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Evaluating Water Temperature, Habitat and Fish Communities in Candidate Coolwater Streams in Illinois

Leon C. Hinz Jr., Brian A. Metzke,
and Ann Marie Holtrop

Prepared for: Illinois Department of Natural Resources

State Wildlife Grant / Project Number (T-13-P-001)

INHS Technical Report 2011 (21)
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Executive Summary:

Coolwater streams are less common in Illinois than their warmwater counterparts, but because of their unique temperature patterns they have the potential to harbor biota not typically found in warmwater streams. However, these systems are poorly understood and few attempts to define and characterize coolwater streams have been made in Illinois. This study was designed to provide a comprehensive evaluation of coolwater streams as a foundation for managing these resources.

The primary objectives of this study include validating initial attempts to locate cool streams, conducting *in situ* measurements of stream temperature throughout Illinois, characterizing physical components and biota in cool streams, and evaluating methods for rapid estimation of stream temperature. We were able to obtain 280 temperature records from 232 locations collected between 1999 and 2010 (early collections from previous studies). More than one third (35.3%) of sampled locations were classified as cold or cool (<21.0 ^{o}C mean daily July temperature). Although this proportion is artificially high since we targeted streams we suspected to be cool for monitoring in this study, one in five (20.8%) of our random survey of wadeable stream sites was observed to have coolwater conditions. In addition, maps of their distribution indicate that they are fairly common in some watersheds (e.g., Apple River, Rock River, upper Kishwaukee River).

Prior to initiation of this study, potential coolwater streams were identified using the locations of fish species considered indicators of cool temperatures and a GIS derived model of potential groundwater discharge. Observed stream temperatures revealed that the majority of these fish species were not reliable as indicators of cool conditions and that the groundwater model was effective only under certain conditions. However, the distributions of four fish species (brook stickleback, longnose dace, mottled sculpin, brown trout) correlated well with cold and cool temperatures, and indicator analysis revealed a coldwater fish community type. Coolwater and warmwater fish communities were generally similar in their species makeup. Although it was beyond the scope of this study combining multiple characteristics into predictive models may hold promise for differentiating stream thermal patterns amongst Illinois streams.

Landscape features, instream habitat, vegetation, fish, mussels, and macroinvertebrates were evaluated in streams where temperature data were available in an effort to discover characteristics that might aid in rapid estimation of thermal conditions. Few physical characteristics correlated well with stream temperature, and conclusive patterns related to prediction of thermal regime remain elusive. Vegetation character and macroinvertebrate taxa (including mussels) from summer collections were not related to coolwater conditions. Overall, few individual characteristics were related clearly to temperature.

Models derived temperature classes were reviewed and revised for stream segments throughout Illinois as part of this study. Model predictions were more accurate in identifying the thermal character of stream segments than the biological indicators that were examined in this study. However, only a small fraction of all stream segments have been monitored for temperature and additional validation of the model is needed.

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Project Overview:

Coolwater streams can be defined many ways, but most generally they are streams that have low summer water temperatures due to input of groundwater via springs, seeps through the stream channel. Coolwater streams have been studied throughout much of the United States, but in the southern portion of the Midwest these systems are presumed to be uncommon and are rarely evaluated. Streams are thus generally considered warmwater in these areas and temperature monitoring is rare unless directly associated with springs or industrial discharges. However, the presence of fish species associated with cooler waters and anecdotal evidence of cool conditions based on research and monitoring for other purposes suggests that coolwater streams occur in Illinois.

Recent studies regarding the distribution and characteristics of cool streams have been conducted in the Midwest (e.g., Aquatic Research Center of the Indiana Biological Survey 2007, Iowa Department of Natural Resources 2004, Lyons *et al*. 2009, Wehrly *et al*. 2003). Although these studies vary with respect to definition and classification of cool streams, each has a common theme; stream thermal regime is broken into multiple categories and each thermal category has its own unique characteristics. Lyons *et al*. (2009) and Wehrly *et al*. (2003) divide stream temperature into three or four categories that are defined by fish community structure. Each category has its own expectations in terms of thermal patterns and composition of biota. Studies from Iowa (Iowa DNR 2004) and Indiana (IBS 2007) recognize biological differences between coolwater and warmwater streams. Taken together, these studies highlight the unique biotic and physical qualities of cool streams in the Midwest.

Differences amongst studies conducted in Wisconsin, Michigan, Indiana, and Iowa emphasize the need for coolwater research in Illinois. Some of the most basic questions related to distribution and characterization of cool streams in Illinois cannot be answered due to lack of information about these systems. By expanding state agency and scientists' comprehension and awareness of cool streams, these rare systems and the unique biota within them can be more adequately protected.

This study attempts to fill gaps in understanding of coolwater streams in Illinois by providing fundamental knowledge regarding the distribution and characteristics of these systems. This objective was approached by measuring thermal patterns in streams and by examining potential relationships between temperature and biotic or physical characteristics at multiple scales. Additional data and analyses related to methods for rapid detection (i.e., indicators of cool conditions) of cool streams are also presented. Findings are described below under the Jobs outlined in the original grant agreement (T-13-P-001).

Job Outcomes:

Job 1: Review list of candidate streams and indentify a subset of those streams for validation.

Defining thermal categories:
Although many methods for categorization of stream thermal patterns exist, this study uses the mean daily July temperature (Wehrly *et al*. 2003) to quantify stream temperature. Categorical temperature thresholds defined by Wehrly *et al*. (2003) are: coldwater ≤18.9 °C, coolwater 19.0-21.9 °C, warmwater ≥22.0 °C. Mean daily July temperature provides a measurement of the average condition for a stream. Because aquatic biota can tolerate temperatures above preferred levels for short periods of time and Illinois streams can experience large diel variation in temperature, an average measure of temperature is preferred over one based solely on maximums. Accordingly, we used mean daily July temperature to determine thermal categorization for all analyses requiring set temperature thresholds.

Creation of preliminary cold-/coolwater streams list:
Prior to initiation of this study, candidate cold-/coolwater streams in Illinois were identified by evaluating distribution of fish species with potential as indicators of cold/cool thermal conditions and by locating stream reaches with potential for groundwater discharge. Fish species used during this process were identified through literature review and by professional judgment of thermal preferences. Seventeen species were selected for use as cold-/coolwater indicators (Table 1). Groundwater discharge was estimated using output from an Illinois specific version of a GIS model of subsurface water potential (referred to here as the Darcy Model, Baker *et al.* 2003). This model uses Darcy's Law, which incorporates hydraulic conductivity and slope to determine likelihood of groundwater discharge. Darcy model outputs were used to calculate a value for each stream arc (confluence to confluence stream reach) that represents the probability that groundwater will enter (or leave) the stream. For the purposes of this selection process, whole-watershed Darcy values were calculated for each stream arc and those arcs that were at least one standard deviation below (negative values) the mean were considered groundwater discharge streams (i.e., those with high potential to receive groundwater inputs; Holtrop *et al.* 2005). Darcy values for the whole-watershed (Figure 1) were used because the watershed scale was correlated significantly with the existing temperature model (see Job 3 below for temperature model explanation).

An initial list of potential coolwater streams was developed by the Illinois Department of Natural Resources (IDNR) prior to initiating this project from the complete complement of Illinois Environmental Protection Agency (IEPA)/ IDNR sample sites using two criteria: the presence of one or more of the seventeen indicator fish species (distributions presented in Appendix A), or high potential for groundwater discharge (based on the Darcy Model) in addition to presence of at least one of those species. One hundred and ninety-nine sites were identified using these two methods (Figure 2): 88 sites based on presence of fish alone and 111 based on fish present in areas of high groundwater potential (Table 2).

Validation of candidate streams list:
Three methods (indicator fish list, Darcy model, and stream summer water temperature model) were available to locate potential cold-/coolwater streams in Illinois during this project. However, none of these three methods had been validated with *in situ* data collection, and therefore a subset of predicted cold-/coolwater sites was chosen for measurement of thermal characteristics. Sixty-six sites (30 of the 88 candidate cool sites based on fish, and 36 from the 111 candidate cool sites based on fish and groundwater) were successfully sampled, and summer temperature patterns are summarized as detailed below (Job 2 and Job 4).

Job 2: Characterize the thermal regime, habitat (e.g., channel morphology), and vegetation in each stream identified in Job 1.

Validation of subset of sites from the candidate streams list:
Temperature data loggers (Onset Computer Corporation: HOBO Pendant, HOBO Water Temp Pro v2, or StowAway TidbiT) were placed in stream segments selected from the initial list of candidate locations for validation of thermal status (Job 1). Most loggers were set in May or June once water levels approached summer (baseflow) conditions. Temperature was recorded at one hour intervals and loggers were generally retrieved from streams after summer data had been collected. Some data loggers were maintained in the stream throughout the year; however, this frequently resulted in the loss of the logger during high flow events in late winter and early spring. Mean daily July temperature was calculated for each site and was used to place each stream into a thermal category (cold, cool, warm). Mean daily August temperature was used if July data were incomplete (see *Validation of assessment methods* in Job 3 for justification of this substitution). Candidate coolwater sites (Figure 2) were compared to thermal category based on observed temperatures. Measured temperatures confirmed that 12 of the 30 sites identified as coolwater candidates based solely on fish (i.e., 40%) were indeed cool or cold (Table 3). Additionly, 29 of the 36 sites identified as coolwater candidates based on fish and the Darcy Model (i.e., 80%) were confirmed as cool or cold (Table 3). These results suggest using multiple indicators (i.e., fish and groundwater) increases the accuracy of predicting locations of cold-/coolwater streams. Furthermore they suggest that the initial list of coolwater indicator fish contained species that are not good indicators of coolwater conditions (i.e., many species were warmwater or eurythermal).

Habitat and vegetation data were collected at candidate sites where temperatures were monitored and will be discussed below (Job 4) with similar information from sites identified using other methods (Job 3). An evaluation of spatial temperature patterns (i.e., between and within selected and adjacent reaches) is provided in Job 4.

Job 3: Determine availability and applicability of other data to predict additional coolwater streams.

The initial coolwater candidate list was developed using potential indicator fish species and a groundwater model related to physical characteristics of stream segments. To further refine identification of coolwater streams, we used output from a model of stream temperature developed in a previous project (Holtrop *et al.* 2006 [T-2]) and searched for commonalities in biological, habitat, and landscape characteristics within predicted cool stream segments that could be used to identify potential thermal conditions in Illinois streams that had not been monitored. Characters used in this analysis include presence of fish and macroinvertebrate species, fish community structure, habitat and landscape features, and presence of aquatic and riparian vegetation.

Additional assessments of instream thermal characteristics were conducted to gain an understanding of lateral and longitudinal temperature variation, interstitial temperature patterns, and the degree to which sun and shade impact temperature. Characterization of cold-/coolwater streams (including evaluation of thermal thresholds) and the utility of these characteristics as thermal predictors will be discussed below (Job 4). Here we will focus on validation of the assessment methods and using computer-based (modeling) methods of predicting stream temperature patterns.

Validation of assessment methods:
If temperature thresholds for each thermal category have been appropriately set, then differences in temperature patterns should be apparent. However, given that streams were categorized using a single summary statistic based on data collected during a limited period of time (i.e., mean daily July temperature during one year), the uncertainty associated with the classification and any conclusions based on it is dependent upon our ability to detect actual differences in thermal regimes. We calculated mean weekly temperature at noon for sites within each thermal category to determine if sufficient discriminatory power exists for this assessment technique. Between calendar days 134 and 274 (approximately mid May to early October) each thermal category exhibits a unique temperature pattern (Figure 3), with the largest degree of distinction occurring between calendar days 163 and 247 (approximately mid June and early September). The largest difference between warm and cold sites and warm and cool sites occurs on calendar day 212 (late July), while cold and cool sites differ most in late June on day 177 (although July contains four of the eight largest differences between these two categories). These results indicate that summer, especially July, is the best period in which to observe distinctions in stream temperature between thermal classes.

When July temperature data were unavailable or incomplete, August data were used to determine thermal category. We examined differences in classifying stream segments when using the thermal record for July or August in an effort to validate this substitution. Mean daily temperature was compared between the two months for each site where data were available to assess variation in this summary statistic and for differences that may lead to changes in thermal categorization. Complete July and August data sets were available from 142 monitoring records at 125 sites. The mean difference between July and August mean daily temperature was 0.27 ^{o}C (July value minus August value) with a maximum difference of 6.02 ^{o}C for July minus August values and 6.57 ^{o}C for August minus July (Table 4). As mean daily temperatures are used to determine thermal category of streams, variation in thermal category between July and August is most relevant to validating use of August temperature data. No clear pattern was observed when categories were compared between July and August. Thirteen monitoring events (20%) would have been categorized at least one category warmer (e.g., cold to cool) when using August data instead of July, while 25 (22%) would have been categorized cooler (e.g., warm to cool).

The absence of any clear pattern between July and August stream temperatures suggests that differences between these temperatures are related to natural variability in weather patterns. Differences in July and August air temperature data (ISWS 2010) were compared with differences in July and August mean daily water temperature at individual sites to examine the relative influence of regional weather patterns on stream temperature patterns (Table 5). Difference in monthly mean air temperature in Springfield, IL exhibited a similar pattern to that of difference in mean daily water temperature (Figure 4). This suggests that using August temperature data to determine a thermal category is also appropriate. Observed shifts in thermal category occur only in approximately 21% of samples and the direction of these changes was not predictable without additional knowledge of local air temperatures during the monitoring period.

Modeling stream temperature in Illinois:
Prior to this study, IDNR had collected temperature data in Illinois streams primarily during two studies. The first was the Pilot Watershed Study (Dodd *et al*. 2005 [F-136-R]) that collected water temperature as part of a habitat characteristic analysis at four pairs of sites in selected river basins (i.e., Spoon, Embarras, Kaskaskia, Cache). The second was an effort with collaborators in Michigan and Wisconsin that examined water temperatures and a host of other characteristics at representative sites across the region (Holtrop *et al*. 2005 [T-3], Holtrop *et al.* 2006 [T-2]). Summer temperature records were collected at 77 sites in Illinois (Figure 5) during these two efforts, representing 68 different streams (there were multiple sites per stream in the Pilot Watershed Study).

