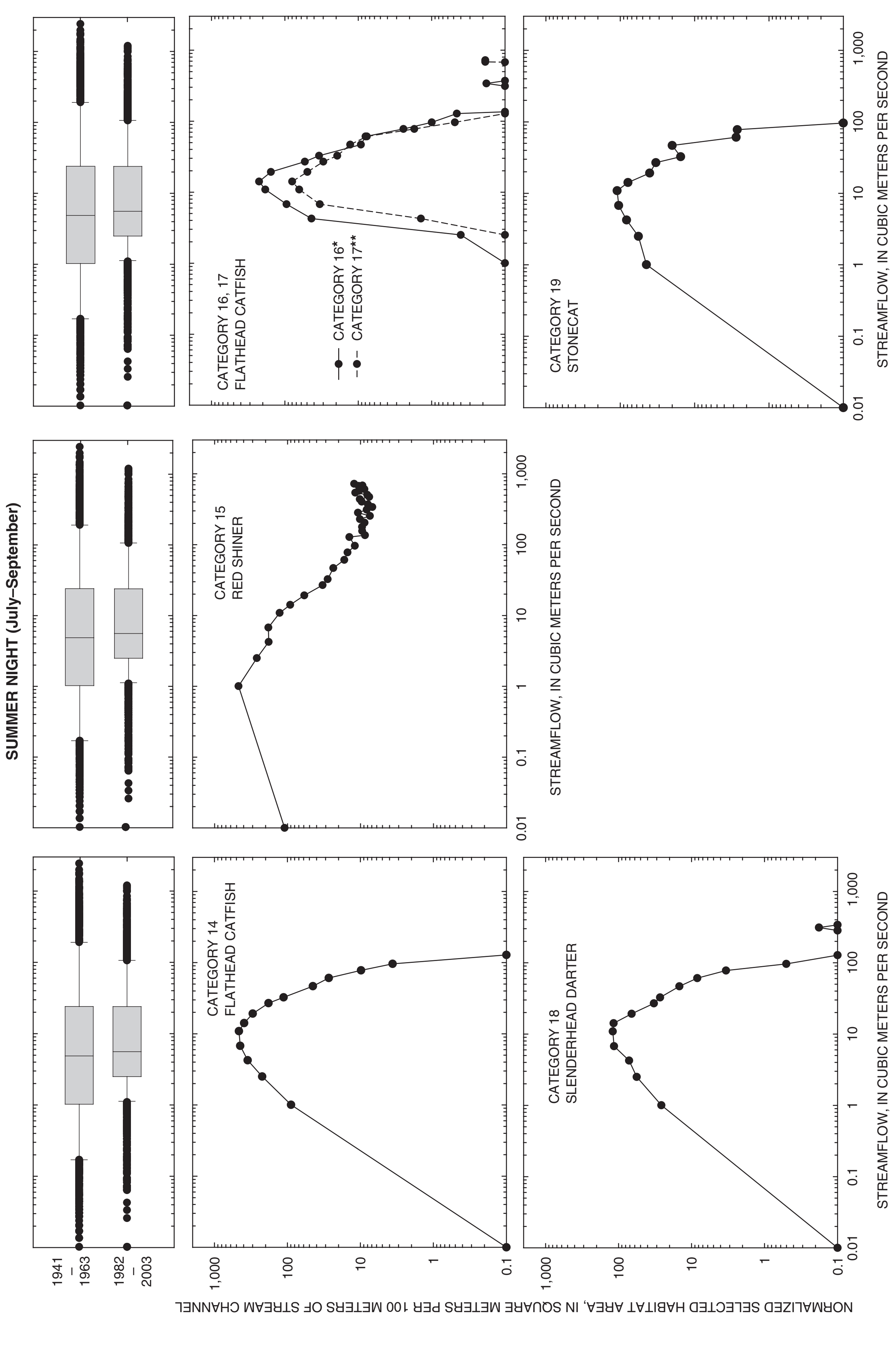

Figure 29. Relation between normalized selected habitat area and daily streamflow distribution for spring, summer day and night, and fall conditions at the Marais des Cygnes River site MDC3—Continued.

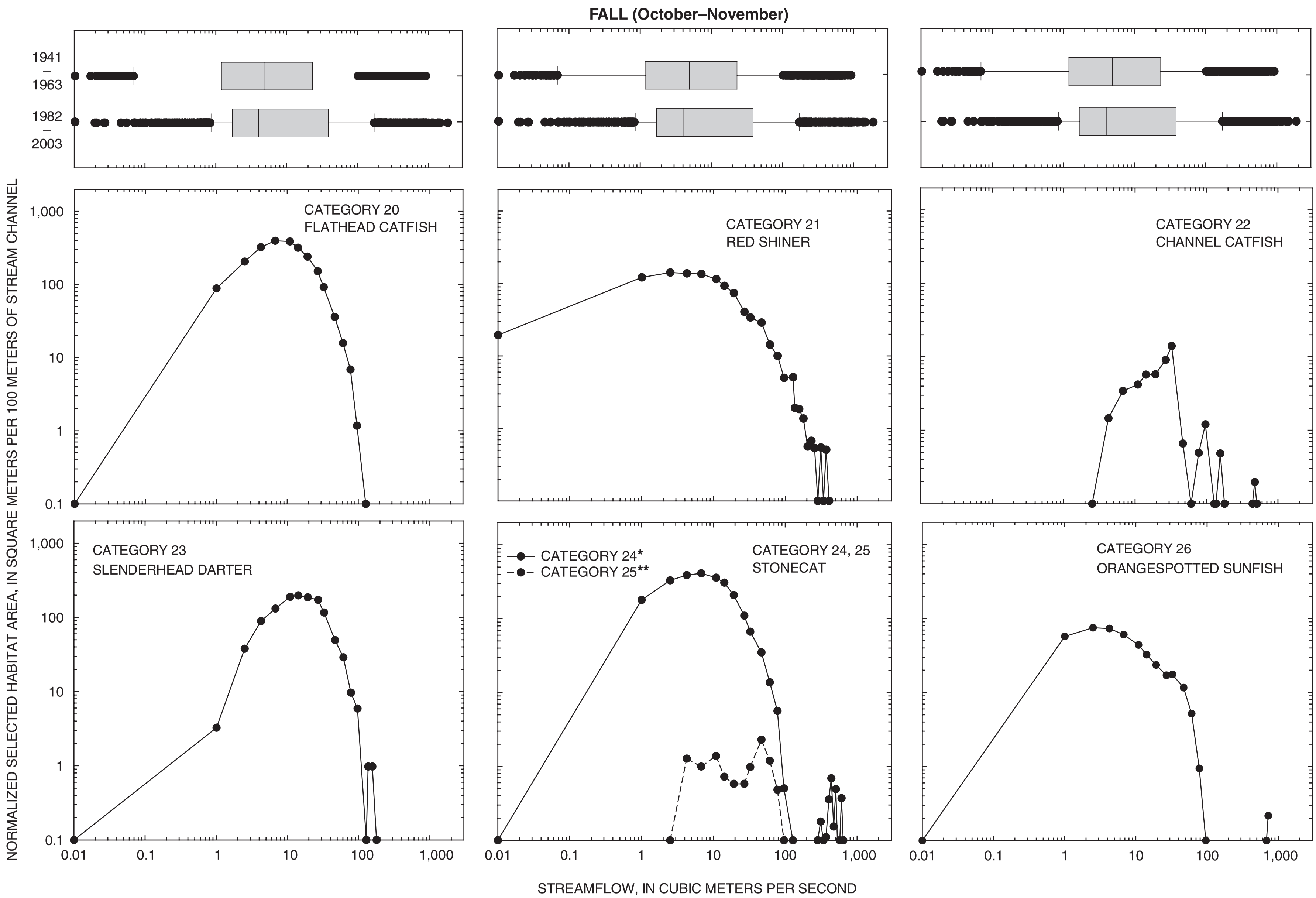

Figure 29. Relation between normalized selected habitat area and daily streamflow distribution for spring, summer day and night, and fall conditions at the Marais des Cygnes River site MDC3—Continued.

MDC3 were similar to those at the other Marais des Cygnes River and Marmaton River sites.

The 1982 through 2003 fall median streamflow at site MDC3 was about 4 m^3/s with peak availability of SHA, similar to most other sites and most other periods, at streamflows of about 1 to 30 m^3/s. Habitat generally was available for streamflows as large as 100 m^3/s. All fall habitat categories at site MDC3 were shown to be susceptible to both dewatering (less than 3 m^3/s for channel catfish) and habitat limitations at flows greater than 100 m^3/s (fig. 29). This upper limitation also was lower than at the un-channelized Marais des Cygnes River sites, because velocity and depth category criteria were exceeded at lower flows in the uniform channel.

All category criteria, including velocity, depth, and substrate, were a limiting factor for habitat availability for some species in some seasons and at some sites. Velocity or substrate availability was the most common limiting factor for habitat availability under dewatering conditions, whereas depth was the limiting factor at high flows. Conversely, an extended range in selected velocity or substrate type (fines) resulted in a substantial increase in the range of habitat availability for some species under dewatering conditions and high streamflows. For species habitat categories that were subdivided into multiple velocity components (table 6; category pairs 4, 5; 11, 12; 16, 17; and 24, 25) the higher velocity category (greater than 1 m/s) accounted for a substantially smaller part of habitat than the lower velocity categories for all category pairs and at all sites. This was because exceeded depth criteria limited habitat availability despite the higher velocity criteria.

Spatial and Temporal Distribution of Habitat

Spatial Distribution and Persistence

Whereas total SHA is a useful indication of habitat availability, it fails to describe how the habitat is spatially distributed. Descriptive statistics can provide additional information regarding the number of habitat patches and minimum, maximum, and mean patch size (tables 8, 9, 11 to 13). Maps of habitat distribution with flow for selected categories (appendixes 1 to 5, on compact disc at the back of this report) and corresponding habitat persistence tables (tables 14 to 18, on compact disc at the back of this report) provide greater insight into habitat distribution characteristics. Paddlefish habitat was the most persistent of the categories studied (tables 14 to 18, figs. 1-13 to 1-28 in appendix 1; 2-12 to 2-25 in appendix 2; 3-34 to 3-56 in appendix 3; 4-22 to 4-47 in appendix 4; and 5-20 to 5-47 in appendix 5) because habitat for this species was based on velocity and depth criteria that were not as restrictive as for other categories. Flathead catfish SHA was the most persistent of the remaining categories (tables 14 to 18; figs. 1-29 to 1-35, 1-42 to 1-48 in appendix 1; 2-26 to 2-29, 2-36 to 2-40 in appendix 2; 3-57 to 3-73, 3-90 to 3-102 in appendix 3; 4-48 to 4-57, 4-77 to 4-85 in appendix 4; and 5-48 to 5-57, 5-72 to 5-81 in appendix 5). An animated series of habitat maps illustrate the persistence in paddlefish habitat and the substantial differences in the relation between habitat area and streamflow between two spring habitat categories (slenderhead darter and paddlefish) at site MDC1 during a moderate rise on May 5 to 20, 1996 (film 1, on compact disc at the back of this report).

