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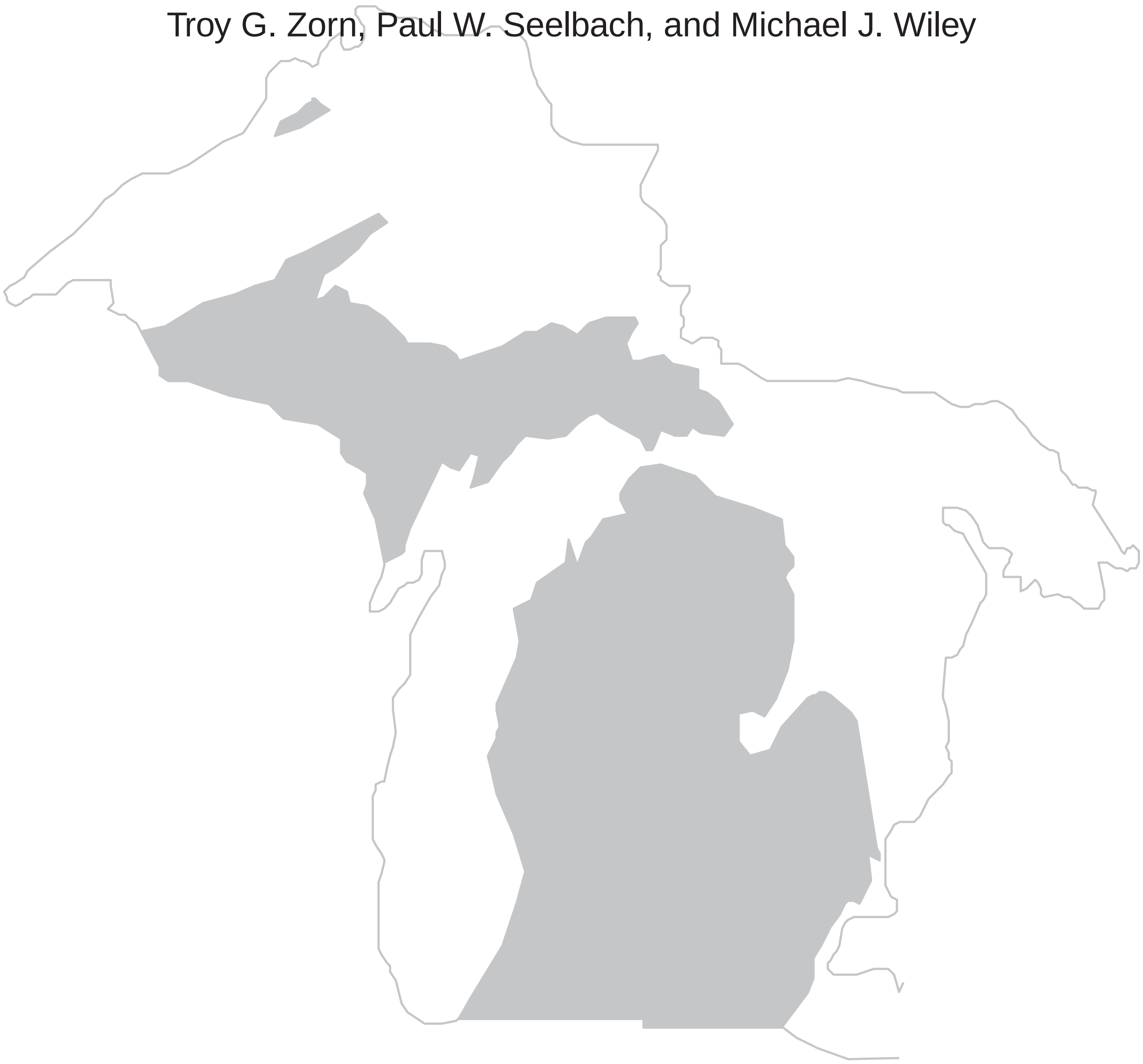

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Relationships Between Habitat and Fish Density in Michigan Streams

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Abstract.–We developed simple decision support tools (plots) for fishery managers in Michigan that are based on habitat data and fish population estimates for several hundred stream sites throughout the state. We generated contour plots to show patterns in fish biomass for over 60 common species (and 120 species grouped at the family level) in relation to axes of catchment area (CA) and low-flow yield (LFY; 90% exceedance flow divided by CA), and then against axes of mean and weekly range in July temperature. The plots showed distinct patterns in fish density at each level of biological organization studied and were useful for quantitatively comparing river sites. Contour plots were also made for fish assemblage attributes such as species richness and total density. We demonstrated how these plots can be used to support stream management and provided examples pertaining to resource assessment, trout stocking, angling regulations, chemical reclamation of marginal trout streams, indicator species, instream flow protection, and habitat restoration. These tools are electronically available, so managers can easily access and incorporate them into decision protocols and presentations.

Introduction

Management of stream fisheries at the local scale would benefit from decision support tools (i.e., quantitative fish-habitat relationships) derived from data collected locally or regionally. Existing regional or national datasets, such as Habitat Suitability Index models (e.g., Raleigh et al. 1986) may lack samples for a particular stream type or include such a broad array of hydrologic types that the resolution of the data is inadequate for supporting local-scale decisions. For example, a national sample of trout streams (e.g., Poff and Ward 1989) may include rivers where habitat conditions are driven by mountain elevations, snowmelt, hydropower dam flow releases, or groundwater inputs, though only a subset of these factors may significantly influence streams in a particular region (e.g., groundwater inputs are key in glaciated Midwestern states). On the other hand, fish-habitat relationships (models) from detailed, location-specific studies may be difficult to apply to other regions if stream conditions differ (Fausch et al. 1988) or if making predictions of fish density requires additional resources (e.g., software, technical expertise, funding, etc.). Though much fishery management occurs by state agencies, state-scale summaries relating fish density and habitat data are often lacking, not standardized (gear specific), or have yet to be synthesized at the state scale.

Through the Michigan Rivers Inventory (MRI) project (Seelbach and Wiley 1997), data have been collected for describing aquatic assemblages and habitat at several hundred sites in the state. These data have been used to develop models for understanding and classifying systems (Seelbach et al. 1997; Wiley and Seelbach 1997; Zorn et al. 2002). The models have also enabled prediction of streamflow characteristics (Wiley and Seelbach, unpublished data), summer water temperatures (Wehrly et al. 1997), and fish assemblages (Zorn et al. 2004) for the state's rivers. The MRI database would readily lend itself to development of simple decision support tools (e.g., plots) relating fish density to habitat, but such synthesis was lacking.

Previous studies have demonstrated that spatial patterns in fish distribution and abundance in glaciated Midwestern streams can largely be accounted for by relatively few habitat variables. The importance of stream size, measured as catchment area, is both well known and documented (e.g., Hynes 1972; Lyons 1996; Zorn et al. 2002). Low-flow yield, defined as 90% exceedance flow divided by catchment area, is a measure of groundwater contribution to streams and an index of important parameters such as stream temperature, hydrologic stability, and current velocity (Hendrickson and Doonan 1972; Poff and Allan 1995; Zorn et al. 2002). Summer temperature is one of the major factors affecting growth (Brett 1979), survival (Smale and Rabeni 1995a), and distribution of fish (Magnuson et al. 1979; Smale and Rabeni 1995b; Lyons 1996; Wehrly et al. 2003; Zorn et al. 2004) throughout the Midwest and worldwide. The objective of this study was to develop simple decision support tools for Michigan biologists that relate key habitat variables to densities of commonly occurring fish species, species grouped at the genus or family level, and other groupings deemed useful to fishery managers.

Methods

Study Area

Data were obtained for this study from several hundred stream sites scattered across Michigan. The entire state was influenced by Pleistocene glaciation, and except for portions of the Upper Peninsula, it is covered by unconsolidated glacial deposits ranging in texture from coarse sands and gravels associated with moraines and glacial outwash, to clays from former glacial lakes. The thickness of these deposits ranges from a few feet to several hundred feet. The texture, depth, and associated hydrologic properties of these deposits have a strong influence on river flow, channel conditions, and fish assemblages (Hendrickson and Doonan 1972; Zorn et al. 2002).

Data Sources

Fisheries survey data were obtained for 332 stream sites in the Lower Peninsula from the MRI database (Seelbach and Wiley 1997), and 46 sites on Upper Peninsula waters from a companion study to the MRI (Baker 2006). Surveys were conducted in wadeable stream reaches during summer from 1982 to 2001. Density estimates were available for the entire fish assemblage at 298 sites sampled via rotenone or multi-pass electrofishing depletion surveys, and mark-recapture estimates for salmonids were obtained at an additional 80 sites (Figure 1). Seelbach and Wiley (1997) and Seelbach et al. (1988) provide greater detail regarding fish sampling techniques and computation of abundance estimates.

The large number of sites with fish density data provided an excellent sample of Michigan streams, with a few caveats. Small streams (i.e., having catchment areas < 10 mi^2) and Upper Peninsula waters were somewhat undersampled, given their abundance on the landscape (Figure 1). Fish density estimates from rotenone surveys may represent only about 75% of actual values because of sampling inefficiency (Seelbach et al. 1994). To make density estimates of all species captured, we assumed equal catchability of all fishes at electrofishing depletion sites (Zippen 1958), but there was undoubtedly variation in catchability among species. While no replicate samples occurred at specific sites, the overall data captured temporal variation to some degree by covering a broad sampling period. So, although any individual sample may not perfectly represent a site's typical fish assemblage, the existence of fish density data from the several hundred sites essentially provided replicate samples for many types of Michigan rivers. In addition, we expected density patterns for most species at the statewide scale to be dramatic enough (e.g., contrasts of high versus low versus zero density levels) that sampling induced biases would not significantly alter our findings.

Three types of stream habitat data were used for this study. Catchment area (CA) was measured for each site using geographic information system techniques. Ninety percent exceedance flow values were obtained from the same sources as the fish survey data and consisted of a combination of measurements from United States Geological Survey gauging stations and regression model predictions (Seelbach and Wiley, unpublished data and Baker 2006). Low-flow yield (LFY) was computed for a site by dividing its 90% annual exceedance flow by its catchment area. July stream temperature data were obtained for 379 sites, and consisted of hourly measurements at the vast majority of sites, and weekly maximum and minimum readings at others. From these data we computed July mean temperature which (depending upon the data source), was the average of the hourly readings or an average of the weekly readings. To determine the comparability of July mean temperature values calculated from these two types of data, we used hourly temperature data from a subsample of sites and compared July mean temperature values computed with both methods. We found that these two calculations produced values that were nearly identical ($r = 0.995$). We also computed July weekly temperature range which was the average of the differences between each week's maximum and minimum temperatures. July temperature values were predicted at sites where measurements were not available (Wehrly et al. 1997).

Data Analysis

The data were analyzed several ways to depict relationships between species density and habitat. We generated contour plots to show patterns in fish biomass, for species and select groups of taxa (Table 1) in relation to axes of LFY and CA, and then against axes of mean and weekly range in July temperature. This was accomplished by describing subsets of MRI sites that met particular LFY, CA, or temperature criteria. We developed sampling matrices, with sites grouped into cells according to their LFY, CA, or temperature values (Figure 2). Average values for fish density and these habitat parameters were calculated from MRI data available for the subset of sites in each cell, and plotted on these axes. This analysis was also done for numerical density of salmonids since they are of particular management interest in Michigan.

We think that plots of fish abundances on these habitat axes may reflect long-term average population levels, since abundances were averaged from many similar sites sampled during different years. Population estimates from individual fish surveys may differ considerably from these values because of natural fluctuations in population levels. For example, replicate rotenone samples available from seven warmwater stream sites (Zorn, unpublished data) showed up to three-fold differences in abundance levels of the more common species (i.e., those having abundances >10 kg/ha). Wiley et al. (1997) suggested that 15 to 20 years of population estimate data may be needed to accurately characterize the long-term mean and variance of trout populations in hydrologically-stable (groundwater-fed) Michigan streams. Since such long-term data do not exist for most Michigan streams, pooling similar sites allowed us to develop initial estimates of the mean and variance in fish populations associated with different stream conditions.

We produced scatterplots of numerical density of brown trout and brook trout against July mean temperature for Michigan streams. The wedge-shaped distribution of data relating July mean temperature to trout density indicated that July mean temperature is an index of conditions that become limiting to trout (Terrell et al. 1996; Thompson et al. 1996). To demonstrate this relation, we visually fit a line along the upper portion of the data to show the relation between maximum (potential) brown trout density and July mean temperature.

We developed a spreadsheet model that described how close conditions of a site were to what is optimal for 68 common fishes in Michigan rivers. First, we standardized (Z-distribution, mean = 0, SD = 1) the fish density data by species. For each species, we selected sites where it was relatively abundant (z-score > 0.75), hereafter referring to them as “optimal” sites, and computed the mean and standard deviation for their LFY, CA, and mean July temperature values. For each species, the spreadsheet model assigned scores to the site’s LFY, CA, and mean July temperature conditions based upon the number of SD’s these values were away from “optimal” LFY, CA, and mean July temperature values for the species. The site received a 4, 3, 2, or 1 score if its values were within 0.5, 1.0, 1.5, or 2.0 standard deviations of the optimal values for a species; a 0 score was given if the site’s value was more than 2.0 standard deviations from the species’ optima value. Composite scores were calculated for each modeled species at a site as the minimum of the three individual variable scores, implying that any one of the three variables (or factors correlated with them) may limit species density at a site. This is justifiable because these habitat variables are tied to aspects of fish habitat important to fish metabolism, survival, and reproductive success (e.g., temperature, dissolved oxygen, current velocity and aeration, depth, permanence of habitats, etc.). An average of the individual variable scores was also computed for each species.

Results

Our Michigan-based habitat suitability models were based upon a broad array of river conditions. The MRI sites studied had attribute values ranging over several orders of magnitude. For example, catchment areas ranged from 0.4 to 5513 mi^2 (stream widths from 2 to 350 feet), low-flow yields from 0.0008 to 2.93 cubic feet per second per square mile ($ft^3 * s^{-1} * mi^{-2}$), July mean temperatures from 48 to 80°F, and July weekly temperature range values were between 4 and 31°F. Low-flow yield and catchment area were closely tied to July mean temperature (Figure 3). Total fish density at sites ranged from 5 to 1004 pounds per acre and species richness varied from 1 to 40 (Appendix A).

The plots are useful for distinguishing habitat affinities among species, comparing river systems, and assessing potential response of systems to various management activities. Some species such as brook trout and smallmouth bass have fairly restricted stream size and hydrology “preferences," whereas other fishes (e.g., white sucker and rock bass) can do well under a broader array of conditions and abundance peaks are not as distinctive (Figure 4). Similar patterns can be seen at higher taxonomic levels, with salmonids being most abundant in rivers with high groundwater inputs, dace becoming more abundant as LFY values decrease, and suckers and catfishes being more prominent in larger rivers with lower LFY’s (Figure 5). Narrow versus broad habitat tolerances could be distinguished among species, and the plots provided a useful means for assessing the suitability of a given set of conditions for species of management interest (Figure 6). For example, opportunities are being explored for reducing the downstream thermal effects of a millpond on the Middle Branch River, a tributary to the Muskegon River (O’Neal 2006). Conditions upstream of the millpond indicated that the impounded river reach and area downstream would have excellent potential for supporting substantial populations of coldwater fishes if warming effects of the impoundment were eliminated (Figure 6).

Our data showed that mean July temperature (or one of its correlates) can limit a stream's potential to support brown trout density, since maximum fish densities observed generally declined with increasing temperature (Figure 7). Such information can be used to assess the potential of waters for different types of management (e.g., stocking, protective regulations, etc.). For example, contrasting thermal conditions (and resulting coldwater fishery potential) in heavily stocked tailwaters of the Au Sable, Manistee, and Muskegon rivers may allow for different management approaches (Figure 7). Minimum size limits for brown trout are lower in waters (i.e., Muskegon River below Croton Dam) where water temperatures are typically warm and annual survival of trout is relatively low (Michigan Department of Natural Resources Fisheries Division, MDNR-FD, unpublished data). Higher size limits (and a trophy trout fishery) appear more feasible in the Au Sable River below Mio Dam, which is often cooler and has better trout survival (MDNR-FD, unpublished data). A similar relationship appears to occur between mean July temperature and brook trout density (Figure 8).

The above results provided just a few examples of the utility of these plots. Their main value, however, is in supporting fisheries management decision-making at the local level. A complete set of plots is provided to help achieve this objective (Appendix A). The plots are also available in electronic format via the Michigan Department of Natural Resources intranet site or can be obtained by contacting the lead author of this report. To facilitate comparisons among rivers, the LFY, CA, and July temperature values for sites with fish density estimates used in this study can also be obtained from the same sources.

The spreadsheet model provided a useful means for assessing the suitability of sites for different fishes. Optimal LFY, CA, and July temperature values for each species allowed for quantitative comparisons of differences in habitat preference among species (e.g., Table 2). For example, plots of optimal CA and mean July temperatures for each species show a progression from species typical of cold- and cool-water small streams to those characteristic of large, warm rivers (Figure 9). Highly ranked species, based on composite suitability scores, from model test runs for the Huron River (a large, warmwater river) and Hunt Creek (a small, trout stream) reasonably corroborated unpublished MDNR-FD survey data on fish assemblage structure for these waters (Table 2 and Table 3). Hunt Creek, like many inland streams, does not have Great Lakes salmonids but was rated highly for them because Great Lakes accessibility was not a model parameter.

Discussion

Management Applications

This analysis fills a basic need of fishery managers, namely to have regionally based, data-rich, simple decision support tools for showing constituents and the public the biological basis behind local river management decisions. The graphs provide a solid base for supporting management decisions because the relationships are based upon observations from several hundred sites, with multiple observations often occurring for a given set of conditions. Fish-habitat relationships are especially strong for species or taxa when graphs show one set of habitat conditions associated with peak fish density, despite the wide range of habitat conditions in the state. The simple axes of the plots can be readily used to plot conditions for a river site of interest, assess its suitability for various species of fish, and compare and contrast it with other sites and rivers. The electronically available plots can be simply cut and pasted into presentations.

This analysis provides useful benchmarks for assessing Michigan rivers for species because we focused on relating species densities to limiting factors (e.g., temperature) and variables (i.e., LFY and CA) well correlated with key aspects of habitat (i.e., temperature, depth, velocity, etc.) and species distributions in Michigan (Bailey et al. 2004; Zorn et al. 2004). Thus, relationships between these habitat factors and fish density can be used with site-based data to better identify what may be limiting a population's abundance at a site.

The relations we depict are analogous to traditional Habitat Suitability Index plots (e.g., Raleigh et al. 1986) in that they show conditions where species do well, as indexed by fish density. However, they differ in several respects including: response variable used (overall population density vs. suitability for individual fish or life stage); measurement scale of response variable (actual densities vs. 0-1 range of suitability scores); habitat variables chosen (a few key variables indexing local conditions vs. many site-scale variables related to an individual fish's use of microhabitats); and our emphasis on describing central tendencies vs. site-scale limits to microhabitat use by individual life stages. Since they are based on a statewide fish community dataset, our plots cover broad array species and taxa, and are specific to Michigan.

Management Scenarios

Fish stocking represents a substantial investment of MDNR-FD's resources, with hatchery-related operations consuming roughly 30% of the agency's budget (MDNR-FD, unpublished data). A good portion of this expense is directed toward stocking streams with trout. These tools can be used to support decisions related to stocking, such as whether or not to stock, and in some instances, what minimum size limits to place on stocked waters. Rivers where temperature conditions are adequate for trout survival (e.g., mean July temperatures consistently 68^{o} F or less) and where there is no (or very little) natural reproduction of trout should be considered for stocking. Obviously, streams with temperature or low-flow yield conditions unsuited for trout should not be considered for stocking, while those with marginal conditions would need to be investigated more closely. The three waters shown in Figure 7 are among the most expensive stocking sites of non-migratory salmonids in Michigan, and it behooves MDNR-FD to manage these fisheries to optimize its return on investment. For example, lower minimum size limits seem appropriate in reaches such as the Muskegon River below Croton dam, where thermal conditions might often limit annual survival. Higher size limits seem more feasible when thermal constraints are reduced and fish can survive to larger (possibly trophy) size. For example, the agency is currently experimenting with higher size limits for brown trout and rainbow trout in a stocked reach of the Au Sable River below Mio Dam.

These statewide data will allow managers to readily assess, to some extent, the restoration or rehabilitation potential of a site for various species of fish. These data could be used to assess thermal impacts of Michigan's 2500+ dams or major water discharges on downstream reaches. For example, data characterizing LFY and CA conditions were used to characterize the Middle Branch River (a tributary to the Muskegon River) downstream of a millpond in Marion (Figure 6). This information suggested that the river at this location would likely be well suited to brown trout. Temperature measurements upstream of the impoundment indicated likewise, but conditions below the impoundment show substantial warming (Figure 6). It is likely that management efforts to create a channel bypassing the impoundment will result in good conditions for trout in the river downstream of the confluence of the bypass channel and the original river channel.

Development of fish passage at downstream dams on Great Lakes tributaries has the potential to substantially increase population levels of migratory Great Lakes salmonids (e.g., Chinook salmon, rainbow trout, coho salmon) and decrease the Michigan's reliance on hatcheries for production of these species. The plots (and associated data) could be used to provide general estimates of the densities of these species in tributaries. Data relating maximum potential density to habitat variables (e.g., Figure 7) may be especially appropriate for restoration work where thermal impacts are the primary impediment.

Data relating fish densities to LFY also provide useful demonstrations as to the influence of low-flow water withdrawal on fishes. Reduced LFY values (and increased temperatures) associated with water withdrawal would lower the potential of some streams for salmonids, especially in reaches that presently provide thermally marginal conditions for trout reproduction and survival. For example, reducing the LFY for the Iron River at the city of Iron River from its current value to 0.2 $ft^3*s^{-1}*mi^{-2}$ would result in the stream becoming ill-suited for brook trout (Figure 4). Likewise, diminishing the LFY of Middle Branch River at Marion from its current value to 0.05 $ft^3*s^{-1}*mi^{-2}$ would in all likelihood severely reduce its capacity to support self-sustaining brown trout populations (Figure 6). Coldwater stream ecosystems may be most obviously affected by water withdrawal, but such effects are likely not limited to them. Our study showed that for a given size of stream, densities of many cool- and warm-water species declined with reductions in LFY (Figure 5; Appendix A). Such patterns indicate these species may also be detrimentally affected by water withdrawal.

The products we developed are useful for comparing habitat use relationships among species. For example, these data shed light on the usefulness of certain taxa (e.g., mottled sculpin) as indicators of "coldwater" streams and their subsequent use in justifying trout stocking. Our data show lower thermal tolerances of salmonids relative to mottled sculpin, suggesting that mottled sculpin presence is not necessarily an indicator of a stream highly suited to salmonids (Figure 6). The data also demonstrate distinct differences between mottled sculpin and slimy sculpin in thermal conditions where each species is most abundant in Michigan (Appendix A). Similarly, our analyses suggest that large populations of white suckers and low populations of trout may be more indicative of stream temperature conditions marginal for trout (Figures 3 and 4) than competition with white sucker (Moyle et al. 1983). Thus, these relationships support MDNR-FD's current position to limit chemical reclamations in marginal trout streams.

The spreadsheet model provides a simple tool with many potential uses. Managers having the requisite physical data can use it to estimate the type of fish assemblage that might be expected at a site. Such predictions might be useful when little or no fish survey data are available, and would provide benchmarks for comparison with existing surveys. Managers can get some sense of how fish assemblage structure changes upstream or downstream of a site by changing the CA value in the model. At a larger scale, statewide stream classification and mapping efforts, such as Michigan's valley segment ecological classification (Seelbach et al. 1997), have used the model to predict fish community structure in river segments throughout the state.

Managers can also use the spreadsheet model to explore how management actions that change key habitat parameters (e.g., temperature) might influence the fish assemblage at a site. For example, a next-generation version of the spreadsheet model described here has been developed to project fish community responses to water withdrawal (i.e., LFY reductions and temperature increases), and was used in support of groundwater protection legislation recently passed in Michigan (Zorn et al. 2008).

Limitations

The findings of this study and the utility of our results are limited in several ways. The surface plots show where each species does well and where it might not do well (assuming equal historic access). Despite the large number of sites included in this study, relatively few data (i.e., $n < 10$) were available for certain combinations of LFY, CA, or July temperature conditions (Figure 2). Sometimes this represented a lack of samples for a particular type of stream, while other times it resulted from a lack of these types of streams in Michigan (e.g., streams with CA greater than 600 mi^2 and LFY values higher than 0.6 $ft^3*s^{-1}*mi^{-2}$). Inadequate data could result in under-representation of the range of suitable conditions for a species, and may lead to LFY-CA versus fish density plots for some species with distinct peaks rather than a smooth surface with a single peak representing optimal conditions (minor variation in peaks might also be attributed to how data were stratified for summarization and plotted). Most pronounced examples of distinct peaks occurred for the set of streams bound by CA values of 250 and 600 mi^2 and LFY values of 0.05 and 0.10 $ft^3*s^{-1}*mi^{-2}$. Three of the six sites that met these criteria and had fish density data were on the Maple River. The Maple River is a tributary to the Grand River that flows within an extremely low gradient, former glacial drainageway (i.e., the valley is much larger than the present river), and supports large populations of lake fishes. The low sample size and uniqueness of the Maple River resulted in discrete density peaks for nine species, including black crappie, bluegill, bowfin, common carp, channel catfish, flathead catfish, largemouth bass, pumpkinseed, tadpole madtom, and white crappie (Appendix A). In these cases, broad patterns showing the general relation between habitat conditions and species density still occurred frequently.

Errors or biases associated with data collection or model prediction could limit the accuracy of the relationships we described. Ninety-percent exceedance flow values were often predicted and temperature values were predicted when measurements were not available. Biases associated with these modeling efforts were introduced into this analysis. However, we tried to minimize such errors by excluding known problem sites, such as a set of very small (i.e., CA < 6 mi^2) trout streams we identified as having biased flow predictions (Zorn et al. 2002). Catchment area values, fish densities, and nearly all temperatures were measured, so there is likely little error for these variables except errors due to fish misidentification, equipment malfunction, or collection of temperature data not representative of average conditions. Finally, our fish abundance data were limited to summer collections, so resulting plots do not represent year-round densities for species that show strong seasonal migrations or variation in density levels (e.g., Chinook salmon, coho salmon, and rainbow trout).

The intent of developing simple, data-driven products limits the application of our results to basic decision support uses. The strength of this study's findings rests on the hundreds of surveys that went into building the relations we portrayed. Our wedge-shaped scatterplots of trout density versus temperature (Figures 7 and 8) show when temperature limits fish abundance, but do not identify other factors limiting fish density beyond the thermal constraints of the stream (Terrell et al. 1996; Thompson et al. 1996). With the fish density surface plots, we attempted to show dominant relations between species density and habitat conditions by averaging measured values across groups of similar sites. Our results do not show the amount of variation in conditions and fish densities that occurs within each group of sites. Habitat and fish density values were simply averaged and plotted for each subset of sites meeting particular habitat criteria. Comparison between the range of individual site conditions (Figure 2) and range of the average values plotted (e.g., Figures 4 and 5) show this. As a result, conditions of some sites (e.g., the Manistee River in Figure 5) now appear to lie off the surface of the graph. In such cases, it is usually appropriate to extrapolate the observed fish density trend beyond the surface of the plot to the conditions of the site. Though multivariate modeling approaches would certainly have explained more variation in species abundances, we limited our summaries to two dimensional plots to make them more user-friendly. In a similar fashion, the spreadsheet model for characterizing suitability of sites for species included three variables, but could be further refined by adding additional variables (e.g., Great Lakes accessibility). Despite these shortcomings, our experience with MDNR-FD managers and the public indicate that these simple, data-driven, decision support tools will prove quite useful.

We believe the approach of using LFY, CA, and July temperature as axes for contrasting streams and displaying fish abundance patterns is widely applicable. The relationships we describe are most applicable to Michigan and may also apply to adjacent glaciated regions. This seems especially true for relationships between fish abundance and July temperature, which are more directly tied to fish bioenergetics than those for LFY and CA (Zorn et al. 2002). Thus, our LFY-CA based plots may have limited applicability to other regions due to differences in relationships fish density and key factors influencing it (e.g., climate, latitude, altitude, watershed geology, etc.). Still, we think our approach could be used to develop models for other regions that relate fish density to key habitat variables. In addition, the Michigan plots can serve as initial models for comparison with fish-habitat relations developed in other regions.

Acknowledgments

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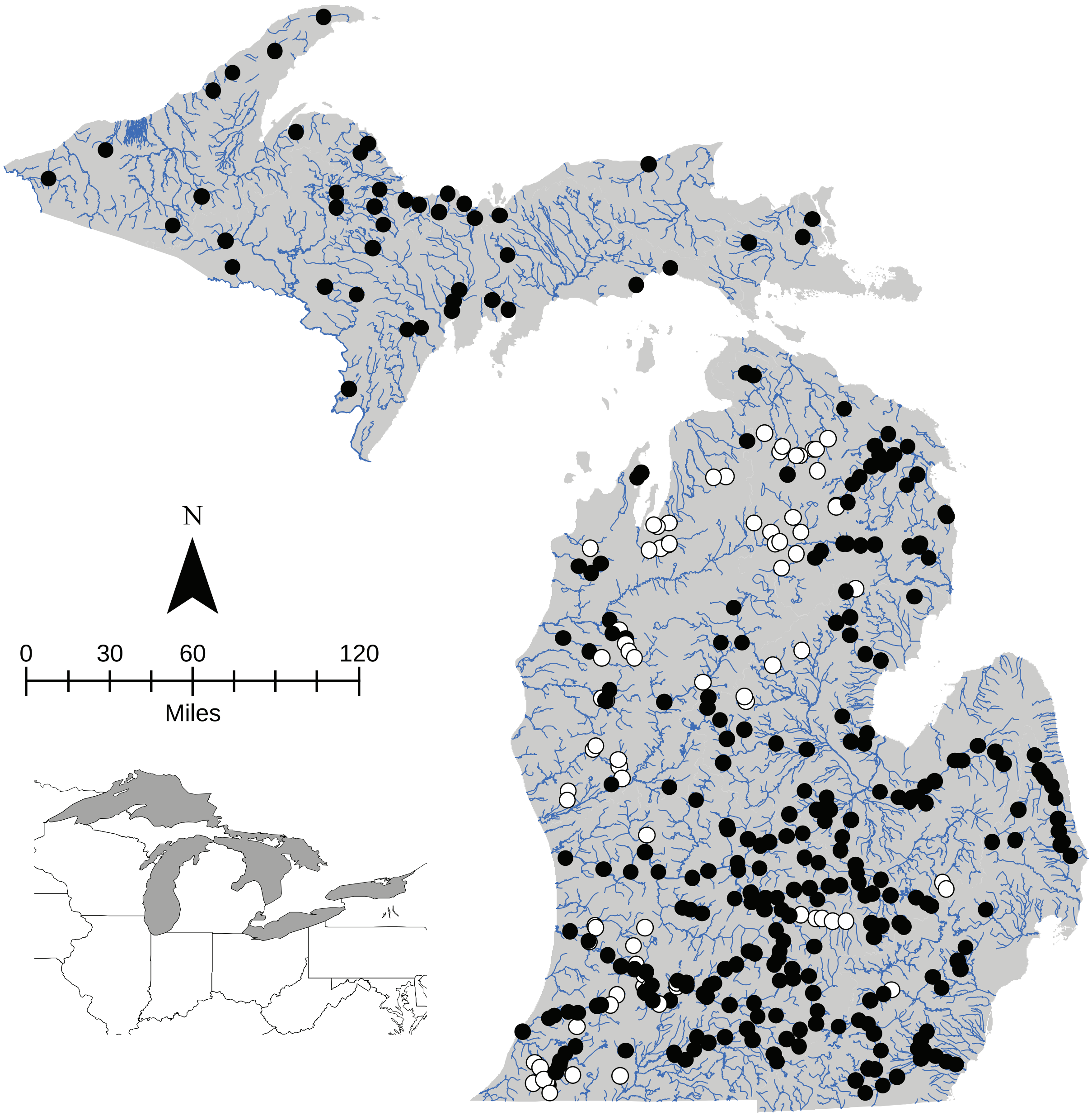

Figure 1.–Sites on Michigan streams with fish density data for salmonids (80 sites as open circles) or the entire fish assemblage (298 sites in black).

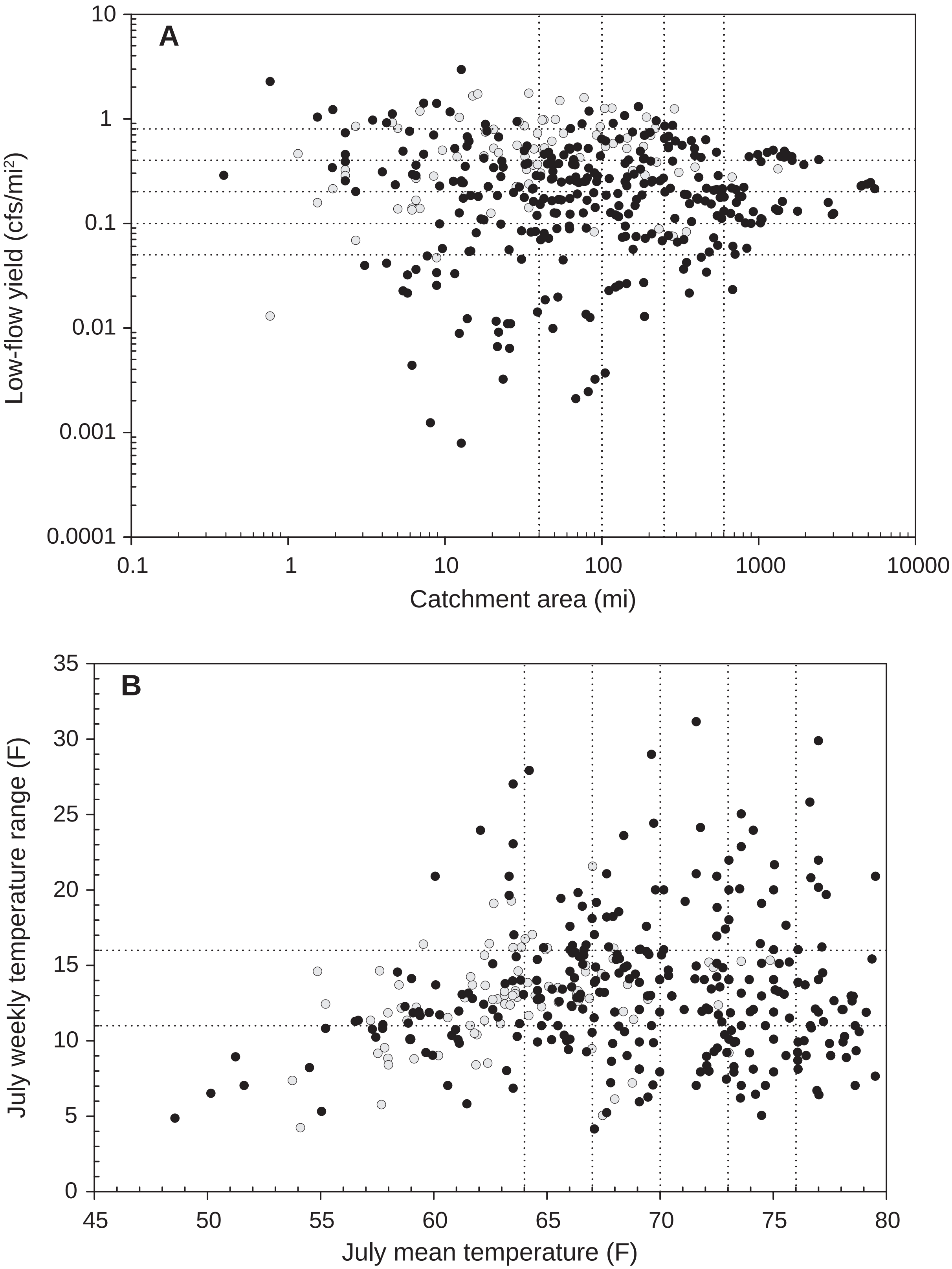

Figure 2.–Data summary grids used to summarize species density and habitat conditions at Michigan Rivers Inventory sites along axes of low-flow yield and catchment area (A) and mean and weekly range in July temperature (B). Symbols distinguish between sites where fish were sampled by mark-recapture (gray circles) and rotenone or multi-pass depletion (black circles) methods.