Temperature summaries from 72 of these sites were used to develop multiple linear regression models that estimate summer water temperatures using a stepwise regression procedure (Holtrop *et al.* 2006). Several models were developed for different temperature summaries (e.g., maximum daily maximum temperature for June - September, minimum daily mean temperature for July). We found that averaging two of the model outputs (July maximum daily mean and July minimum daily mean) gave us fewer extreme estimates of the average July daily thermal signature than using the models that directly estimated mean July daily temperature. We have expressed these averages as the mean daily mean temperature and have assigned a thermal code (cold, cool, warm) to each stream arc based on our temperature criteria (Wehrly *et al*. 2003). Model based cold-/coolwater segments made up approximately 13% of the total number of coded segments state-wide (Figure 6, Table 2).

Collection and summary of additional temperature records:
We used summaries from the available temperature model and the Darcy Model output to select additional stream segments to assess throughout the state. In addition to the 77 previously monitored sites (described above), 172 sites on 159 streams were monitored during this study (203 summer temperature records from 2007-2010). Sites for monitoring were selected by identifying stream segments that contained multiple indicators that coolwater temperatures may be present (e.g., multiple species present, extreme Darcy model values). Most of these additional sites were selected based on predicted cold-, cool-, or warmwater temperatures and characters related to physical or biotic conditions that might be associated with these thermal regimes. The remaining sites were suggested by Illinois Department of Natural Resources (INDR) streams biologists, or directly sampled by the biologists themselves during the study period. Some stream segments with existing records were also monitored during multiple years to examine interannual temperature patterns. To date we have 280 temperature records from 232 sites in Illinois (Figure 5). All sites were used for validation of Darcy Model and temperature model summaries as well as characterizations related to site-specific attributes (see Job 4) reported for this study unless specified elsewhere in this report.

Of the 280 temperature records, 34 records met the criterion for coldwater and 72 records were categorized as coolwater (Table 6). The majority of records were determined to be warmwater (174 records). Most of the cold- and coolwater streams are located in the northern third of the state (Figure 7). Only one coolwater site (IXF-01) was discovered in the southern (Shawnee Forest area) portion of Illinois. Potential relationships between spatial arrangement of thermal classes within the state and physical variables (e.g. climate, geology) are explored in later sections.

Eighty-two of the 232 (35.3%) sites monitored were cold or cool during at least one sample year, a proportion much higher than the 0.13 predicted by the temperature model (Table 2). However, this high proportion of cold and cool sites likely indicates our success at targeting these streams with our monitoring program rather than the true proportion of these systems within Illinois.

Testing temperature model as a predictor of coolwater sites:
Observed temperature summaries were compared at each site to the thermal category assigned by the temperature model (Figure 6). The model correctly associated the thermal category with the observed thermal category sixty-three percent of the time (Table 7). However, the model tended to over-predict temperatures and was thus less accurate when assigning cold (18% but some were predicted to be cool) and coolwater (30%) streams. Warmwater streams were correctly categorized by the model for 85% of the temperature records.

Revision of the Illinois Stream Temperature Model:
We selected temperature records from 207 site-year placements that occurred between 1999 and 2010 to revise the Illinois Stream Temperature Model. A primary site record included only information from the most recent recorded year available and excluded those sites that were either too small to occur on the 1:100,000 NHD or were part of the

randomly selected survey sites sampled in 2010. Secondary site records included all other records. Since the distribution of site-temperature records was skewed due to our sampling design that targeted locations expected to have cooler water temperatures we randomly selected records from the primary sites for model development that represented the observed state-wide range of temperatures. The primary site records were stratified into five thermal classes (<17.5 °C, 17.5-19.5 °C, 19.6-21.0 °C, 21.1-22.0 °C, >22.0 °C) based on their mean daily water temperatures during July. Fifty-five records selected for modeling were from the warm class (>22 °C) and the remainder were from the cooler water classes (110 records total). Ten records were randomly selected from the coldest class (<17.5 °C) and fifteen records from each of the other coolwater classes.

Mean July daily water temperatures at the primary sites varied greatly (minimum 11.4 °C, maximum 28.7 °C) with the overall average at the high end of the cool water category (mean July daily water temperature 21.7 °C). The secondary sites (97 sites-year placements with temperature records) were reserved to test the model predictions. Secondary sites had a slightly narrower range (minimum 15.0, maximum 26.9) but were slightly warmer on average than the primary sites (mean July daily water temperature 23.0 °C).

Potential predictor variables were selected from GIS based summaries of landcover/use, surficial geology, bedrock geology, weather and soil conditions, and characteristics of the stream channel developed in an earlier project (Holtrop *et al.* 2005). Specific summaries were selected at one or more scales (local channel, local riparian, upstream watershed) based on our expectation on how they would influence local water temperature. Forty-one different summary-scale combinations were included in the modeling dataset.

We developed multiple linear regression models to estimate mean summer water temperatures using a stepwise regression procedure similar to that used in the initial model development (Holtrop *et al.* 2006). Patterns of mean annual air temperature in Illinois show a relatively distinct geographic gradient associated with the north-south extent of the State's boundaries. To examine this effect we developed two major series of models that differed primarily in the direct use of site location as a predictor. Models that allowed latitude and longitude (location of site) to be selected as predictor variables consistently included catchment size characteristics (drainage area and link number), air temperature (July max, July mean, and mean annual growing degree days), and the presence of bedrock near the surface. Models that excluded latitude and longitude as possible predictors included catchment size (drainage area), air temperature (mean annual air temperature, July-maximum, July-mean, growing degree days) or precipitation, and surficial geology associated with higher infiltration (coarse) or runoff (fines) as predictors. Overall models that included site location had better fits then those that did not. Since our objective was to identify thermal conditions for wadeable streams in Illinois we selected a single model (Table 8) that included information on the site location and applied the model to stream reaches statewide (Figure 8).

Mean differences between modeled and observed temperatures averaged 0.5 °C and ranged from - 6.6 °C to + 6.6 °C of the observed mean daily July temperature based on

204 sites with existing records. Observed temperature summaries were compared at each site to the thermal category assigned by the temperature model. The model correctly associated the thermal category with the observed thermal category sixty-nine percent of the time using the criteria from Wehrly *et al.* 2003 (Table 9). This model did a better job predicting coldwater (50%) and coolwater (65%) stream segments then the earlier model but was slightly less efficient at predicting warmwater locations (74%). If we combine cold and coolwater predictions into a single group (e.g., non-warmwater) the model correctly classified these segments 85% of the time and had a 78% overall correct classification rate (Table 9).

Testing Darcy Model as a predictor of coolwater sites:
Stream reaches with potential groundwater inputs were identified by locating arcs with a Darcy Model value less than or equal to negative one standard deviation (SD) from the statewide mean at the watershed scale (Figure 1). Stream segments meeting this threshold were considered potential cold-/coolwater streams for this analysis. In total 1766 stream arcs (3.7% of the total) were predicted as cold or cool based on Darcy Model values (Table 2). Observed temperatures from each site were compared with the Darcy model value assigned to the corresponding stream segment (arc).

Less than four percent of all stream reaches in Illinois have Darcy Model values ≤ 1 SD from the mean (Table 2). Twenty-three percent of the stream reaches with measured cold or cool temperatures had Darcy Model values ≤ 1 SD. Overall this method assigned thermal categories correctly 70% of the time (Table 10) for all sampled sites. Only two sites with an observed warmwater thermal regime had a Darcy Model value this low (99% of sites with higher values did not meet the coolwater criteria). Therefore, this method appears to be an efficient way to eliminate sites with high Darcy Model values as potential coolwater reaches. Caution must still be taken in assigning such reaches to a coolwater category since a few stream segments with these low Darcy Model values were observed to have warm water thermal characteristics. We recommend targeting stream reaches with very low Darcy Model values for in situ temperature monitoring to determine the current thermal regime.

Another approach for using the Darcy Model as a predictor of thermal regime is to identify thresholds at which streams can be divided into thermal categories. Upon observing the numerical distribution of Darcy Model output for monitored streams, a value of -50 appears to be a reasonable prediction threshold (Figure 9). A positive relationship occurs between water temperature and Darcy Model value with values higher than -50 generally associated with warmwater conditions and lower values with coolwater conditions. Overall, 69% of sites with thermal records were correctly classified using this -50 threshold for the Darcy Model value (Table 10). Much like using the standard deviation approach, Darcy Model values were less accurate at classifying cold-/coolwater locations (22% correctly classified) than warmwater sites (98%).

Job 4: Characterize a subset of streams identified in Job 3.

Selected physical and biological characteristics were sampled at the majority of the 232 sites with temperature records to identify patterns between sites within the same thermal category and to look for differences between categories. Spatial and temporal temperature patterns were examined to describe the longitudinal and temporal extent of observed thermal conditions.

Random site selection and monitoring:
As described in Job 3, most temperature loggers were placed at sites with the potential for cool temperatures (e.g., presence of potential coolwater species, low Darcy Model values), a method which likely created bias towards sampling coolwater streams. In an effort to improve our understanding of the distribution and abundance of the thermal character of streams in the state, 30 stream segments were randomly selected from all potential stream segments in Illinois. These random segments were chosen using a stratified selection method where small and large streams (i.e., first order and greater than seventh order) and those segments with poor access (i.e., no road crossings) were removed from the selection pool. A group of 30 alternate segments were chosen during to be used as substitutes if an initially selected segment was deemed inappropriate when visited (e.g., not wadeable, intermittent, inaccessible). A site was selected on each stream segment (usually at a bridge crossing), temperature loggers were deployed out of the influence of the bridge, and data were collected following methods outlined in Job 3. All random site monitoring data were collected in the summer of 2010.

Of the 30 random sites monitored, 24 loggers were recovered (Figure 10). Twenty-three of the random sites were in steams that had not been sampled during other sampling efforts, but all sites were located in major watersheds that had already been sampled at other locations. Five of the random sites (20.8%) fell into the coolwater category, while none were coldwater (Table 4, random sites identified by GIS Processing Unit [PUGap code] designation rather than IEPA/IDNR station code). These coolwater sites were found in regions of the state where previous coolwater segments had been observed. Although this sample of segments was relatively small it suggests that one in five wadeable stream segments in Illinois experiences a coolwater thermal regime.

Interannual temperature patterns:
Temperature data were collected during two or more years at 28 sites to examine interannual variation in thermal patterns (Table 11). The degree of interannual variation in temperature varied with a mean difference of within-site mean daily July temperature of 3.7 ^{o}C, a maximum difference of 7.5 ^{o}C, and a minimum of 0.4 ^{o}C (Figure 11). Twelve (42.9%) of the sites had mean daily July temperatures that fell within adjacent thermal categories (i.e., cold and cool, or cool and warm) between years, and one site (station MND-01) had events in both the cold and warm categories. These results suggest that annual patterns in local weather (i.e., temperature, rainfall) can play an important role in the observed thermal pattern at some sites. These results are not surprising given the positive relationship between air and water temperatures observed between years (Figure 4). However, given the degree of variability at some sites, further examination of the

mechanisms underlying interannual temperature variation is warranted. These results suggest that stream reaches should be characterized using mean conditions over several years whenever possible. We used the mean daily temperature from July calculated from all available temperature records to describe the thermal character of stream reaches in Illinois and classified 23 sites as coldwater, 55 as coolwater, and the remainder as warmwater (151, Figure 7).

Spatial temperature patterns:
Spatial temperature patterns, including longitudinal (upstream or downstream) and lateral (adjacent streams) variation, are poorly documented for Illinois streams. One specific aspect of spatial temperature variation that requires consideration is the applicability of the observed temperature beyond the location at which they were recorded.

Lateral and longitudinal temperature patterns were assessed using strategically positioned sampling sites (identified as network sampling) within 15 watersheds throughout Illinois (Figure 12). Network sampling utilized multiple temperature loggers placed within a single watershed during a period of two to four weeks. Most network locations were chosen based on an expectation of cool temperatures within the watershed (given prior sampling in the watershed or some other indicator), while individual sample locations were arranged so as to discern intersegment and intrastream thermal variability within the watershed.

Each watershed displayed a unique pattern of spatial variability with some networks containing sites consistently in the same thermal category while other networks had sites in all three categories (Figure 12 and Appendix B). This suggests that extrapolating beyond the monitored reach must be done with great care as local conditions influence realized temperatures at individual sites even when in close proximity.

Measurement of hyporheic water temperature:
As thermal regime of streams often is related to input of groundwater, direct measurement of hyporheic temperature may allow for determination of groundwater levels relative to channel morphology. In summer streams receiving groundwater inputs will have a hyporheic thermal pattern that quickly cools with increasing depth. Those streams that are groundwater rechargers will have a slowly cooling pattern resulting from interstitial flow. Furthermore, groundwater in Illinois maintains a temperature within a small range, usually within the low teens. Observing these temperatures below the stream channel indicates presence of groundwater. Interstitial water temperature was measured using a Hanna Instruments® waterproof K-Type thermocouple and thermometer (model number HI 93531N) with 1.0m penetration probe (model number HI 766TR2). At each sample location the penetration probe was held perpendicular to the streambed and inserted into the hyporheic zone. To create a hyporheic temperature profile, the first temperature measurement was taken at the streambed surface (0cm) and subsequent samples were taken at 10cm intervals until a depth of 1m was reached. If substrate characteristics prevented insertion of the probe to 1m, the deepest temperature measurement was recorded. Sample location corresponded to temperature logger placement.

Hyporheic temperature profiles were analyzed only if the probe could penetrate at least 50cm below substrate surface. Probe measurements were placed into one of four categories based upon their vertical temperature patterns; likely, probable, unlikely, or not receiving groundwater inputs. Those in the likely or probable categories were expected to be positively correlated with cold or cool thermal categories, while those in the unlikely or not receiving should be negatively correlated (e.g., warm). These categories are somewhat subjective, but they reflect our estimation of groundwater patterns based on a priori observations of hyporheic temperatures within streams of know thermal conditions.