Temporal Distribution

Although habitat-streamflow relations indicate the potential SHA available with incremental changes in streamflow, another valuable source of information is SHA time series based on measured streamflow time series. Monthly streamflow values from water years 1971 through 2003 at the Marmaton River sites were used to create median monthly SHA time series for the 26 habitat categories (figs. 30, 31, on compact disc at the back of this report) along with additional percentiles of monthly habitat time-series values (tables 19, 20, on compact disc at the back of this report). In addition, daily streamflow data from 1941 through 1963 and 1982 through 2003 were used to create median daily SHA time series for the Marais des Cygnes River sites (figs. 32 to 34; tables 21 to 23, on compact disc at the back of this report).

From 1971 through 2003, the category/species in spring with the highest median monthly SHA of the Marmaton River sites M1 and M2 was paddlefish, with the highest habitat availability in April and June (figs. 30, 31). The remaining spring habitat categories had maximum median monthly habitat availability in May and had substantially lower peaks. Peak median monthly habitat availability for summer day and night periods varied by category. Habitat area for the species with the highest median summer day habitat availability, flathead catfish, peaked in September at both sites, while habitat area for the summer night species with the highest habitat availability, red shiner, peaked in August. Most median fall species category habitat areas peaked in October at both sites.

Paddlefish habitat availability at site MDC1 in spring was the highest of all categories, with the 1982 through 2003 period availability typically exceeding 1,000 m^2/100 m (fig. 32; table 21). Median paddlefish habitat availability was two orders of magnitude less during the pre-regulation streamflow regime (June 1941 through 1963) than the post-regulation (1982 through 2003) period as a result of lower flows (table 10). Summer (day and night) daily habitat time-series characteristics at site MDC1 (fig. 32) were similar to that for Marmaton River sites (figs. 30, 31). Of the summer night categories, median flathead catfish SHA was the most available for both pre- and post-regulation periods. In fall, flathead catfish again had the most SHA availability (approaching 300 m^2/100 m; fig. 32).

At site MDC2, the median paddlefish habitat area was the highest of any spring category, with values near 2,000 m^2/100 m (fig. 33, table 22). The spring SHA availability for red shiner and sand shiner at site MDC2 (fig. 33) was substantially less than that at MDC1 (fig. 32), but suckermouth minnow and stonecat SHA time series were substantially greater at site MDC2 than at site MDC1, reflecting the differences in substrate/hydraulic conditions (and resulting SHA) between sites at similar streamflows. Daily SHAs for suckermouth minnow and stonecat for periods in May and June 1982 through 2003 were one to two orders of magnitude less than the 1941 through 1963 values, whereas pre-regulation paddlefish habitat values typically were less than post-regulation values. Pre- and post-regulation SHAs were similar to those at site MDC2, with the exception of a greater variability in the pre-regulation summer day slenderhead darter and stonecat, pre-regulation summer night channel catfish, and pre-regulation fall slenderhead darter SHA relative to post-regulation time series values.

Paddlefish again had the highest available spring habitat area (approaching 2,000 m^2/100 m) at site MDC3; post-regulation median habitat availability for this species typically exceeded pre-regulation availability (fig. 34) as a result of higher flows. Late May/early June median SHAs for suckermouth minnow and stonecat, two species vulnerable to habitat alterations during this spawning period, dropped below 1 to 2 m^2/100 m in 1982 through 2003. No spring habitat was determined to be available for red shiner and sand shiner at site MDC3 because of the lack of gravel-size substrate. Flathead catfish and stonecat had the highest median SHA availability for summer day categories. Pre-regulation summer day slenderhead darter and summer night channel catfish SHA values were more variable than that of the post-regulation period.

The overall spring, monthly, time-series distributions for Marmaton River sites M1 and M2 indicate that paddlefish habitat had the highest median and maximum availability, whereas stonecat had the lowest median availability by species (figs. 35, 36). The higher depth and velocity criteria for paddlefish resulted in greater habitat availability during typical spring high flows. Site M2 had greater availability of paddlefish habitat than site M1 as a result of higher flows. Median habitat availability for other spring spawning species (suckermouth minnow and slenderhead darter) also were higher at site M2 than site M1, although maximum availabilities were similar between sites.

Substantial differences in habitat availability distributions for juvenile Ictalurids occurred in summer day and summer night categories at Marmaton River sites M1 and M2. The summer night categories had more restrictive velocity and depth criteria than summer day categories, and therefore, more limited habitat availability. Red shiners spawn in the summer, and habitat generally was greater at site M1 because higher flows at the downstream site M2 limited habitat availability. Flathead and channel catfish had the least variability in habitat distribution under summer day conditions because the habitat variability with flow was the least for these species/categories (figs. 25, 26). Fall monthly SHA availability for Marmaton River sites was highest for red shiner and least for channel catfish (figs. 35, 36).

Differences in daily SHA time series between pre- (1941 through 1963) and post-regulation (1982 through 2003) time periods varied by species/category and by Marais des Cygnes River sites (figs. 37–39). Although the distribution of spring spawning habitat for suckermouth minnow and slenderhead darter declined between pre- and post-regulation periods at all three sites, the 25 to 75 percentile values of paddlefish habitat increased under post-regulation conditions. Maximum paddlefish habitat was reduced under post-regulation conditions at all three sites compared to pre-regulation conditions as peak discharges were reduced, likely as a result of flow regulation (table 10). Post-regulation spring habitat availability distributions for red shiner, sand shiner, and stonecat at sites MDC1 and MDC2 generally were lower in the 25 to 75 percentile range than pre-regulation habitat distributions.

All of the summer day and summer night category SHA distributions generally increased under post-regulation conditions when compared to pre-regulation conditions at the three sites. Summer day red shiner and channel catfish, however, showed declines in SHA in the 25 to 75 percentile range under post-regulation conditions at site MDC1. Most fall categories showed increases in habitat distributions for post-regulation periods with the exception of channel catfish habitat availability, which showed a decrease in the 50 to 75 percentile range at all three sites.

IMPLICATIONS FOR FISHERY-COMMUNITY MANAGEMENT

Based on the calculated SHA and streamflow relations, as well as the SHA time series, no single flow met the habitat requirements for all categories or even for categories within a particular season at a site (fig. 40). The relation between SHA and streamflows differed substantially between categories and study sites, even for sites on the same river. Habitat availability was not proportional to drainage area for most categories at the Marmaton River and Marais des Cygnes River sites, because habitat area is not necessarily proportional to streamflow (figs. 25 to 29) and the substantial differences in local substrate and hydraulic characteristics result in variable relations between habitat availability and streamflow. Because the habitat-streamflow relation is dependent on site hydraulic characteristics and local substrate composition, the transfer of results from one location to another within a basin, or between basins, is difficult. Transferability of habitat criteria may be further limited by a lack of consistency in specific fish species habitat criteria between rivers or life-stage categories (Thomas and Bovee, 1993).

Despite apparent differences in habitat characteristics at the five study sites, some consistent relations were noted, including the flow range for which habitat availability is maximized and, in the case of the Marmaton River sites, the range of streamflows for which habitat is available. Another similarity among most study sites was that paddlefish had the highest habitat availability in spring, whereas flathead catfish had the highest habitat availability in summer and fall. Susceptibility to dewatering was apparent from category velocity criteria, because categories with a velocity range, including zero (table 6), will be less susceptible to dewatering than those with positive velocity requirements. Finally, high-flow limitations varied

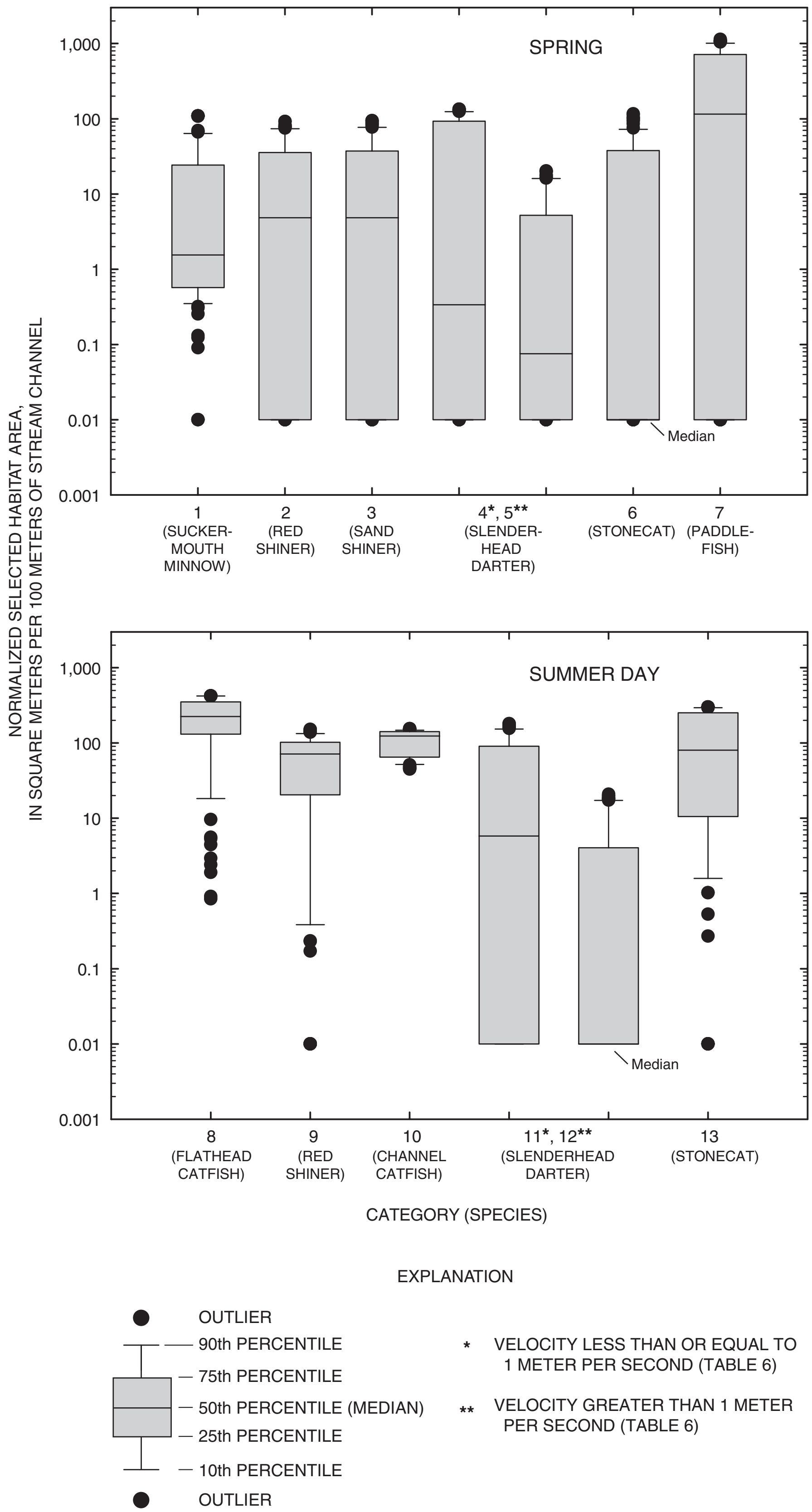

Figure 35. Summary distributions of monthly habitat area time series at the Marmaton River site M1, 1971–2003.