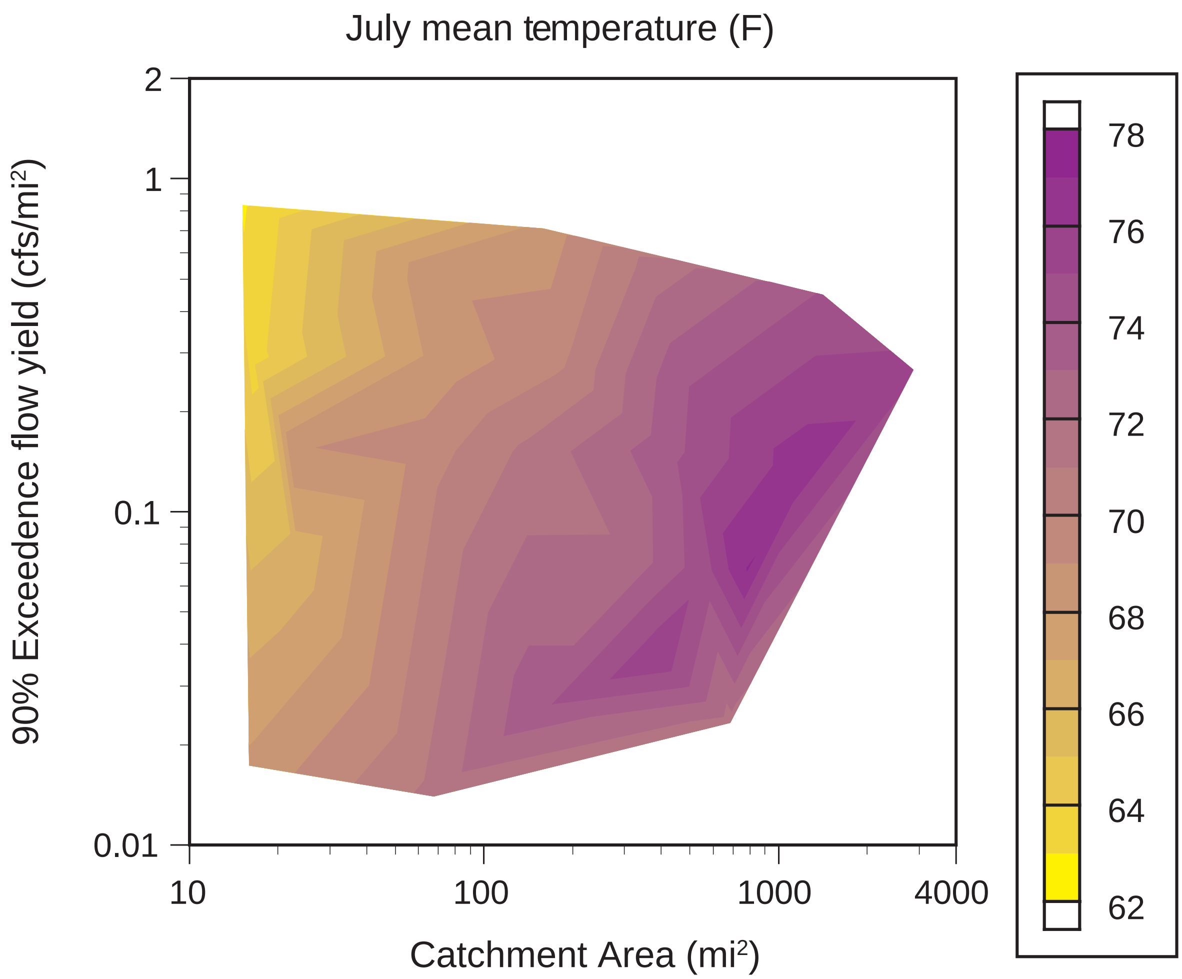

Figure 3.–Relationship between July mean temperature, catchment area, and low-flow yield for Michigan rivers.

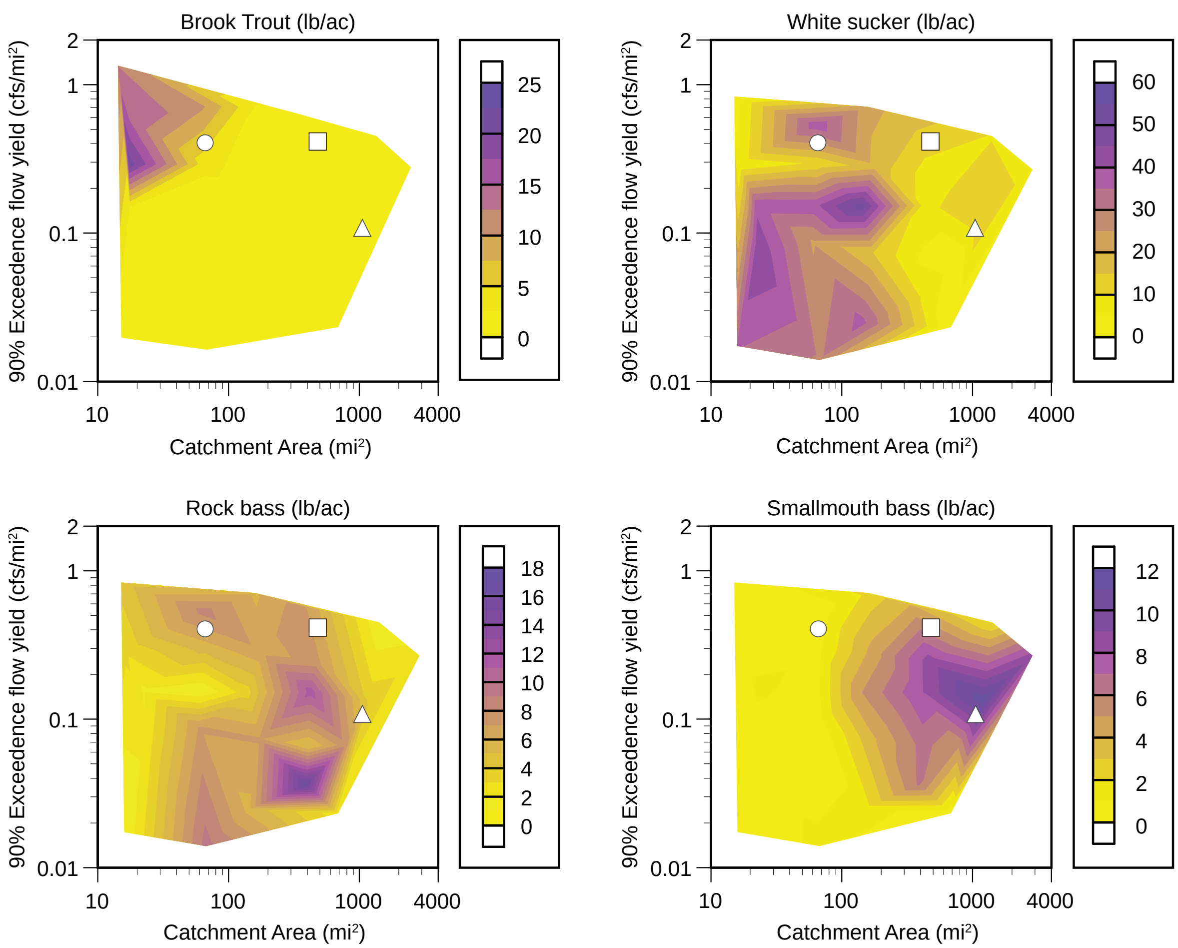

Figure 4.–Average density of brook trout, white sucker, rock bass, and smallmouth bass in Michigan streams versus low-flow yield and catchment area. Conditions are shown on each plot for the Iron River at Iron River (circle), the Flat River at Belding (square), and the Raisin River at Monroe (triangle). Note that density scales differ among graphs.

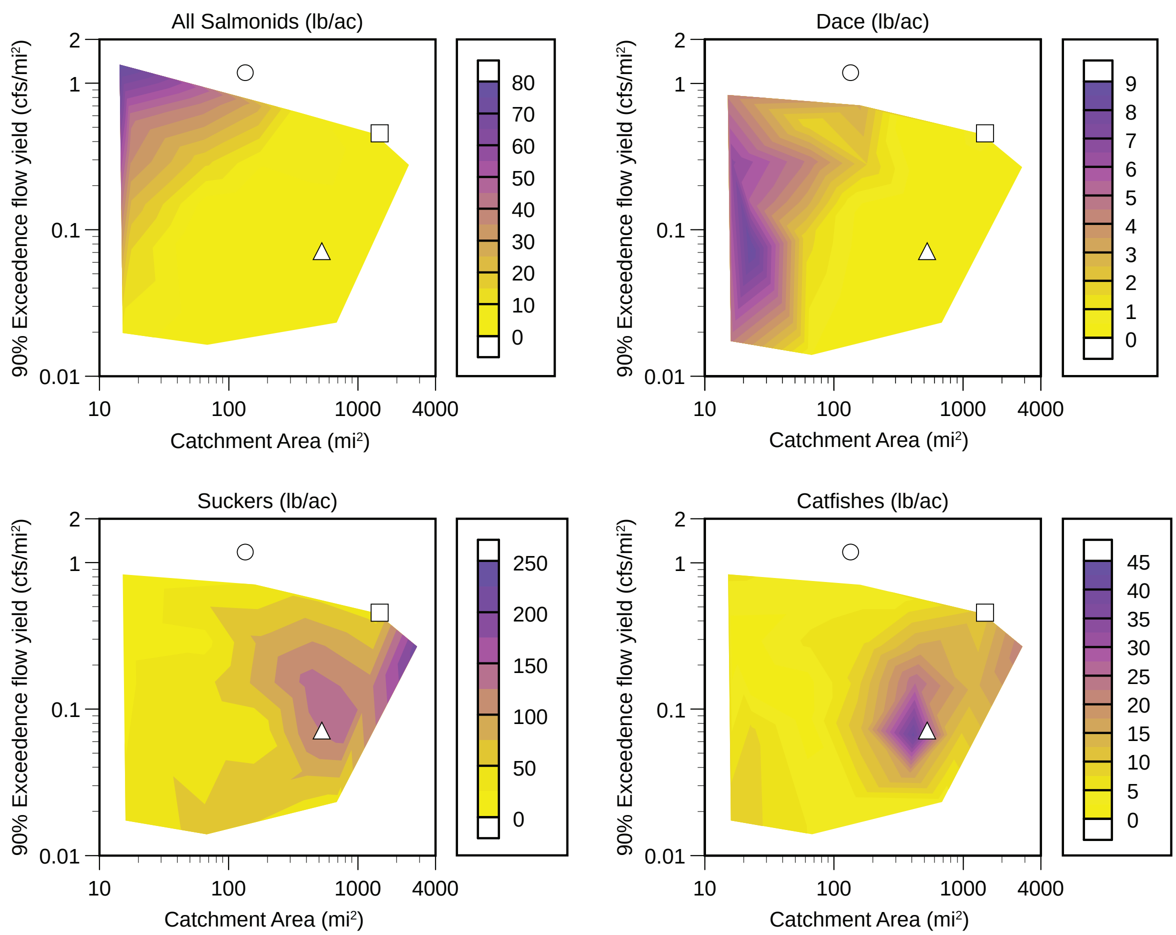

Figure 5.–Average density of trout, dace, suckers, and catfishes in Michigan streams versus low-flow yield and catchment area. Conditions are shown on each plot for the Manistee River at Grayling (circle), the Maple River (a Grand River tributary) at Maple Rapids (triangle), and the Manistique River at Manistique (square). Note that density scales differ among graphs.

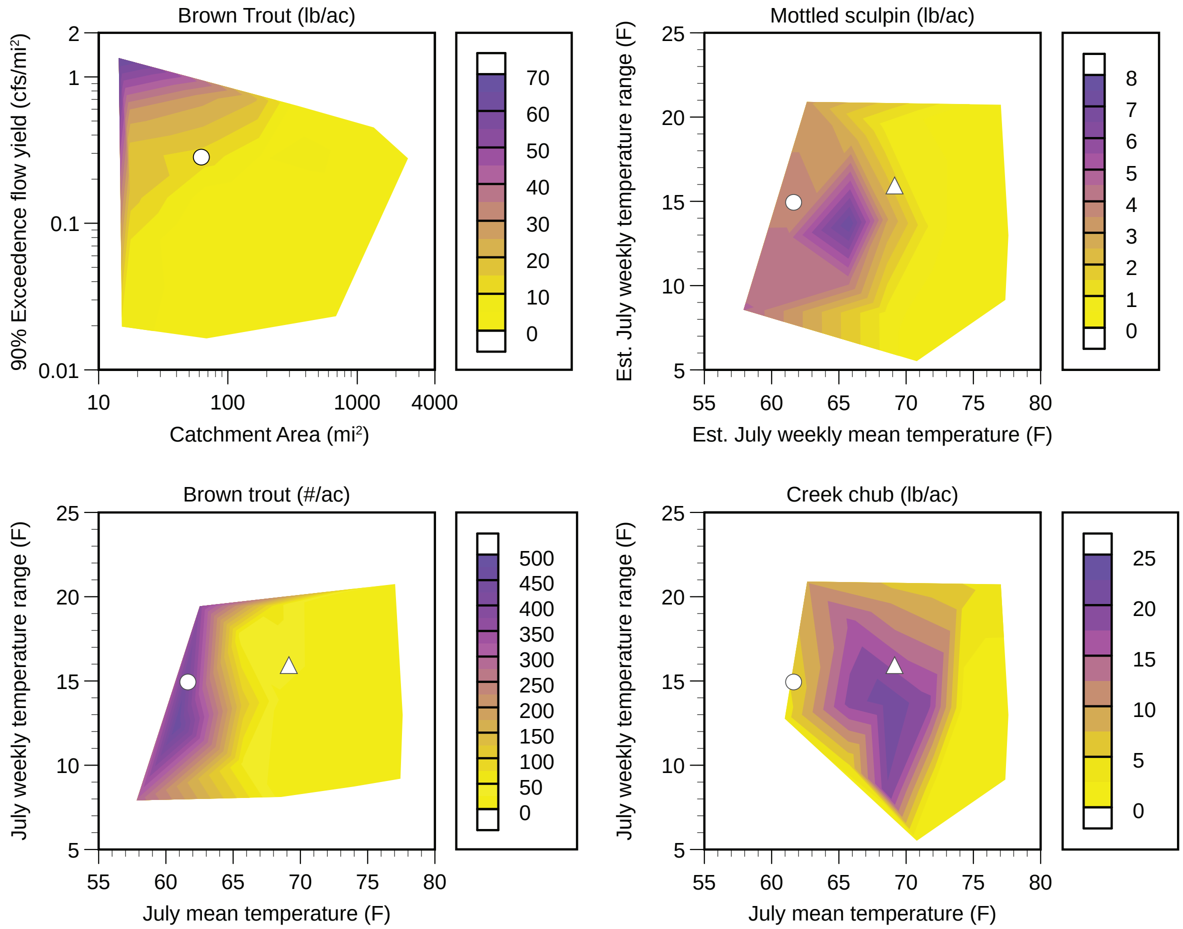

Figure 6.–Relationships of biomass density of brown trout, creek chub, and mottled sculpin and numerical density of brown trout to low-flow yield, catchment area, and July mean temperature. Conditions of the Middle Branch River upstream (circle) and downstream (triangle) of Marion Millpond are shown on temperature plots. July weekly temperature range for Middle Branch River is estimated from the monthly temperature range. Note that density scales differ among graphs.

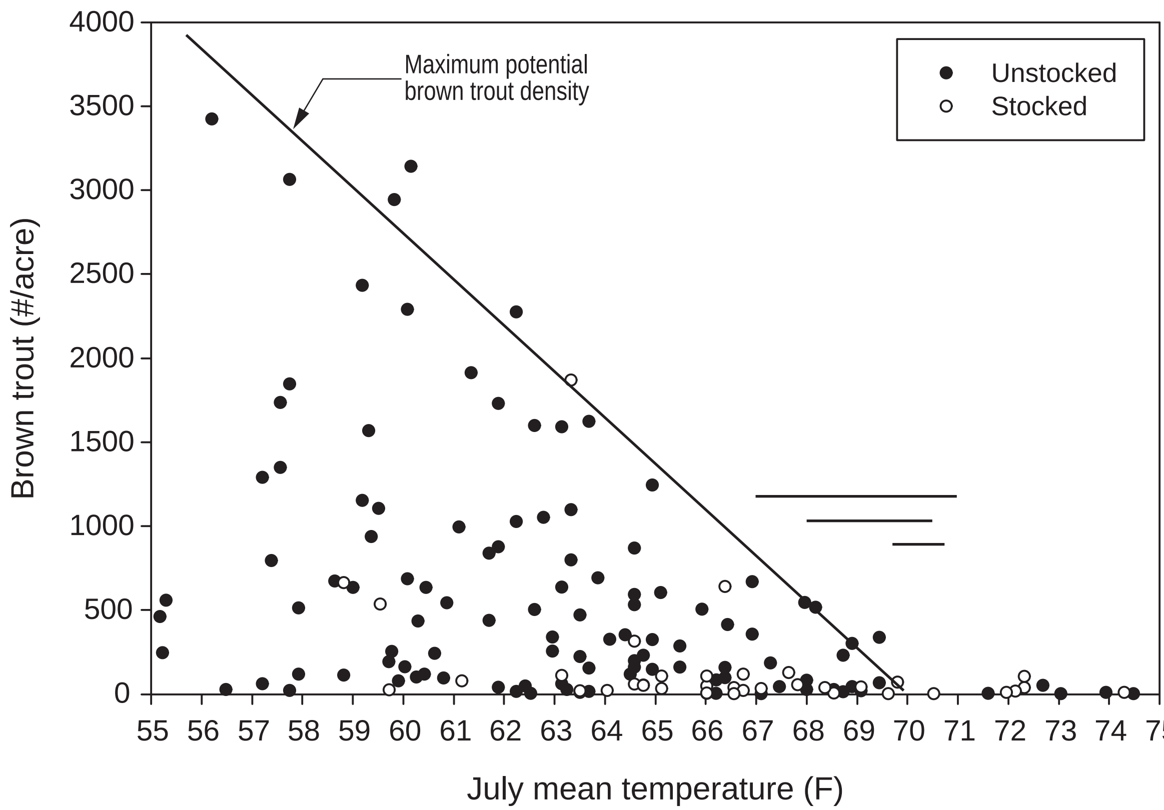

Figure 7.–Numerical density of brown trout in unstocked (squares) and stocked (triangles) Michigan streams versus July mean temperature (n = 152). The line fitted along the upper portion of the data represents a hypothesized relationship between July mean temperature and the maximum potential brown trout density for Michigan rivers. Zero density values are not shown. Horizontal lines show range in mean July temperature from 1998 to 2001 for the Au Sable River below Mio dam (longest line), the Manistee River below Hodenpyle dam (medium length line), and the Muskegon River below Croton dam (shortest line). Data for an additional 29 unstocked sites were obtained from Michigan Department of Natural Resources Fisheries Division Status and Trends surveys (T. Wills, unpublished data).

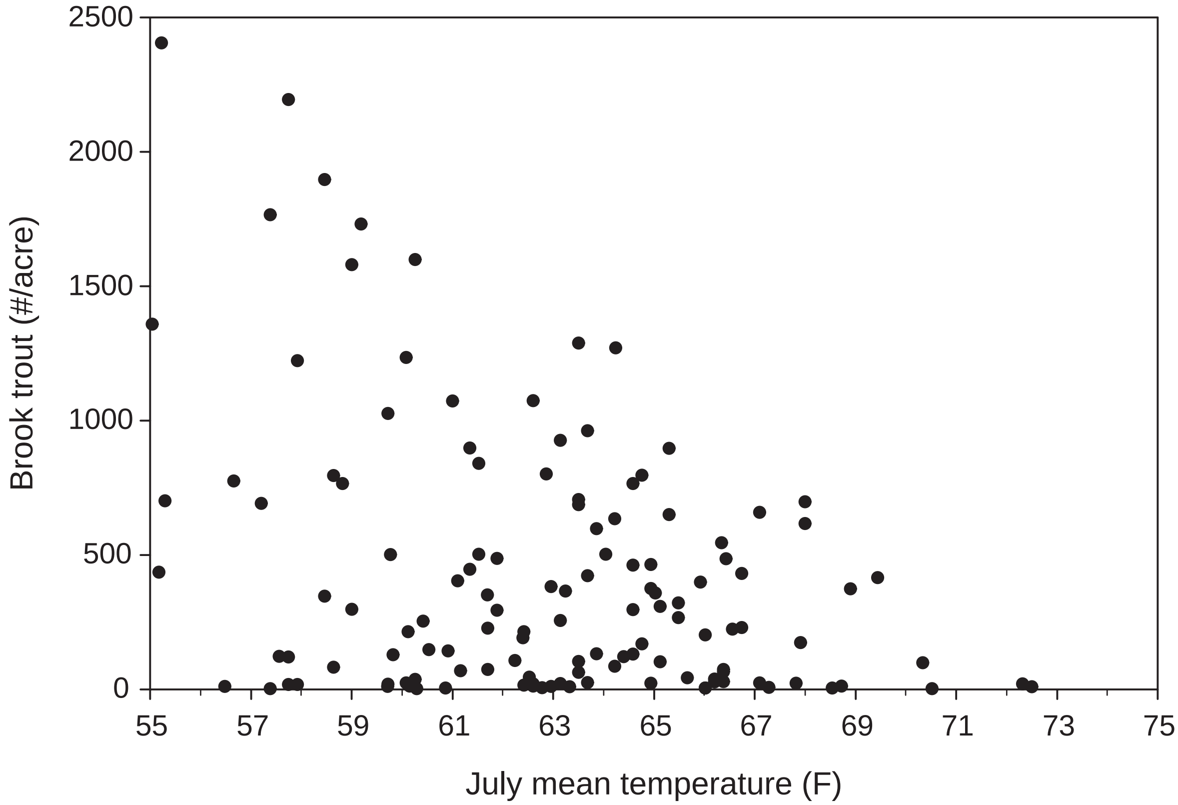

Figure 8.–Numerical density of brook trout in Michigan streams versus July mean temperature (n = 139). Zero density values are not shown. Data for 29 unstocked sites were obtained from Michigan Department of Natural Resources Fisheries Division Status and Trends surveys (T. Wills, unpublished data).

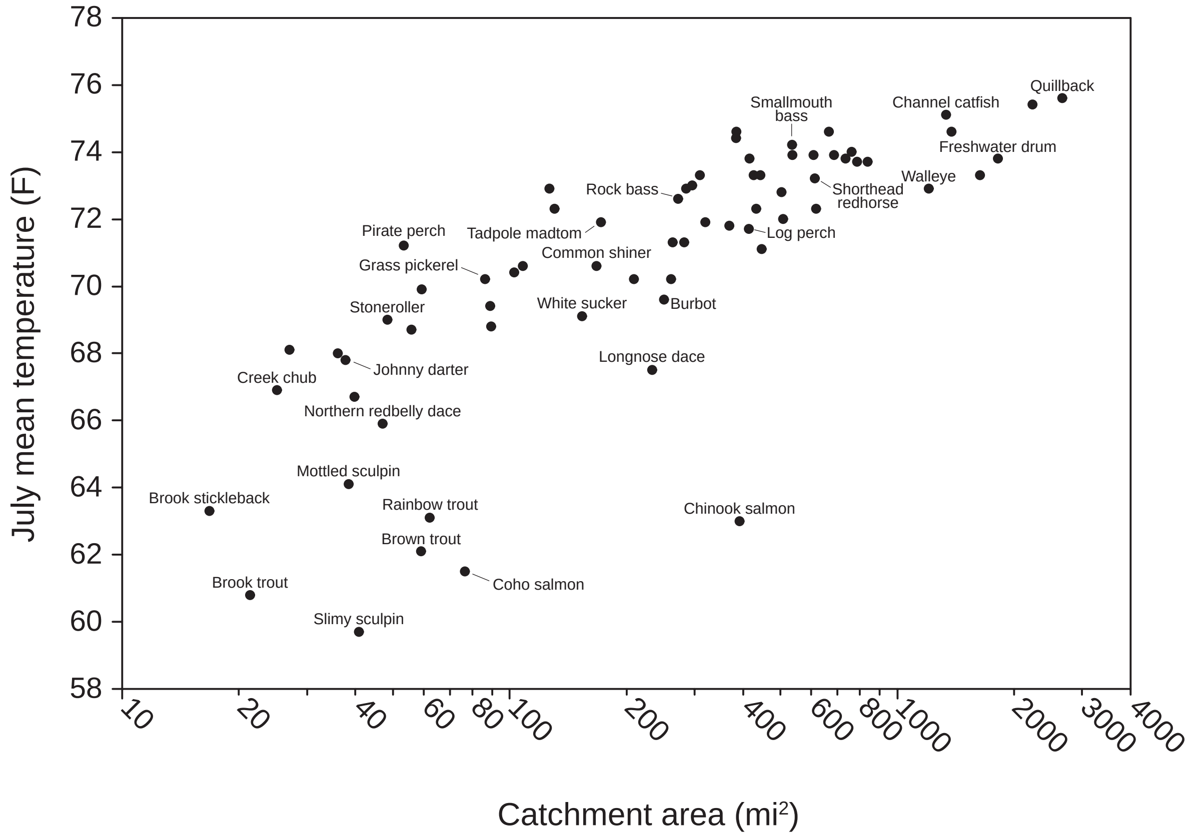

Figure 9.–July mean temperature and catchment area values of "optimal" sites for 68 common fishes in Michigan rivers. Common names of select fishes are shown in the vicinity of their optimal values. Optimal values occur in Table 2.

Table 1.–Species and taxonomic groups used in surface plots of fish density versus habitat. Numbers by species names indicate membership in numbered groups (in bold type). Densities of less common species (not listed) were included with their corresponding taxonomic group.

Group	Species or group name
	Shiners (1)
1	Spotfin shiner *Cyprinella spiloptera*
1	Common shiner *Luxilus cornutus*
1	Striped shiner *Luxilus chrysocephalus*
1	Redfin shiner *Lythrurus umbratilis*
1	Golden shiner *Notemigonus crysoleucas*
1	Rosyface shiner *Notropis rubellus*
1	Sand shiner *Notropis stramineus*
1	Mimic shiner *Notropis volucellus*
	Minnows (2)
2	Bluntnose minnow *Pimephales notatus*
2	Fathead minnow *Pimephales promelas*
	Chubs and stoneroller (3)
3	Central stoneroller *Campostoma anomalum*
3	Creek chub *Semotilus atromaculatus*
3	Hornyhead chub *Nocomis biguttatus*
3	River chub *Nocomis micropogon*
	Carp and goldfish (4)
4	Common carp *Cyprinus carpio*
	Dace (5)
5	Blacknose dace *Rhinichthys atratulus*
5	Longnose dace *Rhinichthys cataractae*
5	Northern redbelly dace *Phoxinus eos*
	Suckers (6) and Redhorses (7)
6	Quillback *Carpiodes cyprinus*
6	White sucker *Catostomus commersonii*
6	Lake chubsucker *Erimyzon sucetta*
6	Northern hog sucker *Hypentelium nigricans*
6	Spotted sucker *Minytrema melanops*
6,7	Silver redhorse *Moxostoma anisurum*
6,7	Black redhorse *Moxostoma duquesnei*
6,7	Golden redhorse *Moxostoma erythrurum*
6,7	Shorthead redhorse *Moxostoma macrolepidotum*
6,7	Greater redhorse *Moxostoma valenciennesi*
	Catfishes (8)
8	Black bullhead *Ameiurus melas*
8	Brown bullhead *Ameiurus nebulosus*
8	Yellow bullhead *Ameiurus natalis*
8	Channel catfish *Ictalurus punctatus*
8	Stonecat *Noturus flavus*
8	Tadpole madtom *Noturus gyrinus*
8	Flathead catfish *Pylodictis olivaris*
	Pikes (9)
9	Grass pickerel *Esox americanus*
9	Northern pike *Esox lucius*
	Salmonids (10)
10	Brook trout *Salvelinus fontinalis*
10	Brown trout *Salmo trutta*
10	Coho salmon *Oncorhynchus kisutch*
10	Rainbow trout *Oncorhynchus mykiss*
10	Chinook salmon *Oncorhynchus tshawytscha*
	Sculpins (11)
11	Mottled sculpin *Cottus bairdi*
11	Slimy sculpin *Cottus cognatus*
	Sunfishes (12)
12	Rock bass *Ambloplites rupestris*
12	Green sunfish *Lepomis cyanellus*
12	Bluegill *Lepomis macrochirus*
12	Longear sunfish *Lepomis megalotis*
12	Pumpkinseed *Lepomis gibbosus*
12	Smallmouth bass *Micropterus dolomieu*
12	Largemouth bass *Micropterus salmoides*
12	White crappie *Pomoxis annularis*
12	Black crappie *Pomoxis nigromaculatus*
	Perches (13) and Darters (14)
13	Walleye *Sander vitreus*
13	Yellow perch *Perca flavescens*
13,14	Logperch *Percina caprodes*
13,14	Blackside darter *Percina maculata*
13,14	Greenside darter *Etheostoma blennioides*
13,14	Rainbow darter *Etheostoma caeruleum*
13,14	Johnny darter *Etheostoma nigrum*
	Species not pooled
	Bowfin *Amia calva*
	Gizzard shad *Dorosoma cepedianum*
	Central mudminnow *Umbra limi*
	Pirate perch *Aphredoderus sayanus*
	Burbot *Lota lota*
	Brook silverside *Labidesthes sicculus*
	Brook stickleback *Culaea inconstans*
	Hybrid sunfish
	Freshwater drum *Aplodinotus grunniens*

Table 2.–Projected suitability of the Huron River at Delhi Road for common Michigan fishes based upon comparisons with "optimal" July mean temperature, catchment area, and low-flow yield conditions for each species. Catchment area is 690 mi^2. July mean temperature was 72.6°F and low-flow yield was 0.278 cfs/mi^2. Species list is sorted based upon mean and minimum composite suitability scores. Species "optimal" data are shown for reference.

							Species optima data					
							July mean temp. (°F)		Log_{10} catchment area (mi^2)		Log_{10} low-flow yield (cfs/mi^2)	
	No. of	Composite score		Score by variable (4=Hi)								
Species	optimal sites	Min	Mean	JulyMn	CA	LFY	Mean	S. Dev	Mean	S. Dev	Mean	S. Dev
Silver redhorse	15	4	4.0	4	4	4	73.9	4.6	2.72	0.34	-0.73	0.37
Spotted sucker	15	4	4.0	4	4	4	73.7	3.3	2.60	0.51	-0.73	0.39
Walleye	19	4	4.0	4	4	4	72.9	2.7	2.85	0.48	-0.68	0.43
Carp	40	3	3.7	4	4	3	74.0	3.6	2.59	0.54	-1.00	0.51
Log perch	24	3	3.7	4	3	4	71.7	4.1	2.33	0.56	-0.66	0.32
Northern hog sucker	33	3	3.7	4	4	3	73.7	3.5	2.67	0.43	-0.77	0.29
Rosyface shiner	24	3	3.7	4	3	4	72.3	3.1	2.51	0.34	-0.60	0.39
Sand shiner	13	3	3.7	4	3	4	72.0	3.8	2.56	0.39	-0.70	0.37
Shorthead redhorse	15	3	3.7	4	3	4	73.2	3.0	2.65	0.35	-0.65	0.34
Striped shiner	13	3	3.7	4	3	4	73.3	3.7	2.42	0.52	-0.66	0.46
Black crappie	24	3	3.3	3	4	3	74.6	3.0	2.81	0.58	-0.79	0.41
Bowfin	14	3	3.3	4	3	3	72.3	4.5	2.24	0.62	-0.91	0.62
Gizzard shad	6	3	3.3	4	3	3	73.3	3.6	3.04	0.39	-0.97	0.45
Largemouth Bass	28	3	3.3	4	3	3	72.8	3.6	2.12	0.80	-0.85	0.54
Smallmouth bass	42	3	3.3	4	3	3	73.9	2.8	2.55	0.50	-0.74	0.30
Stonecat	29	3	3.3	4	3	3	73.3	3.3	2.51	0.37	-0.89	0.35
Brown bullhead	8	2	3.3	4	2	4	73.3	4.7	1.75	0.98	-0.75	0.45
Freshwater drum	4	2	3.3	4	4	2	73.8	3.8	3.05	0.46	-1.13	0.43
Yellow perch	31	2	3.3	4	2	4	71.1	4.9	2.21	0.59	-0.78	0.58
Black redhorse	12	3	3.0	3	3	3	73.9	2.5	2.56	0.37	-0.71	0.22
Golden redhorse	34	3	3.0	3	3	3	74.2	3.0	2.61	0.33	-0.95	0.41
Mimic shiner	11	3	3.0	3	3	3	74.6	3.4	2.36	0.54	-0.95	0.55
Bluegill	31	2	3.0	4	2	3	71.8	4.3	1.96	0.70	-0.89	0.55
Bluntnose minnow	29	2	3.0	4	2	3	71.3	5.4	2.06	0.66	-1.23	0.69
Brook silverside	8	2	3.0	4	3	2	74.4	4.1	2.42	0.49	-0.72	0.16
Channel catfish	27	2	3.0	3	4	2	75.1	3.0	2.91	0.43	-0.82	0.24

Table 2.–Continued.