Hyporheic temperature probe measurements were taken 49 times at 43 sites where in channel water temperature records had been collected (Table 12). Sample size was small relative to total number of temperature records as substrate composition in some regions prevented probing. Of those eleven samples determined to have likely or probable groundwater inputs, ten were observed to have coldwater or coolwater thermal conditions based on the longer term monitoring of water within the stream channel. Warmwater streams were correctly placed in the unlikely or not receiving categories 31 of 38 times. Assigning thermal classes using hyporheic temperature profiles resulted in 83.7% of segments being correctly classified. However, we were only able to use this technique at a small fraction of the sites monitored during this study since sites with hard substrates, like cobble or packed claypan, could not be sampled using the temperature probe.

Influence of shading on water temperature:

Although groundwater and climate may be the greatest determinants, other factors may also influence observed instream temperature patterns. One such factor investigated during this study is the impact of channel shading created by overhanging vegetation. Shading could reduce thermal inputs from sunlight and prevent or reduce heating during daylight hours, and therefore, lower mean daily or maximum temperatures. Three streams were chosen to examine the influence of sunlight exposure and forested riparian areas on thermal patterns (Figure 13). These streams were selected by using satellite images (Google Inc. 2010) to locate watersheds with a mix of agricultural land use with intermittently forested riparian areas. Individual sites in each stream were arranged in alternating shaded and unshaded reaches. Thermal data loggers were affixed at a standard depth from the water's surface (to standardize the influence of turbidity) and were set to record hourly temperature measurements for approximately two weeks. In general, mean daily temperatures were lower at shaded sites than at unshaded sites within the same stream system (Table 13). This relationship between shading and temperature is consistent at Brush Creek (3) and Robinson Creek (1). Thermal patterns at South Kinnikinnik Creek (2) are less clear, possibly because this stream is categorized as coldwater (Table 4, station code PT-01) while the other two likely are warmwater. Shaded sites had mean maximum temperatures equal or less than unshaded sites while temperature variability was, in all but one case, lower in shaded sites (Table 13). These results demonstrated a reduction in stream temperature and diurnal temperature variability associated with shading over a relatively short reach (~500m) in a warmwater stream. Further evaluation on coolwater streams is needed to examine the potential for shading to assist with maintaining stream temperatures that are near the transition between coolwater and warmwater conditions.

Vertical temperature stratification:

Studies have shown that groundwater inputs can create thermal stratification resulting in areas of cool temperatures in transitional or warm streams (e.g., Tate *et al.* 2006, Torgersen *et al.* 1999). These thermal refugia can provide habitat for species that are cold-/coolwater obligates and allow persistence of species that would otherwise be outside of their tolerance limits. Accordingly, we attempted to identify potential thermal refugia in wadeable streams in Illinois.

Three streams were chosen to examine the possibility of thermal refugia in Illinois streams. Each of these streams was known to have both warm and cold/cool reaches (based on prior data collection) and habitat heterogeneity (i.e., presence of pools). All sites selected in a stream were located within a 1km reach. Loggers were deployed in pools at multiple sites in each stream. We affixed two loggers to a pole at each site with one approximately 0.1m above the substrate surface and the other approximately 0.3m from the water surface. Temperature data were collected at fifteen minute intervals and loggers were removed approximately ten days after deployment.

At all stream-site combinations, the logger closer to the substrate surface had temperature summaries equal to or less than the logger nearer the air-water interface (Table 14). The maximum intra-site difference in mean daily temperature was 1.2^{o}C, but the mean difference was only 0.3^{o}C. West Okaw River saw the largest differences in temperature between the upper and lower loggers, while Kickapoo Creek had the smallest differences (mean = 1.5 ^{o}C and 0.17 ^{o}C, respectively). These results suggest thermal refugia may exist in some Illinois streams; however, this limited analysis failed to detect large temperature differences in assessed streams (i.e., cool, stable refugia in warm streams).

Landuse structure in relation to stream temperature:

Watershed and riparian zone landuse can alter movement and infiltration of rainwater, and thus impact groundwater discharge to streams, and subsequently instream temperature patterns. Therefore, landuse may be a correlate of stream thermal category. The proportions of urban, forest, and agricultural landuse at each monitoring site were determined by GIS mapping (Holtrop *et al*. 2005). Regression analysis was used to compare temperature summaries with local (immediate watershed associated with arc) and upstream (associated with all upstream arcs) riparian summaries, and local (associated with arc) and upstream (entire catchment) watershed landuse composition to examine relationships between thermal category and landscape characteristics at multiple scales. No statistically significant correlations were observed between the proportion of urban landcover and mean daily July water temperature (Table 15). Water temperature was significantly and positively correlated with agricultural landcover in the upstream watershed, but not significantly correlated at any of the other scales. As only one scale yielded significant results, assessing the relationship between temperature and agricultural landcover is difficult. One possibility is that an increase in agriculture near the riparian corridor results in a greater occurrence of field tiles moving cool groundwater to the stream. Alternatively, there may be no direct relationship between the two variables and the observed statistical significance may result from an indirect relationship associated with the geographic location of cool streams within the state (i.e., cool and cold streams are located in the agricultural central and northern parts of the state rather than the forested south). The proportion of forested landuse was positively correlated with mean daily July temperature at all four spatial scales. While this may seem unexpected, forest landcover is more common in the southern third of the state where higher summer air temperatures also occur. Given the strong association between geographic location and air temperature, and the small number of coolwater sites observed in southern Illinois, we did not attempt to further examine the interactions between forested landcover and water temperature at the statewide scale.

Habitat characterization of streams in relation to thermal category:
Streams in Illinois display a wide range of instream and riparian habitat conditions, but the relationship between instream temperature patterns and physical characteristics has not been extensively studied in the state. Instream and riparian conditions were characterized at 500 sites on 442 streams from 2006-2009 to develop a wadeable streams habitat index (Sass *et al*. 2010 [T-25]). Seventy-nine of these habitat sites occurred where temperature records were available and were used to examine the relationships between thermal category and habitat variables. Habitat variables analyzed included predominant substrate, riparian zone width, predominant flow (fast, moderate, slow, none), degree of channel shading, and the number of channel units (defined as riffles, runs, or pools) in each sample reach. We compared the observed frequency of habitat elements within temperature categories to their statewide distributions using chi-squared analysis.

Slightly more than half the habitat elements examined showed no difference between thermal classes from their expected statewide distribution (Table 16). For example, the number of channel units (Figure 14) showed no significant difference between thermal classes. Channel shading and dominant substrate deviated from the state-wide pattern only in the coolwater streams (Table 16). Larger substrates were dominant in coolwater streams which show a higher proportion of gravel than expected (Figure 15) while also having a higher proportion of channel shading (Figure 16). All three thermal categories showed statistically significant deviations from the state-wide pattern with respect to riparian zone width (Figure 17), although no pattern was observed for any of the three thermal categories. Coldwater and coolwater streams have a larger proportion of fast and moderate flow conditions than the state-wide average, while warmwater streams are more likely to exhibit slow or non-flowing conditions (Figure 18). The lack of no flow conditions observed in the coldwater and coolwater streams suggests higher baseflow yields associated with the presence of groundwater inputs, although we did not test this hypothesis.

Vegetation Assessments:
Vegetative communities may be useful for estimating thermal conditions within streams by identifying species that indicate presence of cold or cool thermal regimes. Unfortunately, no practical or spatially extensive database containing aquatic or

semiaquatic plant community data exists for streams in Illinois. Information collected during the wadeable streams habitat index project (Sass *et al*. 2010 [T-25]) yielded some information related to instream macrophytes, and these data were used to compare macrophyte density and bank vegetation type with temperature summaries. Temperature records and vegetation data from the habitat index development project overlapped at 76 sites. We examined the relationships between observed thermal class and within reach mean macrophyte density, and bank vegetation types (mean densities of herbaceous, woody/shrub, and trees), based on a qualitative assessment of condition (0-3 scale) at these sites.

Mean macrophyte density varied between 0.54 and 0.77 with coolwater streams having the highest densities (Table 17). These mean scores place overall macrophyte density between the qualitative categories of absent and sparse. Macrophytes were dense in a few streams, but overall were sparse and little variation existed amongst thermal categories. Bank vegetation showed a similar pattern amongst thermal categories (Table 17). Herbaceous vegetation was the most abundant vegetative component for all three stream types, ranging from 2.53 to 2.71 (which falls between the intermediate and abundant categories), and varied little amongst thermal categories. Woody/shrub, trees, and bare banks (no vegetation) also varied little amongst categories. Both woody/shrub and tree mean densities fell between 1.04 and 1.68 (or between sparse and intermediate), while bare bank was between 0.41 and 0.47. Analyses involving macrophyte density and bank vegetation showed little utility for identifying temperature patterns in large part due to the extremely low occurrence of aquatic macrophytes and highly disturbed banks in Illinois streams.

Fish species as cold-/coolwater indicators:

The IDNR listing of candidate coolwater stream reaches, which this project was developed to test, used fish species as indicators of cold/cool thermal conditions within streams (Job 1). Although Illinois contains few examples of typical coldwater fish communities (i.e., trout, sculpin, daces), some fish species may prefer cold or cool temperatures, and therefore serve as indicators of these conditions. The goal of this analysis was to determine which species, if any, could be used to accurately predict the location of cold-/coolwater streams. Prior to initiation of this study, 17 species of fish were used as indicators of cold-/coolwater streams (Table 1, Figure 2). Due to the preliminary nature of this species list, an additional 31 species that represent a large range of taxonomic and behavioral diversity were added to our analysis (Table 18). For each site with temperature monitoring data we reviewed recent fish surveys (within seven years of temperature record) for the presence of our focal species. Most of these data were collected during IDNR basin surveys, although some originated from special surveys conducted by the INDR or other state agencies. Not all locations with temperature records had associated fish data, and consequently we made supplemental samples at 22 additional sites during the summers of 2007, 2008 and 2010 using a backpack electrofishing unit (Appendix C). These sites were chosen to fill gaps in existing data, however, because standard IDNR fish community sampling protocols were not followed (i.e., block-netting, use of electric seine, time/length minimums), these data were used only to access species presence. To establish thermal preferences, temperature records associated with all 48 fish species were reviewed and each species was placed into a class (e.g., cold, cool, warm, eurythermal) to determine utility as a cold/cool indicator. Only those species that were always collected in cold-/coolwater streams were considered as coolwater indicators in this analysis.

Focal fish species were classified based on observed distributions using the mean daily July temperature. These classifications were compared to Wehrly *et al*. (2003) and Lyons *et al.* (2009) temperature categorization, thermal classes listed in Lyons *et al*. (2009), Indiana's coolwater index (Aquatic Research Center of the Indiana Biological Survey 2007), and those from the Ohio EPA's bioassessment manual (State of Ohio Environmental Protection Agency 1987) to assess thermal preference in other Midwestern states (Table 19, Appendix D).

Most species assessed during this study were classified into the eurythermal category, as they were present in stream segments with each of the three thermal categories (Table 19). Five species (American brook lamprey, brown trout, rainbow trout, longnose dace, ninespine stickleback) were present only in coldwater or coolwater streams, but many of these species have extremely limited ranges within the state (e.g., American brook lamprey has been collected at only one site in Illinois) or too few of the species' know locations have associated temperature data for a robust assessment of thermal preference to be made. These factors effectively eliminate American brook lamprey, rainbow trout, and ninespine stickleback as robust indicators, leaving only the presence of brown trout and/or longnose dace as good indicators of cool or cold conditions. However, brown trout have been found at very few stream sites in Illinois (3 sites in IDNR fisheries database) giving it a limited degree of utility with respect to predicting location of cool streams. Longnose dace also have a limited statewide distribution, known from only two watersheds, although it has been collected at more locations than brown trout. The brook stickleback and mottled sculpin nearly met our rather restrictive criterion, each having been found at one warmwater site in addition to several coolwater sites. For brook stickleback, one of 31 temperature records exceeded the coolwater threshold, although that record was from a site categorized as a coolwater location during a previous monitoring year. Given that streams have been shown to shift thermal categories between years (*Interannual temperature patterns*, Job 4) and fish can tolerate temperatures in excess of their preferred ranges, these two species should not necessarily be eliminated from use as coolwater predictors, but rather given a conditional status and used in conjunction with other predictive methods. Even if used together, though, these four species have limited utility for predicting locations of coolwater streams in Illinois outside their known, but limited range (Figure 19). Additional thermal and fish distribution data would improve the usefulness of this assessment and aid in producing conclusions about those species that occur mainly at sites that have not been monitored for temperature.

Our assessment of fish as indicators of cold or cool conditions was conducted using mean daily July temperature thresholds outlined in the introduction to this report (Wehrly *et al.* 2003). A similar type of assessment was also conducted using Lyons *et al*. (2009) thresholds of cold (< 17.5^{o}C mean daily July temperature), transitional (17.5-21.0 ^{o}C), and warm (> 21.0^{o}C) temperature categories. When we use these thermal thresholds with our data, brown trout, longnose dace, brook stickleback, and mottled sculpin are considered transitional species (Table 19). The transitional category is similar to, but not synonymous with coolwater, and therefore, the species we recognized during our study may receive the same classification in other assessment schemes. In fact, Lyons *et al* (2009) lists brown trout and mottled sculpin as coldwater indicators, but longnose dace and brook stickleback as transitional species. Indiana (Aquatic Research Center of the Indiana Biological Survey 2007) uses a classification scheme with similar thresholds to those used in Lyons *et al.* (2009), yet based on their assessment methods brown trout and mottled sculpin are not coolwater species, while longnose dace and brook stickleback are coolwater indicators (Table 19). The Ohio EPA's (1987) bioassessment manual, which designates certain species as coldwater indicators, does not assess thermal preference of longnose dace, but lists brown trout, brook stickleback and mottled sculpin as coldwater obligates. All three studies (Lyons *et al*. 2009, Indiana 2007, and Ohio 1987) designate cold or cool indicator species that this study does not recognize, and visa versa. These discrepancies in categorization of fish likely indicate that some species have broader than expected thermal tolerances that differ geographically.