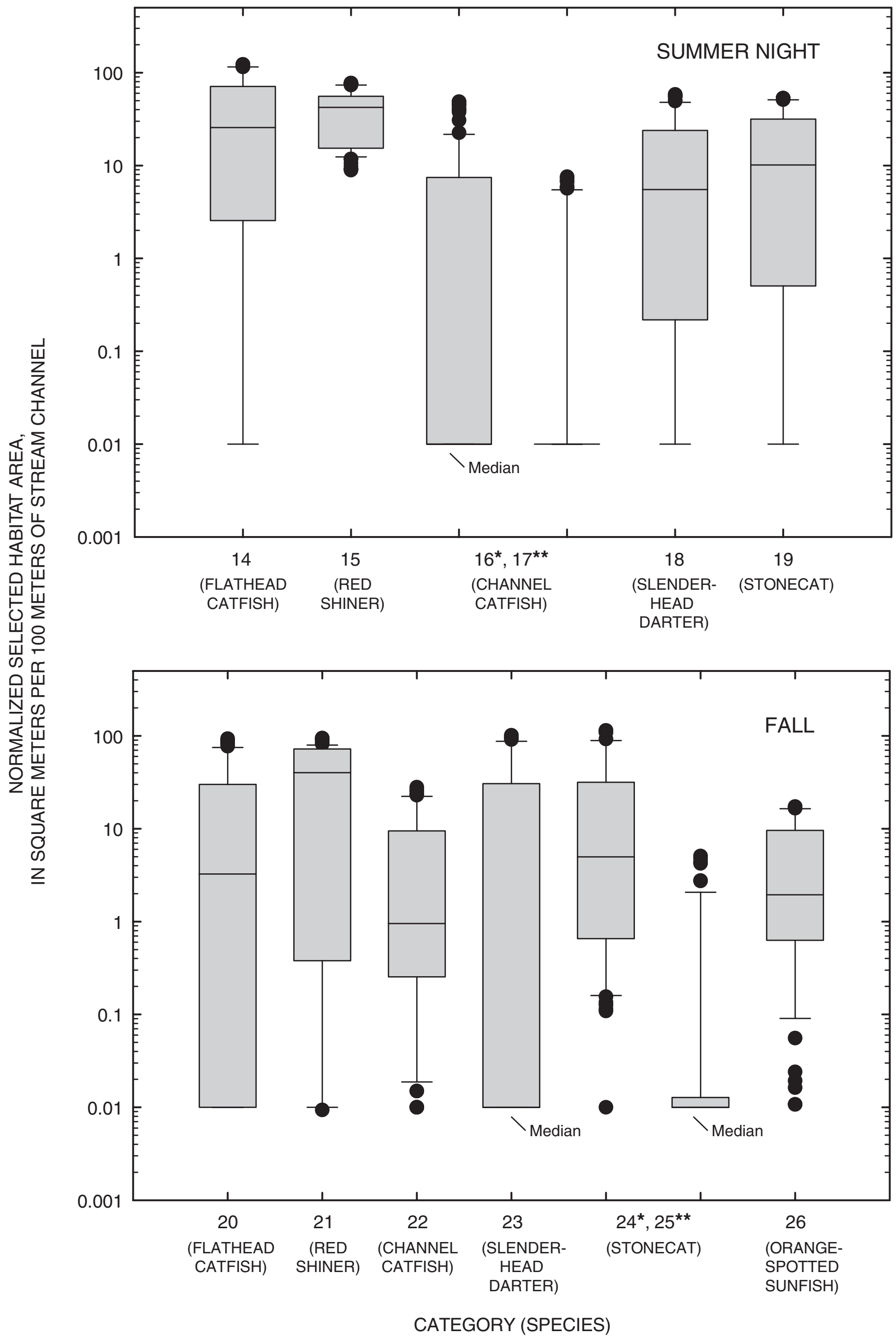

Figure 35. Summary distributions of monthly habitat area time series at the Marmaton River site M1, 1971–2003—Continued.

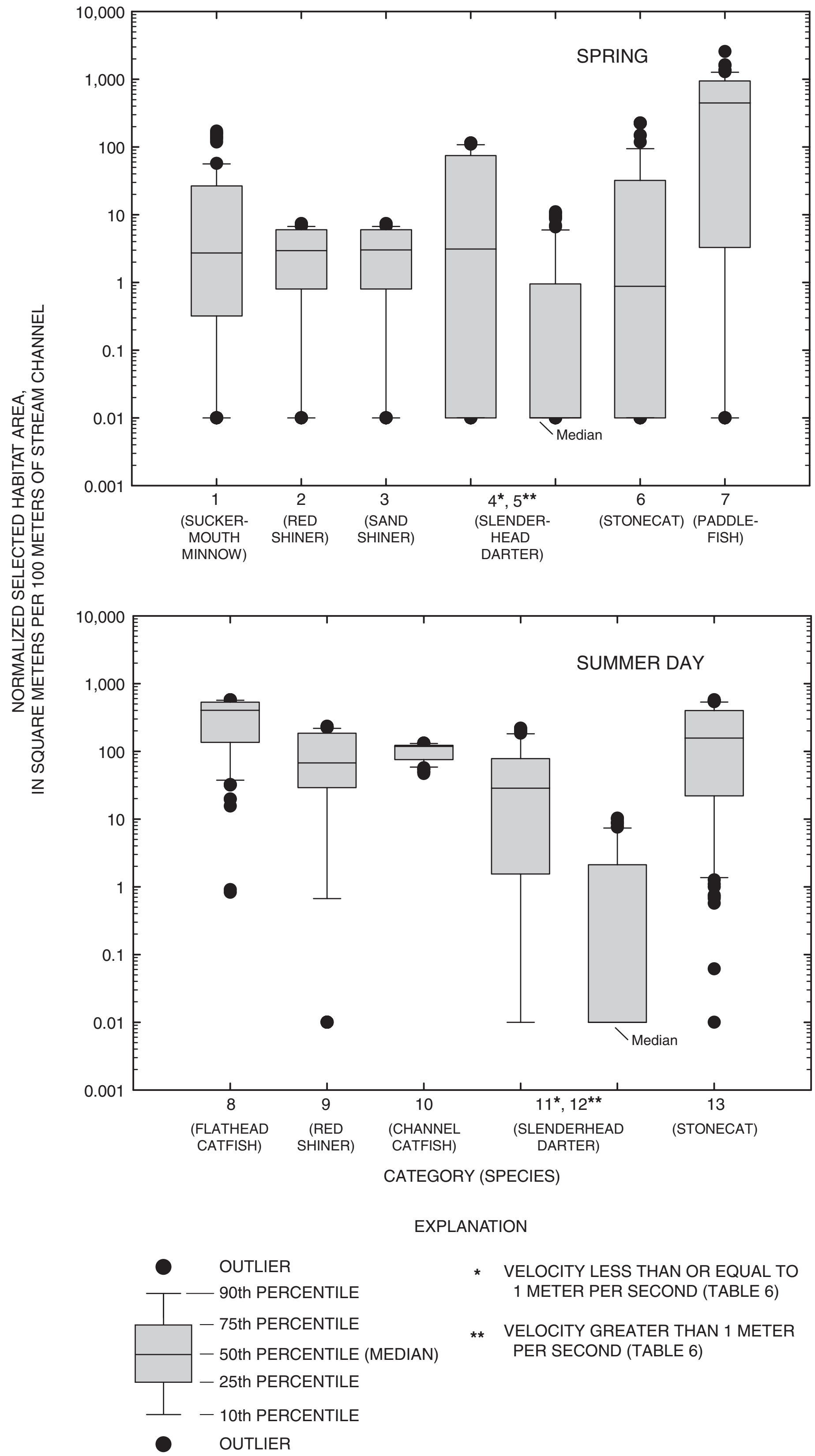

Figure 36. Summary distributions of monthly habitat area time series at the Marmaton River site M2, 1971–2003.

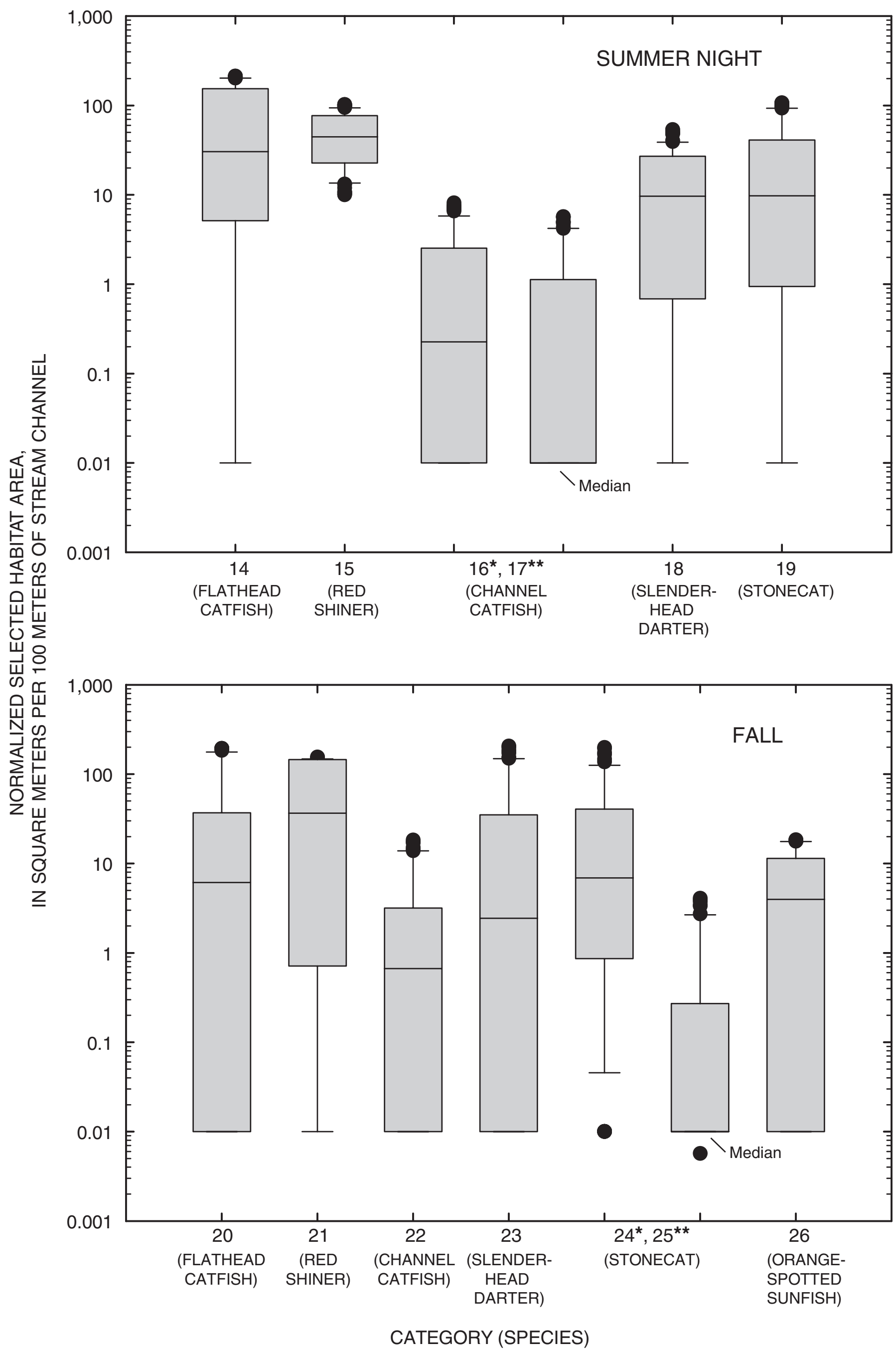

Figure 36. Summary distributions of monthly habitat area time series at the Marmaton River site M2, 1971–2003.—Continued.