Species	No. of optimal sites	Composite score		Score by variable (4=Hi)			Species optima data: July mean temp. (°F)		Species optima data: Log_{10} catchment area (mi^2)		Species optima data: Log_{10} low-flow yield (cfs/mi^2)	
		Min	Mean	JulyMn	CA	LFY	Mean	S. Dev	Mean	S. Dev	Mean	S. Dev
Flathead catfish	10	2	3.0	2	4	3	75.4	2.1	3.11	0.55	-0.81	0.31
Northern pike	33	2	3.0	4	2	3	71.3	3.9	2.22	0.51	-1.06	0.63
Rock bass	43	2	3.0	4	2	3	72.6	3.0	2.22	0.51	-0.85	0.55
Spotfin shiner	18	2	3.0	3	4	2	74.6	2.6	2.71	0.33	-0.81	0.23
Yellow bullhead	37	2	3.0	4	2	3	73.0	3.7	2.11	0.65	-0.95	0.67
River chub	14	1	3.0	4	1	4	72.9	2.3	2.39	0.24	-0.45	0.26
Greenside darter	20	2	2.7	4	2	2	71.9	3.1	2.31	0.45	-0.98	0.38
Longnose dace	18	2	2.7	2	2	4	67.5	4.4	1.90	0.65	-0.57	0.25
Quillback	10	2	2.7	2	3	3	75.6	2.9	3.26	0.46	-0.84	0.38
Rainbow darter	22	2	2.7	3	2	3	70.2	3.6	1.84	0.71	-0.87	0.59
Burbot	19	1	2.7	3	1	4	69.6	3.6	2.15	0.44	-0.55	0.34
Common shiner	42	1	2.7	3	1	4	70.6	3.4	1.79	0.62	-0.84	0.60
Greater redhorse	18	1	2.7	4	3	1	73.8	3.2	2.50	0.40	-1.07	0.31
Longear sunfish	11	1	2.7	4	1	3	72.9	3.4	1.85	0.54	-1.02	0.87
Pumpkinseed	23	1	2.7	4	1	3	72.3	4.1	1.82	0.54	-1.04	0.66
Hornyhead chub	33	0	2.7	4	0	4	70.6	4.2	1.76	0.52	-0.74	0.60
White crappie	7	0	2.7	4	4	0	73.8	3.4	2.61	0.49	-1.17	0.23
Blackside darter	44	1	2.3	3	1	3	70.2	3.3	2.03	0.48	-0.93	0.69
Tadpole madtom	15	1	2.3	4	1	2	71.9	4.7	2.05	0.45	-1.37	0.63
White sucker	39	1	2.3	3	1	3	69.1	4.3	1.80	0.57	-0.96	0.51
Grass pickerel	26	0	2.3	3	0	4	70.2	3.7	1.67	0.49	-0.69	0.56
Lake chubsucker	4	0	2.3	3	0	4	68.0	6.4	1.46	0.34	-0.50	0.15
Golden shiner	7	0	2.0	3	0	3	68.7	4.5	1.54	0.50	-1.35	0.94
Green sunfish	32	0	2.0	3	0	3	70.4	4.2	1.63	0.56	-1.06	0.71
Chinook salmon	8	1	1.7	1	2	2	63.0	5.7	1.65	0.92	-0.08	0.40
Blacknose dace	32	0	1.7	1	0	4	66.7	3.4	1.38	0.45	-0.85	0.61
Fathead minnow	10	0	1.7	3	0	2	69.4	4.4	1.56	0.58	-1.22	0.47
Mottled sculpin	32	0	1.7	1	0	4	64.1	5.4	1.33	0.51	-0.56	0.39
Mudminnow	10	0	1.7	2	0	3	68.1	3.1	1.33	0.32	-1.27	0.87

Table 2.–Continued.

Species	No. of optimal sites	Composite score		Score by variable (4=Hi)			Species optima data: July mean temp. (°F)		Species optima data: Log_{10} catchment area (mi^2)		Species optima data: Log_{10} low-flow yield (cfs/mi^2)	
		Min	Mean	JulyMn	CA	LFY	Mean	S. Dev	Mean	S. Dev	Mean	S. Dev
Black bullhead	18	0	1.3	2	0	2	68.8	3.4	1.68	0.51	-1.24	0.63
Brook trout	38	0	1.3	0	0	4	60.8	4.3	0.89	0.60	-0.42	0.40
Brown trout	52	0	1.3	0	0	4	62.1	3.5	1.40	0.62	-0.35	0.44
Coho salmon	7	0	1.3	1	0	3	61.5	5.9	1.71	0.44	-0.18	0.38
Johnny darter	20	0	1.3	2	0	2	67.8	3.7	1.37	0.44	-1.46	0.72
Pirate perch	6	0	1.3	4	0	0	71.2	4.1	1.59	0.45	-2.44	0.24
Rainbow trout	31	0	1.3	0	0	4	63.1	3.9	1.45	0.65	-0.38	0.44
Redfin shiner	3	0	1.3	4	0	0	69.9	5.4	1.53	0.56	-1.86	0.25
Slimy sculpin	17	0	1.3	0	0	4	59.7	5.3	1.20	0.70	-0.58	0.46
Stoneroller	10	0	1.3	2	0	2	69.0	2.8	1.34	0.57	-1.48	0.77
Brook stickleback	14	0	1.0	0	0	3	63.3	3.3	1.11	0.34	-1.16	0.64
Creek chub	29	0	1.0	1	0	2	66.9	3.1	1.23	0.36	-1.33	0.71
Northern redbelly dace	9	0	1.0	0	0	3	65.9	2.7	1.40	0.45	-0.91	0.59

Table 3.–Projected suitability of the Hunt Creek at East Fish Lake Road for common Michigan fishes based upon comparisons with “optimal” July mean temperature, catchment area, and low-flow yield conditions for each species. Catchment area is 5 mi^2. July mean temperature was 58.5°F and low-flow yield was 0.806 cfs/mi^2. Species list is sorted based upon mean and minimum composite suitability scores. Species “optimal” data are shown for reference.

		Composite score		Score by variable (4=Hi)			Species optima data: July mean temp. (°F)		Species optima data: Log_{10} catchment area (mi^2)		Species optima data: Log_{10} low-flow yield (cfs/mi^2)	
Species	No. of optimal sites	Min	Mean	JulyMn	CA	LFY	Mean	S. Dev	Mean	S. Dev	Mean	S. Dev
Brook trout	38	3	3.3	3	4	3	60.8	4.3	0.89	0.60	-0.42	0.40
Chinook salmon	8	2	3.0	3	2	4	63.0	5.7	1.65	0.92	-0.08	0.40
Slimy sculpin	17	2	3.0	4	3	2	59.7	5.3	1.20	0.70	-0.58	0.46
Brown trout	52	2	2.3	2	2	3	62.1	3.5	1.40	0.62	-0.35	0.44
Rainbow trout	31	2	2.3	2	2	3	63.1	3.9	1.45	0.65	-0.38	0.44
Coho salmon	7	0	2.3	3	0	4	61.5	5.9	1.71	0.44	-0.18	0.38
Mottled sculpin	32	2	2.0	2	2	2	64.1	5.4	1.33	0.51	-0.56	0.39
Brook stickleback	14	1	1.7	2	2	1	63.3	3.3	1.11	0.34	-1.16	0.64
Brown bullhead	8	0	1.3	0	2	2	73.3	4.7	1.75	0.98	-0.75	0.45
Blacknose dace	32	0	1.0	0	1	2	66.7	3.4	1.38	0.45	-0.85	0.61
Bluegill	31	0	1.0	0	1	2	71.8	4.3	1.96	0.70	-0.89	0.55
Common shiner	42	0	1.0	0	1	2	70.6	3.4	1.79	0.62	-0.84	0.60
Creek chub	29	0	1.0	0	2	1	66.9	3.1	1.23	0.36	-1.33	0.71
Golden shiner	7	0	1.0	0	1	2	68.7	4.5	1.54	0.50	-1.35	0.94
Grass pickerel	26	0	1.0	0	1	2	70.2	3.7	1.67	0.49	-0.69	0.56
Green sunfish	32	0	1.0	0	1	2	70.4	4.2	1.63	0.56	-1.06	0.71
Largemouth Bass	28	0	1.0	0	1	2	72.8	3.6	2.12	0.80	-0.85	0.54
Mudminnow	10	0	1.0	0	1	2	68.1	3.1	1.33	0.32	-1.27	0.87
Northern redbelly dace	9	0	1.0	0	1	2	65.9	2.7	1.40	0.45	-0.91	0.59
Rainbow darter	22	0	1.0	0	1	2	70.2	3.6	1.84	0.71	-0.87	0.59
Stoneroller	10	0	1.0	0	2	1	69.0	2.8	1.34	0.57	-1.48	0.77
Black bullhead	18	0	0.7	0	1	1	68.8	3.4	1.68	0.51	-1.24	0.63
Blackside darter	44	0	0.7	0	0	2	70.2	3.3	2.03	0.48	-0.93	0.69
Bowfin	14	0	0.7	0	0	2	72.3	4.5	2.24	0.62	-0.91	0.62
Burbot	19	0	0.7	0	0	2	69.6	3.6	2.15	0.44	-0.55	0.34
Fathead minnow	10	0	0.7	0	2	0	69.4	4.4	1.56	0.58	-1.22	0.47

Table 3.–Continued.

Species	No. of optimal sites	Composite score		Score by variable (4=Hi)			Species optima data: July mean temp. (°F)		Species optima data: Log_{10} catchment area (mi^2)		Species optima data: Log_{10} low-flow yield (cfs/mi^2)	
		Min	Mean	JulyMn	CA	LFY	Mean	S. Dev	Mean	S. Dev	Mean	S. Dev
Hornyhead chub	33	0	0.7	0	0	2	70.6	4.2	1.76	0.52	-0.74	0.60
Johnny darter	20	0	0.7	0	1	1	67.8	3.7	1.37	0.44	-1.46	0.72
Lake chubsucker	4	0	0.7	2	0	0	68.0	6.4	1.46	0.34	-0.50	0.15
Longear sunfish	11	0	0.7	0	0	2	72.9	3.4	1.85	0.54	-1.02	0.87
Longnose dace	18	0	0.7	0	1	1	67.5	4.4	1.90	0.65	-0.57	0.25
Pumpkinseed	23	0	0.7	0	0	2	72.3	4.1	1.82	0.54	-1.04	0.66
Redfin shiner	3	0	0.7	0	2	0	69.9	5.4	1.53	0.56	-1.86	0.25
River chub	14	0	0.7	0	0	2	72.9	2.3	2.39	0.24	-0.45	0.26
Rock bass	43	0	0.7	0	0	2	72.6	3.0	2.22	0.51	-0.85	0.55
Rosyface shiner	24	0	0.7	0	0	2	72.3	3.1	2.51	0.34	-0.60	0.39
Striped shiner	13	0	0.7	0	0	2	73.3	3.7	2.42	0.52	-0.66	0.46
Walleye	19	0	0.7	0	0	2	72.9	2.7	2.85	0.48	-0.68	0.43
White sucker	39	0	0.7	0	1	1	69.1	4.3	1.80	0.57	-0.96	0.51
Yellow bullhead	37	0	0.7	0	0	2	73.0	3.7	2.11	0.65	-0.95	0.67
Yellow perch	31	0	0.7	0	0	2	71.1	4.9	2.21	0.59	-0.78	0.58
Black crappie	24	0	0.3	0	0	1	74.6	3.0	2.81	0.58	-0.79	0.41
Bluntnose minnow	29	0	0.3	0	0	1	71.3	5.4	2.06	0.66	-1.23	0.69
Carp	40	0	0.3	0	0	1	74.0	3.6	2.59	0.54	-1.00	0.51
Gizzard shad	6	0	0.3	0	0	1	73.3	3.6	3.04	0.39	-0.97	0.45
Log perch	24	0	0.3	0	0	1	71.7	4.1	2.33	0.56	-0.66	0.32
Mimic shiner	11	0	0.3	0	0	1	74.6	3.4	2.36	0.54	-0.95	0.55
Northern pike	33	0	0.3	0	0	1	71.3	3.9	2.22	0.51	-1.06	0.63
Quillback	10	0	0.3	0	0	1	75.6	2.9	3.26	0.46	-0.84	0.38
Sand shiner	13	0	0.3	0	0	1	72.0	3.8	2.56	0.39	-0.70	0.37
Shorthead redhorse	15	0	0.3	0	0	1	73.2	3.0	2.65	0.35	-0.65	0.34
Silver redhorse	15	0	0.3	0	0	1	73.9	4.6	2.72	0.34	-0.73	0.37
Spotted sucker	15	0	0.3	0	0	1	73.7	3.3	2.60	0.51	-0.73	0.39
Black redhorse	12	0	0.0	0	0	0	73.9	2.5	2.56	0.37	-0.71	0.22
Brook silverside	8	0	0.0	0	0	0	74.4	4.1	2.42	0.49	-0.72	0.16

Table 3.–Continued.

							Species optima data					
							July mean temp. (°F)		Log_{10} catchment area (mi^2)		Log_{10} low-flow yield (cfs/mi^2)	
	No. of	Composite score		Score by variable (4=Hi)								
Species	optimal sites	Min	Mean	JulyMn	CA	LFY	Mean	S. Dev	Mean	S. Dev	Mean	S. Dev
Channel catfish	27	0	0.0	0	0	0	75.1	3.0	2.91	0.43	-0.82	0.24
Flathead catfish	10	0	0.0	0	0	0	75.4	2.1	3.11	0.55	-0.81	0.31
Freshwater drum	4	0	0.0	0	0	0	73.8	3.8	3.05	0.46	-1.13	0.43
Golden redhorse	34	0	0.0	0	0	0	74.2	3.0	2.61	0.33	-0.95	0.41
Greater redhorse	18	0	0.0	0	0	0	73.8	3.2	2.50	0.40	-1.07	0.31
Greenside darter	20	0	0.0	0	0	0	71.9	3.1	2.31	0.45	-0.98	0.38
Northern hog sucker	33	0	0.0	0	0	0	73.7	3.5	2.67	0.43	-0.77	0.29
Pirate perch	6	0	0.0	0	0	0	71.2	4.1	1.59	0.45	-2.44	0.24
Smallmouth bass	42	0	0.0	0	0	0	73.9	2.8	2.55	0.50	-0.74	0.30
Spotfin shiner	18	0	0.0	0	0	0	74.6	2.6	2.71	0.33	-0.81	0.23
Stonecat	29	0	0.0	0	0	0	73.3	3.3	2.51	0.37	-0.89	0.35
Tadpole madtom	15	0	0.0	0	0	0	71.9	4.7	2.05	0.45	-1.37	0.63
White crappie	7	0	0.0	0	0	0	73.8	3.4	2.61	0.49	-1.17	0.23

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Philip J. Schneeberger, Editor
Alan D. Sutton, Graphics
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Approved by Tammy J. Newcomb

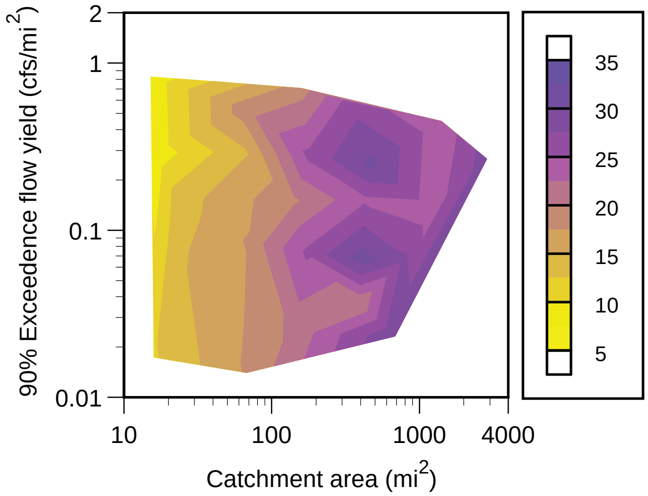
Appendix A

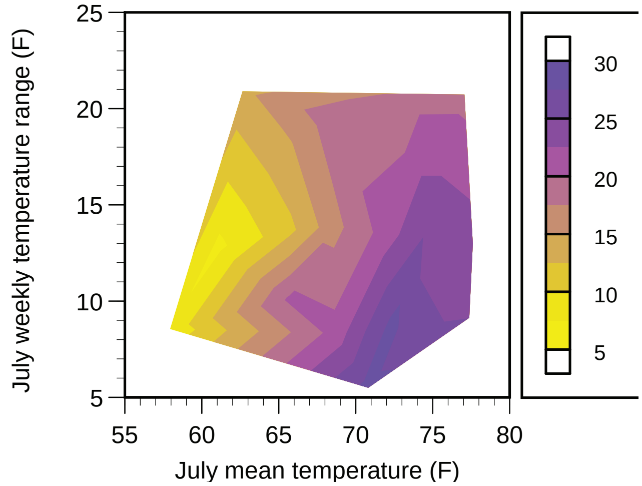
Relationships between low-flow yield, catchment area, July temperature attributes, and fish biomass density at the assemblage, taxonomic group, and species levels. Relationships between July temperature attributes and numerical density are shown for brown trout, brook trout, and rainbow trout.

APPENDIX A INDEX

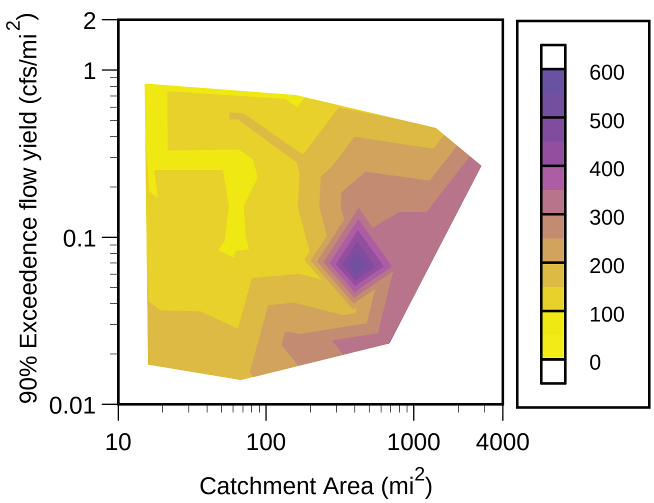
1. Assemblage level

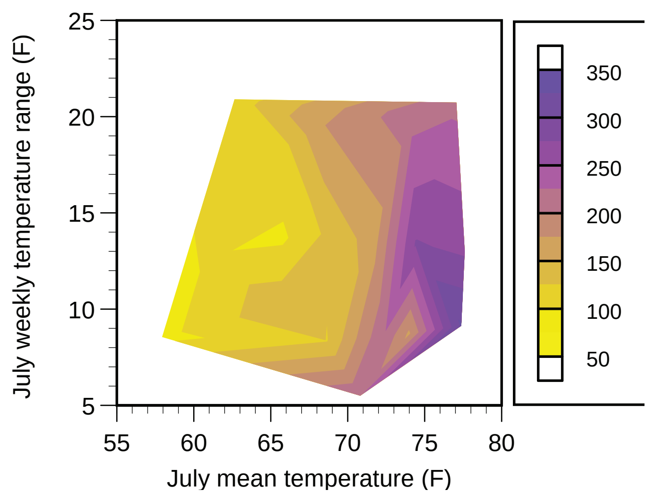
Species Richness





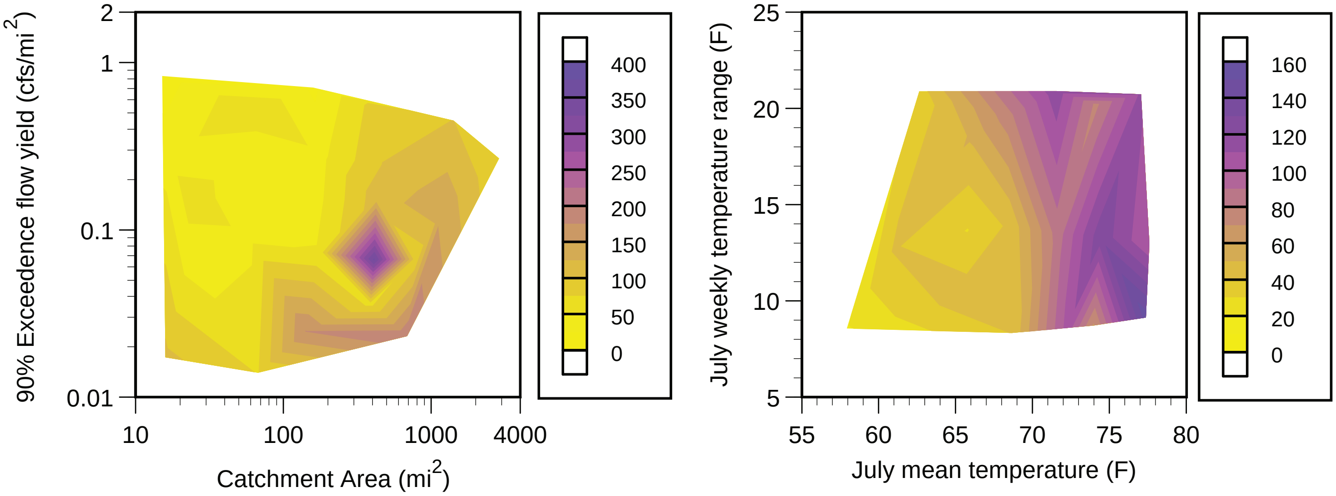
All Species (lb/acre)





2. Taxonomic groupings (lb/acre)

All Cyprinids



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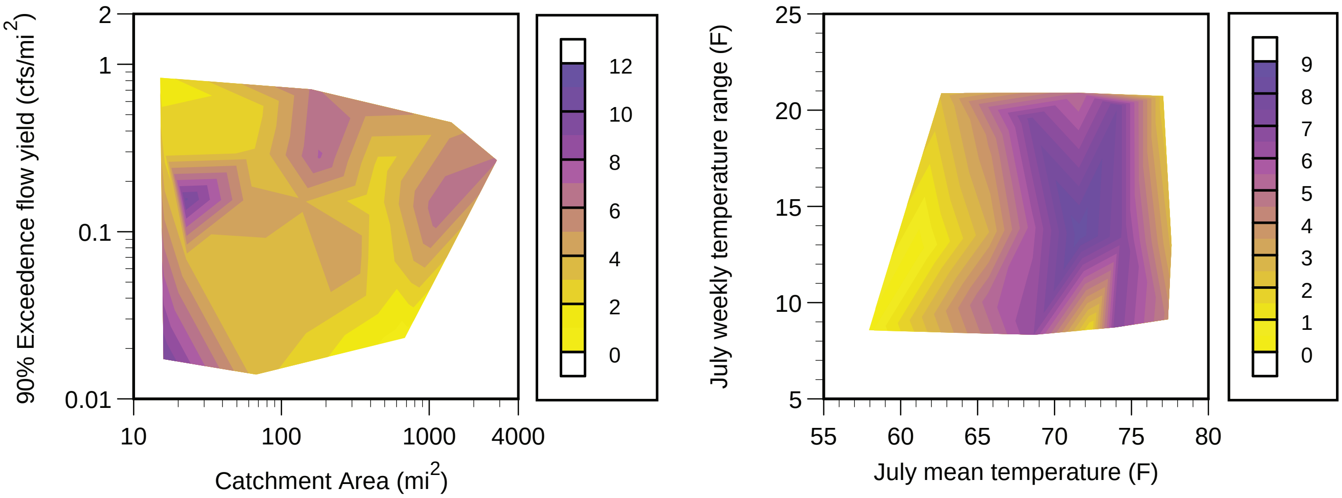
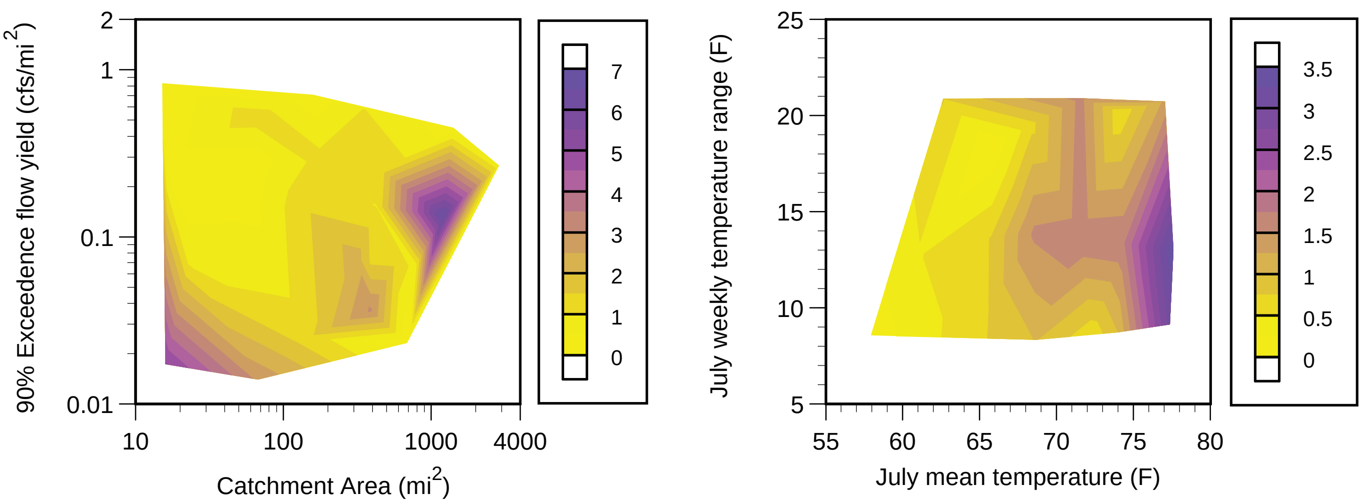
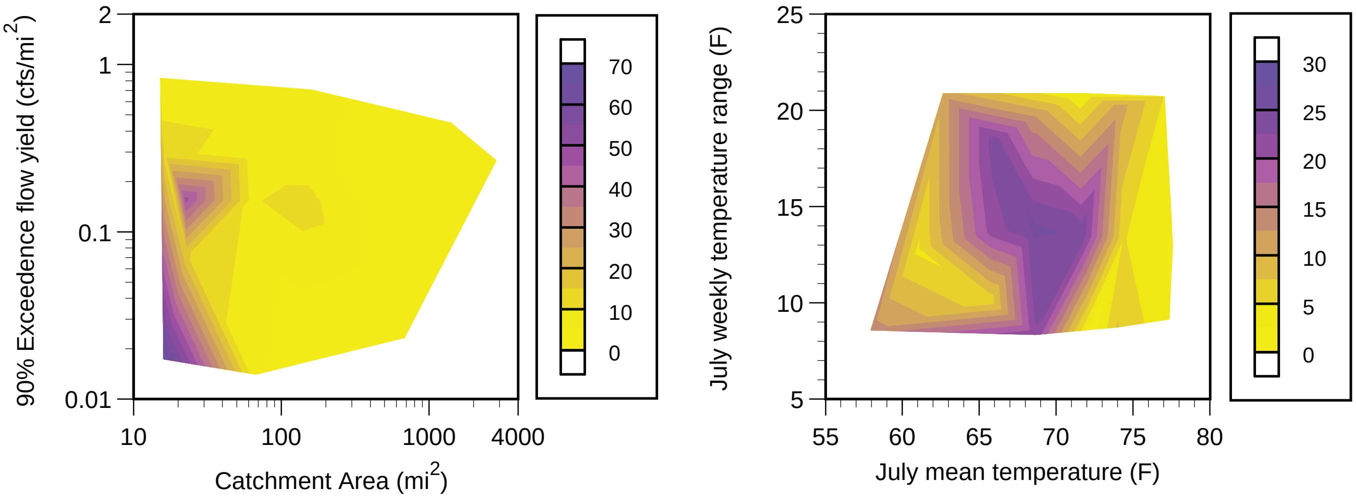


Minnows



Chubs and Central Stoneroller



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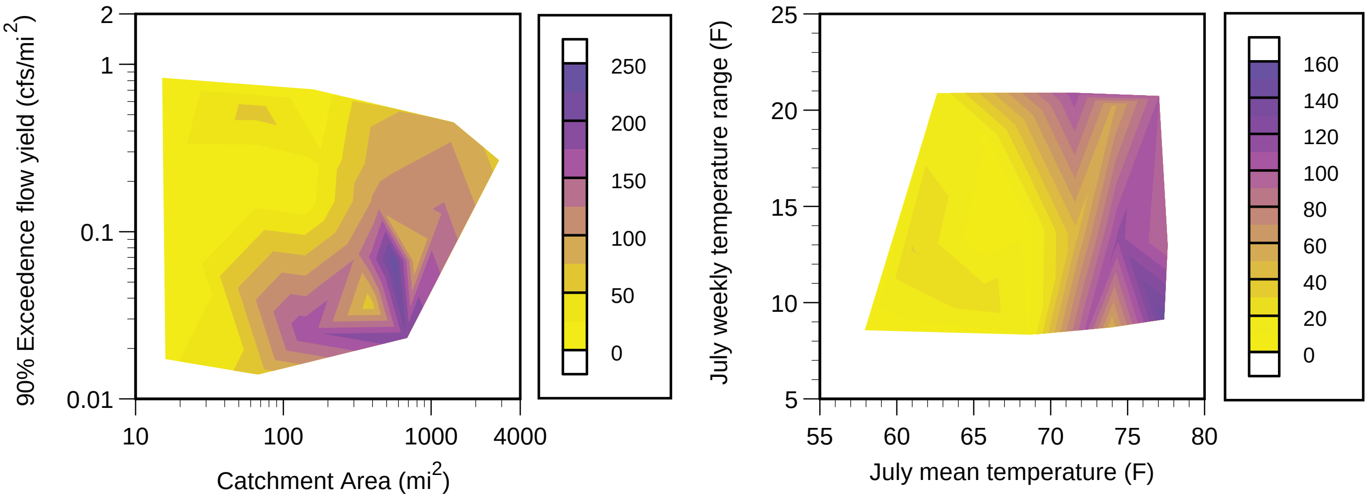
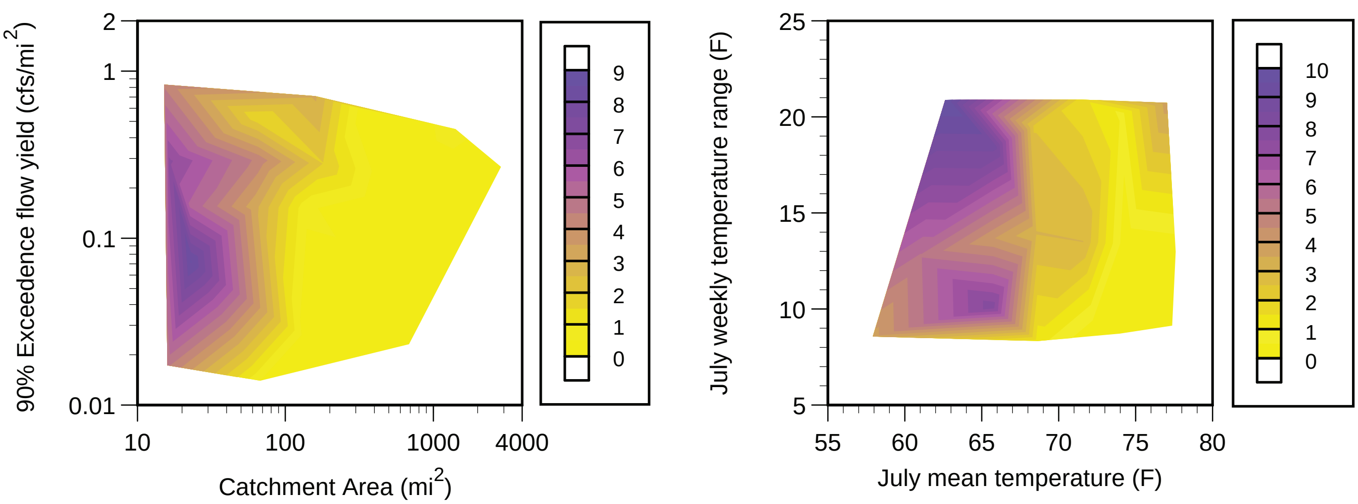
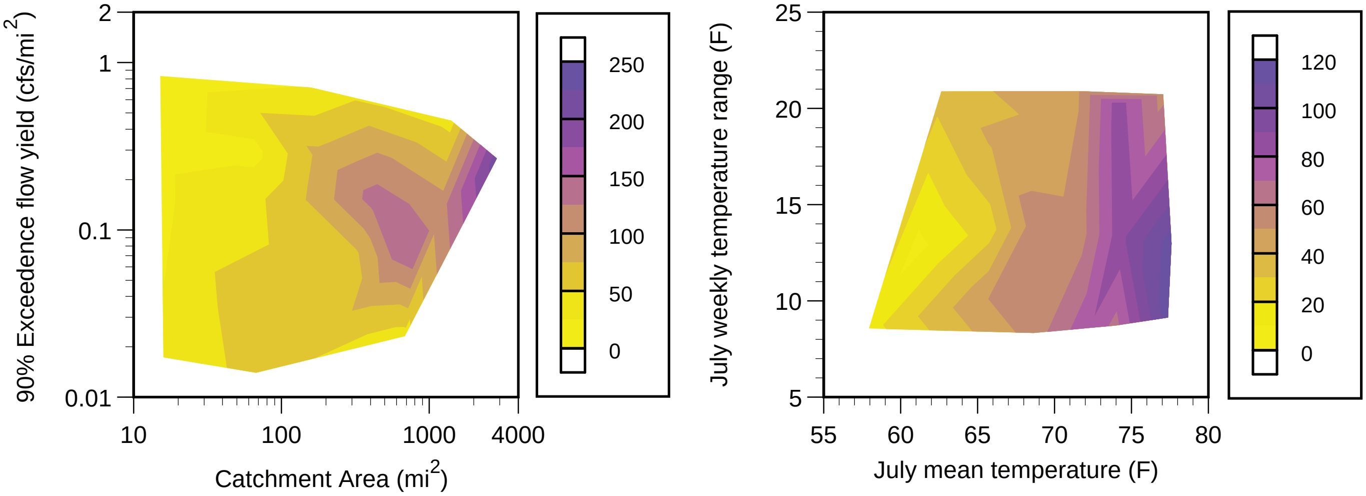