Fish community analysis:
Thermal categories often can be defined by a characteristic fish community present within these streams. For instance, Lyons *et al*. (2009) found that coldwater streams were dominated by trout and sculpin, while transitional species from such diverse taxonomic groups as suckers, daces, and sticklebacks were present in coolwater streams. Many of these cold and cool species are not common in Illinois waters, and accordingly, these community types may not be prevalent in their respective thermal categories. Fish collection records for each site with temperature data were used to determine which species were most common in coldwater and coolwater streams to determine if community types related to temperature could be described for Illinois. Three analyses were used to evaluate community types: an observation of species richness, an analysis of species common to each temperature category, and indicator species analysis.

Species richness was explored in an effort to describe differences between warmwater and cold-/coolwater streams with an expectation that coldwater streams have the lowest richness and warmwater streams the highest. Fish collection records were used to determine species richness at each site with a temperature record. Mean fish species richness was 14.3 (range: 1-29) for coldwater, 18.5 (range: 5-33) for coolwater and 20.3 (range: 8-40) for warmwater sites. Independent sample t-tests indicate species richness at cold sites was significantly different than both cool ($p=0.015$) and warm ($p<0.001$) sites; however, cool and warm sites were not different ($p=0.146$). This positive relationship of species richness and temperature provides insight into the ecological role of temperature in defining cold-/coolwater communities.

For the second analysis of community structure, we defined common species as those present from at least 50% of sampled sites. This value creates an arbitrary threshold for determining dominance, but does provide a baseline for examination of community structure. Eight species were common to both coldwater and coolwater streams (Table

20). The two thermal categories differed in only a few species with southern redbelly dace, blacknose dace, and fantail darter common in cold streams, while bluegill sunfish, smallmouth bass, and sand shiner were common only in coolwater streams.

All species found in cool-/coldwater streams were more common in reaches with those thermal classes than at all surveyed sites (Table 20). When considering just sites with temperature records, only bluntnose minnow in coldwater streams, bluegill sunfish in coolwater streams, and green sunfish in coolwater and coldwater streams were less abundant in their respective categories than in statewide collections. These results suggest that the species included in the cold and cool categories of Table 20 are potentially cold- or coolwater species (excluding the three discussed above). However, we observed these species in streams with a broad array of thermal patterns indicating that most of them have eurythermal or warmwater tolerances (Table 19) rather than being representative of cold of cool communities. We expect that the observed patterns occur as a result of the geographical distribution of these common species being concurrent with the distribution of cold and cool streams mainly in the northern portion of the state (Figure 7).

To consider abundance of fish species in addition to presence/absence patterns, indicator species analysis was conducted to explore the relationship between fish community structure and thermal category. Indicator species analysis is an ordination technique that considers both presence and abundance in assigning a fidelity value (ranging from 0-100; 100 is the strongest indicator) for each species in each category (cold, cool, warm). For each site with existing temperature data, fish community data were downloaded from the IDNR's fisheries database (Fisheries Analysis System was accessed in 2010). Only the most recent collection was used for each site and only those collection records more recent than 1987 were used to assure consistency within the sampling procedures (the current basin survey procedure was implemented in 1988).

Fidelity values were calculated for 140 fish species with values ranging from 0-54, indicating, at best, only moderate species-thermal category relationships. However, 25 species had significant (Monte Carlo test of significance) values for their specific temperature category. If we consider only the ten species in each category with the highest indicator values our analysis indicates five significant species for coldwater, one for coolwater, and six for warmwater streams (Table 21). Brook stickleback was the only coldwater or coolwater species with a significant fidelity value that was included on the list of coolwater indicator species (brown trout, longnose dace and mottled sculpin did not have significant fidelity values).

To test the validity of coldwater and coolwater community structure (as determined by indicator analysis), we identified where these community types were present and compared these locations to measured temperatures. Of those sites with corresponding temperature data, the coldwater community type was present in cold- or coolwater streams for more than 97% of the cases, however, the coolwater community type was found in cold or cool streams approximately as often as warmwater sites (Table 22). These results suggest the coldwater community type has been accurately identified by indicator analysis, but that the coolwater community has little utility in separating coldwater or coolwater streams from warmwater streams in Illinois.

Fidelity values and common species assessments (Table 20) largely overlap for cold and cool streams. Together, these two analyses suggest the occurrence of representative coldwater and coolwater fish communities, even though individual species may not be exclusively found in cold- and/or coolwater streams. For instance, a community containing southern redbelly dace, fantail darter, blacknose dace, and common shiner is likely present in a coldwater or coolwater stream in Illinois. Further analysis (e.g., Classification And Regression Tree [CART] analysis) may allow refinement of community typing although this was beyond the scope of the current study.

Evaluation of Thermal Thresholds:
Throughout this study we have used Wehrly *et al.'s* (2003) thermal thresholds for defining temperature categories. However, upon identifying coldwater predictor species and describing coldwater communities, it appears that the upper threshold for the coolwater category may not be high enough for Illinois streams given the presence of several species that are generally considered coldwater obligates in streams with mean daily July temperatures above 22°C. Lyons *et al.* (2009) described a method for determining the upper and lower boundaries of the coolwater category by using the warmest temperature at which coldwater species are found (for the upper threshold) and the lowest temperature at which warmwater species are found (for the lower threshold). We applied this technique to evaluate the need to adjust thresholds for the coolwater category for Illinois streams.

Defining the upper threshold for the coolwater category requires comparing the distribution of coldwater species with their observed thermal distribution. Fortunately, information for these species had been obtained during previous tasks associated with predictor and community analysis. Each of the four identified predictor species (brown trout, longnose dace, mottled sculpin, brook stickleback) and the four significant coldwater indicator analysis species (Table 21; brook stickleback is included in the predictor group) were used to determine the upper coolwater category threshold. After removing the warmest 10% of mean daily July temperatures associated with each site-species combination, the highest observed mean daily July temperature for any of these eight species was 23.7°C. Overall, 30 of 256 site-species combinations were over Wehrly *et al.*'s (2003) 22°C threshold, suggesting the upper boundary of the coolwater category in Illinois may be slightly higher than what was found in their study. An additional 61 sites that were monitored during this study would be included in the coolwater category if the upper threshold was adjusted to 23.7°C (Figure 20). In contrast to the 22°C threshold sites which are located primarily in the northern third of Illinois, sites within a 23.7°C threshold are distributed throughout the state. This pattern indicates many streams are near the 22°C threshold and could contain transitional species or community types. These transitional streams may also provide an opportunity to investigate expectations regarding community shifts related to climate change scenarios (i.e., they may offer insight into future stream conditions). To identify the lower boundary of the coolwater condition (i.e., upper boundary of the coldwater category) using this method requires determining warmwater fish species' thermal distributions (Table 19) at the coldest temperatures where they occur. This proved difficult with the low number of cold water sites and given the large number of eurythermal species we observed. For example the indicator analysis revealed that the bluntnose minnow was common in all three thermal categories. Due to these issues adjusting the lower temperature threshold for coolwater streams was deemed impractical and we suggest maintaining the 19.0 ^{o}C lower boundary from Wehrly *et al.* (2003) at this time.

Job 5: Conduct macroinvertebrate sampling at a subset of sites.

Macroinvertebrate taxa as cold-/coolwater indicators:
Twenty-four aquatic macroinvertebrate taxa (Table 23) were chosen as potential indicators of cold or cool thermal conditions. These taxa were selected based on their status as cool indicators in other Midwestern states (Iowa DNR 2004) and professional judgment. The Illinois Environmental Protection Agency's (IEPA) macroinvertebrate collection database was used to compare collection records for each taxon to sites with temperature records. Overlapping sites were documented and the mean of mean daily July temperature was calculated for sites in which each taxon was present.

Only eight of the 24 taxa were collected at sites for which temperature records were available (Table 23). Six of the eight taxa had observed mean daily July temperatures above the coolwater threshold, indicating none are useful indicator species. The remaining two taxa had too few associated temperature records to make a determination regarding their utility as indicator species. Although it would appear that the macroinvertebrate taxa proposed are poor indicators of thermal regime, many of these species emerge from streams prior to IEPA summer collection efforts. Some of these taxa may still have utility as indicator species if an alternate sampling protocol that included early spring collection was implemented.

We used macroinvertebrate community data from the IEPA's database to determine taxa richness for each site with a temperature record. Over a wide range in temperatures the standard expectation would be that cooler streams have lower taxa richness, and therefore this measure might be able to be used to identify coolwater streams. Mean taxa richness was 43.1 (range: 11-109) at coldwater sites, 56.8 (range: 8-123) at coolwater, and 61.6 (range: 17-121) at warmwater. Taxa richness was higher in warmwater than coldwater streams (t-test, $p=0.003$) and higher in coolwater than coldwater ($p=0.038$), but coolwater richness did not differ from warmwater ($p=0.375$), a result which mirrors that of species richness for fish communities.

Mussel species as cold-/coolwater indicators:
Patterns of freshwater mussel distribution were also analyzed to determine if species from this group have utility as indicators of cold or cool thermal conditions. Professional malacologists and Natural Heritage Biologists from Illinois (e.g., Kevin Cummings, Robert Szafoni) were consulted to determine which species might favor coolwater conditions. Two species were selected for this analysis of thermal preference; Ellipse,

(*Venustaconcha ellipsiformis*) and Elktoe (*Alasmidonta marginata*). Collection records for these two species were provided by the IDNR and Illinois Natural History Survey (INHS) mussel databases, and inhabited locations were matched with collected temperature records.

Nineteen temperature records from eleven sites were available for the Ellipse. Mean daily July temperature for those records ranged from 18.08 – 24.6^{o}C with eight records above the coolwater threshold, indicating the presence of this species is not suitable as an indicator of cold or cool conditions. Only two temperature records were available at locations in Illinois where the Elktoe was present (20.4 and 22.5^{o}C), and one of the two was above the coolwater threshold.

Job 6: Compile and analyze data and write report.

Study summary and conclusions:
A prevailing goal of this study was to locate cool streams within Illinois, either through direct monitoring of temperature or through surrogate measures (e.g., predictive models or indicator characteristics). To this end, 203 temperature records were collected in addition to the 77 secured prior to study initiation. Of the 232 sites monitored, 106 were classified as cold or cool (Figure 7). Temperature data also were used in conjunction with other information to characterize physical and biotic components of cold-/coolwater streams. Detailed data collection methods and analyses are presented above in Jobs 1-5.

Many physical and biological attributes were examined to characterize coldwater and coolwater streams and allow for rapid determination of where these streams are located. Several analyses yielded results with potential to consistently detect thermal category. Darcy Model predictions of potential groundwater movement are good predictors of cold and cool stream conditions where the Model indicates extreme values. Direct measurements of water temperature in the hyporheic zone were also relatively accurate at detecting cold and cool streams where the substrate permitted these measurements. Several habitat measurements were correlated with thermal character (e.g., water flow and percent forest in riparian zones and watersheds).

Although identifying coolwater streams with potential groundwater inputs was moderately successful (i.e., Darcy Model), the initial list of "coolwater" fish species proved less useful. Monitoring at candidate cold and cool streams in Illinois (Job 2) revealed that only two of the 17 original indicator species were observed to be always located within cold or cool streams (brown trout and longnose dace), although two others (brook stickleback and mottled sculpin) were very rarely observed outside of these conditions. Certain fish community assemblages also had some utility as predictors of stream thermal regimes. This low accuracy is partly a reflection of insufficient information related to thermal preference for these species in Illinois. Further consideration of ecological factors that influence their distributions would assist in determining fish species and biological assemblages that are characteristic of the different thermal habitats occurring in Illinois wadeable streams.

The lack of a single definitive indicator of stream thermal regime suggests that observed water temperatures are based on multiple factors acting at several scales There is little doubt climate and local weather affects stream temperature (e.g., Figure 4), but many of the watershed scale factors we examined were poorly correlated with observed stream temperature (e.g., Table 15). Similarly, many of the local scale factors we measured were poor predictors of stream temperature (e.g., Figures 15, 16). These results may reflect our failure to measure or detect those characteristics that are directly related with observed water temperature (e.g., field tile inputs, depth to groundwater), or that many factors act upon temperature simultaneously and diminish our analytic power in detecting direct correlations. Certainly, additional correlates exist that we have not considered or do not have the ability to measure.

Study's relationship to Species in Greatest Need of Conservation:
Thirteen of the original 17 proposed coolwater fish species, and eight of the 24 additional species examined in this study are listed in the Illinois Wildlife Action Plan as Species in Greatest Need of Conservation (SGNC) (Illinois Department of Natural Resources 2005). Mottled sculpin and brook stickleback, which were determined to be preliminary indicators of cool conditions in Illinois, and longnose dace, a coolwater indicator species, are included in the SGNC list. Data collected during this study will assist future revisions of the IWAP by refining thermal expectations for fish species in greatest need of conservation and for instream habitats. We have also provided additional information regarding the range of thermal tolerance in other lotic species.

Data gaps and proposed future efforts:

As results of this study highlight, coldwater and coolwater streams in Illinois are more common than generally realized and may differ from their counterparts in adjacent Midwestern states. However, many questions regarding their physical processes and ecological function remain. For instance, designating the extent of cold or cool stream reaches based on a single point measurement of temperature is a difficult task. A temperature record is certainly valid for the specific location (i.e., within the immediate habitat) and time, but the lateral, longitudinal, and temporal extent to which this temperature can be applied varies due to catchment wide and local conditions. Network sampling conducted during this study indicates that a point measurement likely does not represent the entire upstream extent or adjacent branches of the stream network. An alternate sampling protocol conducted at a finer scale may be required to verify the thermal regime in adjacent stream reaches although predictive models can be used as a preliminary indicator in their absence. Additional information is also needed to further assess the biological assemblages present in cold-/coolwater streams. Several of the fish species used in the indicator analysis have temperature records associated with only a few of their known locations resulting in an incomplete assessment of their thermal tolerance. Several other species (i.e., mottled sculpin and brook stickleback) have a single associated temperature record above the coolwater threshold we used in this study, thereby eliminating them as a primary indicator species in some of our analyses despite their inclination for cool streams. Further complications regarding fish indicator analysis occur because fish collection records exist for only a small proportion of Illinois stream segments. This is highlighted by the supplemental electrofishing samples taken during this study (Job 4) at three IEPA stations (PQE-10, PQDA-01, and AO-03), which revealed new records at these locations for 14 species including potential indicator species.