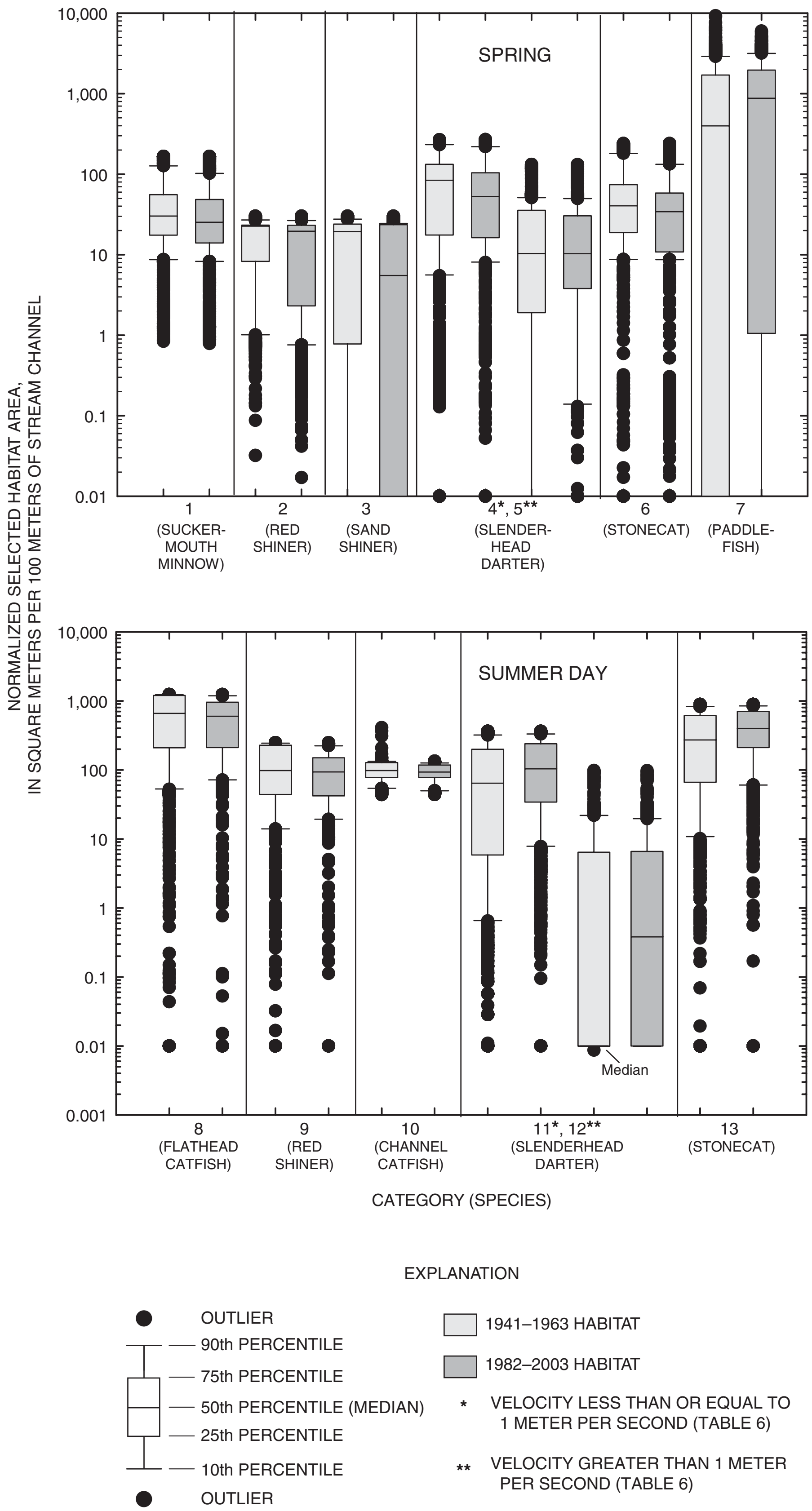

Figure 37. Summary distributions of daily habitat area time series at the Marais des Cygnes River site MDC1, 1941–1963 and 1982–2003.

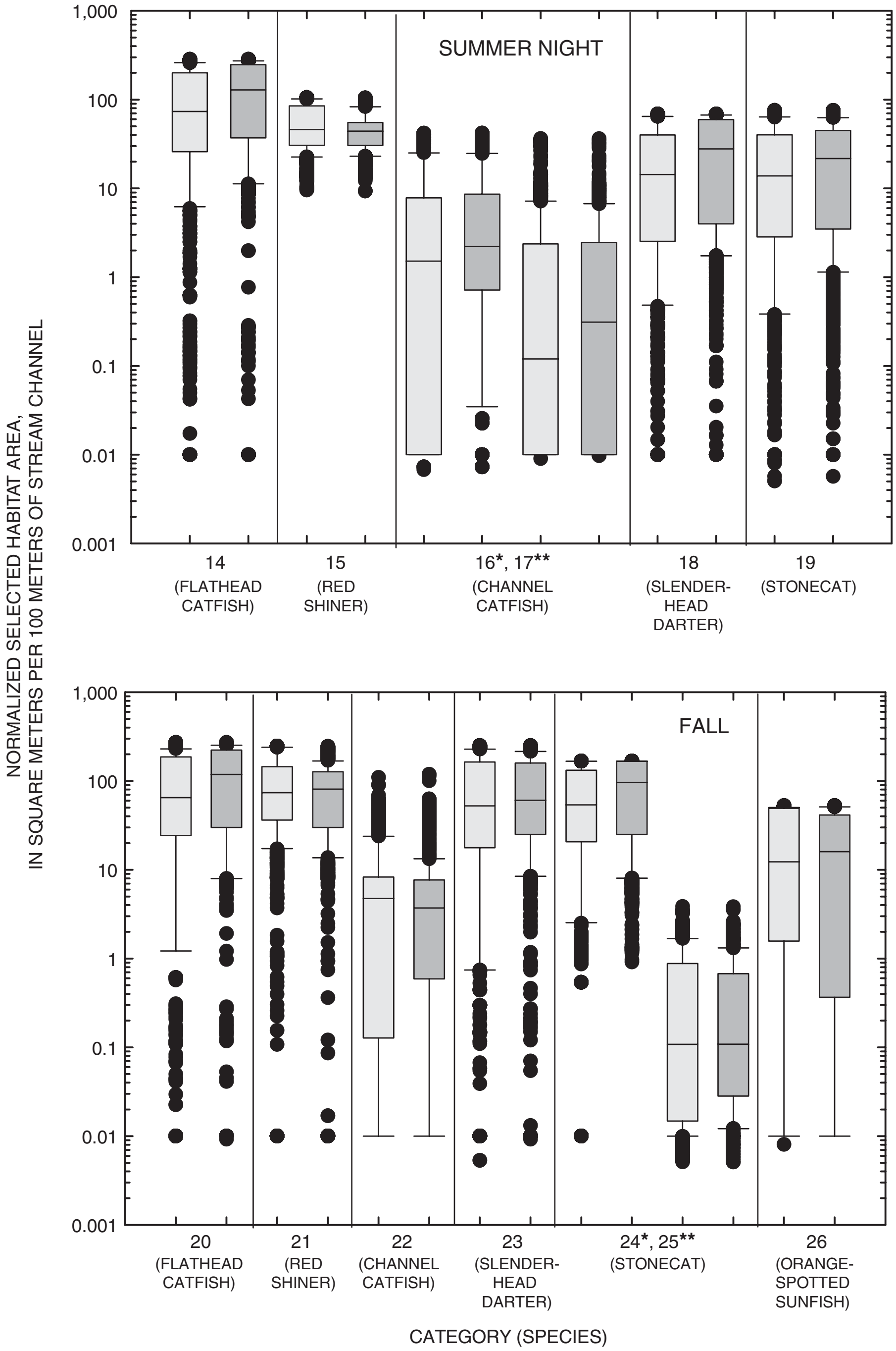

Figure 37. Summary distributions of daily habitat area time series at the Marais des Cygnes River site MDC1, 1941–1963 and 1982–2003—Continued.