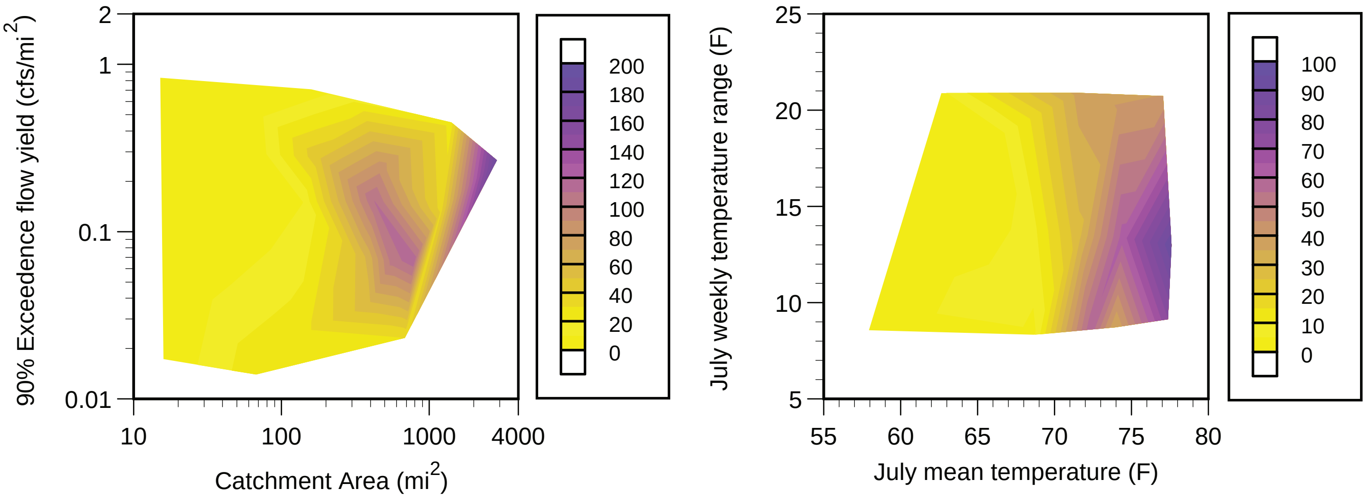
Dace



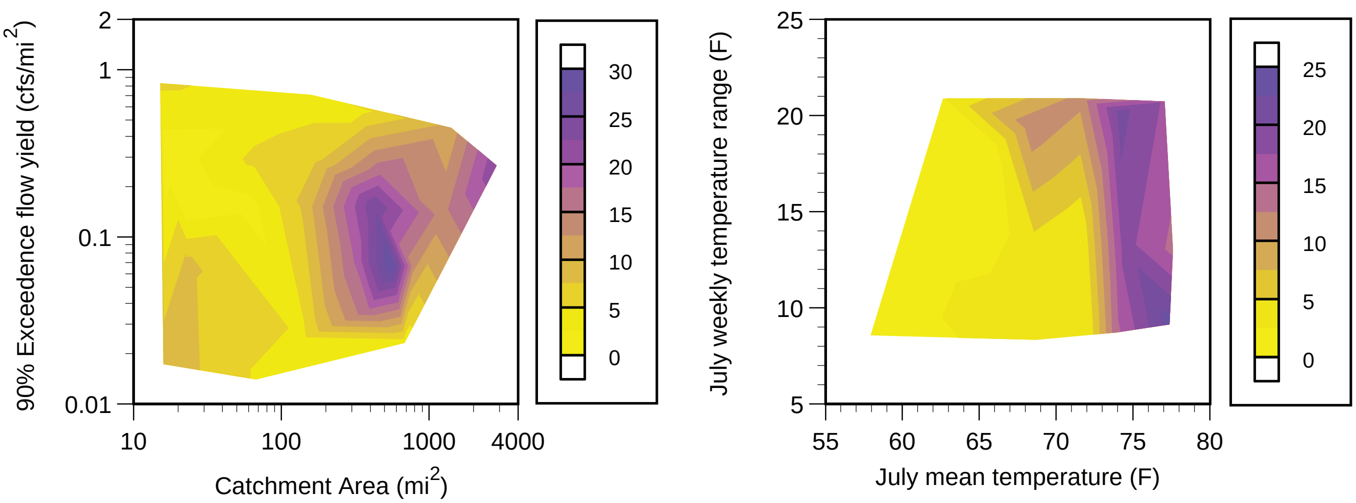
Suckers



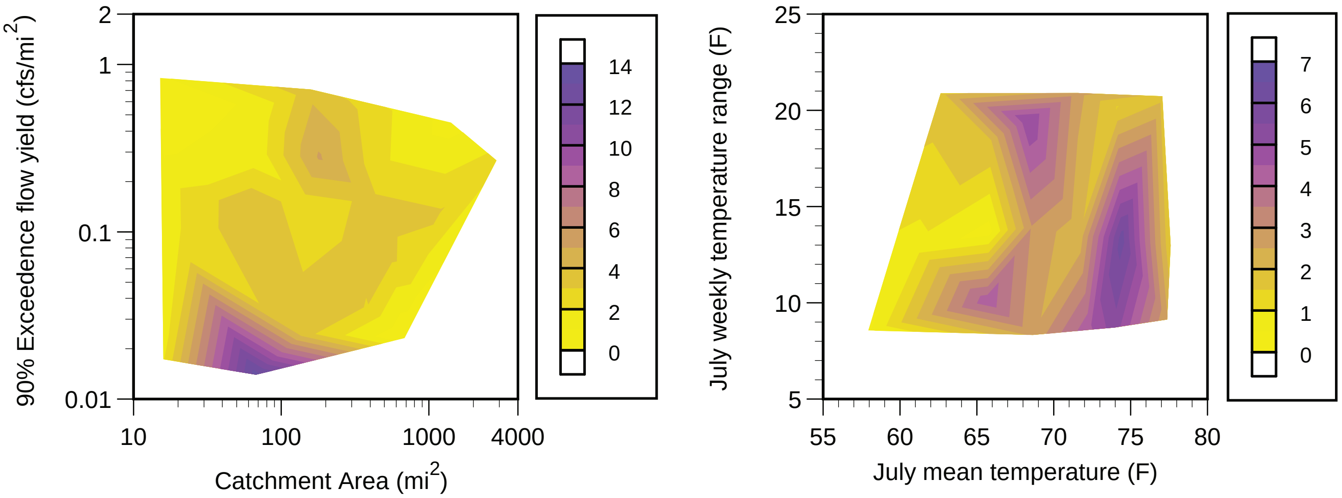
Redhorses



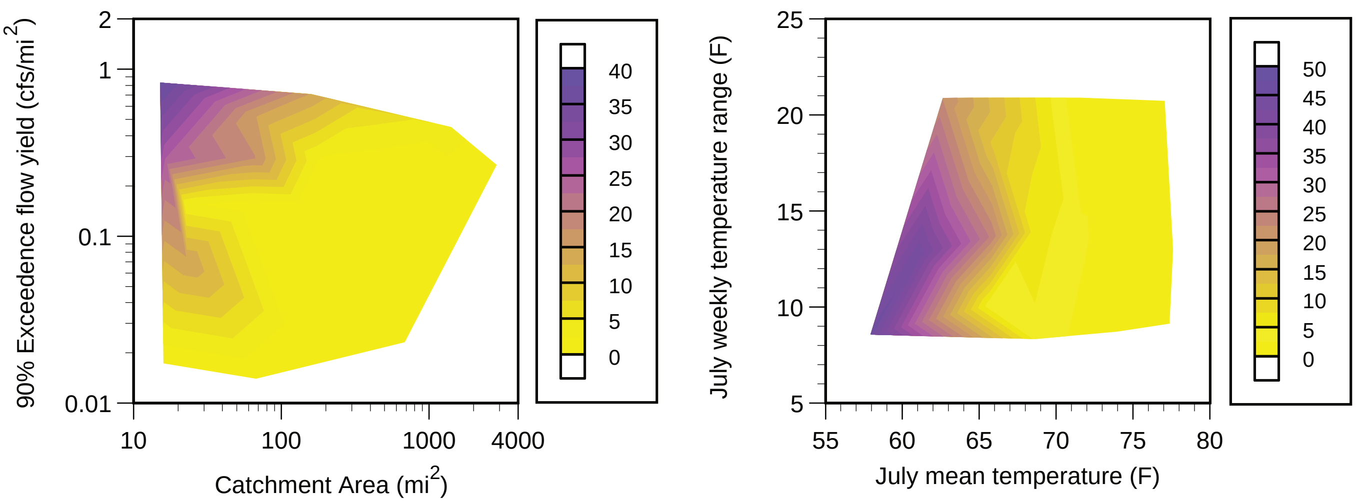
Catfishes



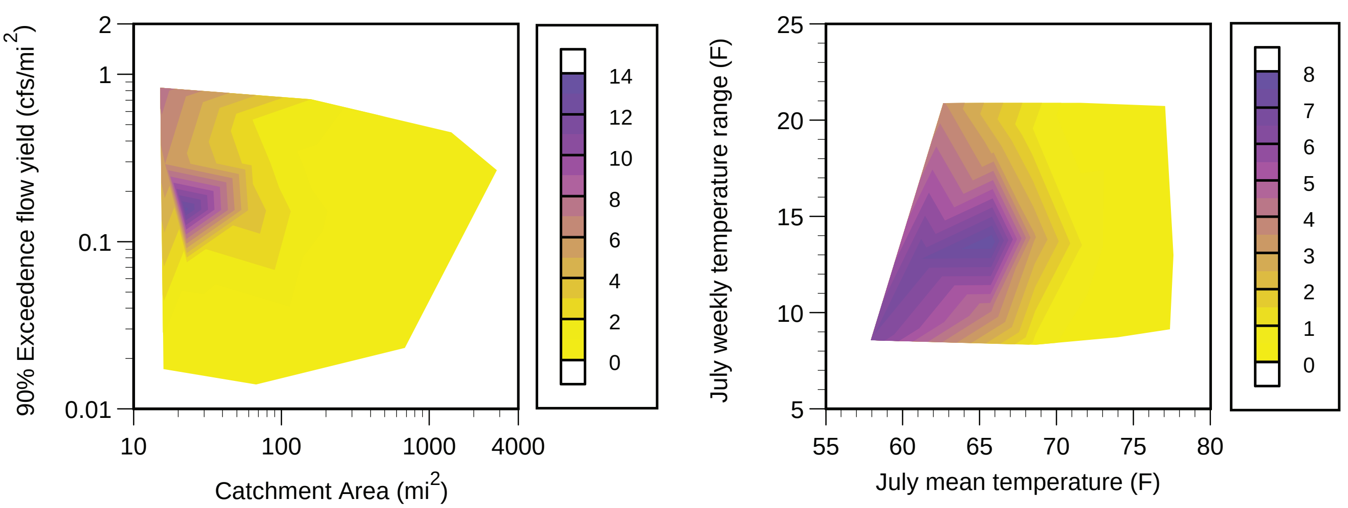
Pikes



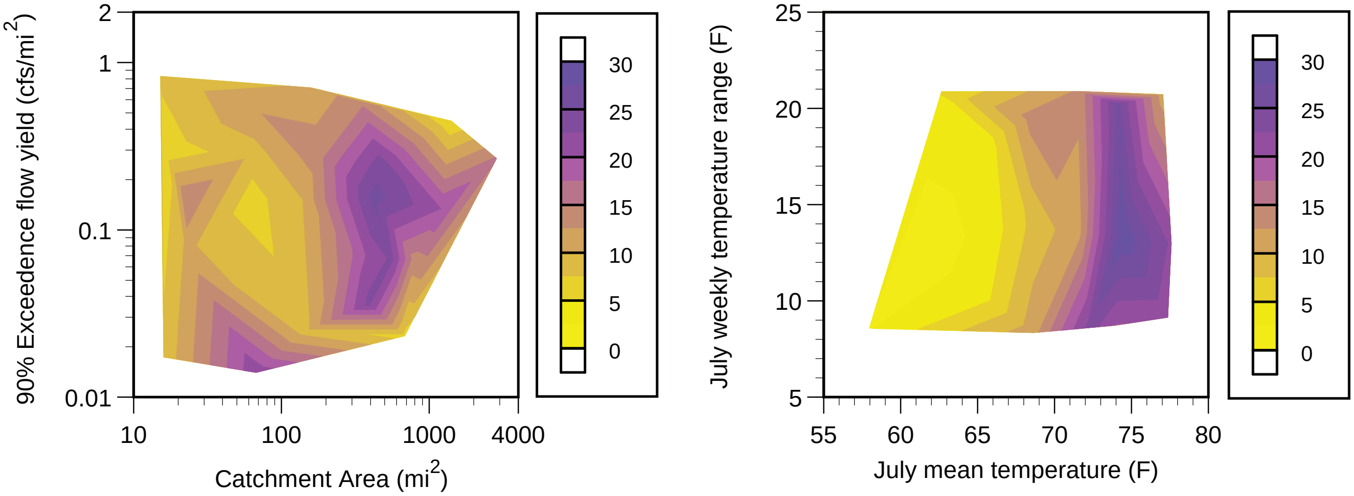
Salmonids



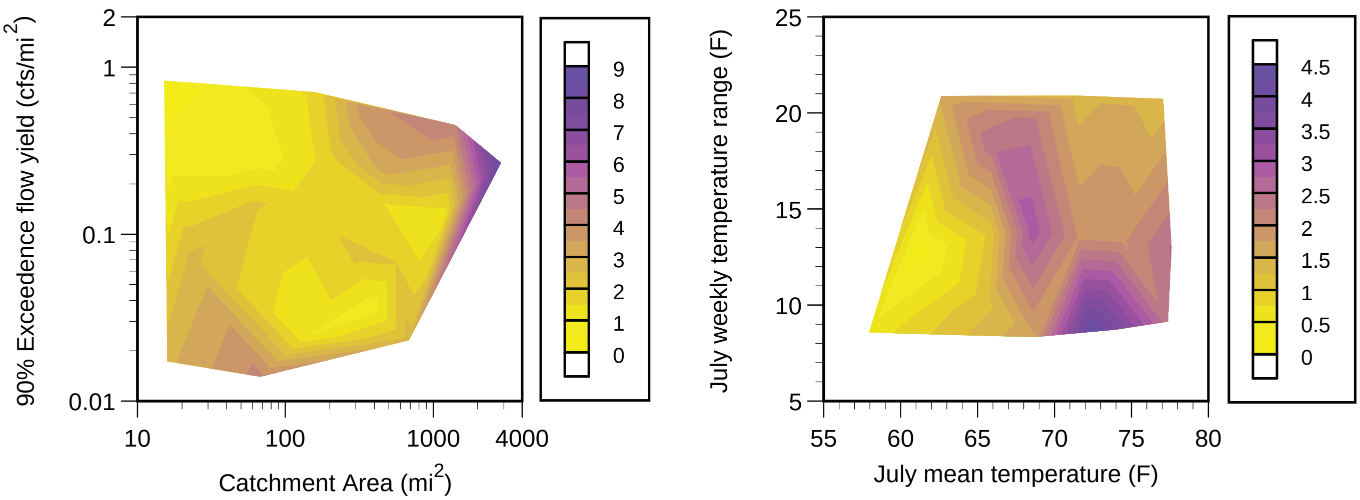
Sculpins



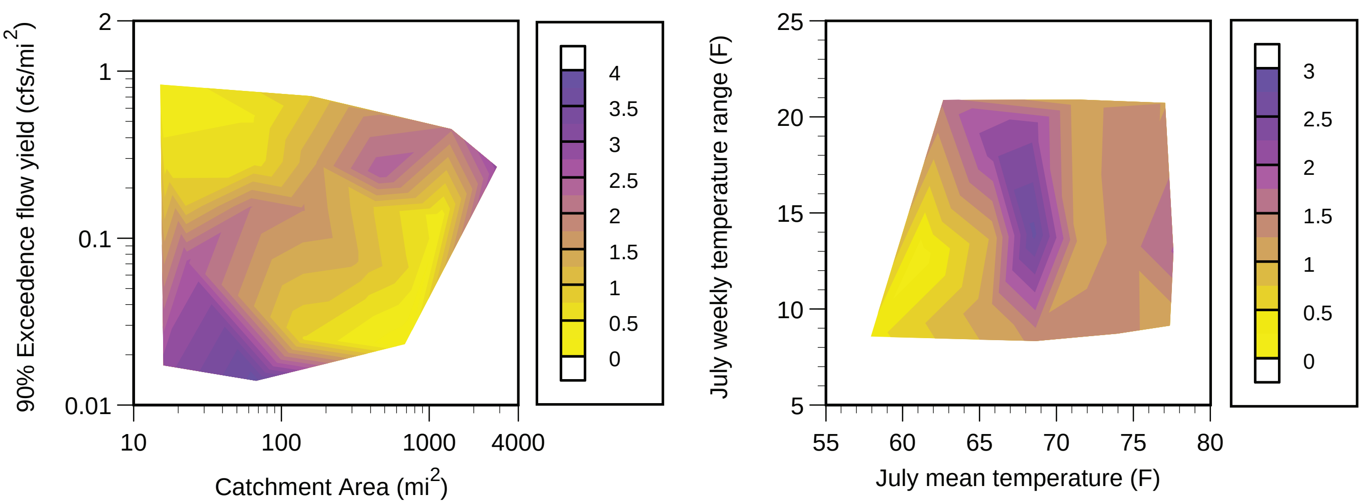
Sunfishes



Perches

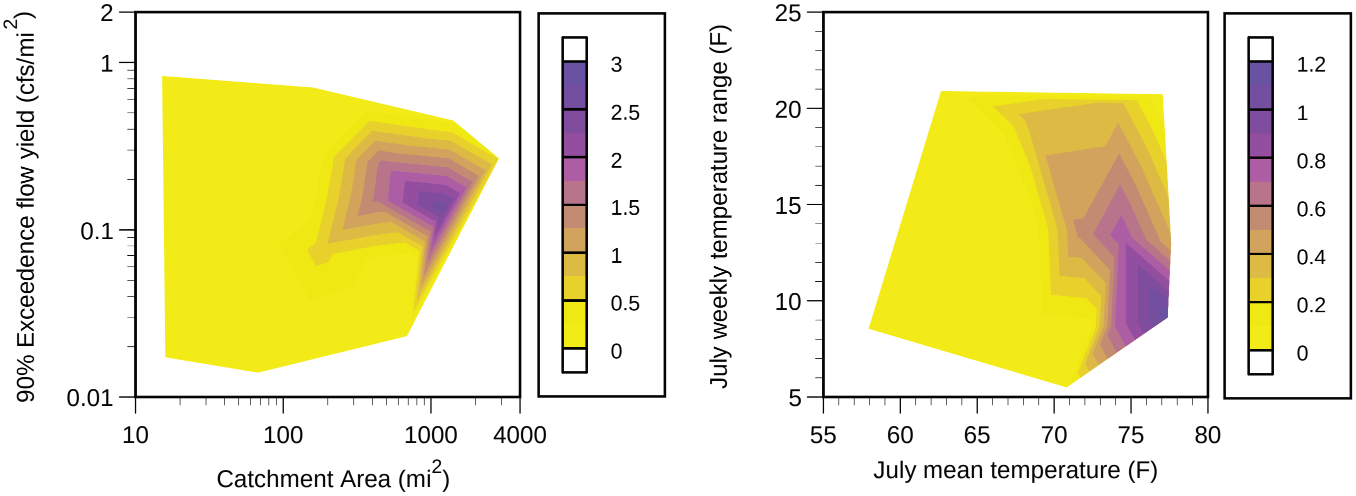


Darters

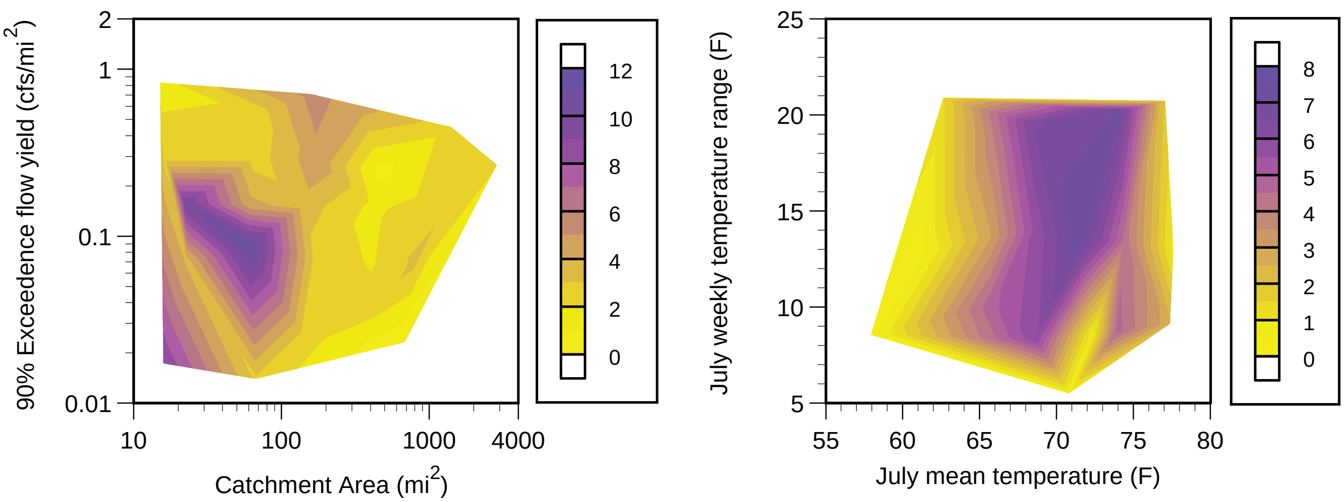


3. Species Level

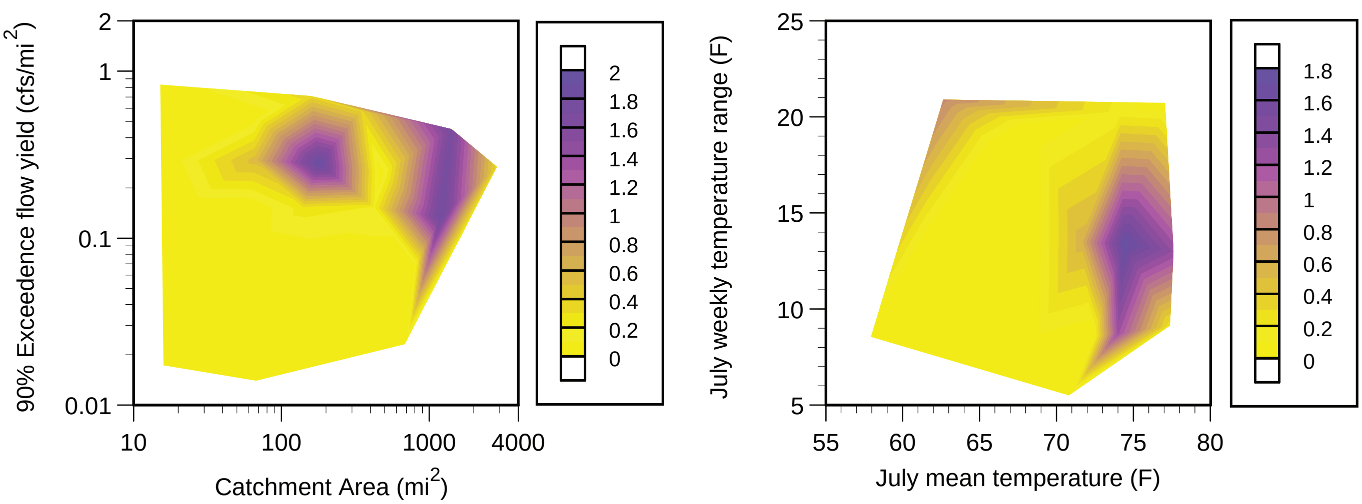
Spotfin shiner



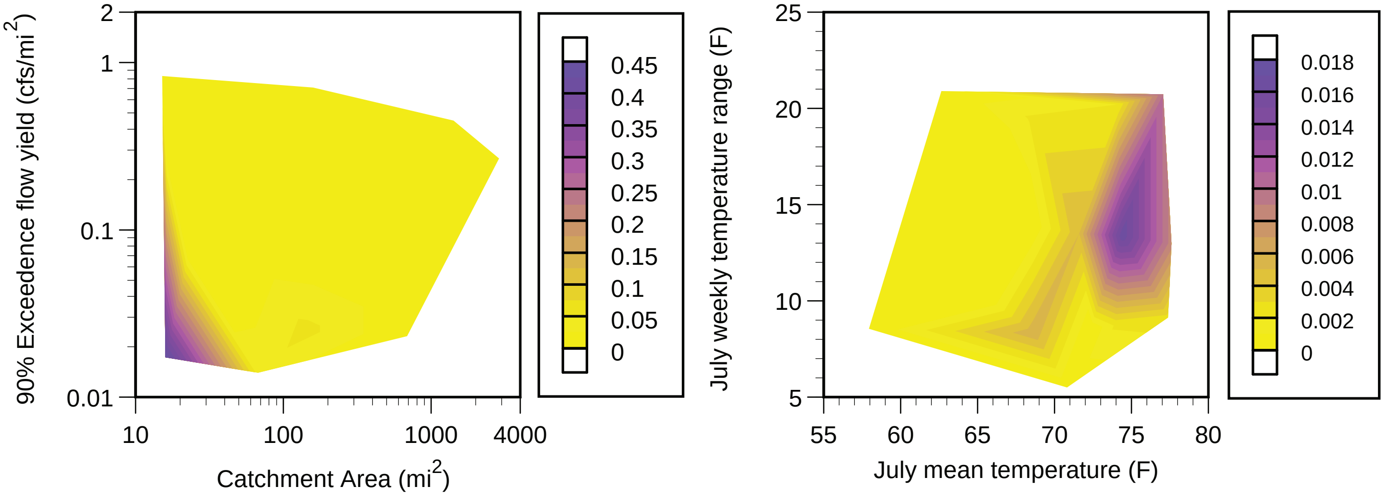
Common shiner



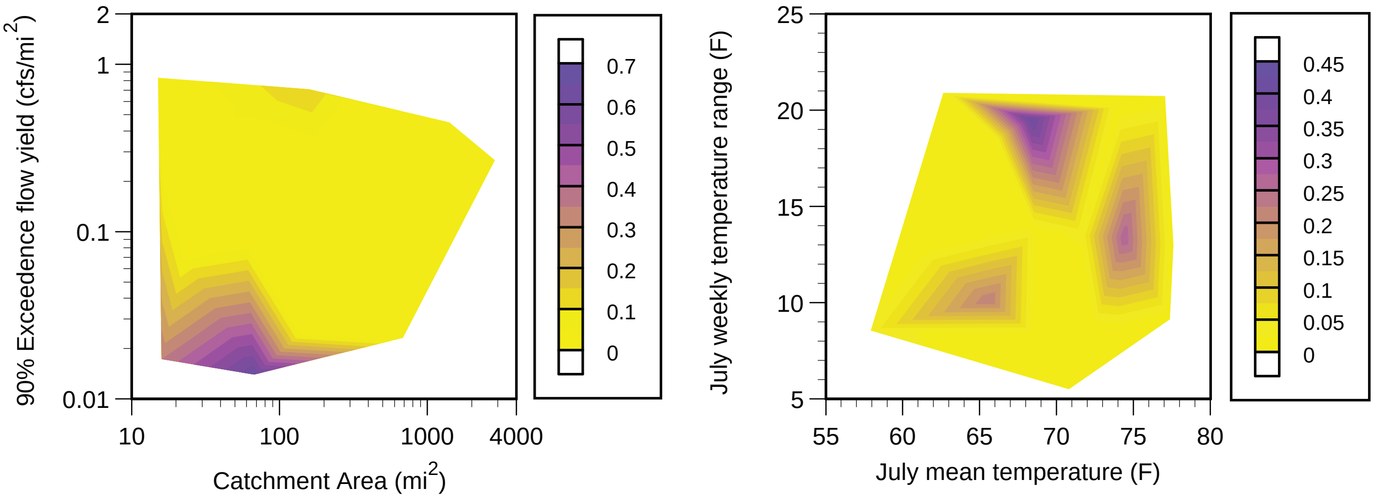
Striped shiner



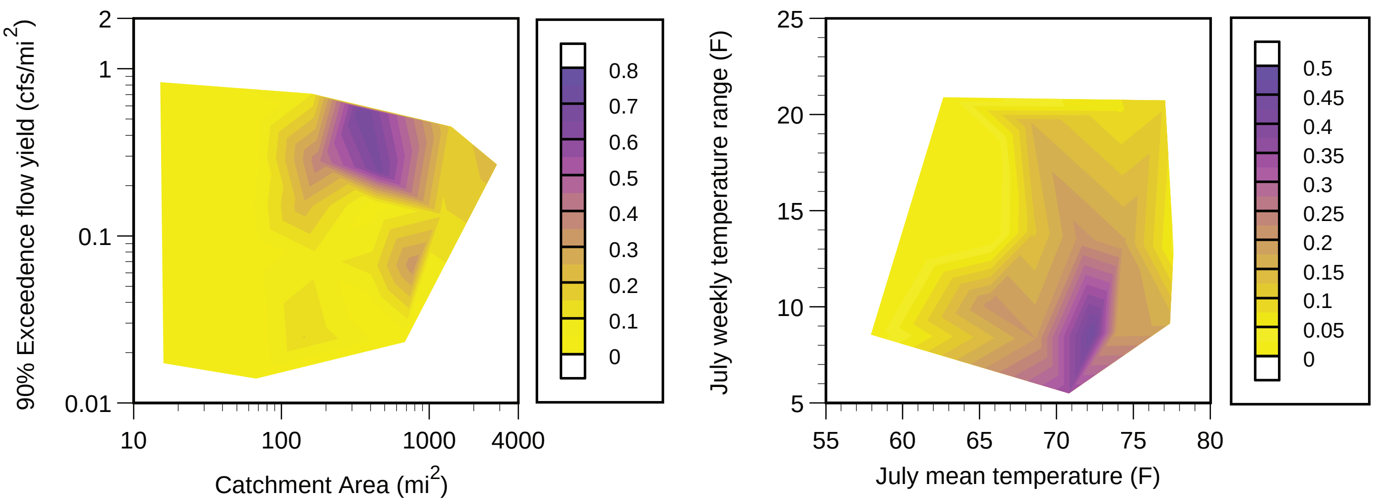
Redfin shiner



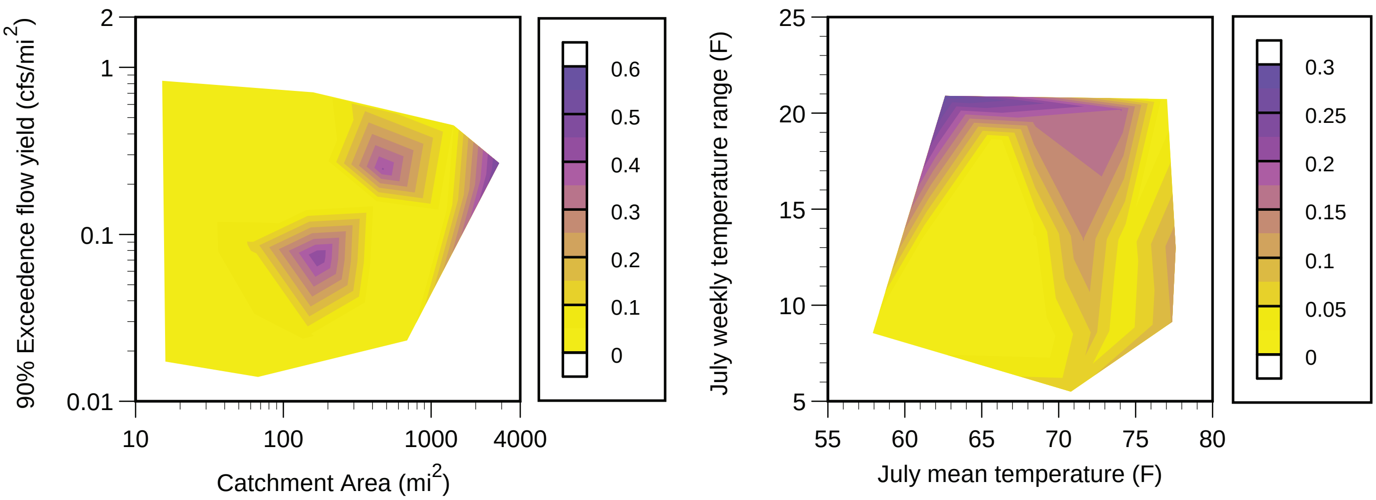