Our study found coolwater and warmwater fish communities that contained similar species but with different relative abundances. Populations of cold- and/or coolwater fish species were also frequently observed at low or very low abundances. Many of these stream segments appear to be thermally stressful for these species and are putting their populations at risk. Continued warming due to changes in landcover, landuse, or climate change will likely exacerbate this problem and could lead to further homogenization of fish assemblages by removing the thermally sensitive species from these unique habitats.

Although it was beyond the scope of this project we suggest that a review of the map based on the temperature model be made by an expert panel with knowledge of local streams conditions. Such an effort was undertaken in Michigan and resulted in a small revision of their stream temperature designations (<5% of segments; P. W. Seelbach personnel communication) and a greater acceptance of the product by managers.

In addition we suggest that temperature monitoring in streams becomes part of normal operations within the comprehensive basin survey program. Temperature loggers are relatively inexpensive (<$100) and simple to deploy. Currently available data are not sufficient for trend analysis, identifying interannual variability in thermal conditions, and are mainly restricted to the summer. Thermal records are also uncommon for headwater segments and are available at few locations on larger streams and rivers. A carefully designed temperature monitoring program linked with biological monitoring would provide information to track potential impacts of landscape alteration and climate change on stream thermal regimes and their associated biota.

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Tables

Table 1. Coolwater fish species candidate list

Common Name	Scientific Name
Northern brook lamprey	*Ichthyomyzon fossor*
American brook lamprey	*Lampetra lamottei*
Least brook lamprey	*Lampetra aepyptera*
Brown trout	*Salmo trutta*
Rainbow trout	*Salmo gairdneri*
Southern redbelly dace	*Phoxinus erythrogaster*
Blacknose dace	*Rhinichthys atratulus*
Longnose dace	*Rhinichthys cataractae*
Ozark minnow	*Dionda nubila*
Weed shiner	*Notropis texanus*
Ironcolor shiner	*Notropis chalybaeus*
Ninespine stickleback	*Pungitius pungitius*
Brook stickleback	*Culaea inconstans*
Banded sculpin	*Cottus carolinae*
Mottled sculpin	*Cottus bairdi*
Iowa darter	*Etheostoma exile*
Least darter	*Etheostoma microperca*

Table 2. Proportion of cold or cool streams in Illinois

Method Used to Determine Proportion	Sites/Arcs Predicted	Statewide Sites/Arcs	Proportion Cold or Cool
Predictive Methods:			
Darcy Model Stream Arcs (≤ 1 negative st. dev.)	1766	47,430	0.037
Candidate List - Fish Sites Only	88	7549	0.012
Candidate List - Fish Plus Groundwater Potential Sites	111	7549	0.015
Temperature Model Stream Arcs (< 22^{o}C)	6247	47,335	0.132
Darcy Model Stream Arcs (≤ -50.0 output value)	3601	47,430	0.076
	Sites Varified	Sampled Sites	Proportion Cold or Cool
Measurements:			
Temperature Measurement Sites (< 22^{o}C)*	82	232	0.353
Site Records of Coolwater Indicator Fish Species**	44	1186	0.037

* if multiple years sampled, at least one year was cold or cool.
** total sites determined by counting the number of sites assessed by the IDNR from 1997-2007.

Table 3. Validation of candidate coolwater sites

Sites Based on Presence of Fish Species (n=88):

Verified Coolwater Sites	Sites Determined to be Warmwater	Untested Sites	
DKV-01	ADD-02	AD-05	LDE-03
DTK-06	ADDB-01	AD-06	MJA-01
DTZD-01	ADL-01	AD-08	MJB-03
MJ-02	AJ-09	ADD-01	MN-04
MN-18*	AJF-16	BE-15	MN-07
MND-01*	AJG-18	BNB-02	MQ-02
MNIA-11	AOA-01	DH-03	MQB-01
PK-01	DI-03	DJ-14	NDD-03
PLE-03	DJJ-04	DJHA-01	O-40
PP-01	DTC-07	DJI-01	PB-05
PWI-01	DZA-02	DJIA-01	PBU-10
QC-03	DZA-03	DJJ-03	PH-16
	FCC-01	DJNA-01	PHE-01
	FLDA-01	DJZS-01	PIA-01
	ICD-02	DK-15	PQ-14
	IXJ-01	DKK-01	PQC-09
	IXJ-02	DLG-01	PQF-08
	PQB-04	DQD-02	PWN-03
		DQF-01	PWNA-02
		DSA-02	PWPA-01
		DTAB-01	PZZL-01
		DTB-02	QC-02
		DTF-04	
		DZJ-01	
		EE-02	
		EE-03	
		EIE-10	
		F-01	
		F-02	
		F-04	
		F-06	
		F-15	
		FLD-01	
		IC-03	
		IXJ-03	
		LDB-01	

Table 3. Validation of candidate coolwater sites (continued)

Sites Based on Presence of Fish Species and groundwater potential (n=111):

Verified Coolwater Sites	Sites Determined to be Warmwater	Untested Sites		
DQD-01	FKA-01	AD-09	DZ3P-01	PWB-03
DTC-05	FLD-03	AO-02	DZG-02	PWBA-01
DTCA-01	FLI-06	AO-03	DZIA-01	PWH-01
DTF-02*	IXD-01	DB-03	EEA-02	PWNA-01
DTZP-04	KCL-01	DJA-02	EH-01	PWNA-03
DTZT-01	OZZD-03	DJBZ-01	EH-03	PZR-01
DTZT-02	PWA-01	DJD-02	F-03	
EH-02		DJDB-01	F-14	
FLDAE-01		DJJB-05	FQ-01	
MJA-02		DJL-02	IC-01	
MNI-12		DJM-01	ICE-01	
PBM-11		DJZA-01	JH-03	
PHB-01		DJZF-01	KCA-02	
PN-02		DJZN-01	KCAA-01	
PN-03		DK-17	OQA-01	
PQCK-01		DK-19	PBD-02	
PQD-05		DKE-01	PBG-10	
PQD-06		DKF-11	PBJA-02	
PQE-06		DLF-01	PBJA-05	
PQEA-01		DM-01	PBO-10	
PQEF-01		DP-02	PBP-01	
PQH-01		DP-03	PH-17	
PQJ-01		DP-04	PLC-01	
PSB-01		DQ-01	POA-01	
PT-01		DQ-03	PQ-02	
PWC-01		DTC-02	PQ-07	
PWIA-01		DTCA-02	PQB-03	
PWPC-01		DTCA-04	PQCB-01	
PWQ-04		DTD-06	PQD-07	
		DTD-07	PQE-07	
		DTD-08	PQI-02	
		DTG-01	PQI-10	
		DTZL-02	PQIC-02	
		DWBB-01	PV-01	

* site also falls into warm category during one or more sample years.

Table 4. Variation in July and August mean daily temperature.

Summary Data:	
n	142
mean difference (July - August mdt*, ^{o}C)	0.27
maximum (July - August mdt, ^{o}C)	6.02
maximum (August - July mdt, ^{o}C)	6.57
*Variation in Thermal Category**:*	
n cold to cool	7
n cold to warm	1
n cool to cold	1
n cool to warm	5
n warm to cold	0
n warm to cool	24
n warmed at least one category (n=64)	13
n cooled at least one category (n=115)	25

* mdt = mean daily temperature

** change in thermal category when July mdt compared to August mdt

Table 5. Air temperature and annual variation in July and August mean daily temperature

Annual variation in July and August stream temperature:

Year	n*	Mean Change in Temperature, ^{o}C**	Maximum Difference, ^{o}C**	Minumim Difference, ^{o}C**
1999	4	3.65	6.57	1.85
2001	5	0.81	2.54	-0.91
2002	4	1.03	1.53	0.09
2003	15	-0.12	3.32	-3.08
2004	12	2.15	3.66	-0.24
2005	4	1.86	4.59	-0.02
2006	1	n/a	0.52	n/a
2007	25	-0.71	1.16	-3.19
2008	31	0.35	5.24	-6.02
2009	39	-0.84	1.03	-5.21
2010	2	-0.05	1.21	-1.31

* number of sites with comlete July and August temperature data.

** July minus August mean daily temperature

Illinois climate summary, Springfield weather station:

Year	July Mean Temp., ^{o}C	August Mean Temp., ^{o}C.
1999	77.9	71.5
2001	76.6	74.1
2002	78	75
2003	75	75.3
2004	73.1	68.8
2005	76.7	76.6
2006	74.9	64.5
2007	73	79.3
2008	74.2	71.6
2009	71.3	71.8
2010	79.2	78.6

Table 6. Summary of sampled streams.

Site Code*	Stream Name	Mean Daily July Temperature	Maximum Daily Temperature Range	Year Sampled
Coldwater sites:				
BPB-01	Whippoorwill Branch	18.95	5.06	2009
DKU-01	Patton Creek	18.90	10.52	2009
DTC-05	Big Rock Creek	15.92	4.98	2005
DTZD-01	Mission Creek	18.90	4.19	2009
EIEI-03	Little Kickapoo Creek North	18.70	8.66	2007
IXF-01	Mill Creek	18.15	4.95	2008
MJA-02	Camp Creek	17.20	4.00	2009
MND-01	Furnace Creek	18.51	5.62	2009
MNDA-01	Long Hollow	17.71	7.72	2009
MNF-01	Welsh Hollow	16.78	6.00	2009
MNIA-11	Clear Creek	18.20	4.67	2008
PHB-01	Sugar Creek	17.61	4.76	2010
PK-01	Franklin Creek	17.79	4.76	2009
PQE-10	Piscasaw Creek	14.17	7.64	2008
PQE-10	Piscasaw Creek	18.03	6.68	2010
PQFX-XX	Hampshire Creek	18.10	8.39	2009
PQH-01	Rush Creek	18.08	7.82	2009
PSB-01	North Fork Kent Creek	17.36	7.34	2009
PT-01	South Kinnikinnik Creek	18.31	9.81	2003
PT-01	South Kinnikinnik Creek	18.15	6.38	2007
PU-01	North Kinnikinnik Creek	18.46	3.81	2009
PWBA-01	North Branch Otter Creek	17.00	4.48	2010
PWC-01	Rhule Creek	15.77	13.11	2003
PWC-01	Rhule Creek	15.01	11.00	2007
PWC-01	Rhule Creek	14.63	8.50	2008
PWC-01	Rhule Creek	13.71	8.02	2009
PWC-01	Rhule Creek	15.71	9.28	2010
PWI-01	Rock Run	17.86	7.15	2008
PWIA-01	Pink Creek	16.18	5.63	2009
PWNA-04	Crane Grove Creek	16.29	5.25	2009
PWPC-01	East Branch Richland Creek	17.80	6.00	2010
PWX-XX	Tunnison Creek	18.57	6.39	2010
QCA-01	South Branch Waukegan River	17.07	7.73	2009
QF-01	Kellog Ravine	17.17	5.24	2009
Coolwater sites:				
BPJ-09	Salt Fork Vermilion River	21.73	12.25	2003
BPJ-09	Salt Fork Vermilion River	21.85	5.49	2009
BPZA-01	Willow Creek	20.06	4.60	2009
DKK-XX	Panther Creek	21.01	3.24	2009
DKV-01	Henline Creek	20.59	8.09	2009
DQD-01	West Bureau Creek	19.59	6.87	2009
DRA-02	Tomahawk Creek	20.90	4.87	2009

Table 6. Summary of sampled streams (continued).

Site Code*	Stream Name	Mean Daily July Temperature	Maximum Daily Temperature Range	Year Sampled
DTC-05	Big Rock Creek	21.89	4.73	2010
DTCA-01	Little Rock Creek	21.83	7.29	2004
DTE-01	Waubansee Creek	21.77	7.66	2009
DTF-02	Ferson Creek	20.49	5.00	2009
DTK-06	Nippersink Creek	21.05	7.44	2008
DTKA-04	North Branch	21.57	5.34	2008
DTZP-04	Tyler Creek	19.75	5.37	2009
DTZT-02	Boone Creek	20.05	7.15	2008
DZP-03	Spring Creek	19.95	5.63	2009
edwar 558	North Henderson Creek	21.29	6.13	2010
EH-02	Crane Creek	20.69	13.30	2004
EH-02	Crane Creek	21.92	13.34	2007
EH-02	Crane Creek	21.63	8.32	2008
EH-02	Crane Creek	19.69	7.85	2009
EH-02	Crane Creek	21.86	8.39	2010
EIEM-02	Unnamed Trib. To Kickapoo Ck.	19.13	9.47	2007
EQ-01	Mosquito Creek	21.61	5.76	2008
EY-01	Drummer Creek	19.72	9.45	2009
EZZH-02	Dickerson Slough	21.78	9.29	2003
FLDAE-01	Little Beaver Creek	20.88	7.58	2008
GV-01	Bull Creek	21.77	6.23	2003
illin 17241	Fancy Creek	20.63	7.49	2010
illin 7626	Camp Creek	21.81	8.21	2010
illin14115	Main Ditch	20.05	5.35	2010
IXF-01	Mill Creek	19.17	3.66	2009
IXF-01	Mill Creek	20.94	2.96	2010
MJ-02	Plum River	20.65	7.46	2008
MJA-02	Camp Creek	20.04	4.57	2010
MJB-02	Carroll Creek	20.46	4.86	2010
MN-18	Apple River	21.73	9.29	2003
MN-18	Apple River	19.27	6.31	2009
MND-01	Furnace Creek	20.20	6.01	2010
MNI-12	South Fork Apple Rver	20.22	6.08	2007
MPA-01	Smallpox Creek	19.72	5.25	2009
MU-01	Menominee River	20.37	6.01	2010
O-70	Kaskaskia River	21.10	9.25	2008
OJCX-XX	Webster Creek	21.49	2.90	2009
OL-05	Hurricane Creek	21.83	4.52	2009
PBG-10	Big Slough Ditch	21.64	7.98	2010
PBM-11	Fairfield Ditch	19.30	5.77	2009
PK-01	Franklin Creek	20.92	6.44	2003
PK-01	Franklin Creek	20.19	6.52	2007
PK-01	Franklin Creek	19.84	5.24	2008
PK-01	Franklin Creek	21.03	4.79	2010
PL-03	Kyte River	19.68	5.33	2009
PLE-03	Prairie Creek	21.21	5.66	2010

Table 6. Summary of sampled streams (continued).