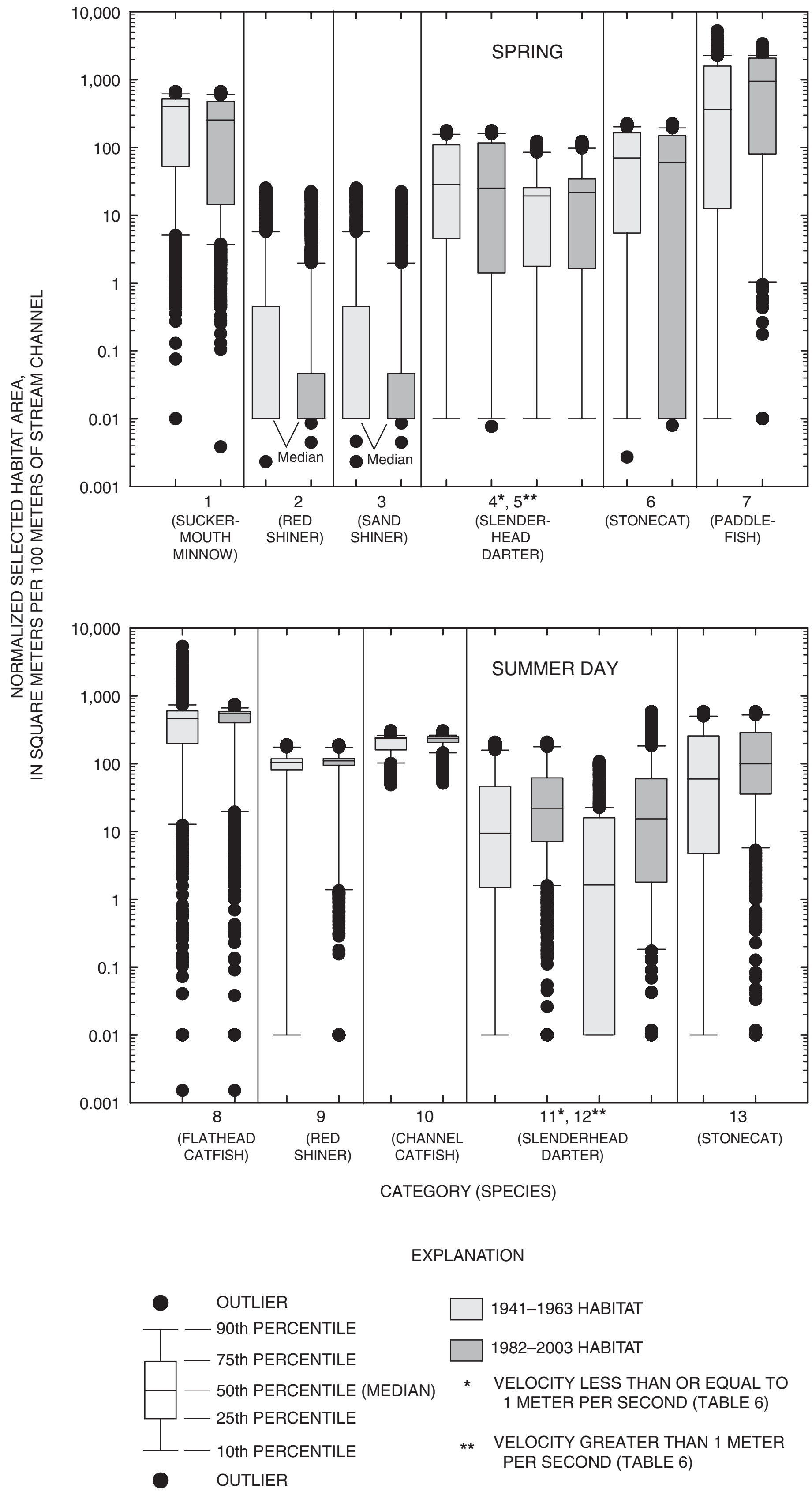

Figure 38. Summary distributions of daily habitat area time series at the Marais des Cygnes River site MDC2, 1941–1963 and 1982–2003.

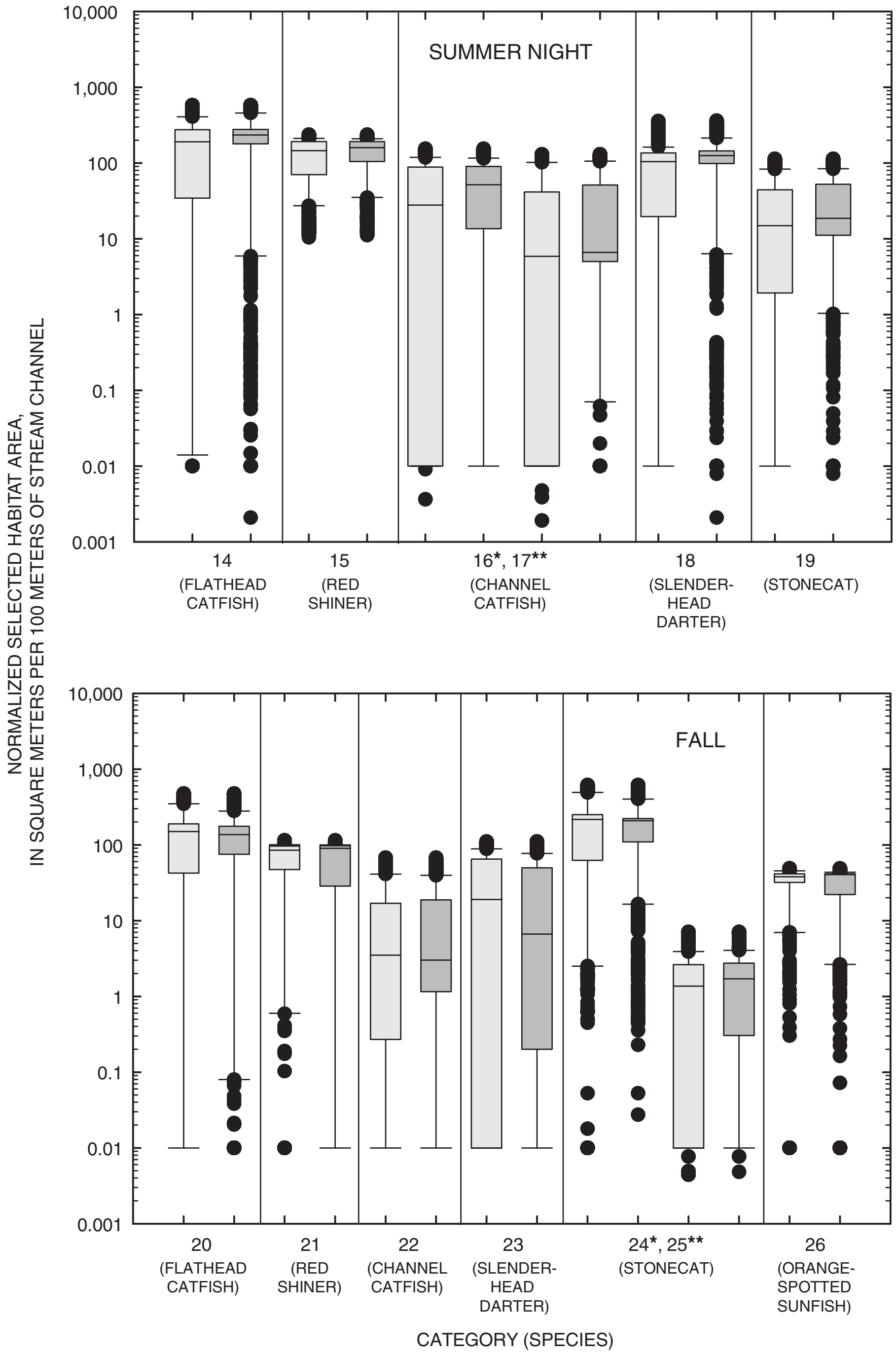

Figure 38. Summary distributions of daily habitat area time series at the Marais des Cygnes River site MDC2, 1941–1963 and 1982–2003—Continued.

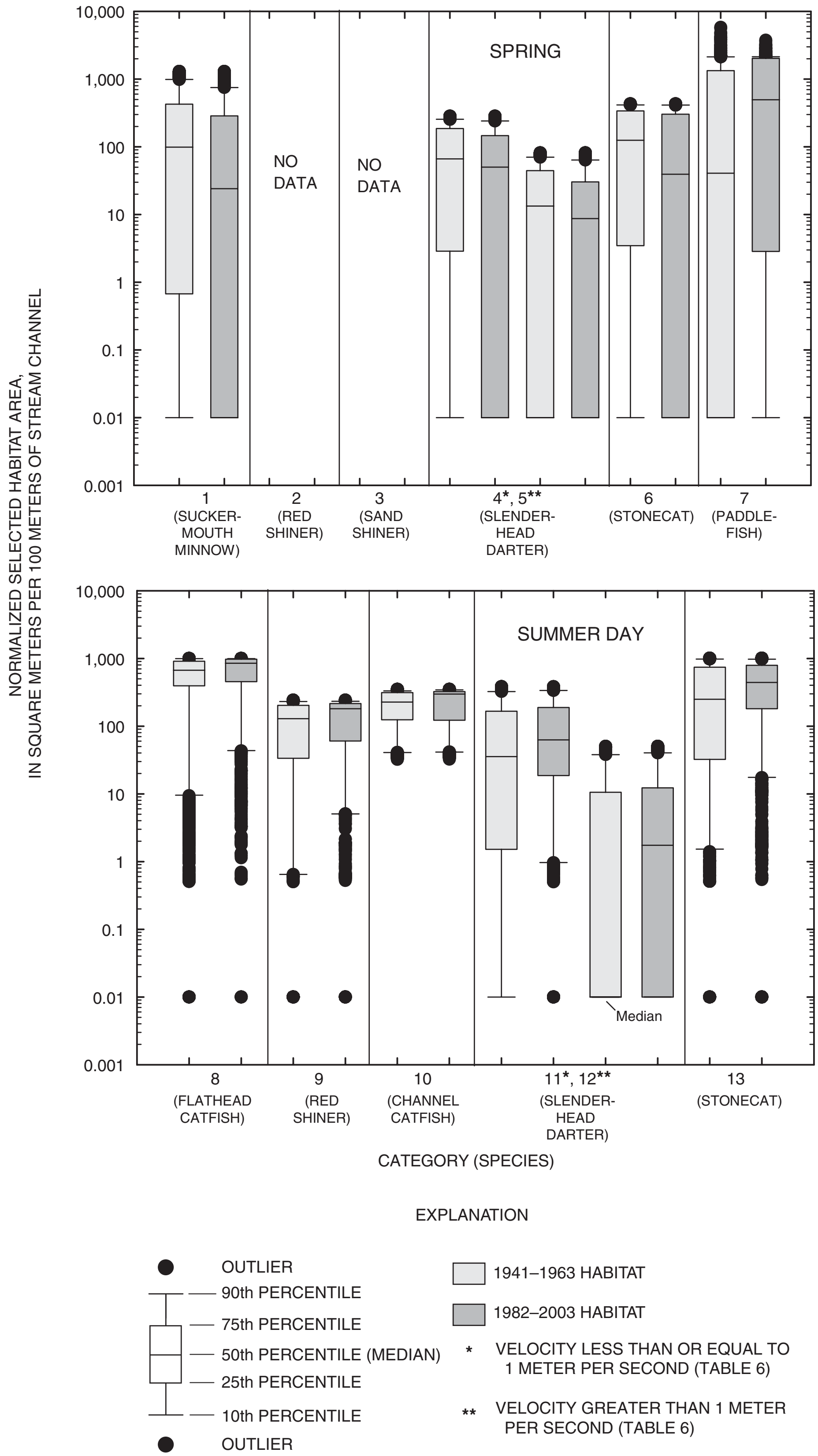

Figure 39. Summary distributions of daily habitat area time series at the Marais des Cygnes River site MDC3, 1941–1963 and 1982–2003.