Golden shiner



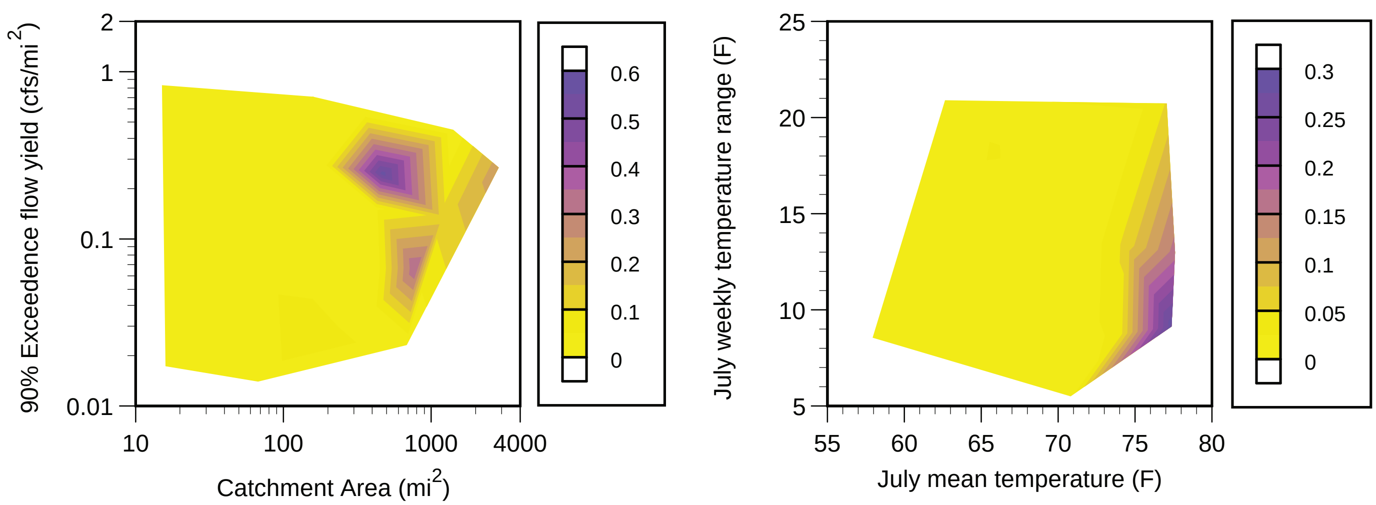
Rosyface shiner



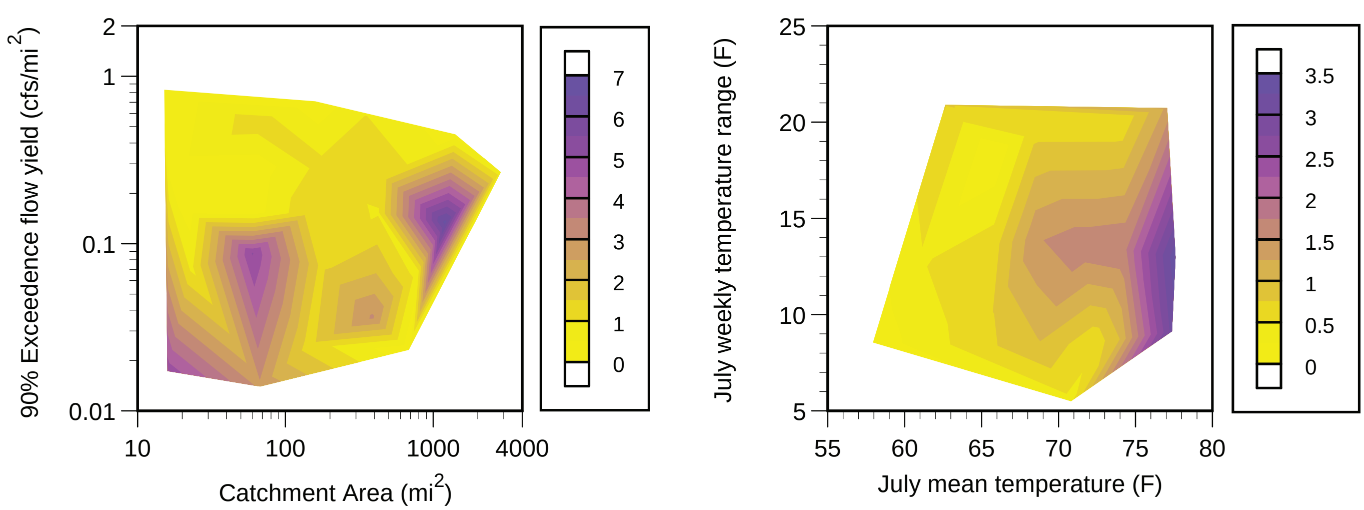
Sand shiner



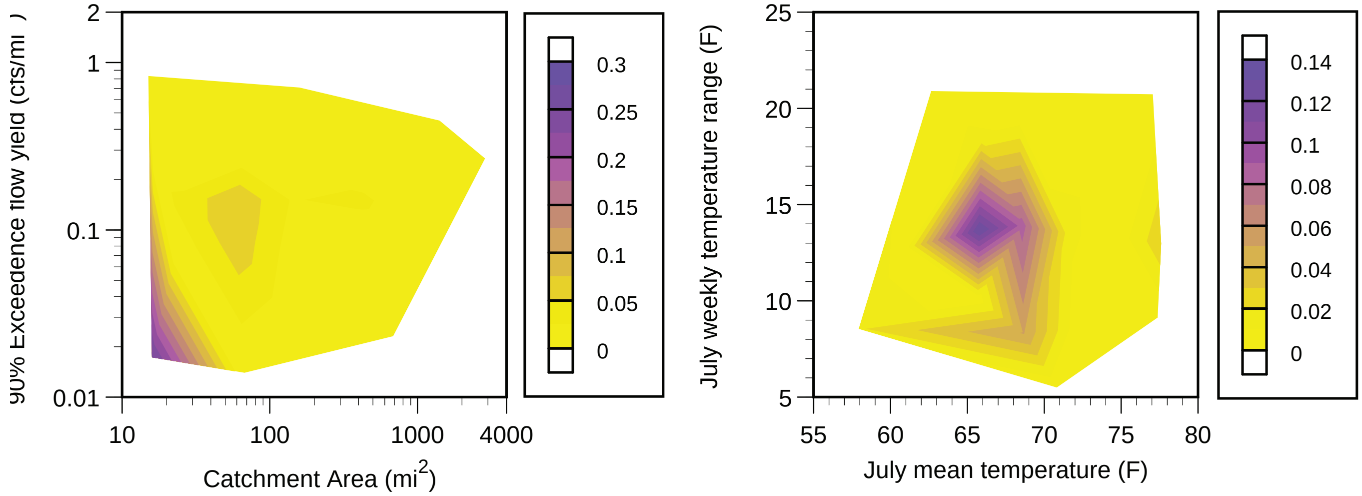
Mimic shiner



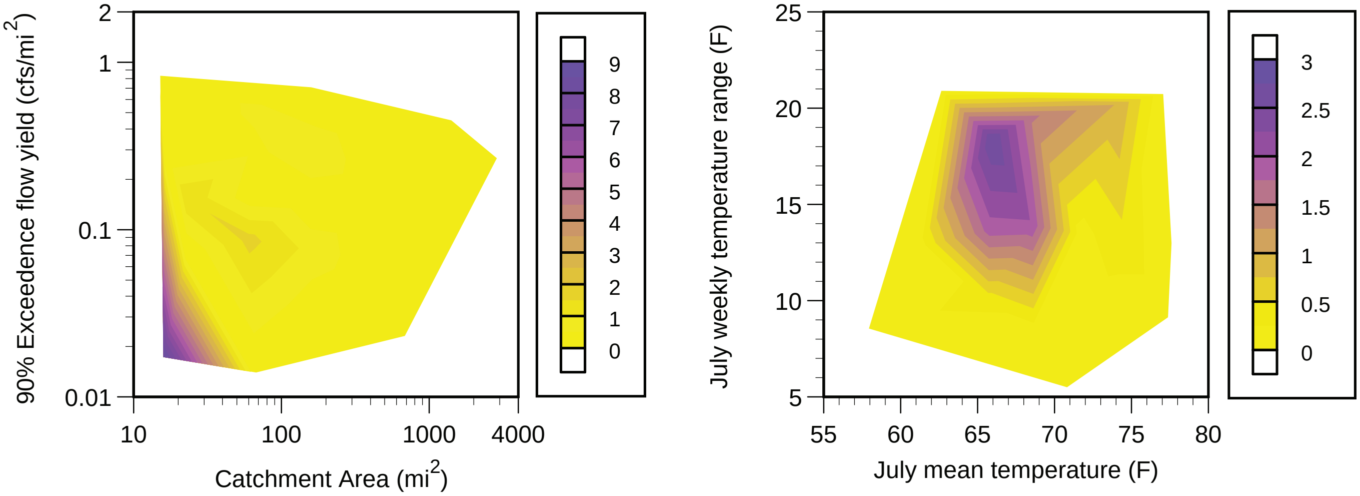
Bluntnose minnow



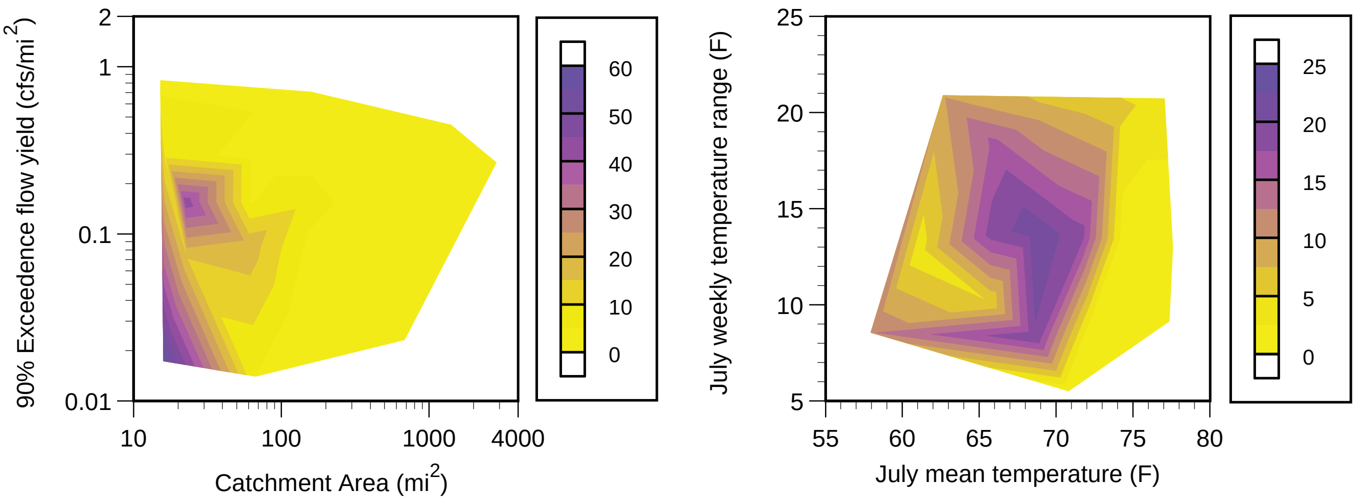
Fathead minnow



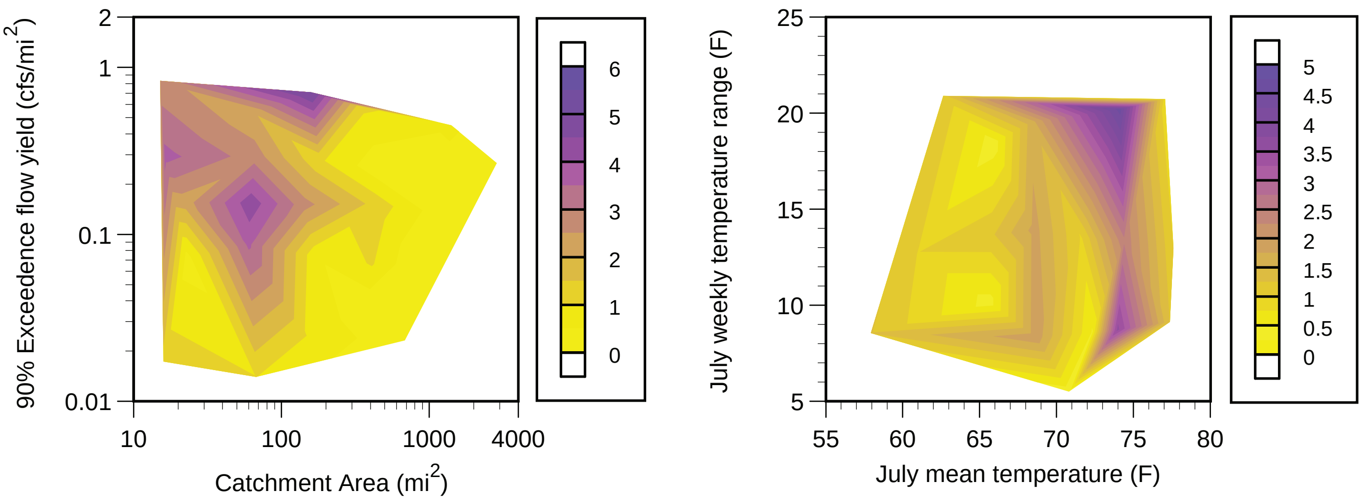
Central stoneroller



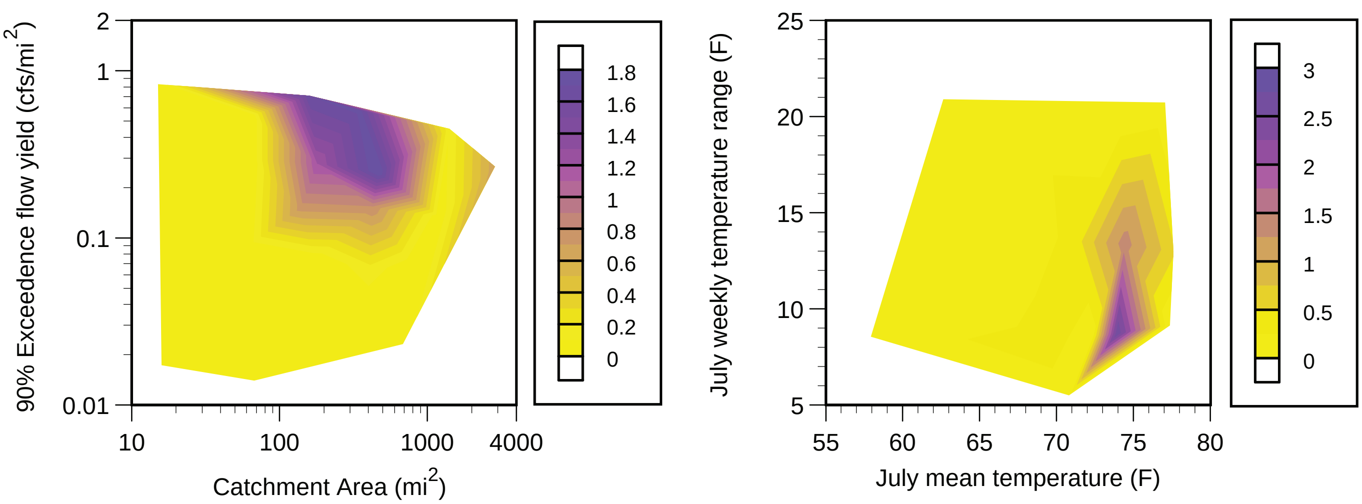
Creek chub



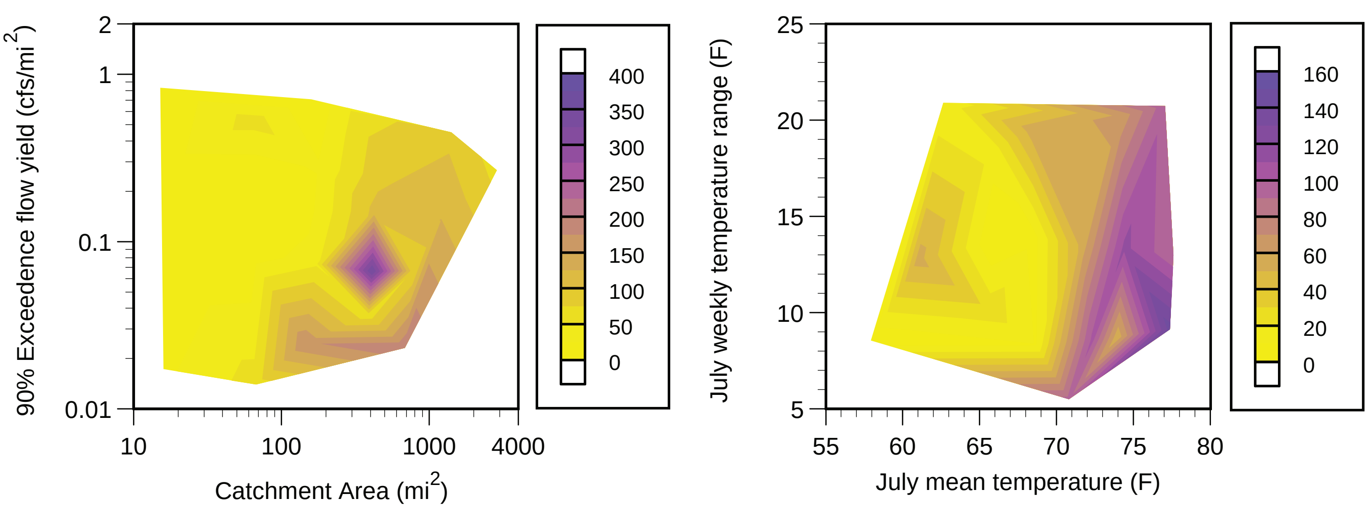
Hornyhead chub



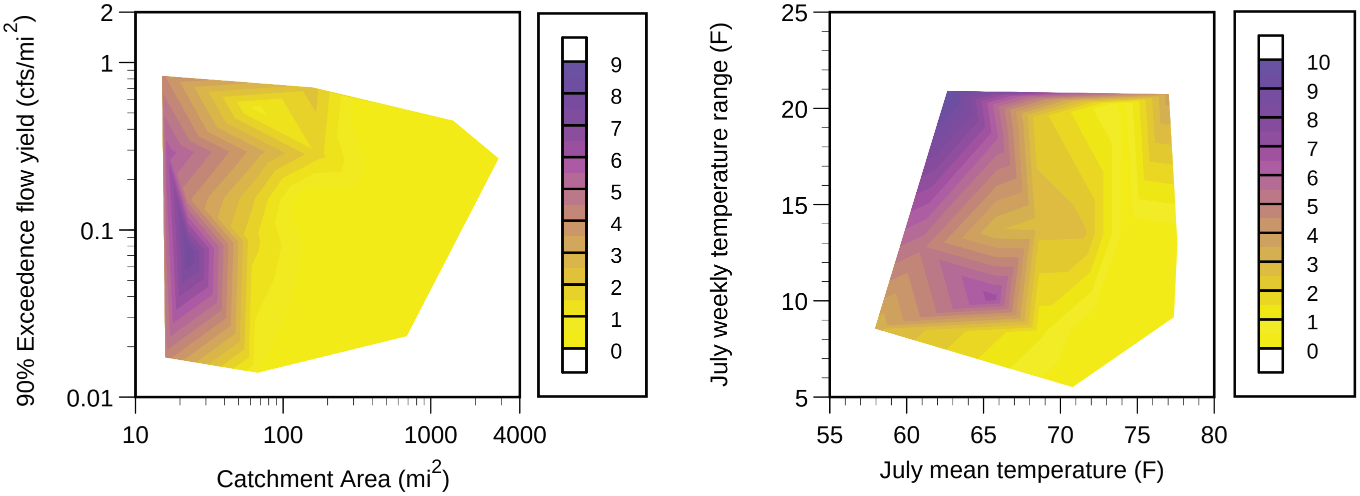
River chub



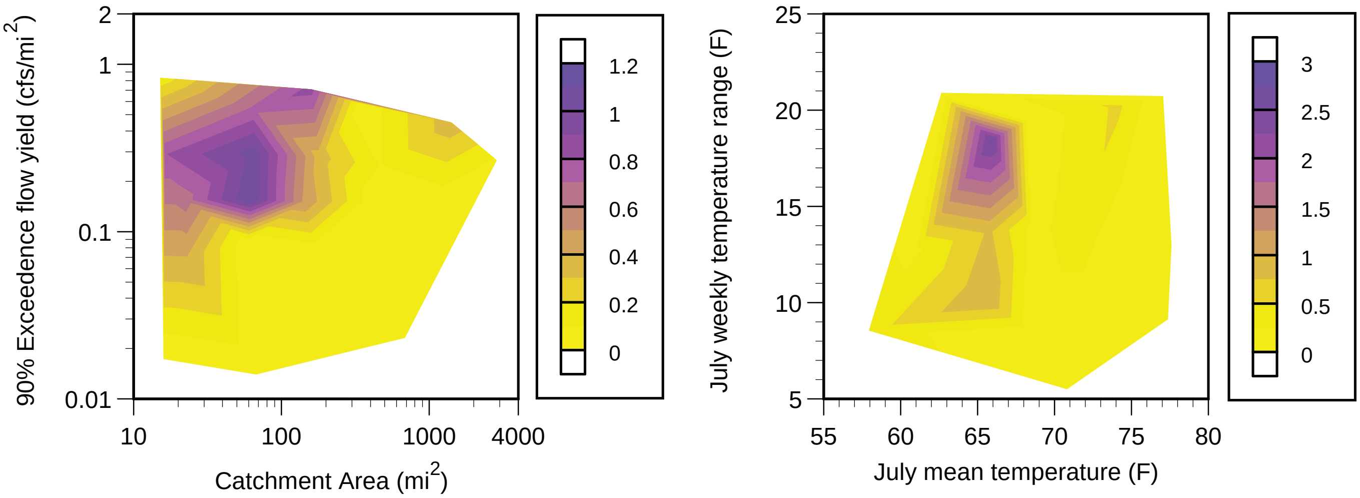
Common carp



Blacknose dace



Longnose dace



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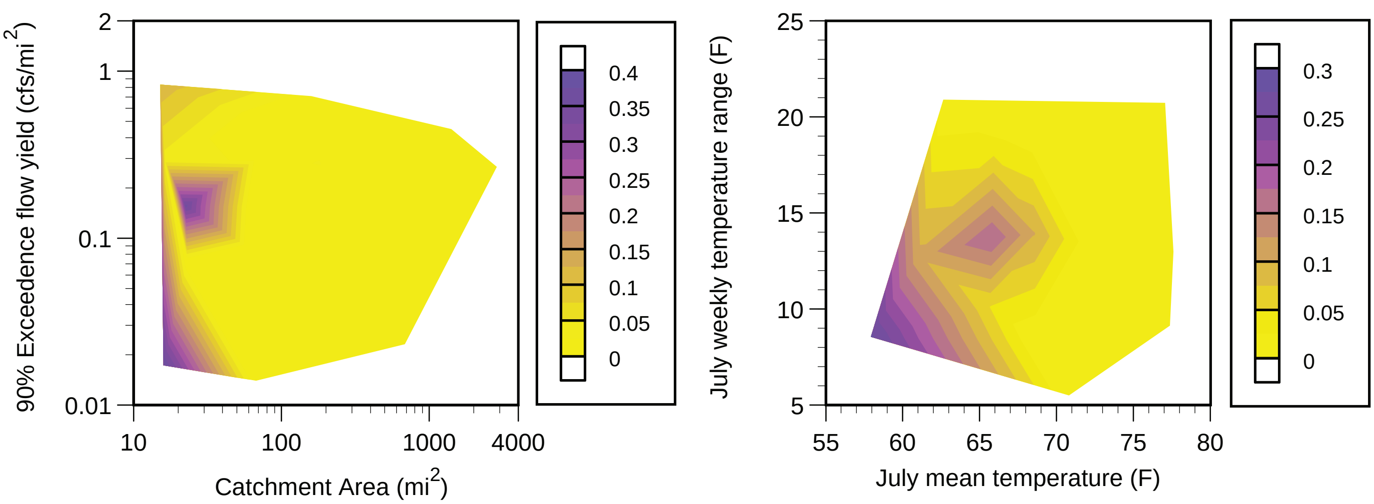
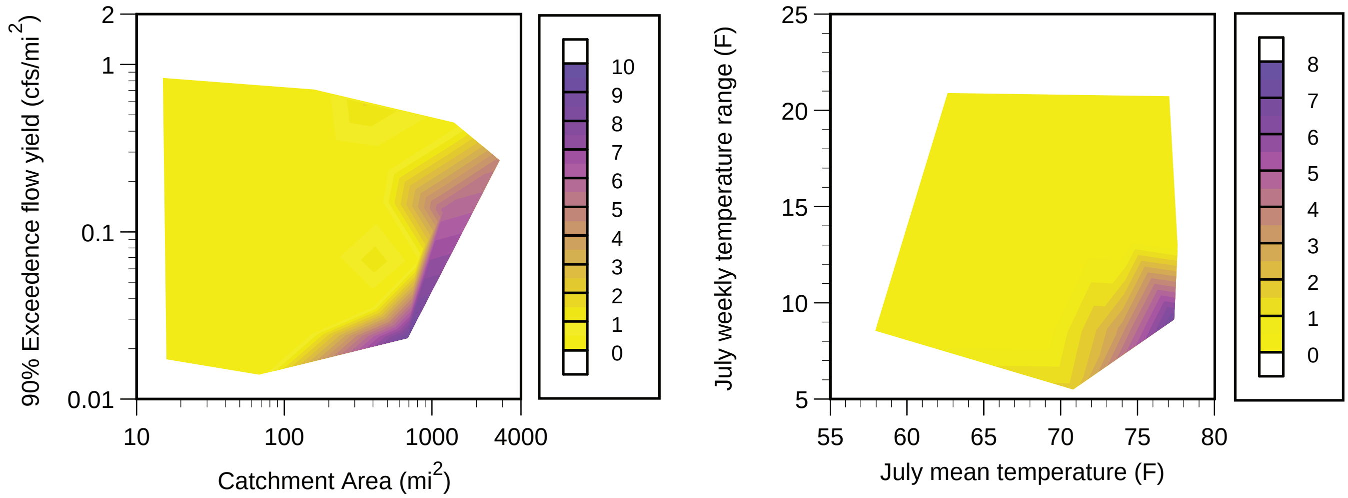
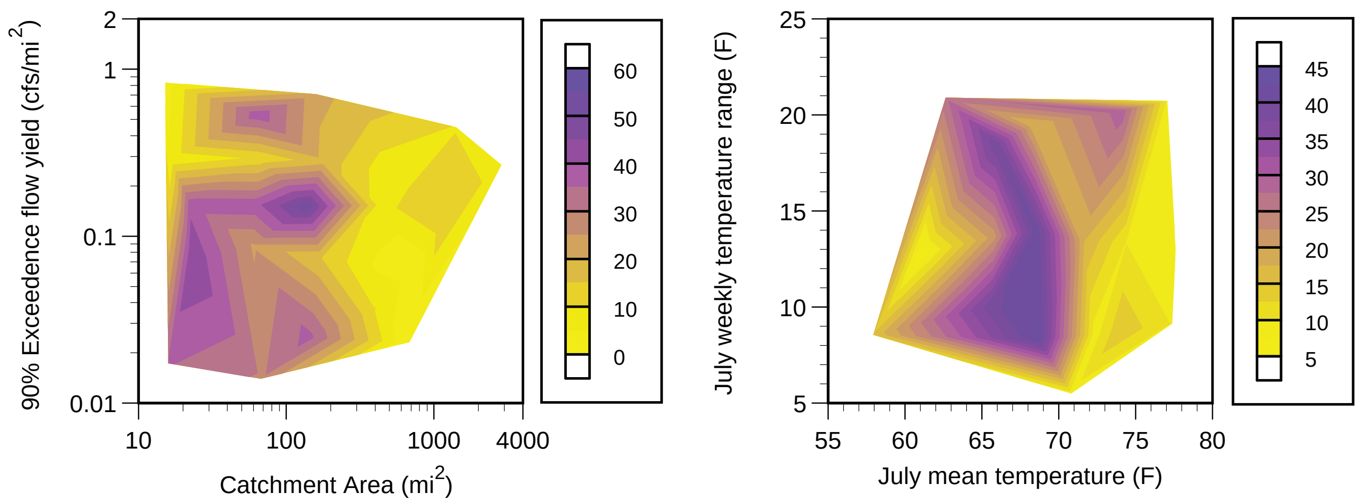