Site Code*	Stream Name	Mean Daily July Temperature	Maximum Daily Temperature Range	Year Sampled
PN-02	Leaf River	20.11	4.30	2007
PN-03	Leaf River	21.88	3.81	2007
PP-01	Stillman Creek	21.68	7.74	2007
PQC-11	South Branch Kishwaukee R.	20.39	4.48	2009
PQCK-01	Rosseter Farm Creek	20.49	8.80	2010
PQD-05	Beaver Creek	21.35	7.57	2007
PQD-06	Beaver Creek	21.25	6.96	2010
PQDA-01	Mosquito Creek	19.10	6.29	2007
PQE-06	Piscasaw Creek	20.05	6.59	2010
PQEA-01	Moakler Creek	19.20	5.52	2008
PQEF-01	Little Beaver Creek	20.27	8.54	2010
PQJ-01	North Branch	19.67	6.58	2009
PSB-01	North Fork Kent Creek	19.96	6.92	2003
PSB-01	North Fork Kent Creek	21.62	7.09	2010
PWQ-04	Waddams Creek	19.13	4.76	2010
PX-XX	Clear Creek	19.12	7.25	2010
QC-03	Waukegan River	21.29	4.48	2008
rockr 6825	Trib. To Kyte River	20.33	7.46	2010
Warmwater sites:				
ADCD-01	New Columbia Ditch	25.33	9.01	2008
ADD-02	Dutchman Creek	24.25	5.89	2008
ADDB-01	Little Cache Creek	24.12	2.32	2008
ADL-01	Lick Creek	22.88	3.85	2008
AJ-08	Bay Creek	24.07	3.36	2007
AJ-09	Bay Creek	24.53	5.63	2008
AJ-11	Bay Creek	27.04	3.28	2007
AJF-16	Cedar Creek	22.25	3.08	2008
AJG-18	Hayes Creek	23.19	2.20	2003
AK-02	Lusk Creek	24.68	4.25	2009
AK-02	Lusk Creek	28.03	1.66	2010
AK-02	Lusk Creek	25.10	4.66	2003
AK-07	Lusk Creek	27.01	2.53	2007
AL-01	Big Grand Pierre Creek	27.25	5.72	2007
AOA-01	Hog Thief Creek	22.10	4.45	2008
ATF-06	North Fork Saline River	27.79	11.77	2003
ATHD-01	Little Saline River	25.46	3.18	2007
ATHD-03	Little Saline River	25.31	2.09	2007
ATHG-02	Sugr Creek	26.51	7.80	2007
ATHG-07	Sugr Creek	26.83	3.01	2007
ATHW-01	Maple Branch	24.51	3.84	2007
BE-01	Embarras River	22.80	8.37	2003
BE-17	Embarras River	24.93	4.08	2003
bearc 158	Rocky Run	25.00	10.56	2010

Table 6. Summary of sampled streams (continued).

Site Code*	Stream Name	Mean Daily July Temperature	Maximum Daily Temperature Range	Year Sampled
BEL-03	Hurricane Creek	25.89	6.75	1999
BEN-01	Kickapoo Creek	25.37	4.59	2002
BEN-02	Kickapoo Creek	25.83	8.13	1999
BENA-01	Riley Creek	22.46	6.06	2004
BEZZ-05	Brushy Fork	23.84	3.90	2008
BF-01	Sugar Creek	23.08	7.84	2004
BFC-11	Robinson Creek	27.73	7.83	2003
BFC-20	Robinson Creek	23.03	4.74	2003
BJ-01	Big Creek	23.67	9.91	2009
BJ-02	Big Creek	24.22	9.84	2009
bmudd 2128	Lake Creek	23.59	6.88	2010
BNB-01	Crabapple Creek	22.35	6.86	2008
BPJA-01	Jordan Creek	26.11	9.43	2005
BPJC-10	Saline Branch	23.40	5.15	2007
BPJC-10	Saline Branch	22.24	4.52	2008
broui 76	South Fork Brouilletts Creek	24.92	7.49	2010
BZO-01	Hutson Creek	25.39	4.51	2010
CA-08	Skillet Fork	23.63	3.02	2003
CAGC-01	Auxier Creek	25.39	17.04	2004
CAGC-01	Auxier Creek	25.81	13.00	2009
CJ-06	Big Muddy Creek	23.29	4.33	2003
DF-05	Indian Creek	24.10	10.32	2004
DGL-04	East Fork La Moline River	23.56	5.38	2003
DGLC-01	Drowning Fork	22.85	8.68	2003
DI-03	Otter Creek	23.89	4.76	2008
DJH-03	Haw Creek	25.25	7.95	2002
DJH-04	Haw Creek	25.18	11.00	2002
DJJ-04	Court Creek	24.45	6.60	2002
DJJB-04	North Creek	24.45	6.60	2002
DKJ-03	Walnut Creek	25.25	7.95	2002
DKV-01	Henline Creek	23.76	7.50	2006
DSB-02	Otter Creek	22.99	7.79	2003
DSG-01	Mud Creek	22.70	7.86	2003
DSH-01	Scattering Point Creek	23.60	6.34	2003
DSH-02	Scattering Point Creek	24.90	6.92	2003
DTC-04	Big Rock Creek	23.04	6.93	2005
DTC-07	Big Rock Creek	22.98	4.54	2007
DTD-02	Blackberry Creek	24.94	6.37	2008
DTF-02	Ferson Creek	24.63	5.47	2010
DTZI-01	Rob Roy Creek	22.24	9.40	2008
DVE-03	West Fork Mazon River	23.30	10.53	2009
DZA-02	Otter Creek	27.48	5.48	2007
DZA-03	Otter Creek	23.65	7.53	2004
E-05	Sangamon River	26.98	4.35	2003
edwar 1591	Cedar Glen Creek	23.99	6.64	2010
edwar 37	Camp Creek	22.17	5.41	2010

Table 6. Summary of sampled streams (continued).

Site Code*	Stream Name	Mean Daily July Temperature	Maximum Daily Temperature Range	Year Sampled
EI-11	Salt Creek	25.17	3.96	2007
EI-11	Salt Creek	23.92	5.76	2008
EID-01	Sugar Creek	23.78	9.41	2004
EIE-18	Kickapoo Creek	22.24	10.21	2007
EIEI-02	Little Kickapoo Creek North	23.67	9.69	2007
EIG-02	Lake Fork	26.23	12.89	2007
EIH-01	Ten Mile Creek	22.52	6.05	2003
EL-01	Spring Creek West	24.47	7.40	2007
embar 1224	East Crooked Creek	25.72	4.90	2010
EOC-02	Horse Creek	22.81	5.75	2007
EOH-01	Flat Branch	26.31	7.45	2007
EOH-01	Flat Branch	24.64	5.53	2008
EQ-01	Mosquito Creek	23.17	9.27	2007
EQ-01	Mosquito Creek	24.52	3.34	2010
ES-13	Steven's Creek	23.25	4.76	2003
EY-01	Drummer Creek	26.41	10.92	2010
EY-01	Drummer Creek	24.64	12.25	2003
FCC-01	East Branch Horse Creek	24.23	10.64	2008
FKA-01	Exline Slough	22.45	5.97	2008
FLD-03	Beaver Creek	24.86	5.15	2006
FLDA-01	Little Beaver Creek	23.69	7.54	2003
FLDA-04	Little Beaver Creek	25.33	10.51	2004
FLE-01	Langan Creek	24.93	5.85	2008
FLE-01	Langan Creek	23.81	3.72	2007
FLF-01	Pike Creek	24.25	9.62	2006
FLH-01	Spring Creek	23.77	6.16	2007
FLH-01	Spring Creek	23.59	6.53	2008
FLH-03	Spring Creek	26.77	14.08	2007
FLHA-01	Shavetail Creek	26.50	10.27	2007
FLI-06	Sugar Creek	23.91	11.76	2008
FLIA-01	Coon Creek	22.75	3.91	2007
FLIA-02	Coon Creek	25.68	6.99	2007
FLIDB-01	Gay Creek	26.16	7.38	2007
G-26	Des Plaines River	23.82	4.05	2003
GHE-01	Long Run	22.41	8.38	2003
HBE-02	Plum Creek	23.34	6.27	2008
ICD-02	Dutch Creek	25.72	4.05	2008
II-9X	Mary's River	23.50	1.94	2008
illin 18559	Spring Branch	23.39	5.62	2010
illin 20243	Little Sandy Creek	24.13	5.70	2010
illin 2957	Big Bureau Creek	24.99	4.35	2010
illin 4305	Pond Creek	23.67	8.52	2010
illin 4548	Forked Creek	25.32	7.24	2010
IXD-01	Sandy Creek	26.70	6.78	2008
IXFX-XX	Jackson Creek	24.04	3.98	2009
IXJ-01	Big Creek	25.23	3.73	1999

Table 6. Summary of sampled streams (continued).

Site Code*	Stream Name	Mean Daily July Temperature	Maximum Daily Temperature Range	Year Sampled
IXJ-02	Big Creek	25.23	4.04	2001
IXM-04	Cypress Creek	25.51	7.32	1999
IXM-05	Cypress Creek	22.30	4.82	2001
JMAA-01	Prairie DuPont Creek	24.15	5.11	2003
JND-01	Judy's Branch	23.03	5.84	2004
JND-01	Judy's Branch	22.34	6.61	2007
JV-01	Piasa Creek	28.29	9.18	2007
kasky 2186	Sandy Run	24.09	4.58	2010
kasky 2301	Hickory Creek	25.76	4.70	2010
kasky 3335	Burbacker Creek	24.42	3.85	2010
kasky 4368	North Creek	25.59	4.46	2010
kasky 715	Sand Creek	22.13	9.03	2010
kasky 969	Middle Fork Shoal Creek	26.90	14.76	2010
KCA-01	Bay Creek	23.49	3.16	2009
KCA-01	Bay Creek	27.16	4.95	2007
KCB-05	Six Mile Creek	25.87	9.59	2007
KCL-01	West Panther Creek	22.15	2.28	2007
KI-05	Bear Creek	23.38	7.10	2003
LF-05	Edwards River	23.81	6.32	2003
ltwab 1194	Skillet Fork	25.46	3.93	2010
marys 169	North Fork Cox Creek	26.84	4.33	2010
MN-18	Apple River	22.33	6.11	2007
MND-01	Furnace Creek	22.02	5.72	2007
MPA-01	Smallpox Creek	22.01	4.48	2007
MPA-01	Smallpox Creek	22.60	4.60	2010
MX-XX	Unnamed Trib. to Mississippi R.	26.42	8.80	2008
NDD-04	Grassy Creek	25.35	4.35	2003
NDC-99	Drury Creek	24.44	5.60	2008
NJ-07	Casey Fork	25.42	11.38	2004
O-32	Kaskaskia River	26.39	5.57	2003
OCB-97	Prairie Dulong Creek	24.66	3.83	2003
OD-09	Silver Creek	22.86	13.98	2004
OD-09	Silver Creek	25.34	6.74	2007
OE-05	Mud Creek	22.99	7.28	2003
OG-01	Elkhorn Creek	24.67	8.32	2005
OHA-01	Lake Branch East	23.59	6.37	2001
OHA-05	Lake Branch East	26.56	10.15	2001
OHC-XX	Grassy Branch	22.60	3.78	2009
OI-14	Shoal Creek	26.00	4.89	2003
OI-14	Shoal Creek	25.42	7.85	2007
OI-14	Shoal Creek	26.41	4.15	2010
OID-XX	East Fork Shoal Creek	22.14	4.76	2009
OJB-03	Lost Creek	25.83	9.67	2001
OJB-03	Lost Creek	23.09	5.61	2007
OJB-04	Lost Creek	23.99	6.50	2001
OK-01	East Fork Kaskaskia River	25.00	16.57	2003

Table 6. Summary of sampled streams (continued).

Site Code*	Stream Name	Mean Daily July Temperature	Maximum Daily Temperature Range	Year Sampled
OK-01	East Fork Kaskaskia River	24.52	3.90	2007
OK-01	East Fork Kaskaskia River	22.42	3.81	2009
OK-01	East Fork Kaskaskia River	25.60	3.17	2010
OT-03	West Okaw River	22.34	4.72	2008
OW-01	Lake Fork	26.72	10.60	2003
OW-01	Lake Fork	22.84	4.99	2008
OZYA-02	Copper Slough	22.81	8.55	2008
OZZD-01	Ash Creek	22.24	10.02	2007
PBG-12	Big Slough Ditch	23.15	13.95	2003
PH-15	Elkhorn Creek	23.96	7.20	2003
PQ-13	Kishwaukee River	23.02	8.32	2010
PQB-04	Killbuck Creek	22.99	6.80	2007
PWA-01	Racoon Creek	23.09	7.08	2010

* Site code written as the associated EPA station code (e.g. BPB-01), a unique code based on the EPA station code system (if the site did not have an EPA station code, e.g. PQFX-XX), or the PU Gap code for the sampled arc (for randomly chosen sites, e.g. edwar 558).

Table 7. Modeled temperature category and measured temperature category

Measured Temperature Category*	n**	Proportion Correctly Predicted	Predicted Cold	Predicted Cool	Predicted Warm
Cold	33	0.18	6	6	21
Cool	71	0.30	5	21	55
Warm	170	0.85	2	23	145
Overall accuracy:		0.63			

* based on mean daily July temperature.
** each sample event counted separately.