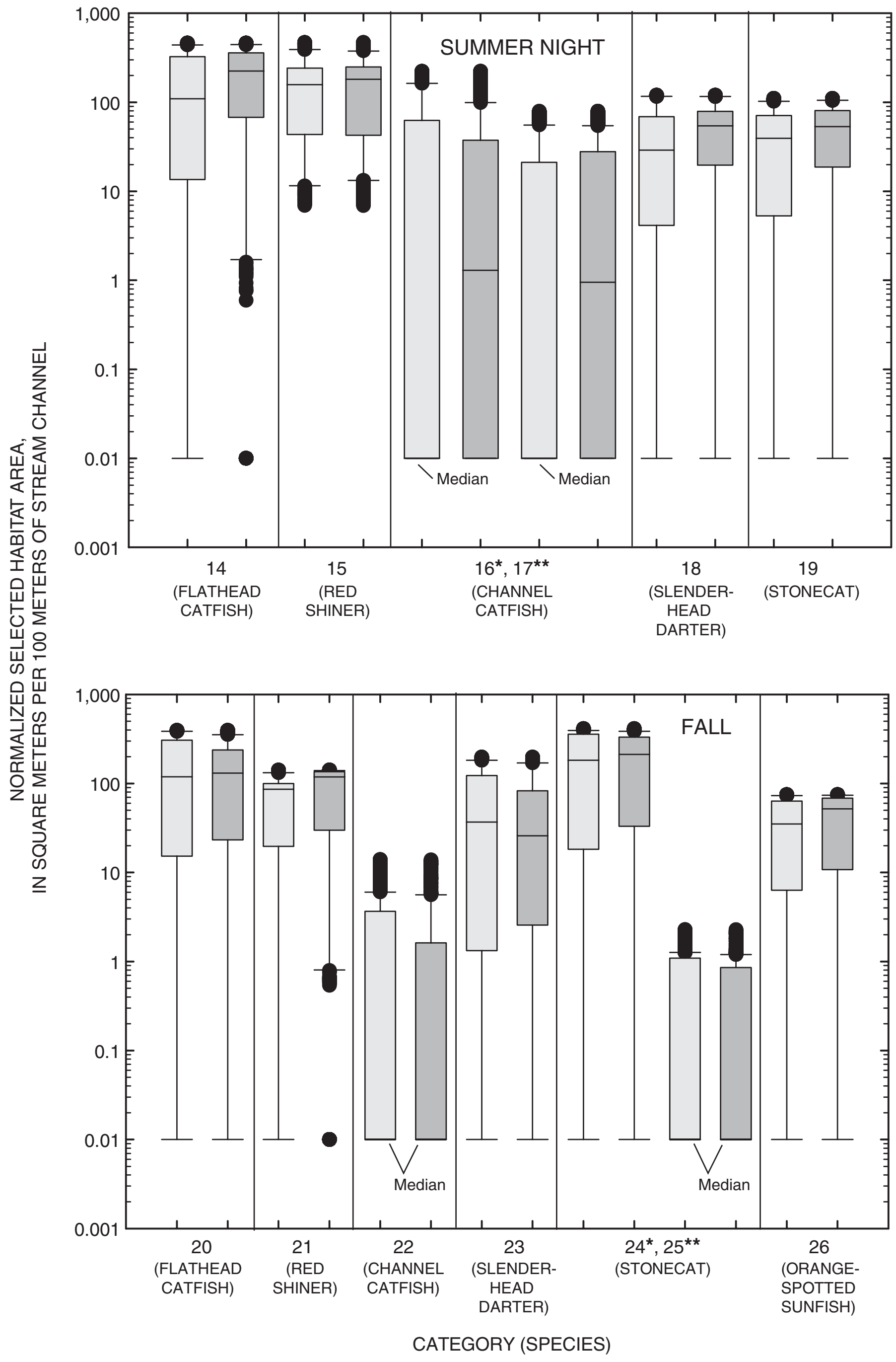

Figure 39. Summary distributions of daily habitat area time series at the Marais des Cygnes River site MDC3, 1941–1963 and 1982–2003—Continued.

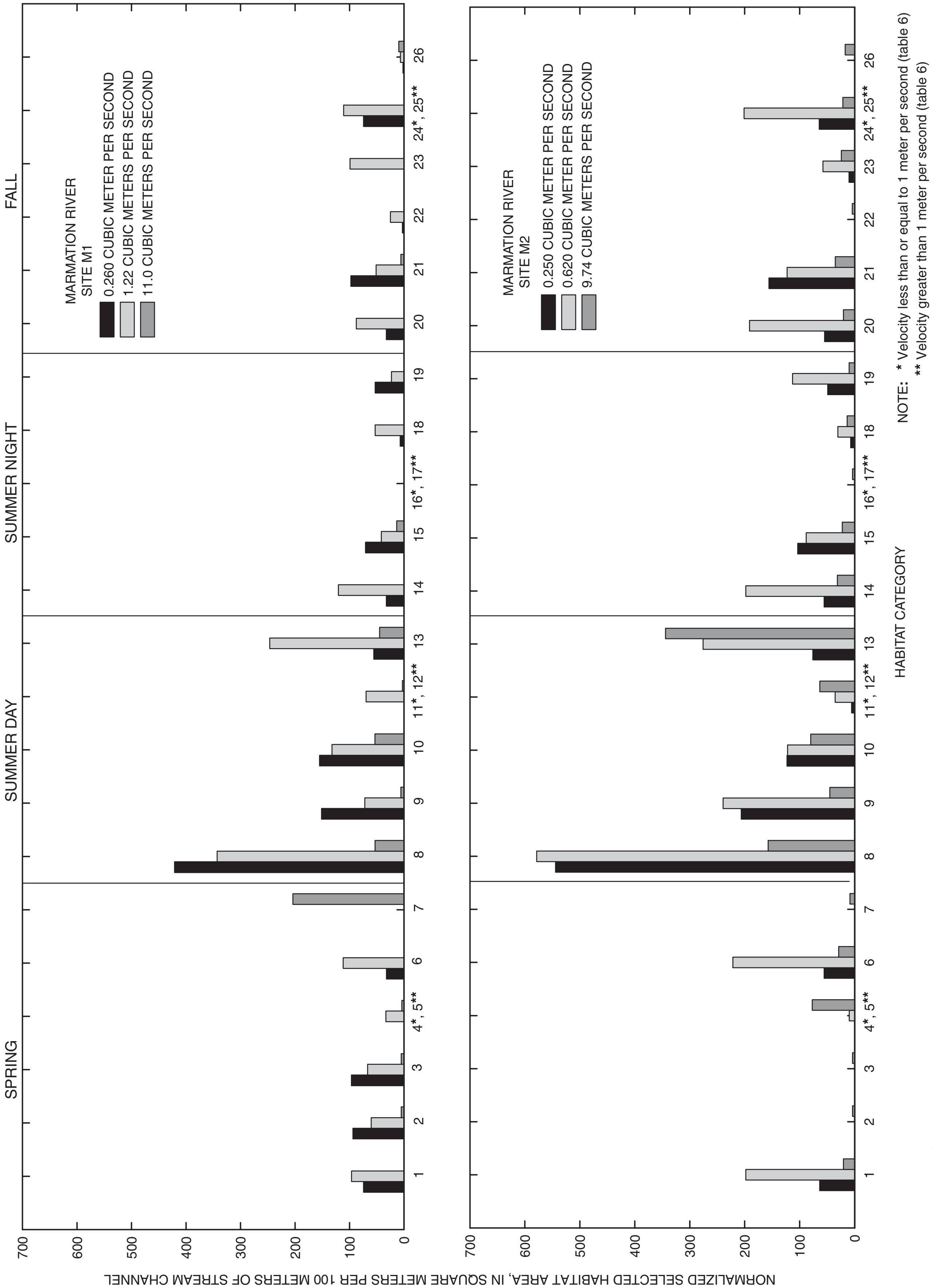

Figure 40. Selected habitat area by category, streamflow, season, and study site.

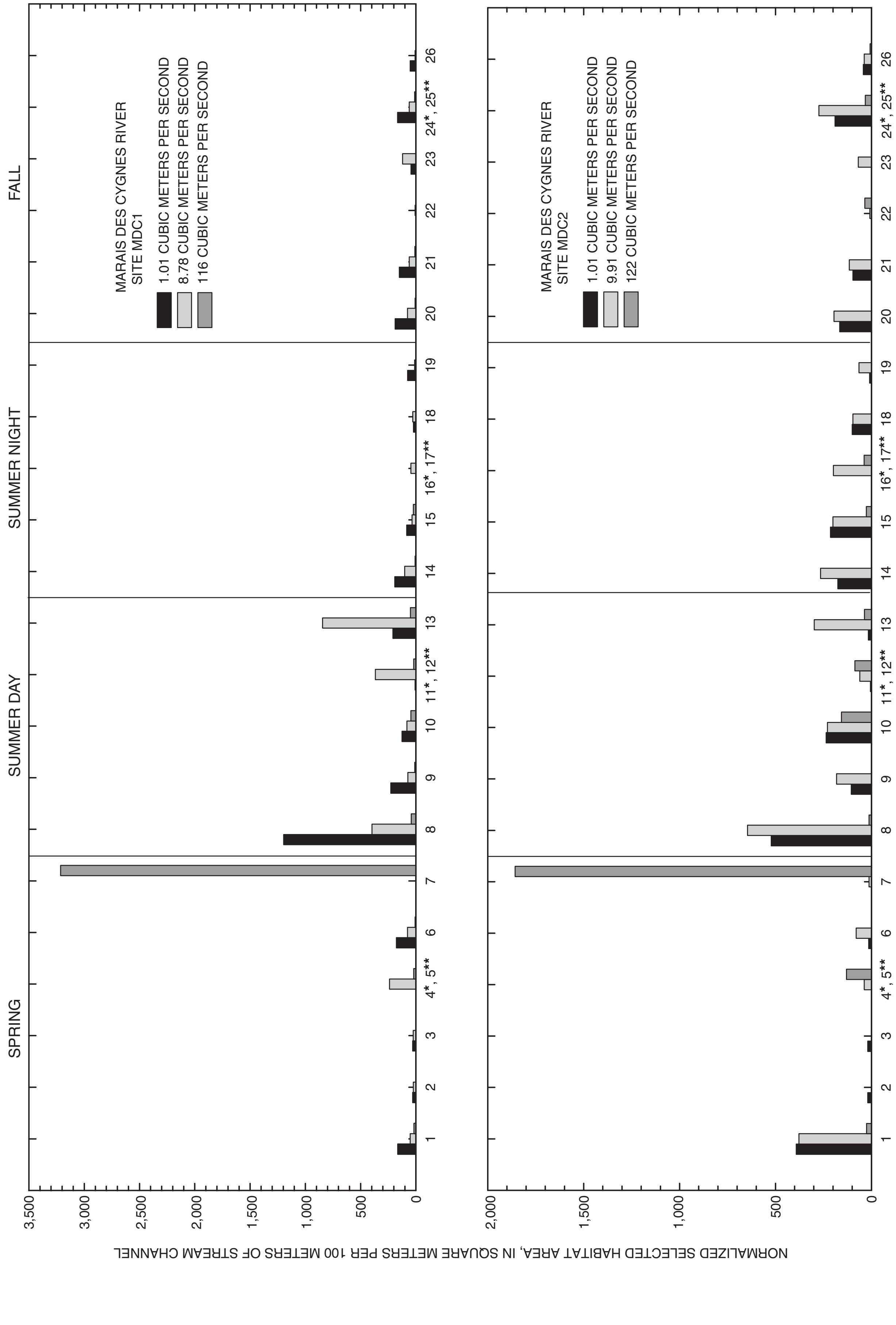

Figure 40. Selected habitat area by category, streamflow, season, and study site—Continued.