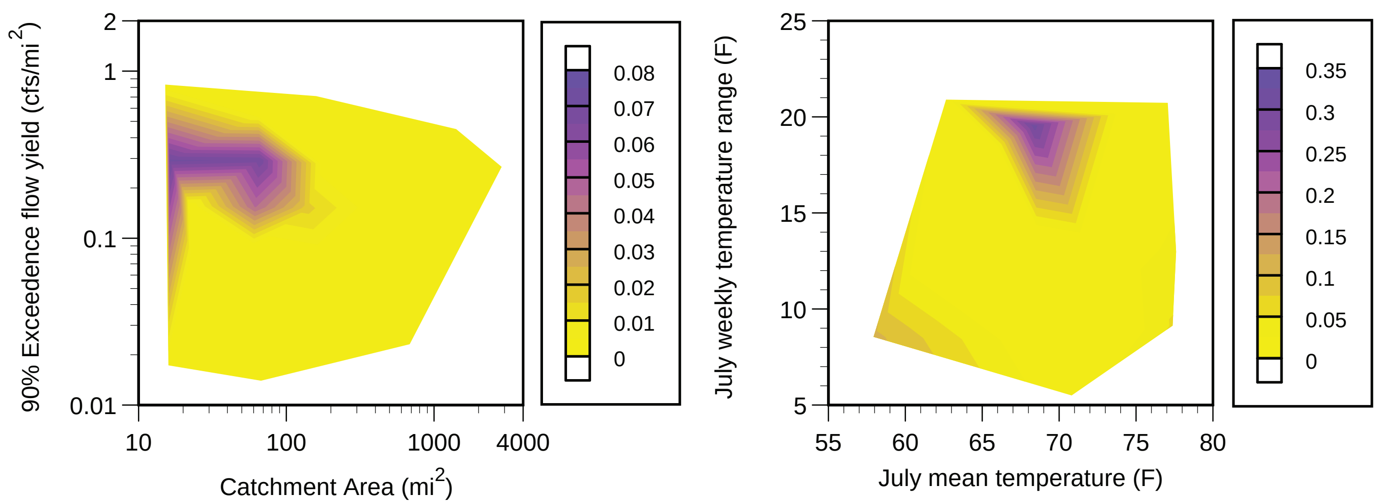
Quillback



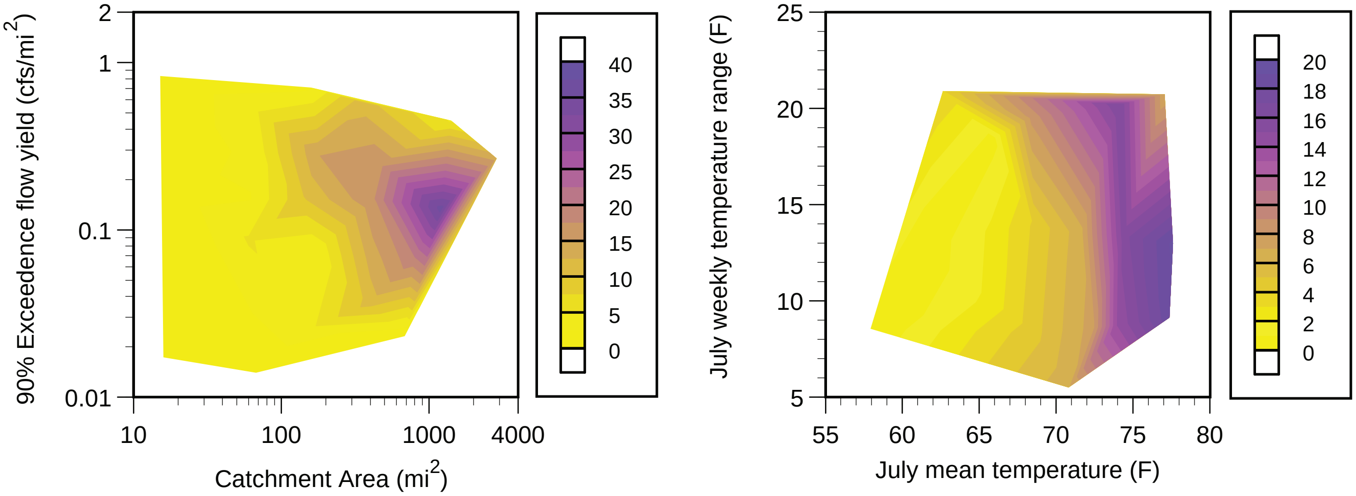
White sucker



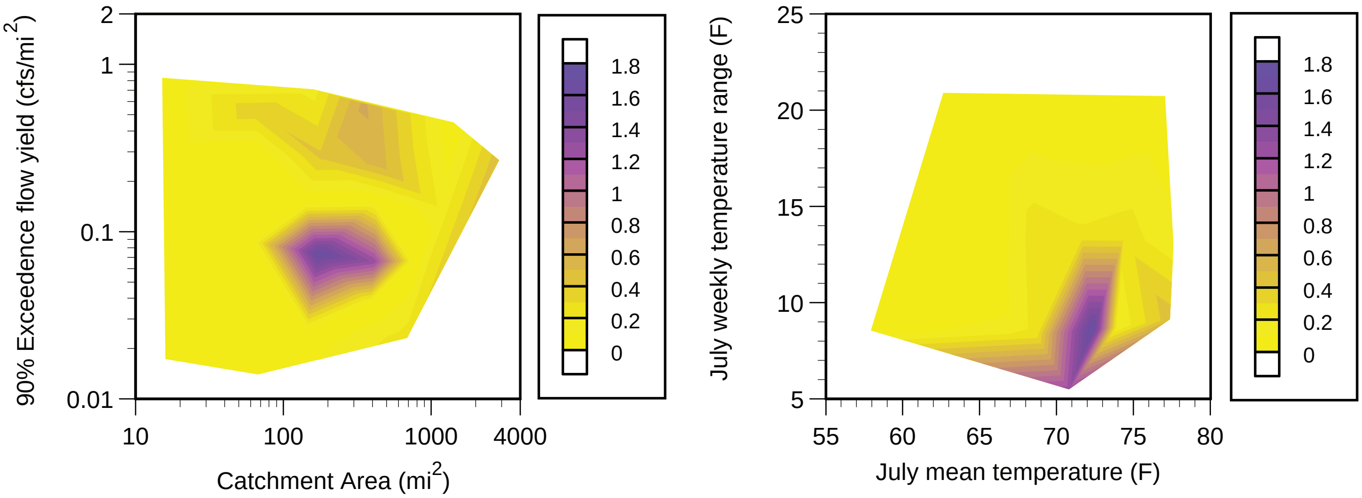
Lake chubsucker



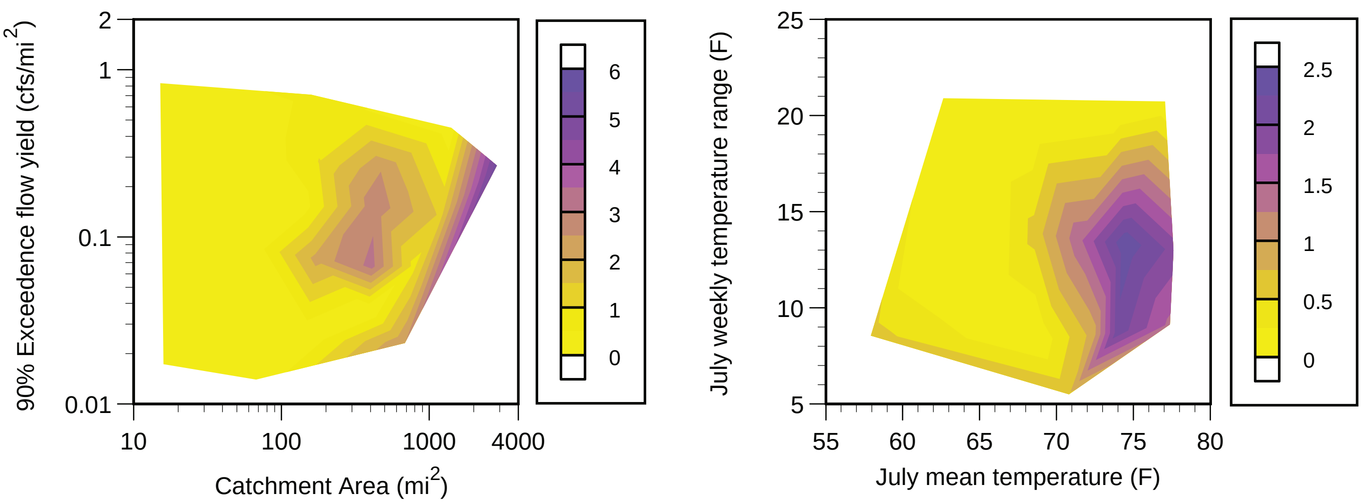
Northern hog sucker



Spotted sucker



Silver redhorse



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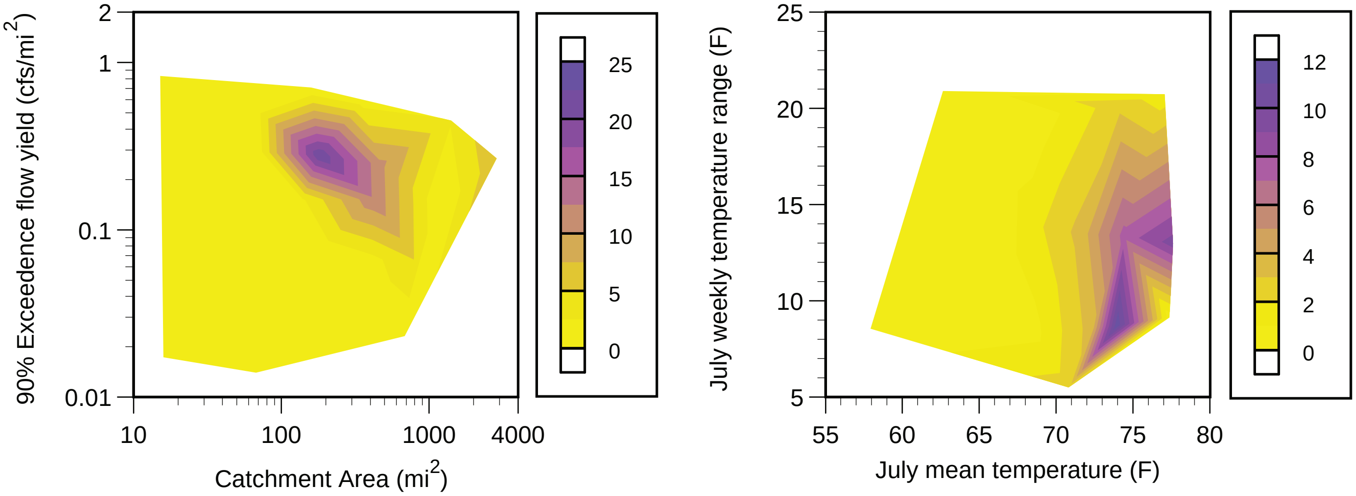
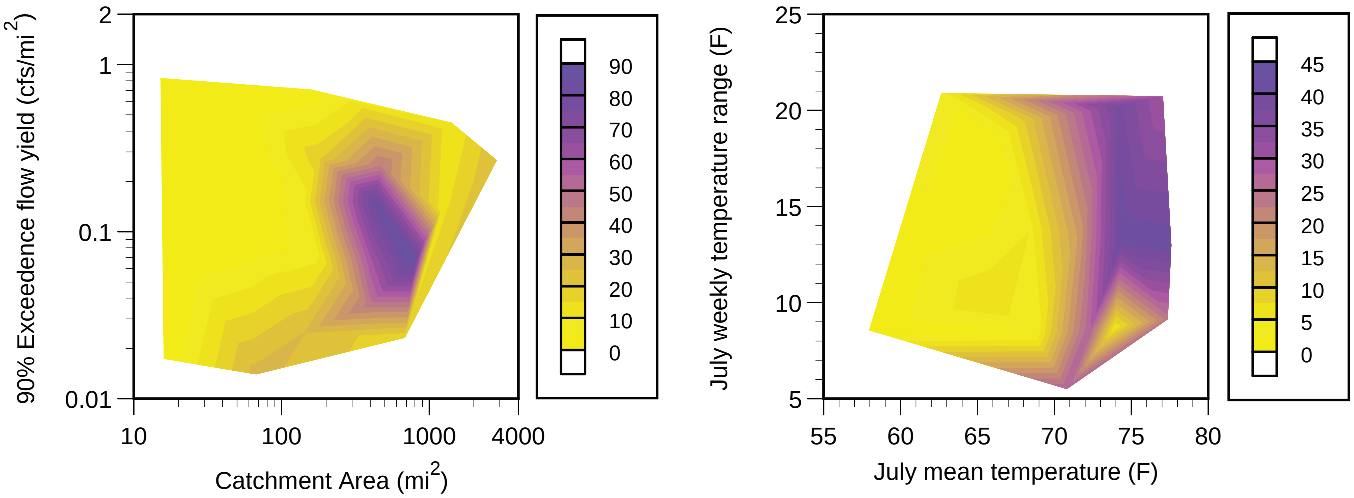
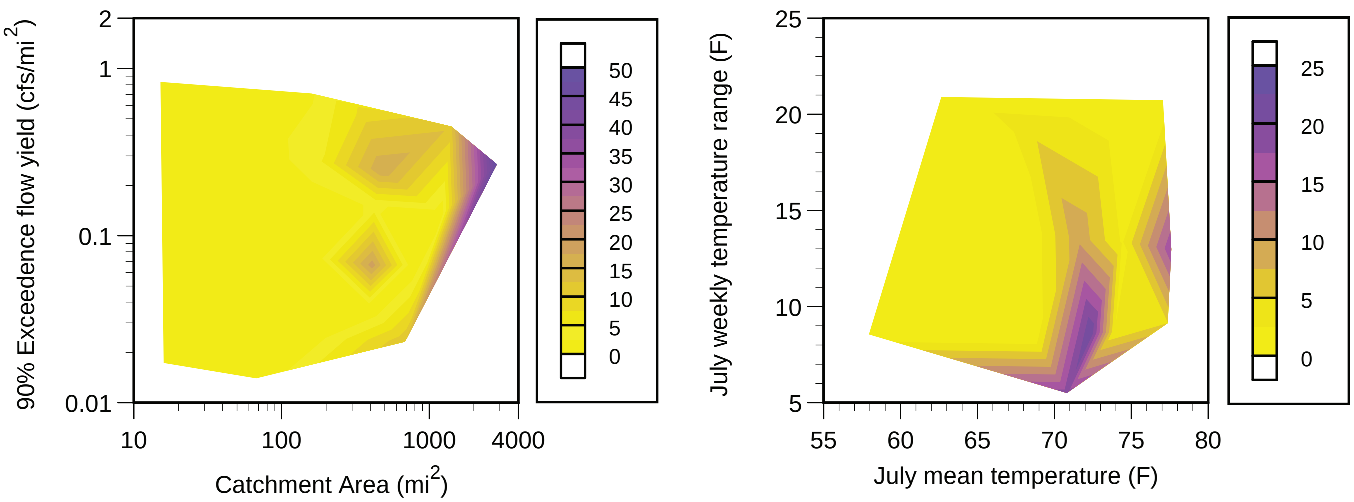