Table 8. Coefficients for Illinois Stream Temperature Model developed from stream temperature data collected 1999-2010 (Adjusted R2 = 63.2%, standard error = 1.7, df = 100). Latitude of the site in decimal degrees, DA is the natural log of the upstream drainage area in km2, Max Air is 10 times the maximum air temperature for the local watershed in July, Mean Air is 10 times the mean air temperature for the entire upstream watershed for the month of July, GDD is 10 times the mean annual growing degree days for the entire upstream watershed, Longitude of the site in decimal degrees, Bedrock is the proportion of bedrock within the entire upstream watershed that is within 50 ft of the surface, Link is the natural log of the link number of the channel at the location of the site.

Constant	Latitude	DA	Max Air	Mean Air	GGD	Longitude	Bedrock	Link number
156.0240	-2.3038	1.6562	-0.3632	0.8064	-0.0137	0.9315	1.1825	-0.6847

Table 9. Effectiveness of revised temperature model at classifying stream segments based on thermal classes of Wehrly *et al*. (2003).

Measured Thermal Class	n*	Proportion Correctly Predicted	Predicted Cooler	Predicted Warmer
Cold	24	0.50	NA	12
Cool	55	0.65	9	10
Warm	125	0.74	32	NA
Overall accuracy	204	0.69	41	22
Cold+Cool	79	0.85	NA	12
Warm or not Warm	204	0.78	32	12

* for those sites used in revised temperature model.

Table 10. Darcy model prediction and measured temperature category.

Standard Deviation Method:

Temp. Category	n	Model Value ≤ 1 SD	Model Value ≥ 1 SD		Accuracy
Cold	35	10	25		0.286
Cool	69	14	55		0.203
Warm	170	2	168		0.988
			overall accuracy:		0.701

Model Value Method:

Temp. Category	n	Model Value ≤ -50.0	Model Value > 50.0		Accuracy
Cold	33	10	23		0.303
Cool	70	13	57		0.186
Warm	168	3	165		0.982
			overall accuracy:		0.694

Table 11. Summary of Sites with Multiyear Temperature Data

Site	Year Sampled	Mean Daily July Temperature	Maximum Daily Temperature Range
AK-02	2003	25.10	4.66
	2009	24.68	4.25
	2010	28.03	1.66
BPJ-09	2003	21.73	12.25
	2009	21.85	5.49
BPJC-10	2007	23.40	5.15
	2008	22.24	4.52
CAGC-01	2004	25.39	17.04
	2009	25.81	13.00
DKV-01*	2006	23.76	7.50
	2009	20.59	8.09
DTC-05*	2005	15.92	4.98
	2010	21.89	4.73
DTF-02*	2009	20.49	5.00
	2010	24.63	5.47
EH-02	2004	20.69	13.30
	2007	21.92	13.34
	2008	21.63	8.32
	2009	19.69	7.85
	2010	21.86	8.39
EOH-01	2007	26.31	7.45
	2008	24.64	5.53
EQ-01*	2007	23.17	9.27
	2008	21.61	5.76
	2010	24.52	3.34
EY-01*	2003	24.64	12.25
	2009	19.72	9.45
	2010	26.41	10.92
FLE-01	2007	23.81	3.72
	2008	24.93	5.85
FLH-01	2007	23.77	6.16
	2008	23.59	6.53
IXF-01*	2008	18.15	4.95
	2009	19.17	3.66
	2010	20.94	2.96
KCA-01	2007	27.16	4.95
	2009	23.49	3.16
MJA-02*	2009	17.20	4.00
	2010	20.04	4.57
MN-18*	2003	21.73	9.29
	2007	22.33	6.11
	2009	19.27	6.31
MND-01*	2007	22.02	5.72
	2009	18.51	5.62
	2010	20.20	6.01
MPA-01*	2007	22.01	4.48
	2009	19.72	5.25
	2010	22.60	4.60
OD-09	2004	22.86	13.98
	2007	25.34	6.74
OI-14	2003	26.00	4.89
	2010	26.41	4.15
OK-01	2003	25.00	16.57
	2007	24.52	3.90
	2009	22.42	3.81
	2010	25.60	3.17
OW-01	2003	26.72	10.60
	2008	22.84	4.99
PK-01*	2003	20.92	6.44
	2007	20.19	6.52
	2008	19.84	5.24
	2009	17.79	4.76
	2010	21.03	4.79
PQE-10	2008	14.17	7.64
	2010	18.03	6.68
PSB-01*	2003	19.96	6.92
	2009	17.36	7.34
	2010	21.62	7.09
PT-01	2003	18.31	9.81
	2007	18.15	6.38
PWC-01	2003	15.77	13.11
	2007	15.01	11.00
	2008	14.63	8.50
	2009	13.71	8.02
	2010	15.71	9.28

* denotes sites that fall into more than one thermal category.

Table 12. Temperature probe results and associated temperature data.

Site Code*	Groundwater Input Potential**	Mean Daily July Temperature (^oC)
ADD-02	N	24.25
ADDB-01	N	24.12
ATHD-01	N	25.46
ATHD-03	N	25.31
ATHG-07	N	26.83
BJ-01	U	23.67
bmudd 2128	N	23.59
edwar 37	N	22.17
edwar 558	U	21.29
EH-02	P	21.92
EH-02 ('10)	L	21.86
EIG-02	P	27.58
EOC-02	U	24.74
FLDAE-01	N	20.88
FLH-03	N	26.77
FLI-06	N	23.91
FLIA-01	N	22.75
FLIA-02	N	25.68
ICD-02	N	25.72
II-9X	N	23.50
illin 18559	N	23.39
IXD-01	N	26.70
IXF-01 ('08)	U	18.15
IXF-01 ('09)	N	19.17
IXF-01 ('10)	U	20.94
IXFX-XX	N	24.04
JND-01	U	23.03
JV-01	N	28.29
kasky 2186	N	24.09
kasky 2301	N	25.76
kasky 4368	N	25.59
KCA-01	N	27.16
ltwab 1194	N	25.46
marys 169	N	26.84
MX-XX	N	26.42
OD-09	N	25.34
OK-01	N	25.00
OZZD-01	U	24.34
PBG-10	P	21.64
PLE-03	U	21.21
PN-02	L	20.11
PQC-11	N	20.39
PQCK-10	P	20.49
PWA-01	U	23.09
PWC-01 ('07)	L	15.01
PWC-01 ('08)	L	14.63
PWC-01 ('09)	L	13.71
PWC-01 ('10)	L	15.71
rockr 6825	L	20.33

* see Table 6 for description of site identification.

** based on vertical temperature profile in hyporheic zone. L = likely receiving groundwater inputs, P = possibly receiving inputs, U = unlikely receiving inputs, N = not receiving inputs.

Table 13. Shading study temperature results.

Stream	Site*	Site Type	Mean Daily Temp.	Difference From Stream Mean**	Mean Daily Min. Temp.	Mean Daily Max. Temp.	Mean Daily Temp. Range
Brush Creek	1	Sun	23.4	0.2	21.9	24.9	3.0
	2	Shade	23.2	0.0	21.9	24.6	2.7
	3	Shade	22.7	-0.5	21.6	24.2	2.6
	4	Sun	23.3	0.1	21.2	26.7	5.5
	5	Sun	23.2	0.0	21.2	26.6	5.0
Robinson Creek	1	Shade	24.4	-0.3	23.6	25.6	2.0
	2	Shade	24.6	-0.1	23.5	25.9	2.4
	3	Sun	24.8	0.1	23.5	26.7	3.2
	4	Sun	24.9	0.2	23.5	26.8	3.4
	5	Shade	24.8	0.1	23.4	26.7	3.3
South Kinnikinnik Creek	1	Shade	19.6	0.0	18.3	20.9	2.6
	2	Sun	19.9	0.3	18.4	21.4	3.0
	3	Sun	19.4	-0.2	17.9	20.7	2.8
	4	Shade	19.4	-0.2	18.0	20.7	2.7

* Most upstream location is site 1 in each stream.

** Difference of site mean daily temperature and stream-wide mean daily temperature.

Table 14. Result of vertical temperature analysis.

Stream	Site	Mean Daily Temp.	Mean Daily Max. Temp.	Mean Daily Temp. Range
West Okaw River	1 Top	23.1	25.6	4.6
	1 Bottom	22.9	25.1	4.0
	2 Top	23.8	28.0	6.7
	2 Bottom	23.2	26.0	4.6
	3 Top	24.3	26.7	4.2
	3 Bottom	23.1	23.8	1.4
	4 Top	23.5	26.1	4.3
	4 Bottom	23.2	25.5	3.7
Crane Creek	1 Top	22.7	27.4	7.5
	1 Bottom	22.5	27.0	7.1
	2 Top	22.0	25.3	5.9
	2 Bottom	22.0	25.2	5.7
	3 Top	20.9	23.6	4.8
	3 Bottom	20.9	23.4	4.6
Kickapoo Creek	1 Top	27.5	29.6	4.1
	1 Bottom	27.5	29.5	4.0
	2 Top	26.0	27.6	3.2
	2 Bottom	26.0	27.6	3.2
	3 Top	26.2	28.0	3.4
	3 Bottom	26.1	27.7	3.0

Table 15. Regression analysis summary for landuse proportions.

Landuse Type	Spatial Scale	Significance Value*	Slope	Adjusted R^2
Agriculture	Whole Watershed	0.182	-0.916x + 23.018	0.003
	Local Watershed	0.836	0.139x + 22.502	-0.004
	Upstream Riparian	**0.024**	-1.727x + 23.342	0.015
	Local Riparian	0.445	-0.542x + 22.717	-0.002
Urban	Whole Watershed	0.925	-0.176x + 22.575	-0.002
	Local Watershed	0.365	-1.271x + 22.629	0.000
	Upstream Riparian	0.787	-0.644x + 22.584	-0.003
	Local Riparian	0.284	-2.130x + 22.623	0.001
Forest	**Whole Watershed**	**< 0.001**	4.434x + 21.945	0.070
	Local Watershed	**< 0.001**	3.202x + 21.837	0.053
	Upstream Riparian	**< 0.001**	4.862x + 21.455	0.125
	Local Riparian	**< 0.001**	3.173x + 21.311	0.095

* df = 272 for all analyses

Table 16. Chi-squared test results for comparison of habitat characters.

Habitat Character	Thermal Category	n samples	Chi-Squared Value
Dominant Substrate	Coldwater	26	0.317
	Coolwater	73	**0.030**
	Warmwater	149	0.196
Riparian Width	Coldwater	53	**< 0.001**
	Coolwater	146	**0.043**
	Warmwater	297	**0.011**
Dominant Flow	Coldwater	26	0.070
	Coolwater	71	**< 0.001**
	Warmwater	151	**< 0.001**
Shading	Coldwater	27	0.089
	Coolwater	72	**0.039**
	Warmwater	152	0.532
Number of Channel Units	Coldwater	27	0.063
	Coolwater	70	0.234
	Warmwater	150	0.700

Table 17. Summary of Vegetation Characteristics at Streams with Temperature Records

	Mean Proportion of Bank Cover[1]				Mean Abundance of
Site Code	Herbaceous	Woody	Trees	No Veg.	Instream Macrophytes[*]
Coldwater streams:					
DTC-05	2.5	1.5	1.5	0.25	0.11
EIEI-03	2	1	2	1	0
IXF-01	1.5	1.5	2.5	1.5	1.2
MND-01	3	0.5	0	0	0.8
MNIA-11	2	3	2	0.5	0.11
PHB-01	3	1	0.5	0	1.63
PK-01	3	0	2	0.75	1.75
PQH-01	3	2	0	0	0.5
PSB-01	2.5	1	2	0.5	0.14
PT-01	3	1	3	0	0
PWC-01	3	2	2.5	0	1
Mean values (cold):	2.59	1.32	1.64	0.41	0.66
Coolwater streams:					
DTE-01	3	2	2	0	0.33
DTF-02	3	2	3	0.5	0.75
DTKA-04	2	1	3	0.25	1
DTZT-02	3	1	2	0	1.67
DZP-03	3	2	3	1	0
EH-02	3	2	0	0	3
IXF-01	1.5	1.5	2.5	1.5	1.2
MN-18	3	0	0	0	0
MND-01	3	0.5	0	0	0.8
MNI-12	2.5	0	0	1	0.38
MPA-01	3	1	1	1	1.44
PK-01	3	0	2	0.75	1.75
PN-03	2	0	1	0.75	0
PP-01	3	0	0	0.38	1
PQDA-01	2	3	3	0.25	0
PQJ-01	3	1	1	0	0
PSB-01	2.5	1	2	0.5	0.14
PWQ-04	3	1	0	0.5	1
QC-03	3	3	3	0	0.11
Mean values (cool):	2.71	1.16	1.50	0.44	0.77

Table 17. Summary of Vegetation Characteristics at Streams with Temperature Records (cont.)

Site Code	Mean Proportion of Bank Cover[1] Herbaceous	Woody	Trees	No Veg.	Mean Abundance of Instream Macrophytes[*]
Warmwater streams:					
ADCD-01	3	1	0	0	3
ADD-02	3	0	3	1	0
ADDB-01	1.75	0.75	2	0.5	0
AJ-09	3	2	3	0	0
AJG-18	2.5	0	1.5	0.75	0
ATHG-02	2	1	2	0.5	1
BEN-01	0	2	3	0	0
BEN-02	0.5	0.5	0	1	0.15
BENA-01	3	0	0	0	0.13
BEZZ-05	1.5	1	3	0.75	2.5
BFC-11	2	0	2	0.75	0
BJ-01	2	2	2	0	0
BPJA-01	3	2	2	0	0
CAGC-01	3	0	0	0	0
DF-05	3	3	3	0	0
DGLC-01	3	0	0	0.75	1
DJJB-04	3	3	3	0	0.25
DSB-02	2	2	2.5	1.25	0.3
DSG-01	3	0	1	0.5	1.67
DSH-01	3	3	3	1.75	0.25
DSH-02	3	2	3	0.5	2.22
DTC-04	3	2	2	0.5	0
DTC-07	2.5	1	1.5	0.75	0.33
DTF-02	3	2	3	0.5	0.75
DZA-03	3	1	2	0.25	0
EL-01	3	1	1	0.5	0
FCC-01	3	0	0	0	3
FKA-01	2.5	1.5	2.5	0.5	2.5
FLD-03	2	1	2.5	0.75	0
FLH-01	3	1	0	0	0
FLIA-01	1	1.5	2	0.5	1
GV-01	1	1	2.5	0.5	0
HBE-02	3	0	1.5	1.25	0
ICD-02	3	2	3	0	0
IXM-04	3	1	0.5	0.5	0
KI-05	3	2	2	0.25	1
MN-18	3	0	0	0	0

Table 17. Summary of Vegetation Characteristics at Streams with Temperature Records (cont.)