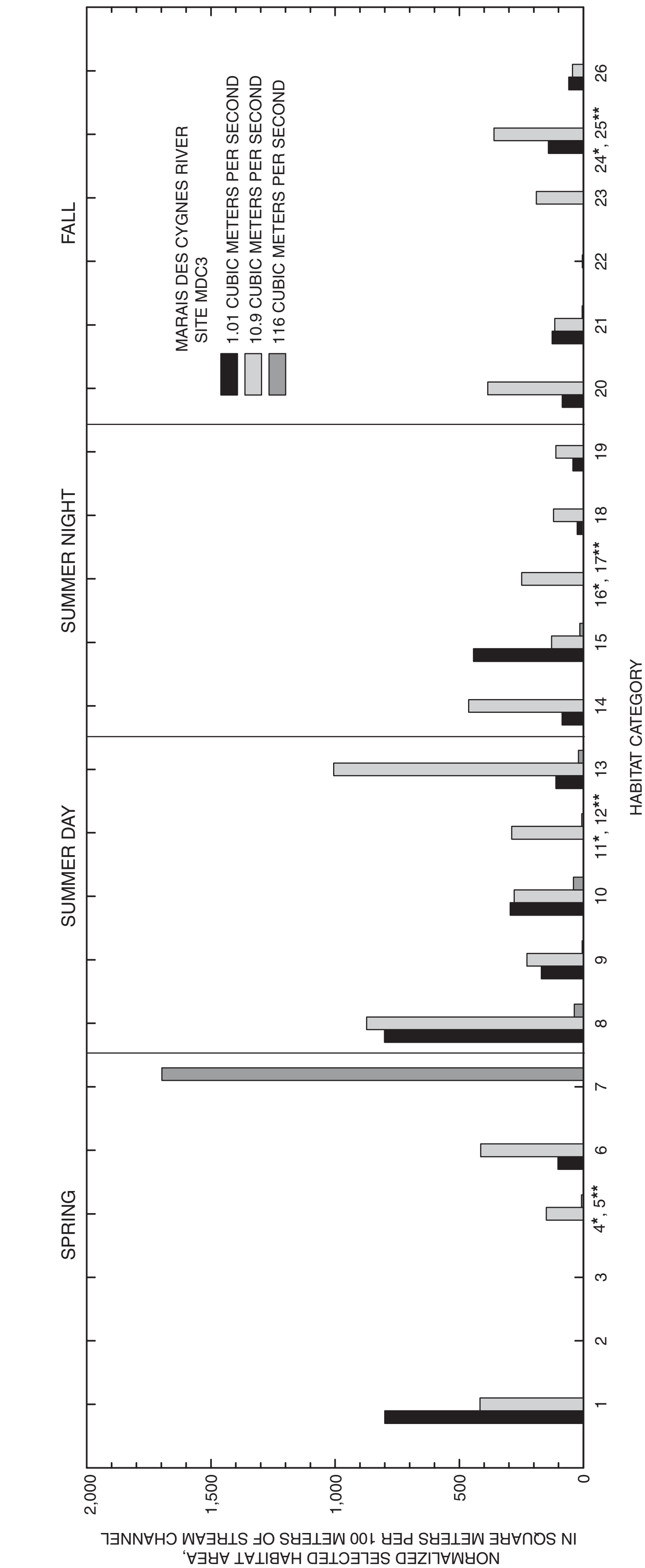

Figure 40. Selected habitat area by category, streamflow, season, and study site—Continued.

Table 24. Range of flows beyond which selected habitat area is limited for seasonal indicator species for the Marmaton and Marais des Cygnes Rivers.

[m^3/s, cubic meters per second; <, less than; >, greater than; --, no data available]

Marmaton River					Marais des Cygnes River						
Indicator species	Low flow, in m^3/s	Low-flow percentile[a]	High flow, in m^3/s	High-flow percentile	Indicator species	Low flow, in m^3/s	1941–1963 Low-flow percentile	1981–2003 Low-flow percentile	High flow, in m^3/s	1941–1963 High-flow percentile	1981–2003 High-flow percentile
Spring											
Suckermouth minnow	<0.1	<1–5	>20–50	>55–95	Suckermouth minnow	<0.1	<1	<1	>100	>75	>65
Slenderhead darter	<.5	<5–10	>20–50	>55–95	Slenderhead darter	<1.0	<6	<5	>100	>75	>65
Paddlefish	<7.0	<25–55	--	--	Stonecat	<.1	<1	<1	>100	>75	>65
					Paddlefish	<10.0	<25	<15	--	--	--
Summer day											
Stonecat	<0.1	<15–25	>30	>90–95	Stonecat	<1	<25	<10	>100	>85	>90
Summer night											
Flathead catfish	<0.1	<15–25	>10–20	>75–90	Flathead catfish	<0.1	<8	<5	>100	>85	>90
Channel catfish	<1.0	<40–55	>10–20	>75–90	Channel catfish	<1.0	<25	<10	>100	>85	>90
Stonecat	<.1	<15–25	>10–20	>75–90	Stonecat	<.1	<8	<5	>100	>85	>90
Fall											
Flathead catfish	<0.1	<20–30	>10–30	>60–75	Flathead catfish	<0.1	<15	<5	>100	>90	>85
Channel catfish	<1.0	<35–45	>10–30	>60–75	Channel catfish	<3.0	<40	<40	>60	>85	>80
Stonecat	<.1	<20–30	>10–30	>60–75	Stonecat	<.1	<15	<5	>100	>90	>85

[a] All percentile information obtained from flow duration data provided in figures 25 through 29 and range denotes variability in flow by site.

from site to site based on local hydraulic characteristics and the substrate types associated with the habitat category.

Fish species categories were assessed as to their vulnerability to habitat alteration based on critical life stages (spawning and juvenile rearing periods; table 6) and their susceptibility to habitat limitations as a result of physical habitat criteria and occurrence (susceptibility to habitat limitations from dewatering or high flows; figs. 25 to 29; tables 8, 9, 11 to 13). Limited potential habitat availability for categories representing critical seasons or life stages may indicate bottlenecks in fish populations. While these habitat limitations can occur under a natural flow regime, expected flow alterations that modify the timing and duration of these conditions will have greater adverse effects on fish populations. These categories with potential bottlenecks can serve as indicator categories and provide a means of aiding managers by allowing them to focus resources on these categories when determining the necessary flows for maintaining these habitats under altered flow regimes. A summary of the indicator-species flow limitations for the Marmaton River and Marais des Cygnes River is given in table 24. Flows within the low and high streamflow limits will not only provide habitat for the indicator categories, but the remaining categories as well. The low- and high-flow limits are based on total SHA and other considerations, including habitat patch-size and distribution requirements, may alter these limits.

SUMMARY AND CONCLUSIONS

A study was undertaken by the U.S. Geological Survey, in cooperation with the Missouri Department of Conservation, to quantify fish habitat by using relations between spatial and temporal distributions of streamflow and fish habitat in selected reaches in the Marmaton and Marais des Cygnes Rivers. Results from this study can be used to identify and mitigate flow alterations that may have adverse ecological effects. Water depth and velocity for selected incremental flows were determined using a two-dimensional numerical model. Substrate characteristics were mapped and combined with simulated hydraulic characteristics to quantify habitat areas for 26 seasonal and life-stage categories. The 26 habitat categories represented critical seasonal (spring, summer, and fall), diel (summer day and night), and life-stage (spawning, juvenile, and adult) conditions of nine fish species.

Potential habitat area for most species was maximized at the Marmaton River sites at flows of about 1 to 10 m^3/s (cubic meters per second), whereas median monthly streamflows ranged from less than 1 to 20 m^3/s depending on site and season. Habitat was available at flows of 0 to 20 m^3/s at the upstream Marmaton River site (M1) and 0.1 to 30 m^3/s at the downstream site (M2) for all species except paddlefish (*Polyodon spathula*). Paddlefish habitat was not available at streamflows less than 7 m^3/s at the upstream site and 4 m^3/s at the downstream site, and was maximized at higher flows that exceeded 100 m^3/s because of higher velocity criteria required by spawning paddlefish. The susceptibility of fish species to habitat limitations at low flow (dewatering) and high flow varied by season, but generally the species whose habitat was most susceptible to dewatering were slenderhead darter (*Percina phoxocephala*), stonecat (*Noturus flavus*), and paddlefish; the least susceptible were red shiner (*Notropis lutrensis*) and sand shiner (*Notropis stramineus*). Habitat was limited for most species other than paddlefish at flows above 20 to 30 m^3/s.

Potential habitat area was maximized at the Marais des Cygnes River sites at flows of about 1 to 50 m^3/s, whereas median monthly streamflows ranged from 4 to 55 m^3/s, depending on site and season. Habitat was available at flows of 0.1 to 800 m^3/s at the upstream (MDC1) and middle (MDC2) Marais des Cygnes River sites for most species (except paddlefish), but the comparable flow range was only 1 to 200 m^3/s at the downstream channelized site (MDC3). Paddlefish habitat was available in the spring beginning at streamflows greater than 10 m^3/s at all three sites, and was maximized at streamflows approaching 1,000 m^3/s. The susceptibility of species habitat to dewatering at the Marais des Cygnes River sites was similar to that of the Marmaton River sites with slenderhead darter, stonecat, and paddlefish the most vulnerable to flows less than 1 m^3/s, and red shiner and sand shiner the least susceptible to low flows. The susceptibility of categories to habitat limitations at high streamflows varied greatly between sites from streamflows above 100 m^3/s, at the channelized site MDC3, to 800 m^3/s at site MDC1. The range of streamflows for which selected habitat area (SHA) was available in summer and fall was substantially less at the channelized site MDC3 than at other Marais des Cygnes River sites and, therefore, the susceptibility of categories to high-flow habitat limitations was greater at this site. The channelized reach was more uniform and had a greater conveyance as a result of the greater slope; therefore, SHA became limited at lower flows.