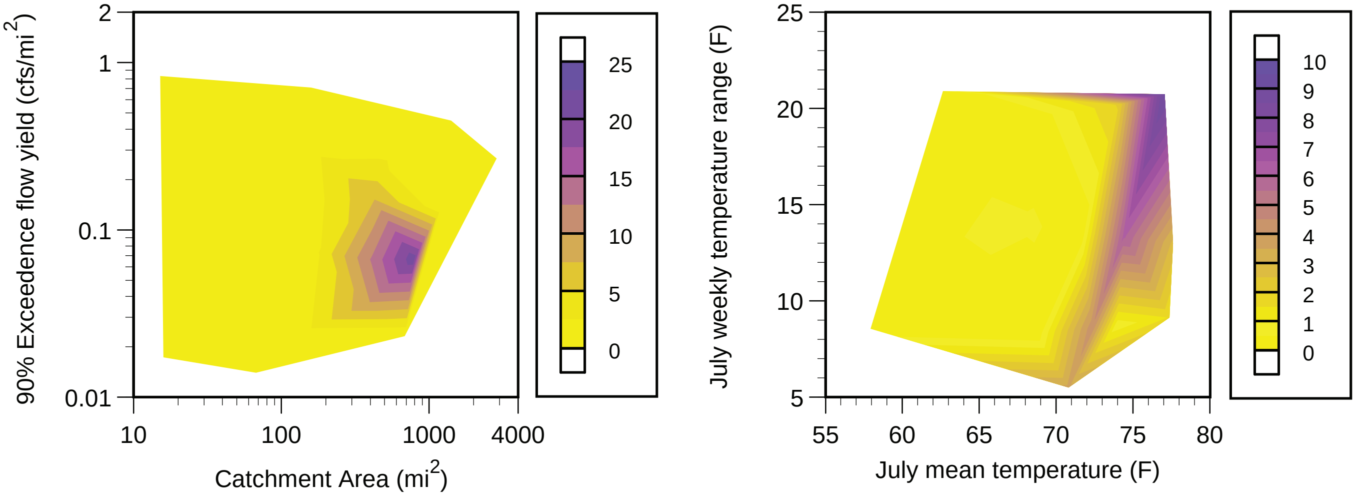
Golden redhorse



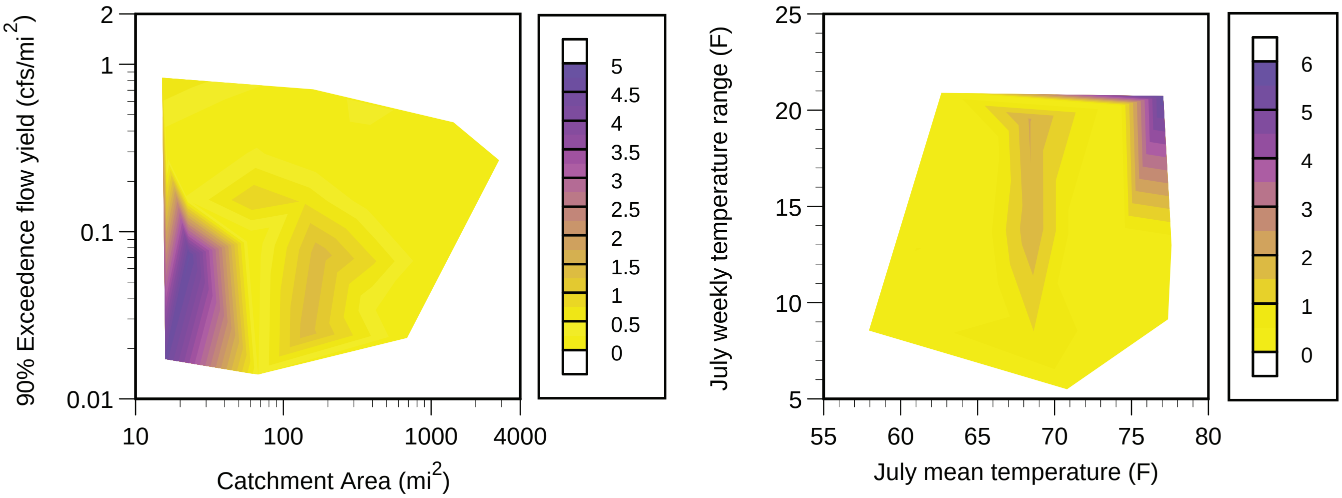
Shorthead redhorse



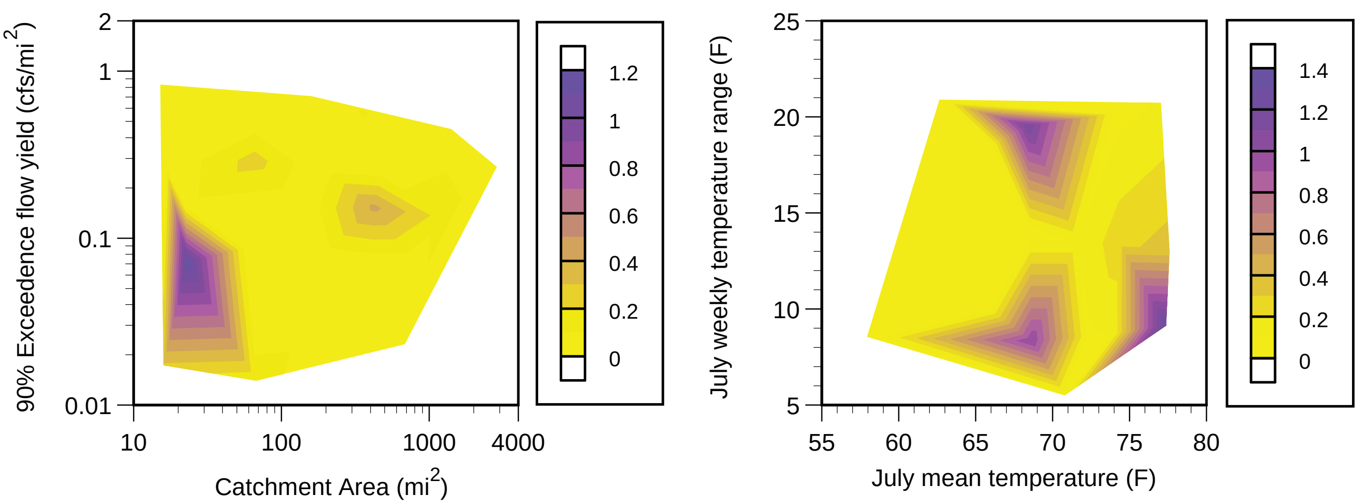
Greater redhorse



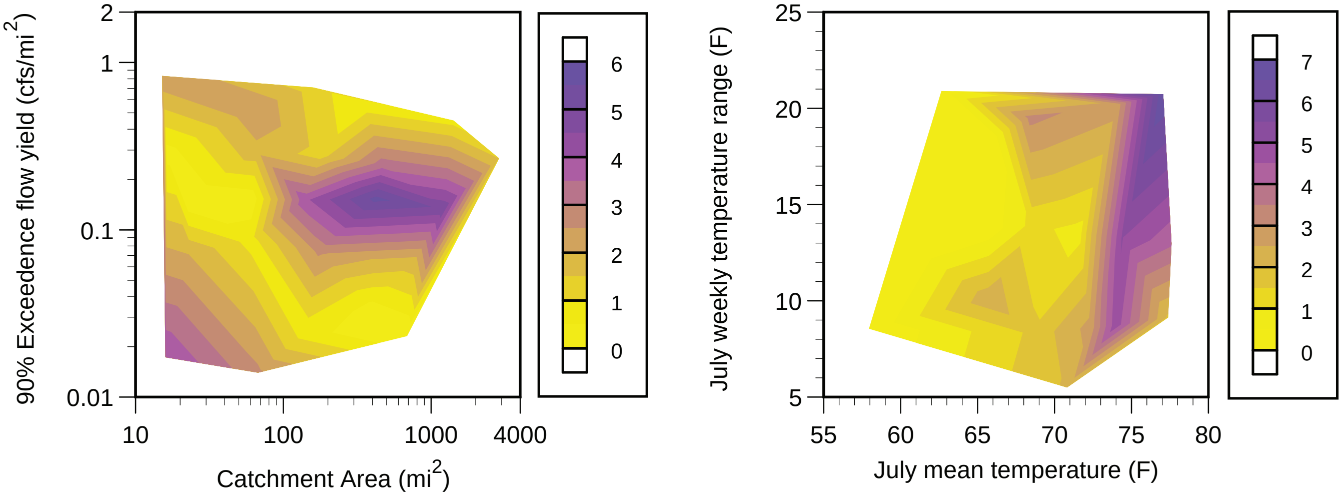
Black bullhead



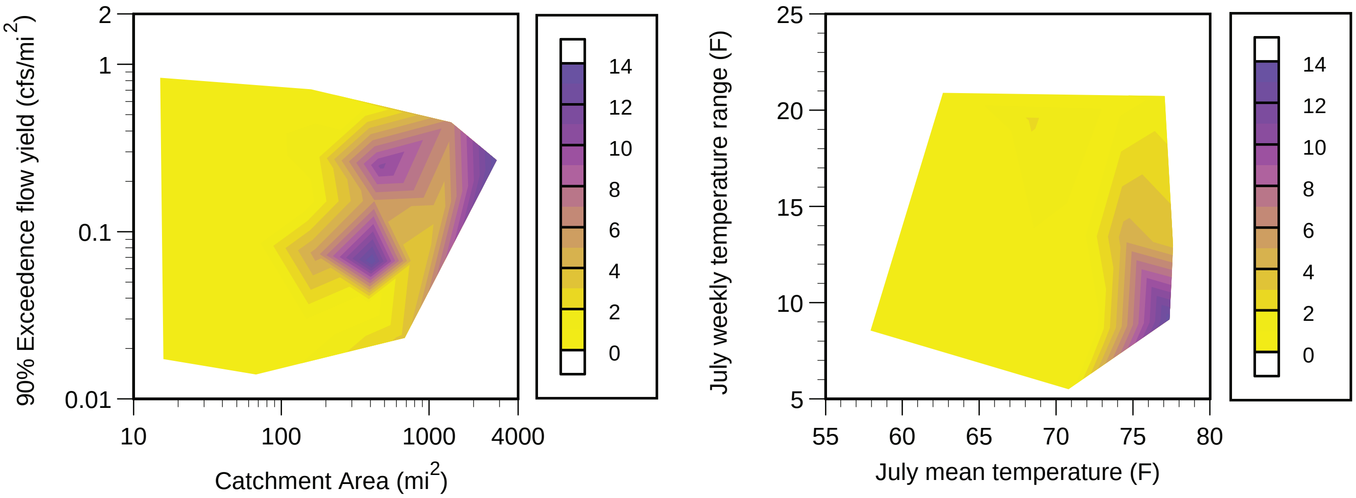
Brown bullhead



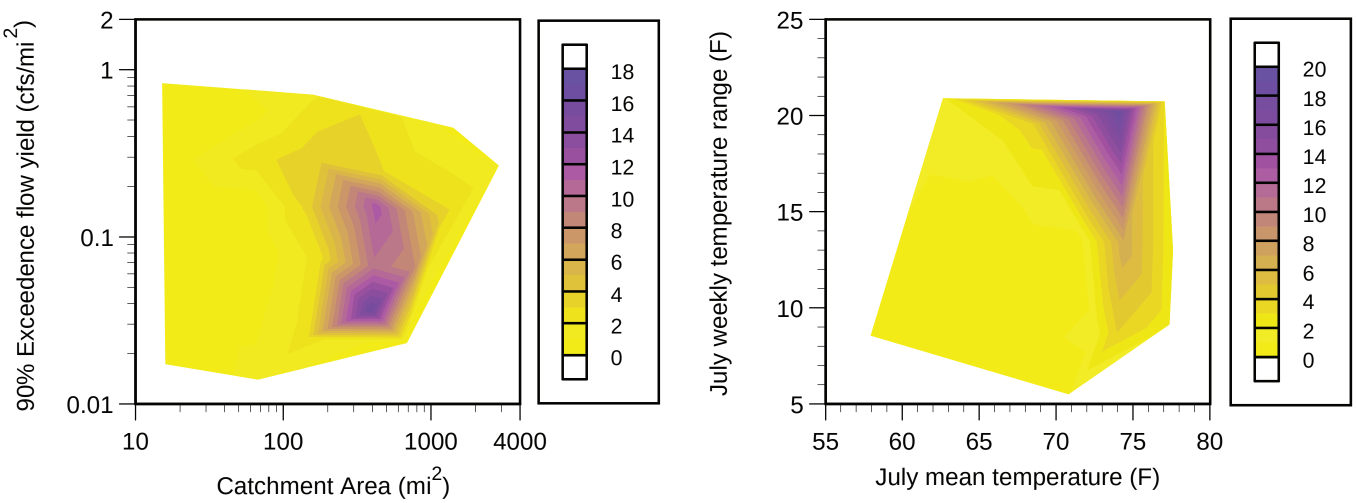
Yellow bullhead



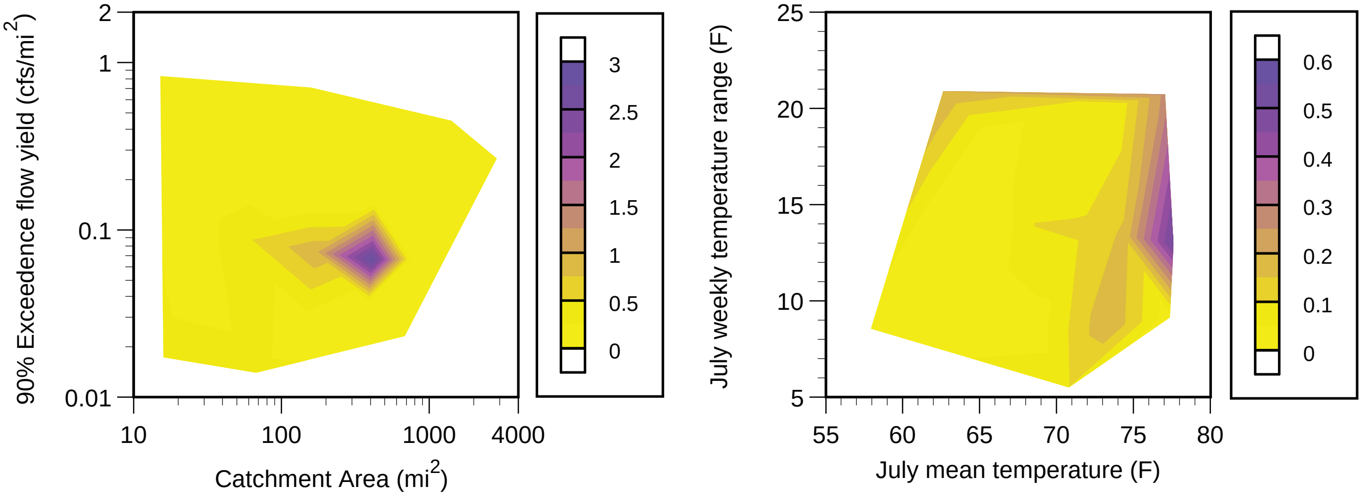
Channel catfish



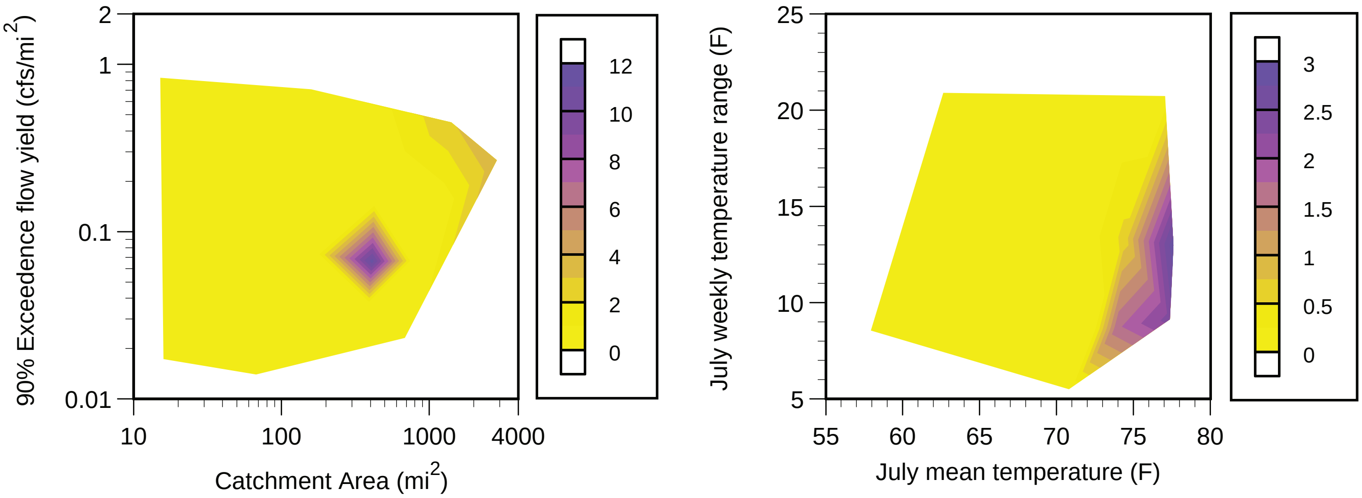
Stonecat



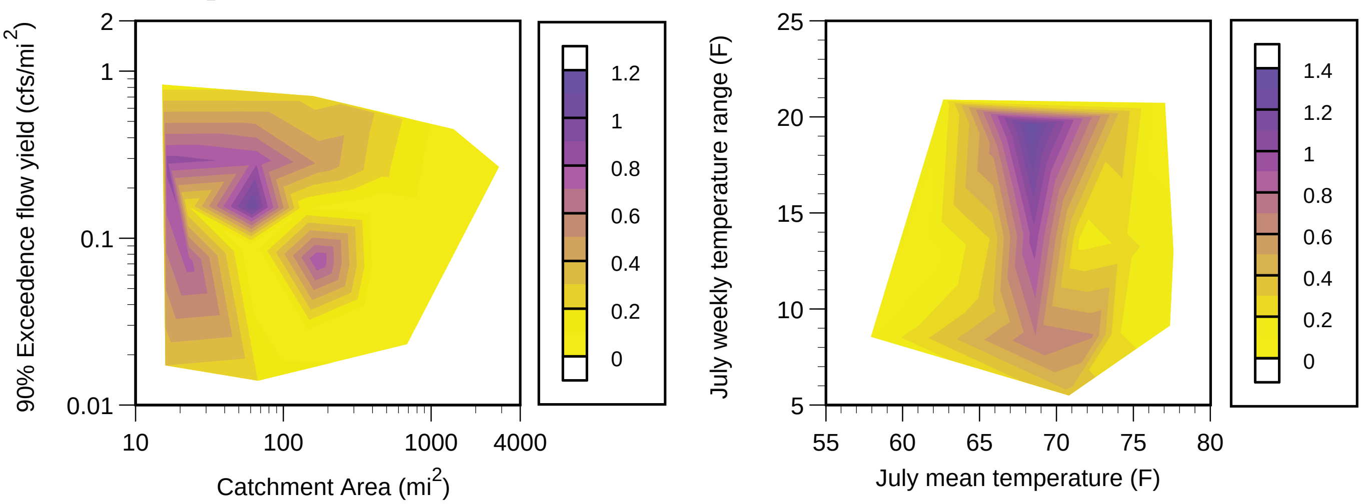
Tadpole madtom



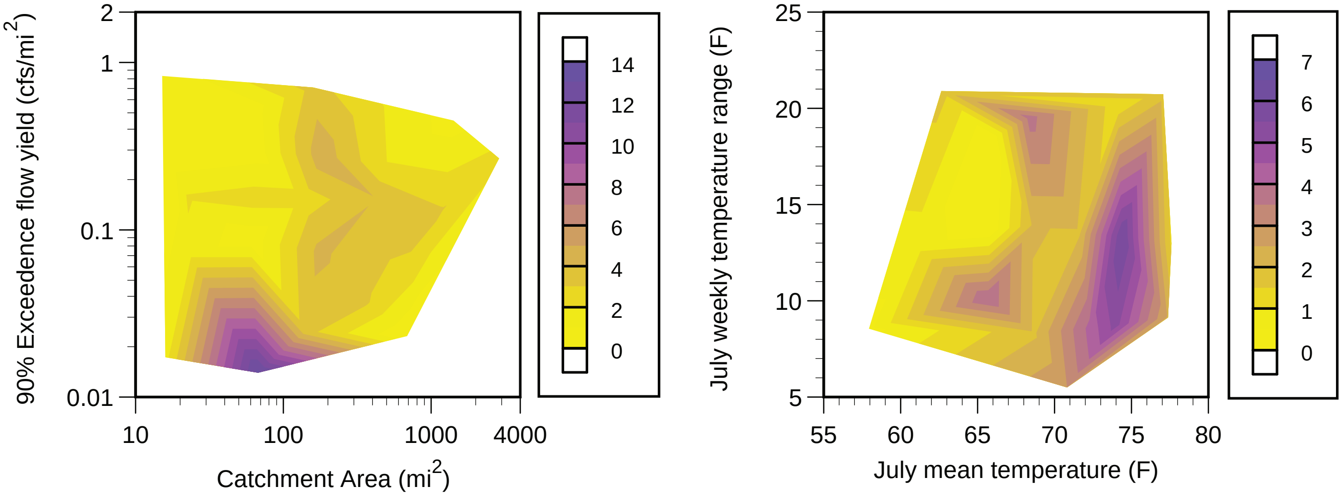
Flathead catfish



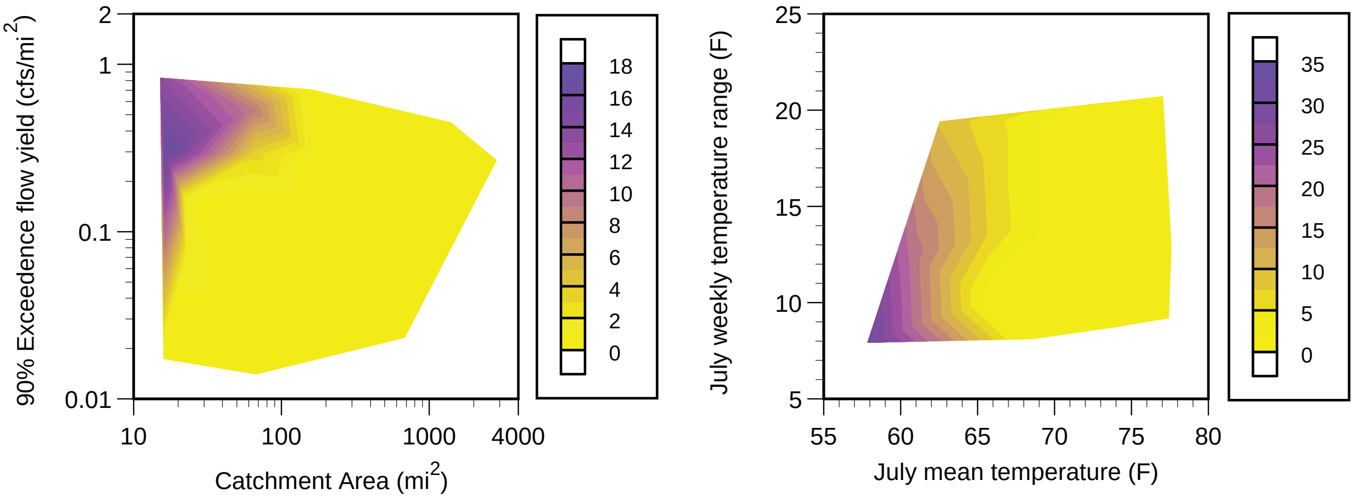
Grass pickerel



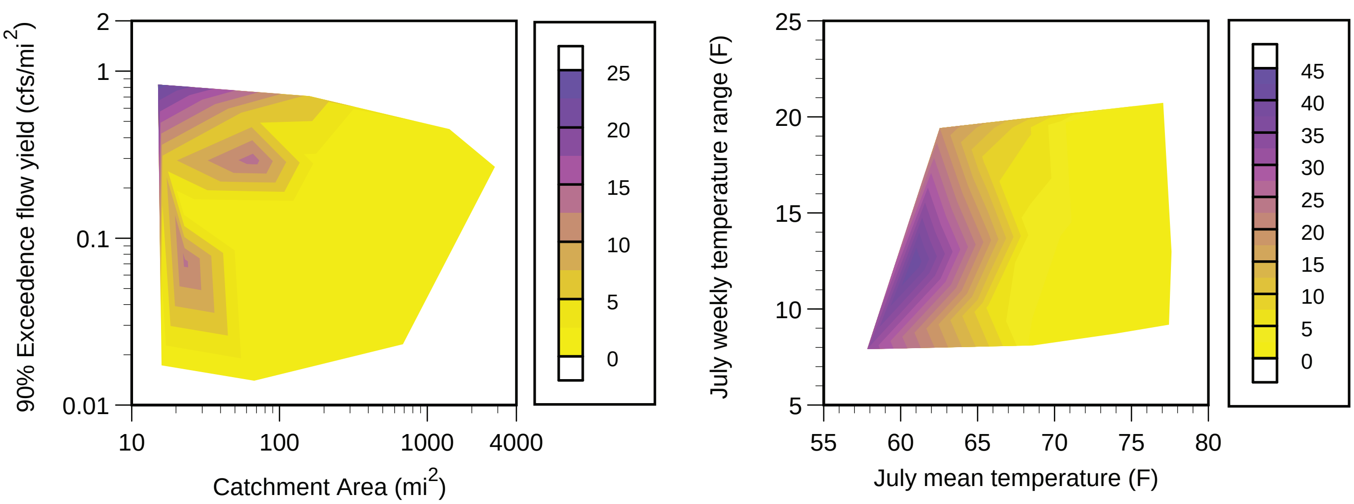
Northern pike



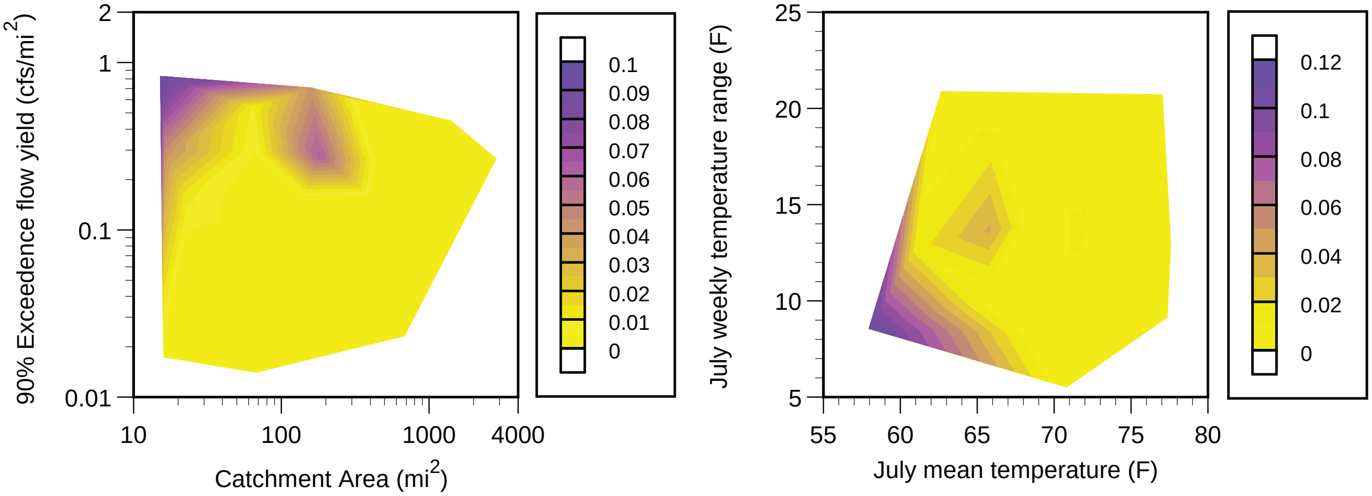
Brook trout



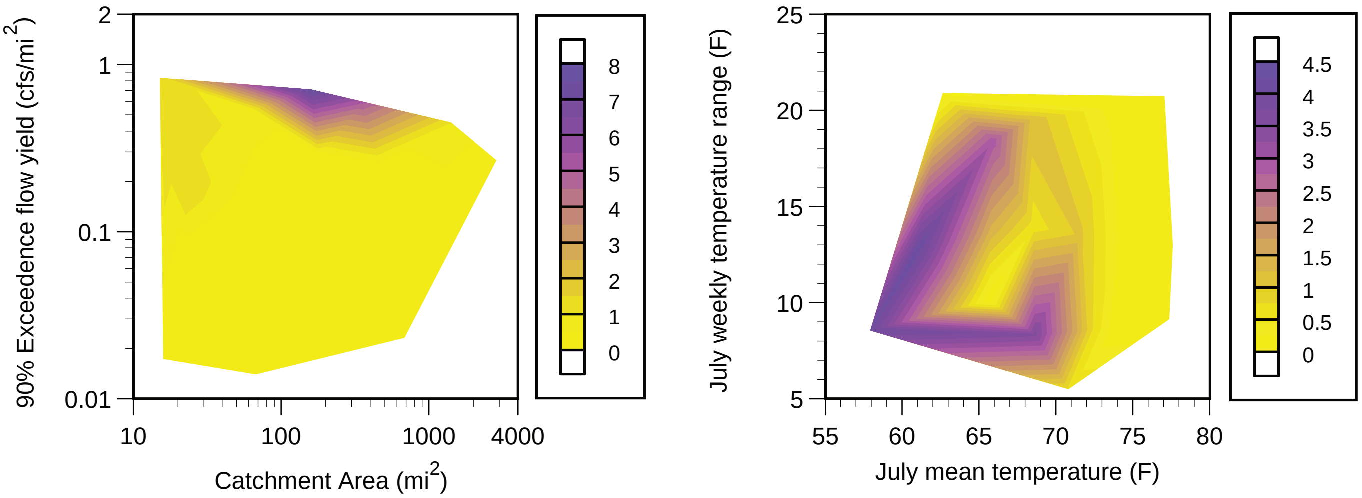
Brown trout



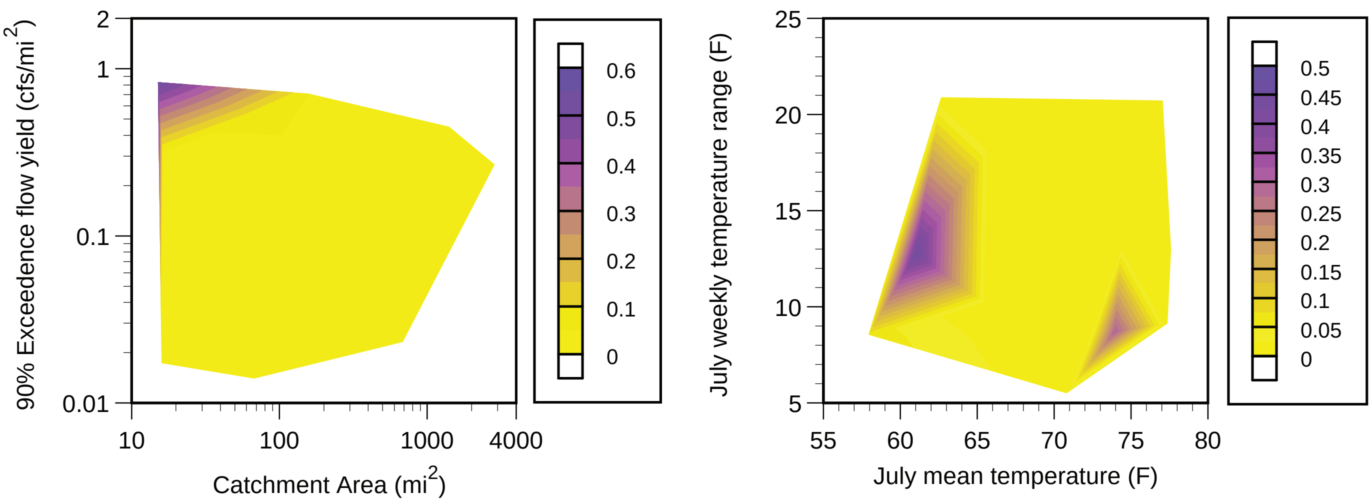
Coho salmon



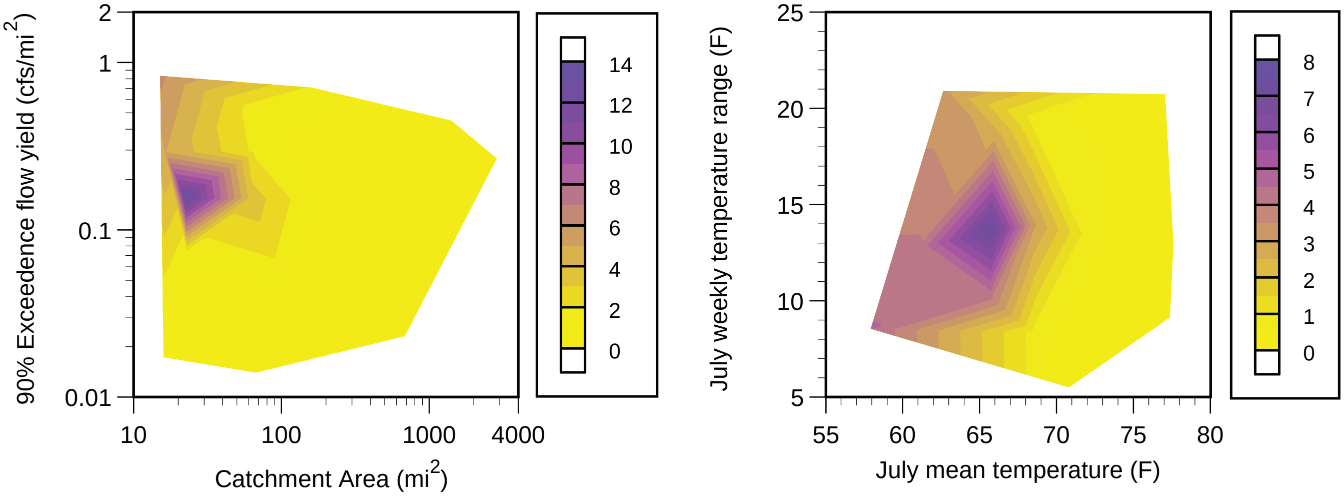
Rainbow trout



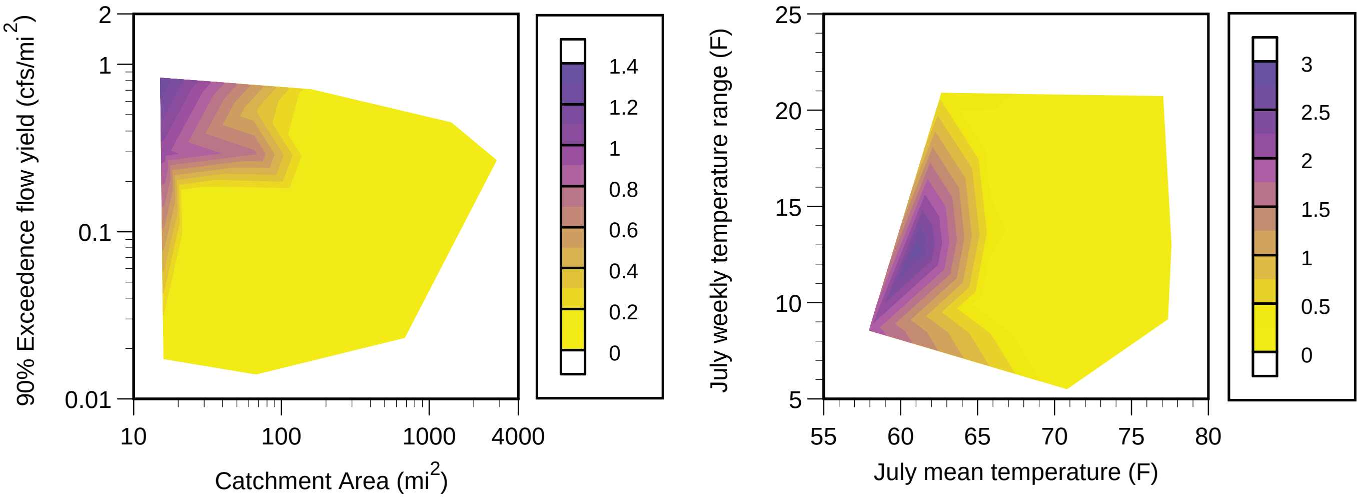
Chinook salmon



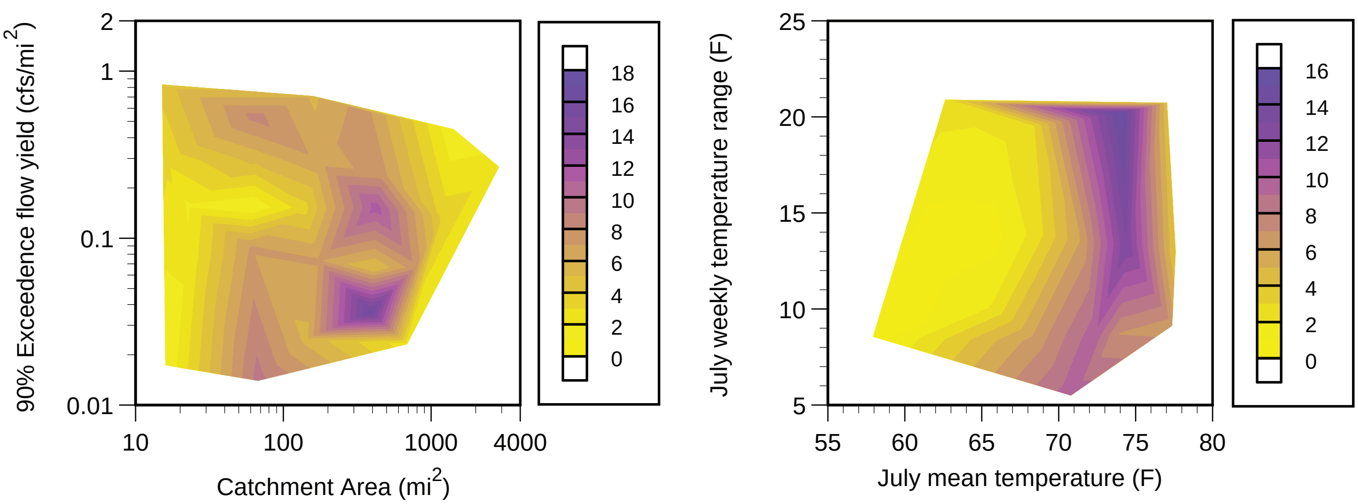
Mottled sculpin



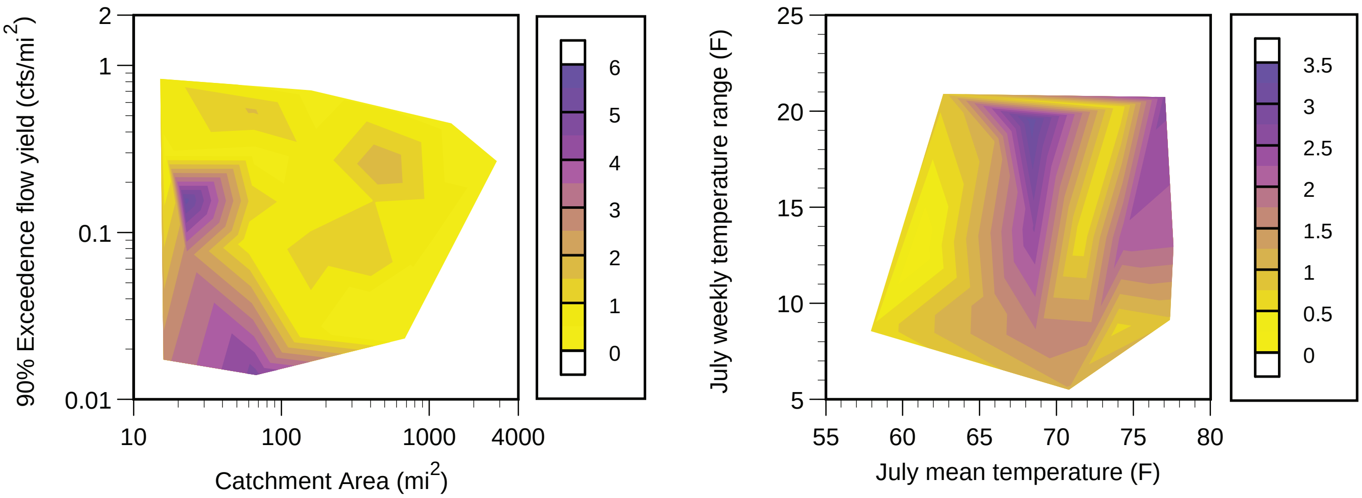
Slimy sculpin



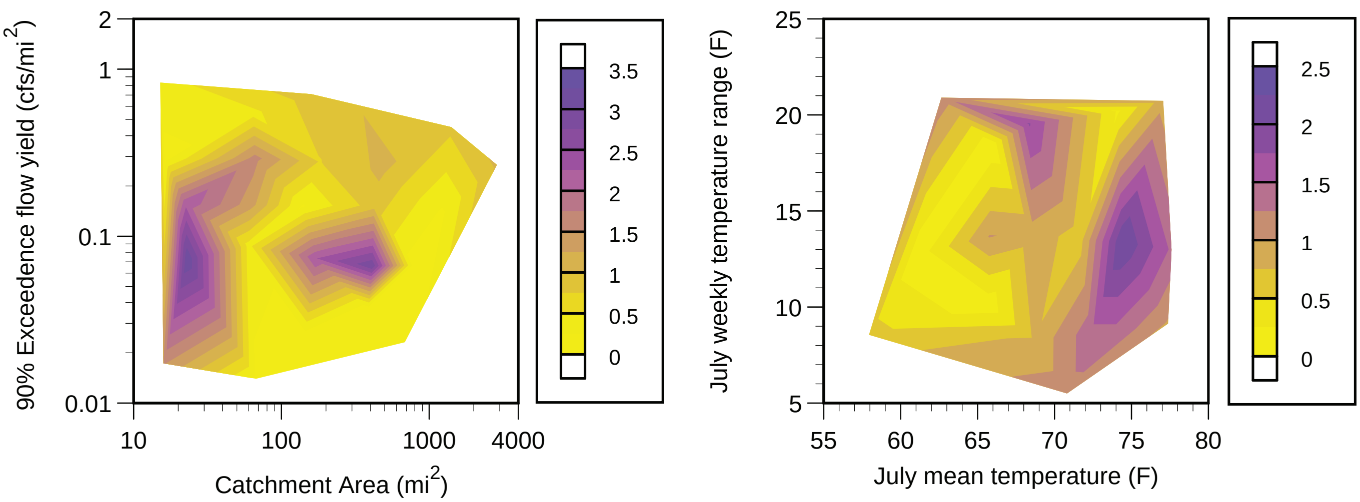
Rock bass



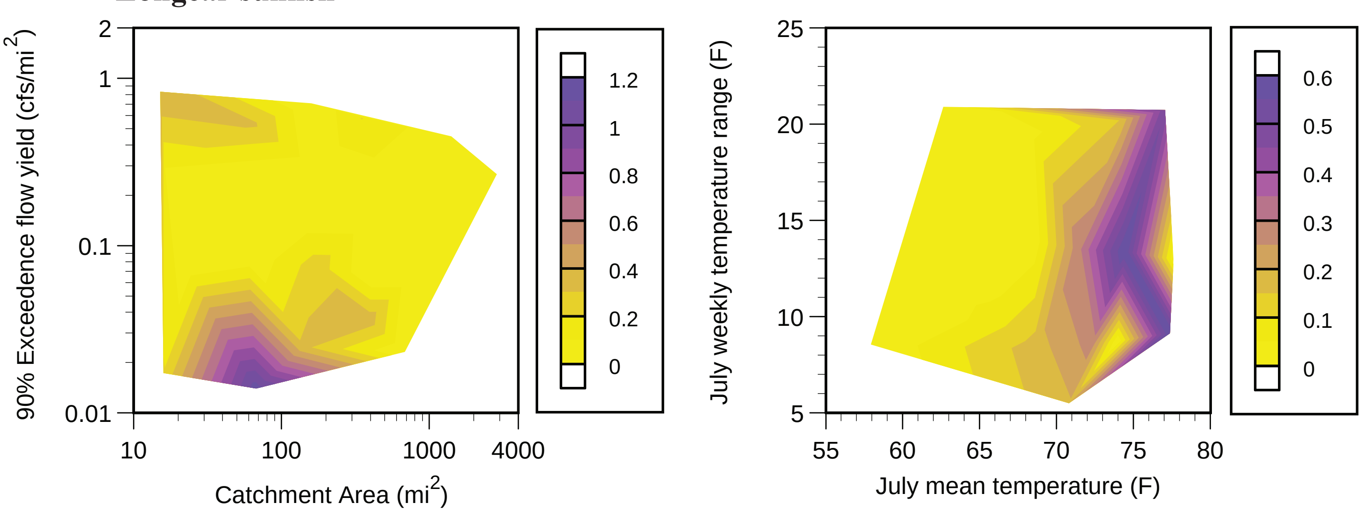
Green sunfish



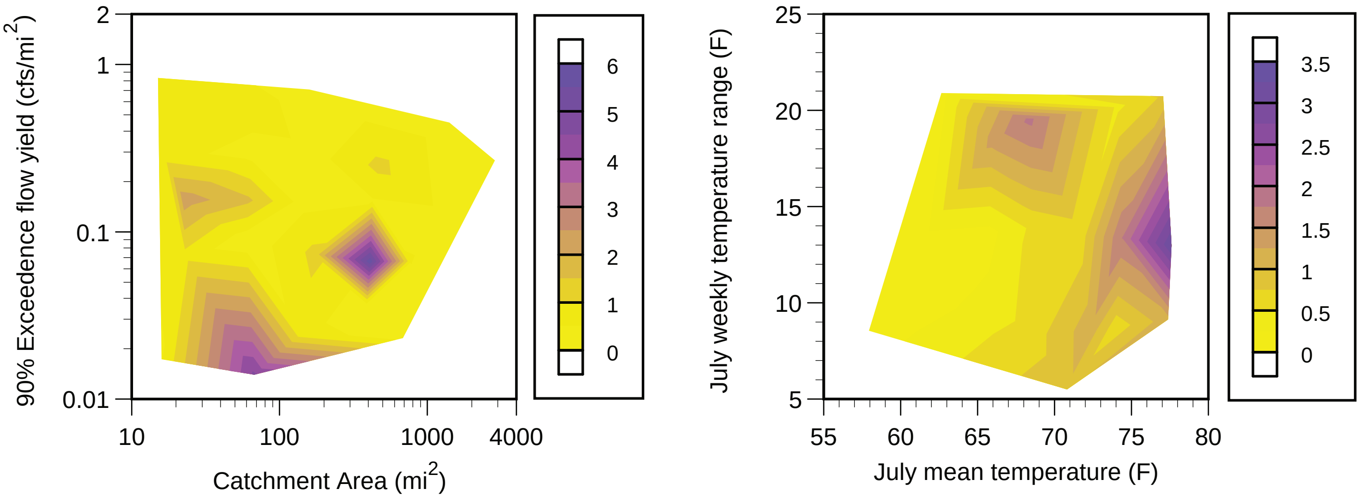
Bluegill



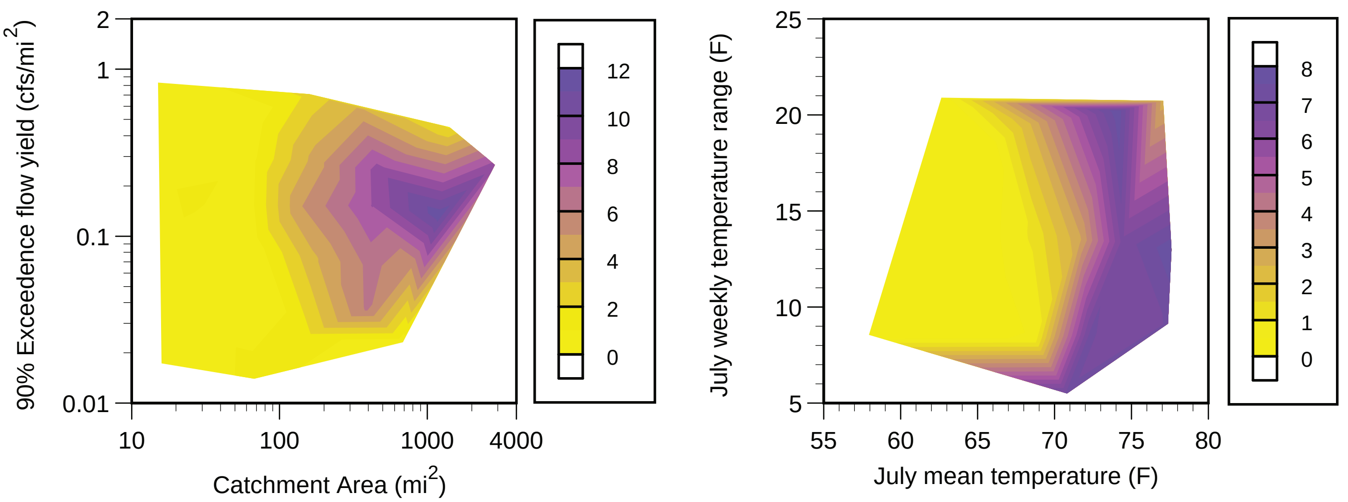
Longear sunfish



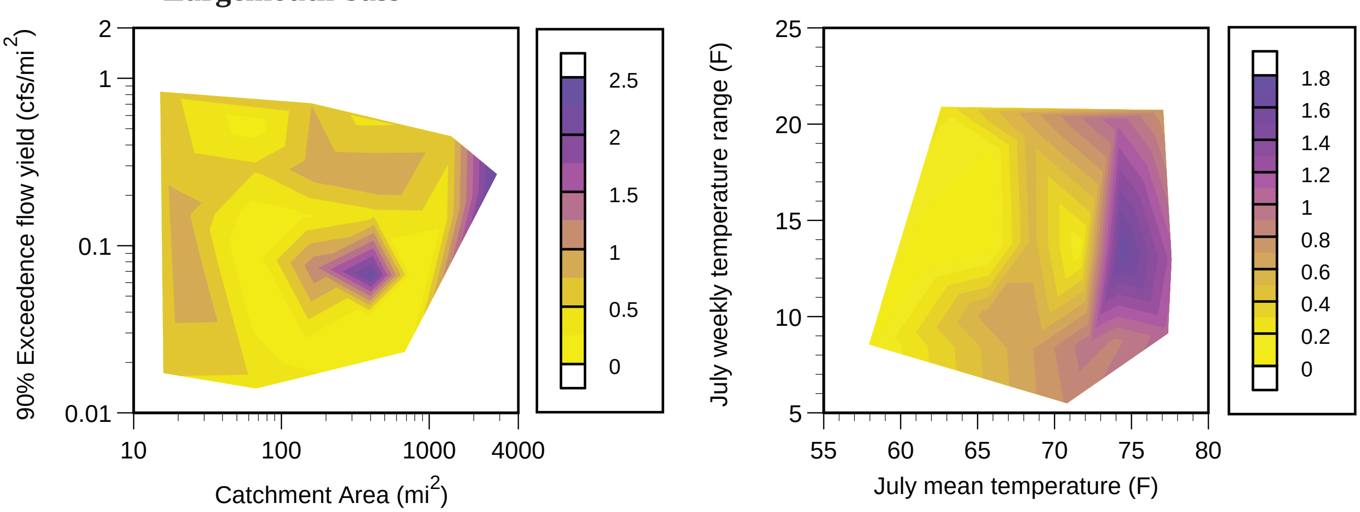
Pumpkinseed



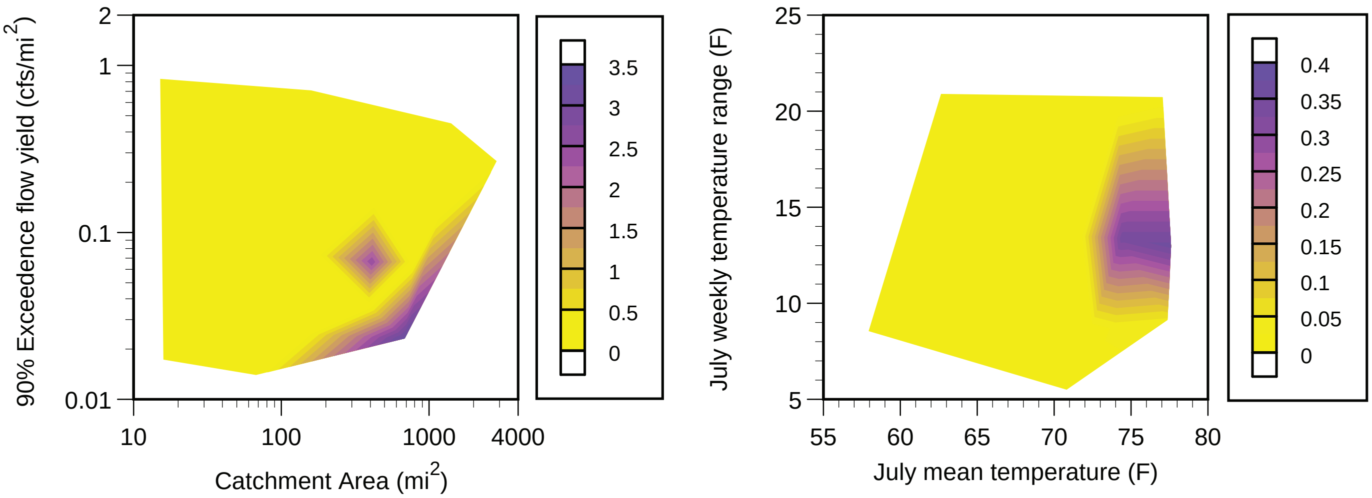
Smallmouth bass



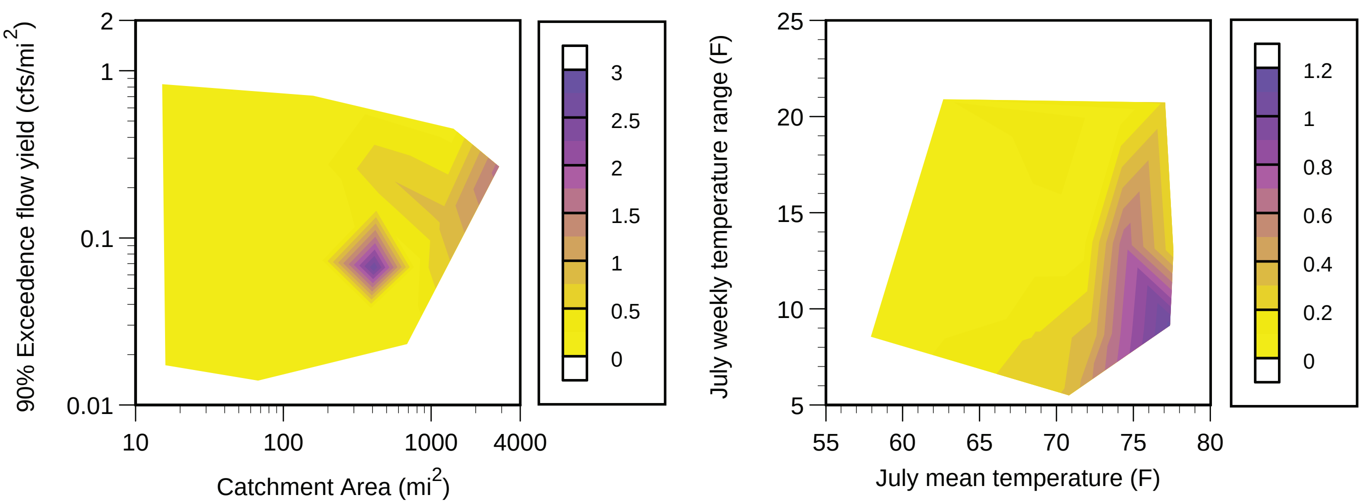
Largemouth bass



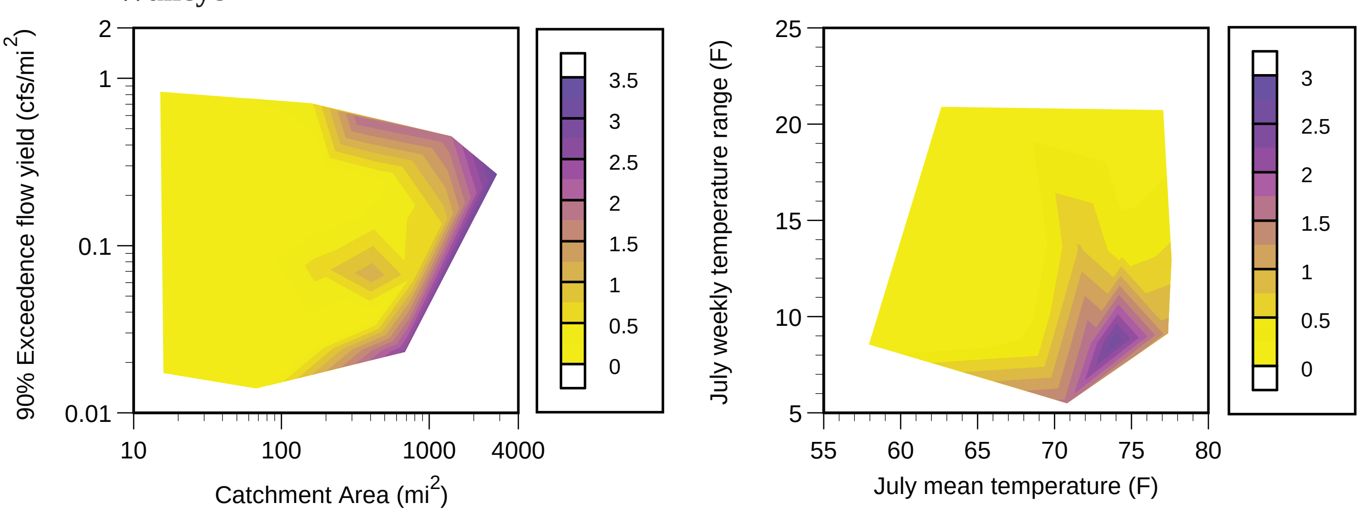
White crappie



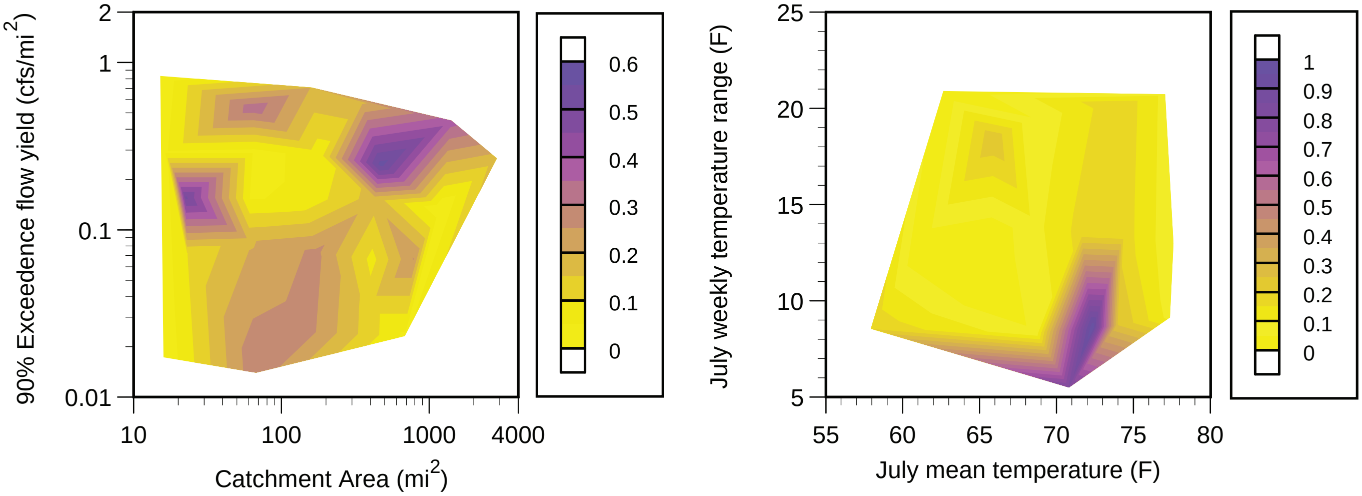
Black crappie



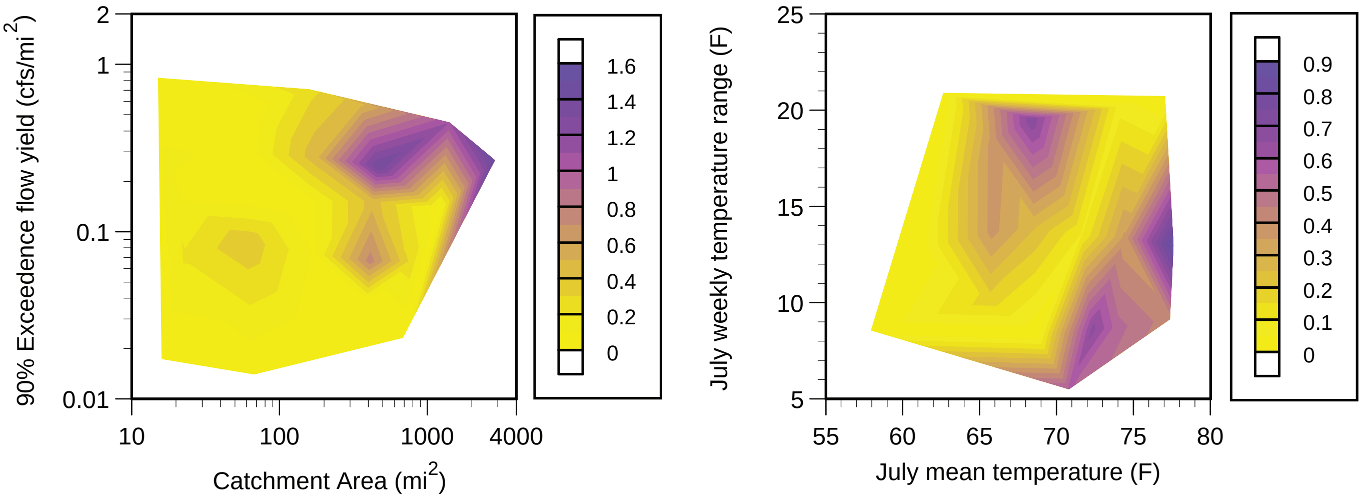
Walleye



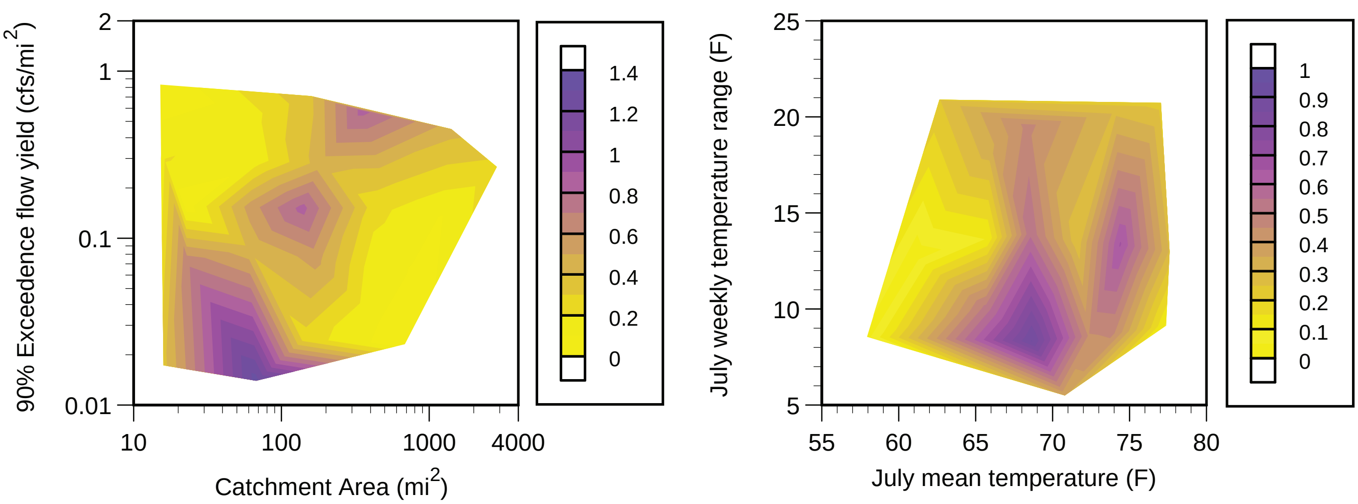
Yellow perch



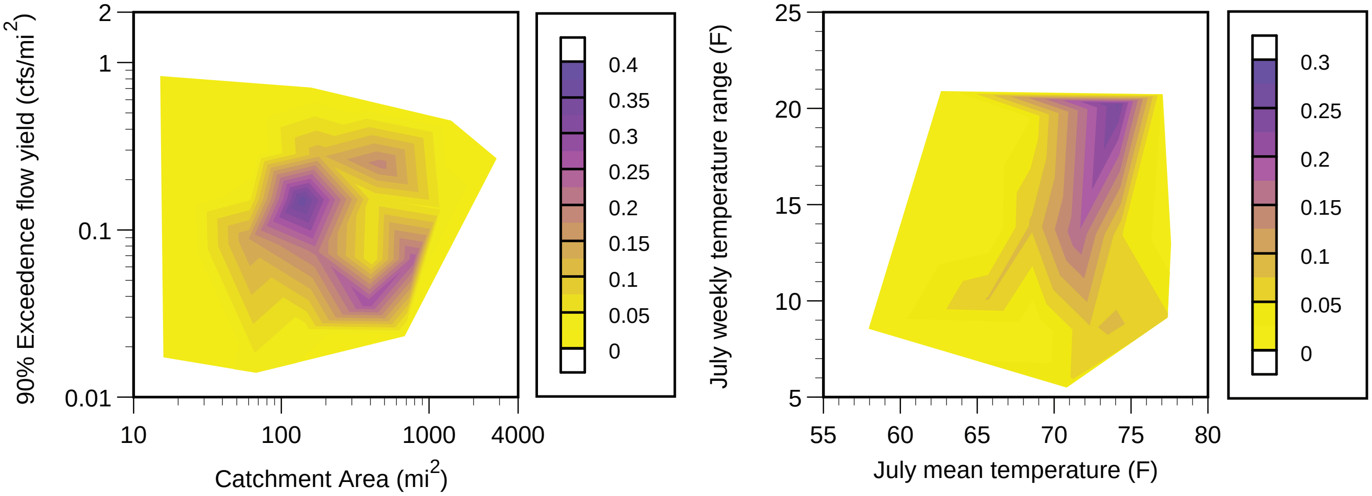
Logperch



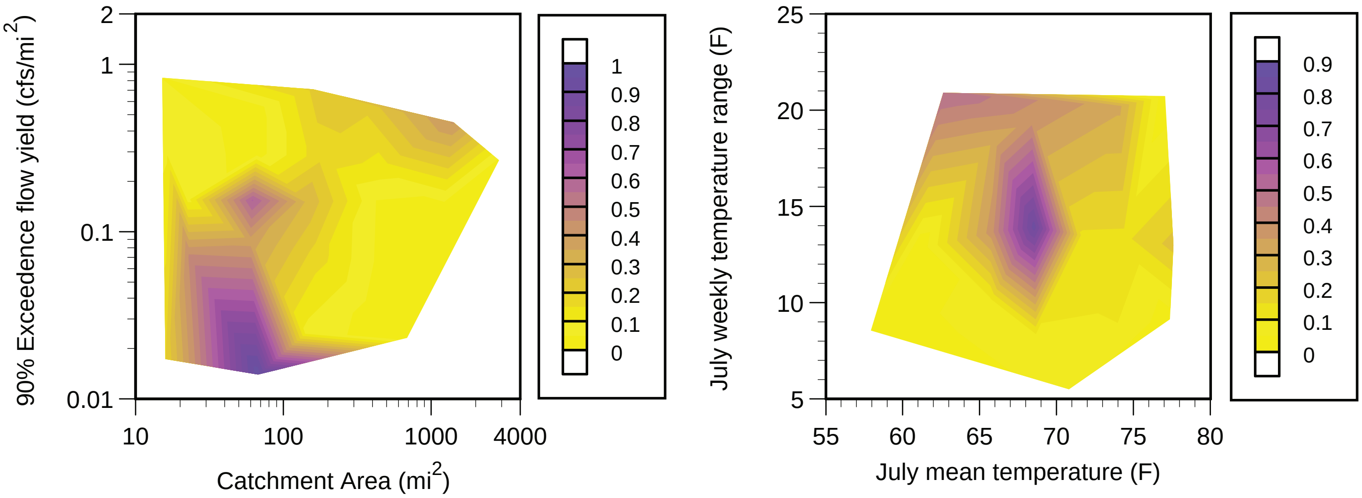
Blackside darter



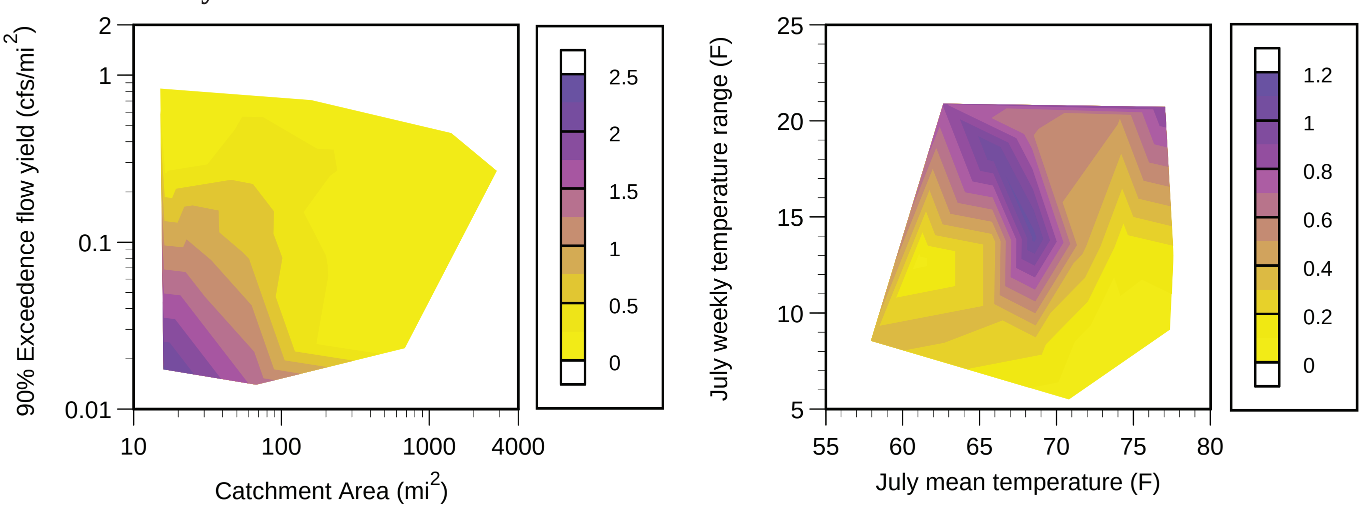
Greenside darter



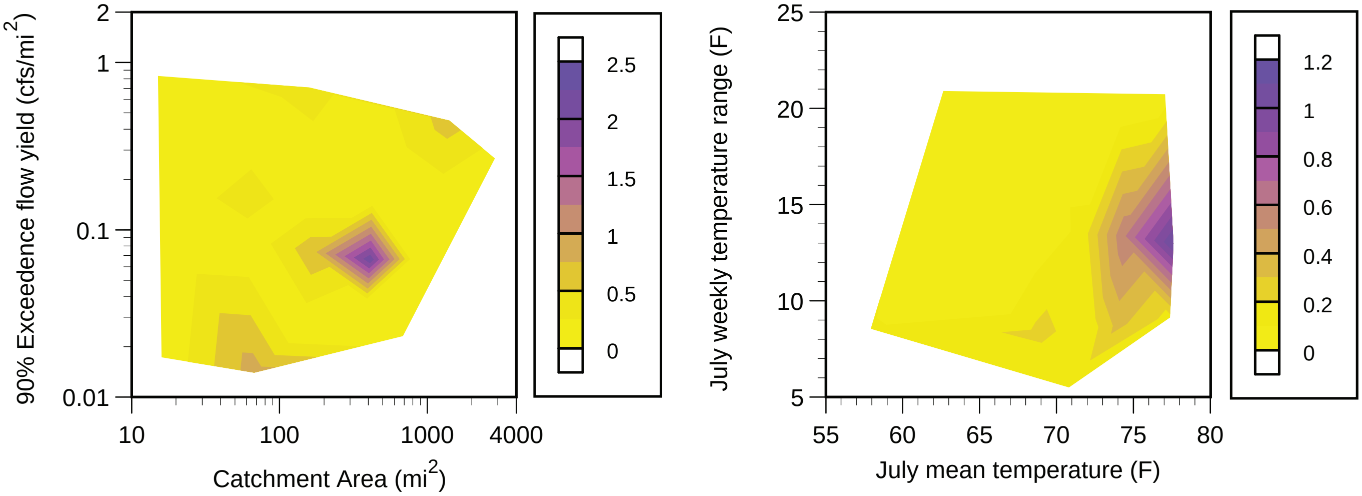
Rainbow darter



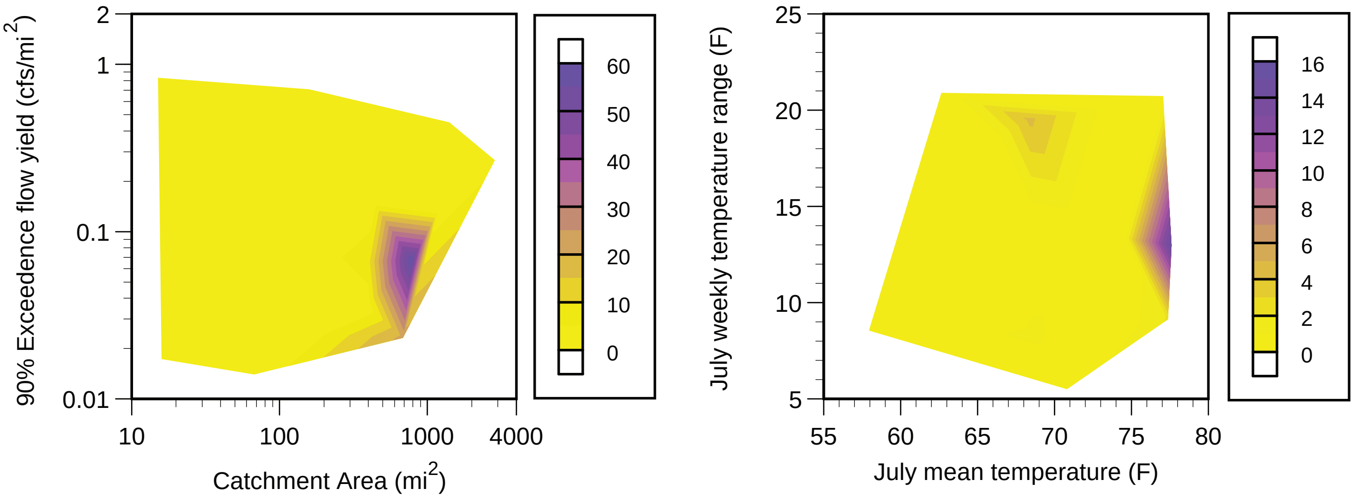
Johnny darter



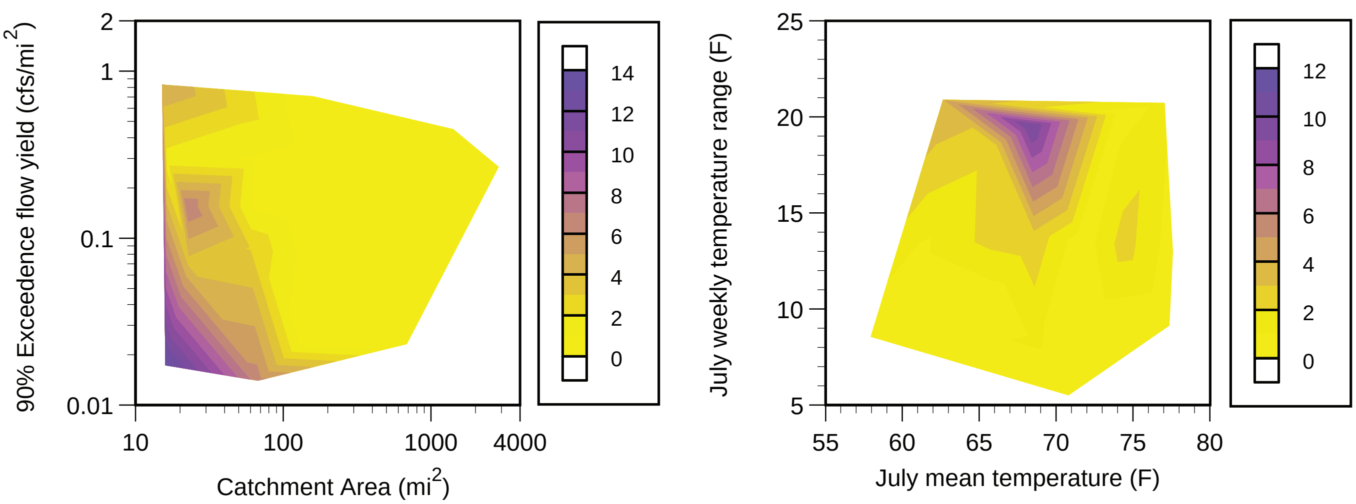
Bowfin



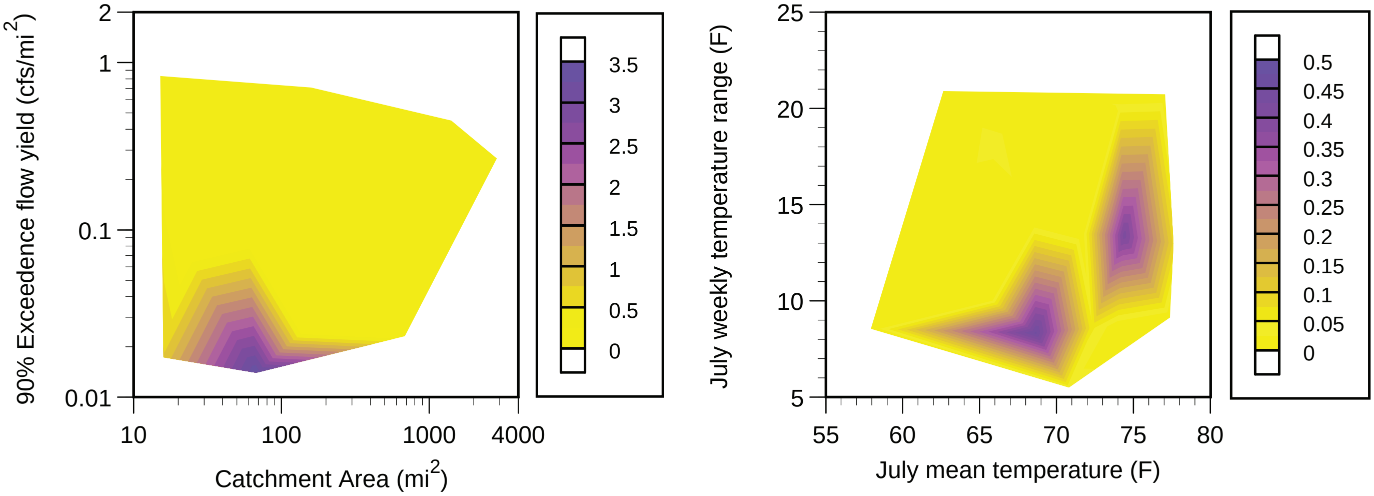
Gizzard shad



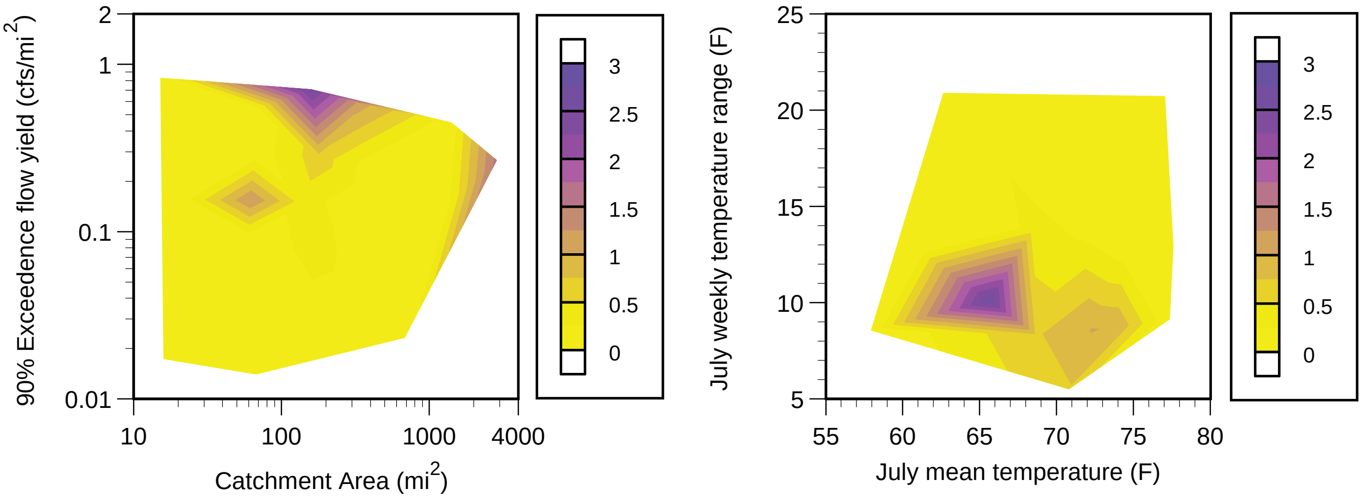
Central mudminnow



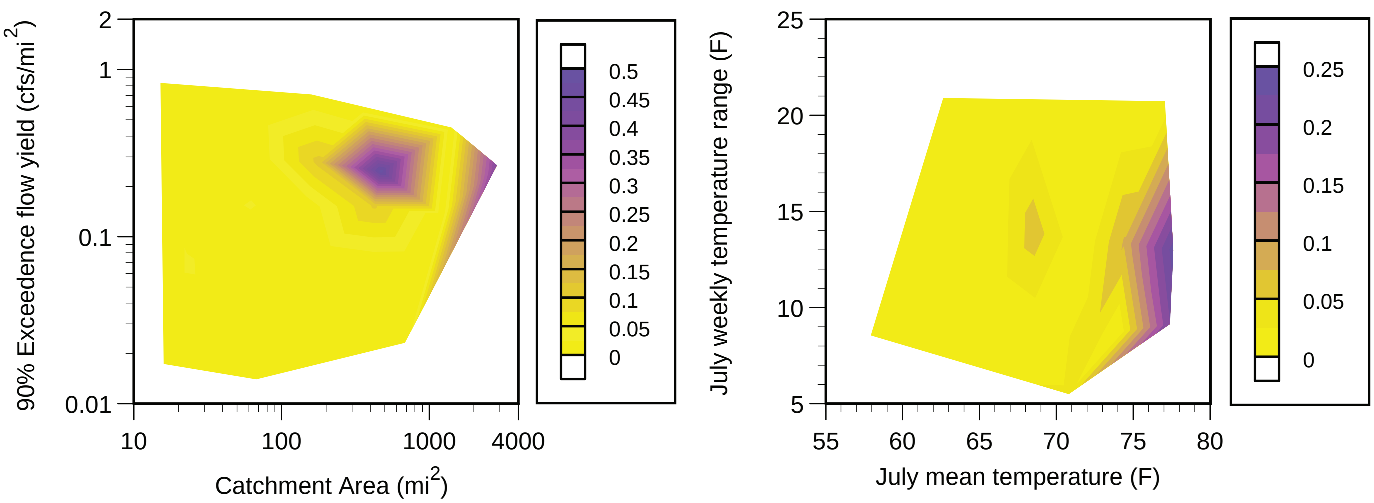
Pirate perch



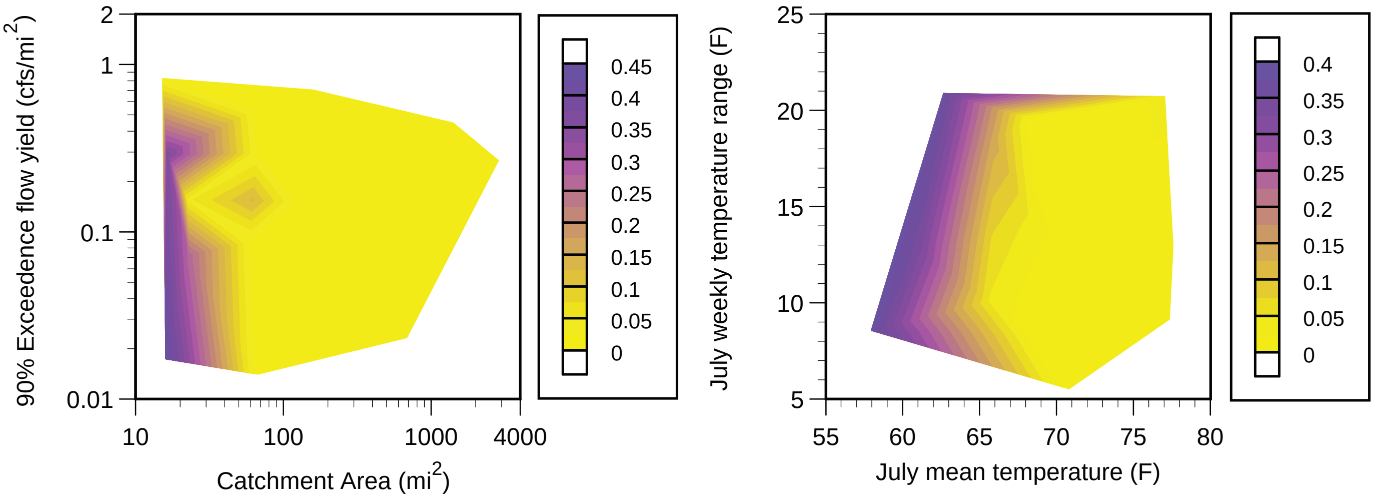
Burbot



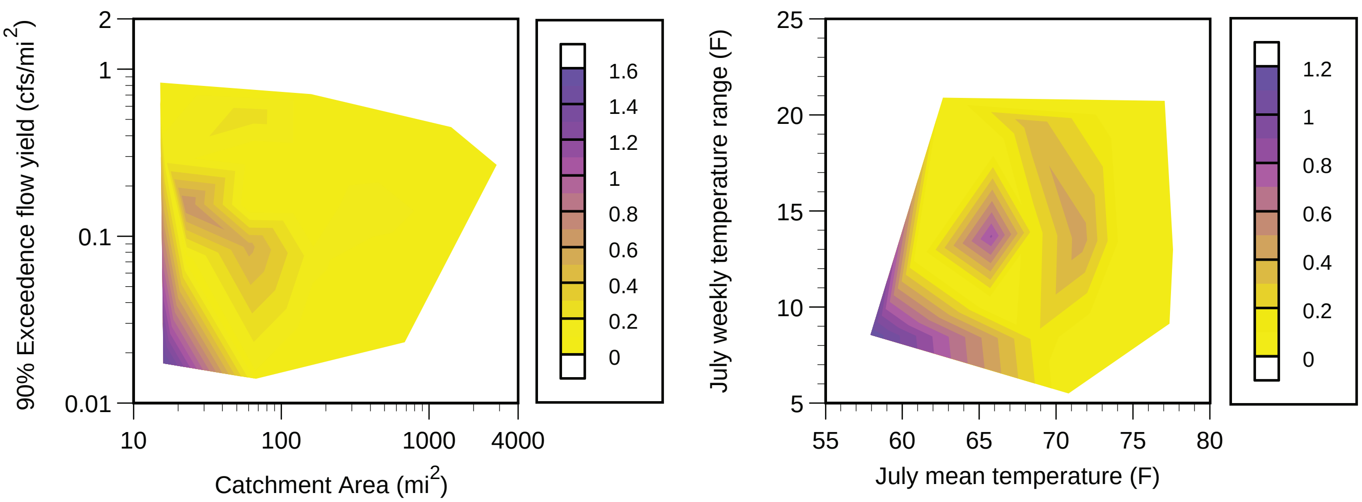
Brook silverside



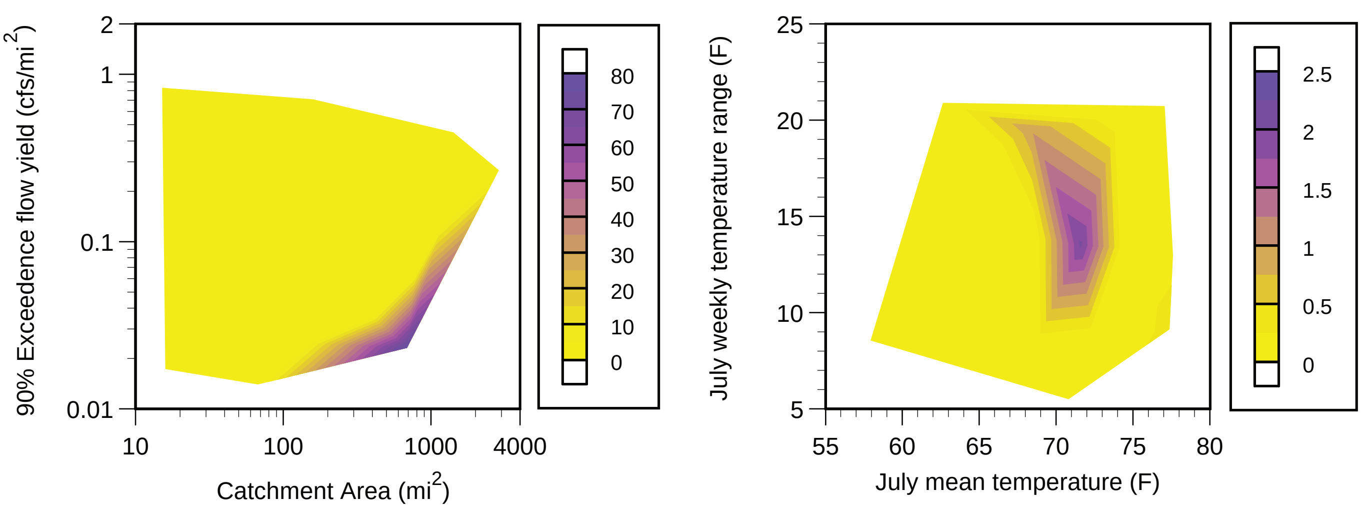
Brook stickleback



Hybrid sunfish

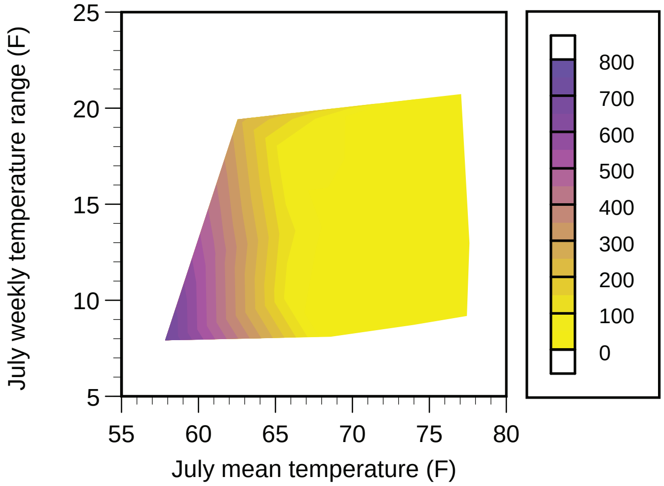


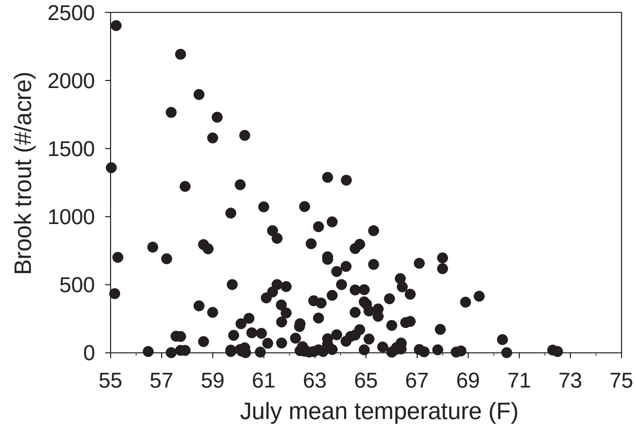
Freshwater drum



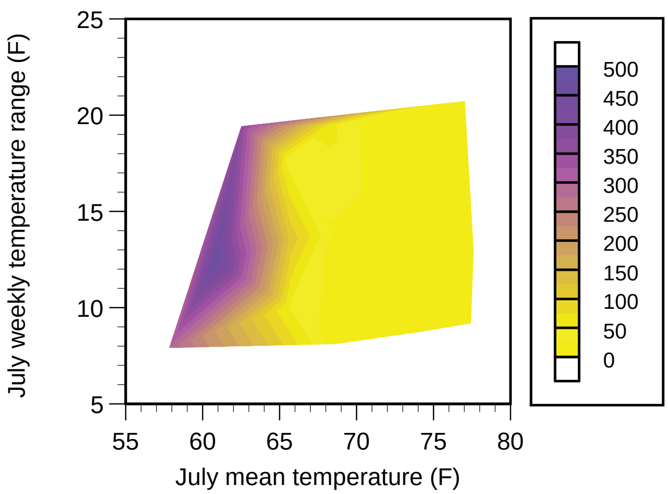
4. Numerical density (#/acre) vs. temperature

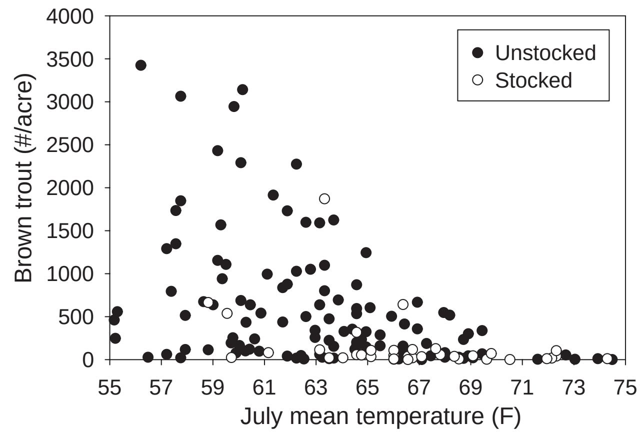
Brook trout





Brown trout





Rainbow trout