Monthly streamflow values from water years 1971 through 2003 at the Marmaton River sites were used to create median monthly SHA time series for the 26 habitat categories. In addition, daily streamflow data from pre-regulation (1941 through 1963) and post-regulation (1982 through 2003) were used to create median daily SHA time series for the Marais des Cygnes River sites. The spring habitat category with the highest median monthly SHA of the Marmaton River sites M1 and M2 was paddlefish with the highest habitat availability in April and June. Peak median monthly habitat availability for summer day and night periods varied by category. The species with the highest median summer day habitat availability, flathead catfish (*Pylodictis olivaris*), peaked in September at both sites, while the summer night species with the highest habitat availability, red shiner, peaked in August. Most median fall species category habitat areas peaked in October at both sites.

The habitat category with the overall highest median monthly selected habitat values for the Marais des Cygnes River sites in spring was paddlefish with median monthly availabilities of as much as 2,000 m^2/100 m (square meters per 100 meters) at all three sites. Red shiner and sand shiner habitats were missing at the downstream channelized Marais des

Cygnes River site because gravel substrate, a required habitat criteria, was not available. Flathead catfish had the highest median SHA availability for summer and fall categories.

The overall spring, monthly, time-series distributions for Marmaton River sites M1 and M2 indicate that paddlefish had the highest median and maximum habitat availability while stonecat had the lowest median availability. Median habitat availability for other spring spawning species [suckermouth minnow (*Phenacobius mirabilis*) and slenderhead darter] also were higher at site M2 than site M1 although maximum availabilities were similar between sites. There were substantial differences in habitat availability distributions for juvenile Ictalurids in summer day and summer night categories at the Marmaton River sites.

Differences in daily SHA time series between pre- and post-regulation time periods varied by species/category and by Marais des Cygnes River sites. While there was a decline in the distribution of spring spawning habitat for suckermouth minnow and slenderhead darter between pre- and post-regulation periods at all three sites, there was an increase in the 25 to 75 percentile areas of paddlefish habitat under post-regulation conditions. There generally were increases in summer day and summer night category habitat area under post-regulation conditions when compared to pre-regulation conditions at the three sites. Most fall categories showed increases in habitat distributions for post-regulation periods with the exception of channel catfish (*Ictalurus punctatus*) habitat availability, which showed a decrease in the 50 to 75 percentile range at all three sites.

No single flow maximized habitat area for all categories or even for species/life-stage categories within a particular season or site. The relation between SHA and streamflows differed substantially between categories and study sites, even those at sites on the same river. Attempts to transfer results from one location to another between basins, or even within a basin, are difficult because the habitat-streamflow relation is so dependent on site hydraulic characteristics and local substrate composition. There were, however, some similarities in relations among site habitat characteristics, including the flow range for which habitat availability was maximized and, in the case of the Marmaton River sites, the range of inflows for which quantifiable habitat area was available. Other characteristics that were similar among most study sites are that paddlefish had the highest habitat availability of all spring categories, whereas flathead catfish had the highest habitat availability in summer and fall periods.

Fish species categories were assessed as to their vulnerability to habitat alteration based on critical life stages (spawning and juvenile rearing periods) and susceptibility to habitat limitations as a result of physical habitat criteria and susceptibility to dewatering or high flows at the study sites. Species categories representing critical life stages with physical habitat limitations represent likely bottlenecks for certain fish populations. These categories with potential bottlenecks can serve as indicator categories and can aid managers when determining the necessary flows for maintaining these habitats under altered flow regimes.

Shallow-water habitats in the Marmaton and Marais des Cygnes Rivers provide a variety of habitat for a number of fish species/life stages. Limitations in SHA occurred at both low and high streamflow thresholds depending on species/life stage and site. Streamflow has been altered in the Marais des Cygnes River Basin between the 1941 through 1963 and 1982 through 2003 periods likely as a result of impoundments and the corresponding controls of streamflow. The degree of regulation is expected to increase in both the Marmaton and Marais des Cygnes River Basins. The alterations in streamflow corresponded with both seemingly beneficial and detrimental effects on SHA depending on site, species, and life stage. The effects of continued flow alterations are likely to be gradual and difficult to discern in the short term given climatic and streamflow variability. Knowing the relation between streamflow and habitat availability and having access to continuous streamflow information will allow for continuous monitoring of potential habitat bottlenecks in shallow-water habitats in these rivers. The ability to effectively identify the timing and duration of chronic habitat bottlenecks will, in turn, aid managers in ensuring sustained and healthy fish populations in these rivers.

REFERENCES

Allison, P.D., 1999, Logistic regression using the SAS System—Theory and application: Cary, North Carolina SAS Institute, Inc., 302 p.

Arcement, G.J., Jr., and Schneider, V.R., 1989, Guide for selecting Manning's roughness coefficients for natural channels and flood plains: U.S. Geological Survey Water-Supply Paper 2339, 38 p.

Bevans, H.E., Skelton, John, Kenny, J.F., and Davis, J.V., 1984, Hydrology of Area 39, Western Region Interior Coal Province Kansas and Missouri: U.S. Geological Survey Water-Resources Investigations Open-File Report 83–851, 83 p.

Bovee, K.D., Newcomb, T.J., and Coon, T.G., 1994, Relations between habitat variability and population dynamics of bass in the Huron River, Michigan: U.S. Geological Survey Biological Report 21, 64 p.

Brewer, S., 2004, Evaluating the role of shallow habitats to the spawning success of fishes in the Marais des Cygnes River: Columbia, University of Missouri M.S. Thesis, 150 p.

Cross, F.B., 1967, Handbook of fishes of Kansas: Lawrence, University of Kansas, Museum of Natural History Miscellaneous Publications, v. 45, 357 p.

Dent, R.J., Jr., Fantz, D.K., Heatherly, W.G., and Yasger, P.A., 1997, West Osage River Basin Inventory and Management Plan: Missouri Department of Conservation, accessed on January 30, 2004, at http://mdc.mo.gov/fish/watershed/wosage/contents/310cotxt.htm.

Ghanem, A., Steffler, P.M., Hicks, F.E., and Katopodis, C., 1995, Two dimensional finite element model for aquatic habitats: Edmonton, Alberta, Canada, University of Alberta, Department of Civil Engineering, Water Resources Engineering Report 95-S1, 189 p.

Ghanem, A.H., Steffler, P.M., Hicks, F.E., and Katopodis, C., 1996, Two dimensional finite element flow modeling of physical fish habitat: Regulated Rivers: Research and Management, v. 12, p. 185–200.

Graham, M.H., 2003, Confronting multicollinearity in ecological multiple regression: Ecology, v. 84, p. 2,809–2,815.

High Plains Regional Climate Center, 2004, Precipitation data: Lincoln, University of Nebraska, accessed on October 19, 2004, at http://www.hprcc.unl.edu/products/historical.htm.

Hoel, S.M., 1998, Evaluation of the relations of fish and invertebrate communities to habitat conditions affected by low and variable flows in two Missouri prairie streams: Columbia, University of Missouri M.S. Thesis, 207 p.

Hosmer, D.W., and Lemeshow, S., 1989, Applied logistic regression: New York, John Wiley and Sons, 304 p.

Humphries, P., and Lake, P.S., 2000, Fish larvae and the management of regulated rivers. Regulated Rivers: Research and Management, v. 16, p. 421–432.

Johnson, D.H., 1980, The comparison of usage and availability measurements for evaluating resource preference: Ecology, v. 61, p. 65–71.

Kansas Water Office, 2004, Marais des Cygnes Basin Section, accessed on February 23, 2005, at http://www.kwo.org/KWP/MDC_BasinPlan_Supp_Assessment.pdf.

Kinsolving, A.D., and Bain, M.E., 1993, Fish assemblage recovery along a riverine disturbance gradient: Ecological Applications, v. 3, no. 3, p. 531–544.

Missouri Department of Conservation, 2004, Assessment of Operational Alternatives for the Osage Hydroelectric Project: Part II—Two-dimensional Modeling Analysis of Lotic Habitats in the Lower Osage River: FERC Project No. 459, v. II, part II, 197 p.

Neter, J., Kutner, M.H., Nachtsheim, C.J., and Wasserman, W., 1996, Applied linear regression models (3d ed.): Chicago, Ill., McGraw-Hill Companies, Inc., 1,408 p.

Pflieger, W.L., 1997, The fishes of Missouri, revised edition: Jefferson City, Missouri Conservation Commission, 372 p.

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.C., Sparks, R.E., and Stromberg, J.C., 1997, The natural flow regime: Bioscience, v. 47, p. 769–784.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow: Volume 1. Measurement of stage and discharge and Volume 2. Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Schlosser, I.J., 1985, Flow regime, juvenile abundance, and the assemblage structure of stream fishes: Ecology, v. 66, no. 5, p. 1,484–1,490.

Simon, T.P., 1999, Assessment of Balon's reproductive guilds with application to Midwestern North America freshwater fishes, *in* T.P. Simon, ed., Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities: CRC Press, p. 97–121.

Skelton, John, 1976, Missouri stream and springflow characteristics: Rolla, Missouri Department of Natural Resources, Division of Geology and Land Survey, Water Resources Report Number 32, 71 p.

Steffler, P., and Blackburn, J., 2002, Two-dimensional depth averaged model of river hydrodynamics and fish habitat: Introduction to Depth averaged modeling and user's manual: Edmunton, Alberta, Canada, University of Alberta, 119 p.

The Nature Conservancy, 2005, Indicators of hydrologic alteration, version 7, User's Manual, accessed on February 10, 2005, at http://www.freshwaters.org/tools/.

Thomas, J.A., and Bovee, K.D., 1993, Application and testing of a procedure to evaluate transferability of habitat suitability criteria: Regulated Rivers Research and Management, v. 8, p. 285-294.

University of Alberta, 2003, River2D download page, accessed on February 15, 2005, at http://www.river2d.ualberta.ca/download.htm.

U.S. Army Corps of Engineers, 1996, User's guide to RMA2, version 4.3: Vicksburg, Mississippi, Waterways Experiment Station, 226 p.

U.S. Army Corps of Engineers, 2004, National inventory of dams, accessed on July 27, 2004, at http://crunch.tec.army.mil/nid/webpages/nid.cfm.

U.S. Geological Survey, 2004a, Missouri water data, accessed on February 23, 2005, at http://waterdata.usgs.gov/mo/nwis/current?type=flow&group_key=basin_cd&search_site_no_station_nm=.

U.S. Geological Survey, 2004b, Kansas water data, accessed on February 23, 2005, at http://waterdata.usgs.gov/ks/nwis/rt.

U.S. Geological Survey, 2005, Office of Surface Water technical memorandums, accessed on March 4, 2005, at http://water.usgs.gov/admin/memo/SW/auto.html.

Waddle, T., and Steffler, P., 2002, R2D_Mesh—Introduction to Mesh Generation and User's Manual: Edmunton, Alberta, Canada, University of Alberta, 31 p.

Winston, M.R., 2002, Spatial and temporal species associations with the Topeka shiner (*Notropis topeka*) in Missouri: Journal of Freshwater Ecology, v. 17, p. 249–261.

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