	Mean Proportion of Bank Cover[1]				Mean Abundance of
Site Code	Herbaceous	Woody	Trees	No Veg.	Instream Macrophytes*
MND-01	3	0.5	0	0	0.8
MPA-01	3	1	1	0.75	1.44
OCB-97	2	0	2	0.5	0
OD-09	3	0	1	1.5	0
OI-14	3	0	3	0.5	0
OK-01	2	0.5	2	0.5	0
OT-03	2.5	1	2	1	0
PQ-13	2.5	1.5	1.5	0	1
PQB-04	3	0	0	0	0.67
Mean values (warm):	2.53	1.04	1.68	0.47	0.54

* Values range from 0 to 3 (0=absent, 1=sparse, 2= intermediate, 3=abundant). Mean bank vegetation calculated from both left and right bank values. Mean instream macrophytes caluculated from values at each channel unit (riffle, run, pool) within sampled stream reach.

Table 18. Additional fish analyzed for thermal preference.

Common Name	Scientific Name
American eel	*Angiulla rostrata*
Banded killfish	*Fundulus diaphanus*
Black redhorse	*Moxostoma duquesnei*
Blackspotted topminnow	*Fundulus olivaceus*
Brassy minnow	*Hybognathus hankinsoni*
Brindled madtom	*Noturus miurus*
Central mudminnow	*Umbra limi*
Chestnut lamprey	*Ichthyomyzon castaneus*
Common shiner	*Notropis cornutus*
Creek chub	*Semotilus atromaculatus*
Fantail darter	*Etheostoma flabellare*
Golden redhorse	*Moxostoma erythrurum*
Grasss pickerel	*Esox americanus*
Horneyhead chub	*Nocomis biguttatus*
Lake chubsucker	*Erimyzon sucetta*
Largescale stoneroller	*Campostoma oligolepis*
Northern hogsucker	*Hypentelium nigricans*
Northern pike	*Esox lucius*
Orangethroat darter	*Etheostoma spectabile*
Rainbow darter	*Etheostoma caeruleum*
Rock bass	*Ambloplites rupestris*
Sauger	*Stizostedion canadense*
Shorthead redhorse	*Moxostoma macrolepidotum*
Silver lamprey	*Ichthyomyzon unicuspis*
Smallmouth bass	*Micropterus dolonieui*
Starhead topminnow	*Fundulus dispar*
Stonecat	*Noturus flavus*
Striped shiner	*Notropis chrysocephalus*
Stripetail darter	*Etheostoma kennicotti*
Walleye	*Stizostedion vitreum*
White sucker	*Catostomus commersoni*

Table 19. Temperature class for selected fish species.

Species	Number of Sites with Temp. Records	Number of Temp. Records	Mean Temp. of Occurrence	Range of Mean Temps.	Wherly Method IL Thermal Class	Lyons Method IL Thermal Class	Published Lyons Thermal Class	Published Indiana Thermal Class	Published Ohio Thermal Class
Northern brook lamprey	0	0	N/A	N/A	N/A	N/A	Trans	Cl	N/A
American brook lamprey	1	1	N/A	18.1	Cd	Cl	Trans	Cl	N/A
Least brook lamprey	1	1	N/A	24.5	Wm	Wm	N/A	Wm	N/A
Brown trout	3	6	19.5	17.4-21.6	Cd-Cl	Trans	Cd	Wm	Cd
Rainbow trout	3	3	18.9	17.1-21.3	Cd-Cl	Trans	Cd	Wm	Cd
Southern redbelly dace	35	48	20.4	16.3-28.3	Eury	Trans	Wm	Cl	N/A
Blacknose dace	34	49	19.6	13.7-25.3	Eury	Trans	Trans	Cl	N/A
Longnose dace	8	9	19.1	16.8-21.3	Cd-Cl	Trans	Trans	Cl	N/A
Ozark minnow	9	16	19.6	16.3-22.3	Eury	Trans	N/A	N/A	N/A
Weed shiner	4	4	23.1	19.3-25.3	Cl-Wm	Wm	N/A	Wm	N/A
Ironcolor shiner	4	8	22.5	19.7-25.3	Cl-Wm	Wm	N/A	Wm	N/A
Ninespine stickleback	2	2	19.2	17.1-21.3	Cd-Cl	Trans	N/A	Cl	N/A
Brook stickleback	22	31	18.6	13.7-23.0	Eury	Trans	Trans	Cl	Cd
Banded sculpin	9	11	24.4	22.1-27.5	Wm	Wm	N/A	Cl	N/A
Mottled sculpin	11	13	19.9	15.9-24.6	Eury	Trans	Cd	Wm	Cd
Iowa darter	3	3	20.3	18.1-23.1	Eury	Trans	Wm	Wm	N/A
Least darter	3	3	23.5	22.5-24.2	Wm	Wm	Wm	Wm	N/A
Grasss pickerel	56	74	23.1	13.7-27.5	Eury	Wm	Wm	Wm	N/A
Horneyhead chub	86	114	21.9	15.9-27.5	Eury	Trans	Wm	Wm	N/A
Striped shiner	62	80	23.1	15.9-28.0	Eury	Wm	N/A	Wm	N/A
Northern hogsucker	64	85	22.2	15.9-28.0	Eury	Wm	Trans	Wm	N/A
Shorthead redhorse	52	65	23.1	15.9-28.3	Eury	Wm	Wm	Wm	N/A
Black redhorse	20	27	22.4	15.9-28.0	Eury	Wm	N/A	Wm	N/A
Golden redhorse	85	112	22.8	15.9-28.3	Eury	Wm	Wm	Wm	N/A
Stonecat	53	71	21.7	15.9-26.4	Eury	Wm	Wm	Wm	N/A
Brindled madtom	7	9	22.6	18.2-27.3	Eury	Wm	N/A	Wm	N/A
Blackspotted topminnow	24	28	24.6	18.1-28.0	Eury	Wm	N/A	Wm	N/A
Rainbow darter	19	21	23.4	18.1-28.0	Eury	Wm	Wm	Wm	N/A
Stripetail darter	9	11	25.5	22.9-28.0	Wm	Wm	N/A	Wm	N/A
Orangethroat darter	40	47	23.1	18.1-28.3	Eury	Wm	N/A	Wm	N/A
Fantail darter	51	69	20.8	14.6-26.4	Eury	Trans	Wm	Wm	N/A
Rock bass	34	42	22.4	17.8-26.4	Eury	Wm	Wm	Wm	N/A
Smallmouth bass	62	79	22.1	15.9-27.5	Eury	Wm	Wm	Wm	N/A
Common shiner	57	76	20.3	13.7-25.4	Eury	Trans	Wm	Wm	N/A
Northern pike	15	16	22.4	16.2-26.8	Eury	Wm	Trans	Wm	N/A
Walleye	6	6	24.7	19.7-28.3	Cl-Wm	Wm	Trans	Wm	N/A
Brassy minnow	2	2	20.2	16.2-24.2	Eury	Trans	Trans	Wm	N/A
Largescale stoneroller	13	20	20.7	15.9-24.6	Eury	Trans	Wm	Wm	N/A
Central mudminnow	9	13	21.3	18.1-25.3	Eury	Wm	Trans	Wm	N/A
Silver lamprey	0	0	N/A	N/A	N/A	N/A	N/A	Wm	N/A
Banded killfish	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Wm	N/A
White sucker	134	174	22.1	13.7-28.3	Eury	Trans	Trans	Wm	N/A
Creek chub	137	173	22.4	16.2-28.3	Eury	Wm	Trans	Wm	N/A
Sauger	5	5	24.4	23.8-26.4	Wm	Wm	N/A	Wm	N/A
American eel	2	2	23.7	20.1-27.3	Cl-Wm	Wm	N/A	Wm	N/A
Starhead topminnow	3	7	21.8	19.7-23.7	Cl-Wm	Wm	N/A	Wm	N/A
Lake chubsucker	3	7	22.1	19.7-24.9	Cl-Wm	Wm	Wm	Wm	N/A
Chestnut lamprey	1	3	25.9	24.7-25.1	Wm	Wm	Wm	Wm	N/A

Table 20. Most common species in cold and cool streams.

Common Name	Proportion of Sites Present	Statewide Proportion (n=5643)	Proportion of Sites Sampled with Fish Collection Records (n=127)
Coldwater sites (n=24)			
White sucker	0.88	0.22	0.72
Creek chub	0.83	0.20	0.71
Johnny darter	0.75	0.16	0.57
Common stoneroller	0.71	0.14	0.58
Fantail darter	0.67	0.05	0.28
Green sunfish	0.58	0.27	0.77
Southern redbelly dace	0.58	0.02	0.16
Bluntnose minnow	0.54	0.26	0.83
Horneyhead chub	0.54	0.12	0.51
Blacknose dace	0.50	0.03	0.19
Common shiner	0.50	0.05	0.32
Coolwater sites (n=45)			
White sucker	0.93	0.22	0.72
Bluntnose minnow	0.89	0.26	0.83
Creek chub	0.84	0.20	0.71
Horneyhead chub	0.73	0.12	0.51
Green sunfish	0.71	0.27	0.77
Johnny darter	0.67	0.16	0.57
Common stoneroller	0.67	0.14	0.58
Common shiner	0.64	0.05	0.32
Bluegill sunfish	0.60	0.24	0.65
Smallmouth bass	0.56	0.11	0.34
Sand shiner	0.56	0.18	0.53
*Warmwater sites (n=72)**			
Bluntnose minnow	0.89	0.26	0.83
Green sunfish	0.86	0.12	0.77
Bluegill sunfish	0.72	0.24	0.65
Sand shiner	0.60	0.18	0.53
Creek chub	0.58	0.20	0.71
White sucker	0.53	0.22	0.72
Common stoneroller	0.49	0.14	0.58
Johnny darter	0.46	0.16	0.57
Horneyhead chub	0.38	0.16	0.51
Smallmouth bass	0.26	0.02	0.34
Fantail darter	0.10	0.27	0.28
Common shiner	0.07	0.05	0.32
Southern redbelly dace	0.01	0.11	0.16
Blacknose dace	0.01	0.03	0.19

* species listed are only those found to be dominant in cold or cool streams and may not represent dominant species for warm streams.

Table 21. Ten highest indicator species analysis values for each temperature category.

Coldwater Species	Indicator Value	Coolwater Species	Indicator Value	Warmwater Species	Indicator Value
Southern redbelly dace	54	White sucker	41	**Red shiner**	49
White sucker	41	**Smallmouth bass**	30	**Longear sunfish**	48
Common stoneroller	40	Hornyhead chub	29	**Green sunfish**	47
Fantail darter	39	Bluegill	27	**Blackstripe topminnow**	44
Creek chub	38	Creek chub	26	**Yellow bullhead**	41
Blacknose dace	35	Common shiner	25	Bluntnose minnow	37
Johnny darter	34	Johnny darter	24	Largemouth bass	33
Common shiner	28	**Stonecat**	23	**Gizzard shad**	33
Brook stickleback	26	Fantail darter	22	Sand shiner	31
Bluntnose minnow*	24	Bluntnose minnow	22	Common carp	31
Hornyhead chub*	24				

Bolded species are those statistically significant within their category.
* Tied for 10th

Table 22. Validation of coldwater and coolwater fish communities (as determined by indicator analysis).

	n sites, statewide	n sites with temp. records	n temp. records	n confirmed coldwater records	n confirmed coolwater records	n confirmed warmwater records	accuracy (records < 22^{o}C)
Coldwater community*	60	25	35	16	18	1	97.1%
Coolwater community*	323	43	59	7	24	28	52.5%

* community structure comprised of species significantly associated with their respective category (coldwater communties contained at least 4 of the 7 species, coolwater communities contained both species).

Coldwater = blacknose dace, brook stickleback, common shiner, fantail darter, longnose dace, mottled sculpin, southern redbelly dace.

Coolwater = smallmouth bass, stonecat.

Table 23. Potential macroinvertebrate coolwater indicator taxa.

Order	Taxa	n locations with temp. records	Mean daily July temp. preference
Ephemeroptera	*Acerpenna macdunnoughi*	0	N/A
	Ephemerella inermis	0	N/A
	Ephemerella subvaria	0	N/A
	Eurylophella sp.	2	27.13
	Timpanoga lita	0	N/A
	Paraleptophlebia debilis	9	25.96
Plecoptera	*Leuctra tenuis*	0	N/A
	Amphinemura linda	0	N/A
	Nemoura trispinosa	0	N/A
Trichoptera	*Brachycentrus americanus*	0	N/A
	Brachycentrus lateralis	0	N/A
	Glossosoma sp.	0	N/A
	Diplectrona modesta	0	N/A
	Parapsyche apicalis	0	N/A
	Hesperophylax designatus	0	N/A
	Frenesia missa	0	N/A
	Chimarra aterrima	0	N/A
	Rhyacophila vibox	0	N/A
Megaloptera	*Corydalus sp.*	21	24.04
	Sialis sp.	51	23.24
Diptera	*Eukiefferiella sp.*	2	21.37
	Thienemanniella sp.	1	20.11
Gastropodia (Class)	*Ferrissia sp.*	18	23.06
Malacostraca (Class)	*Hyalella azteca*	57	23.31

Figures

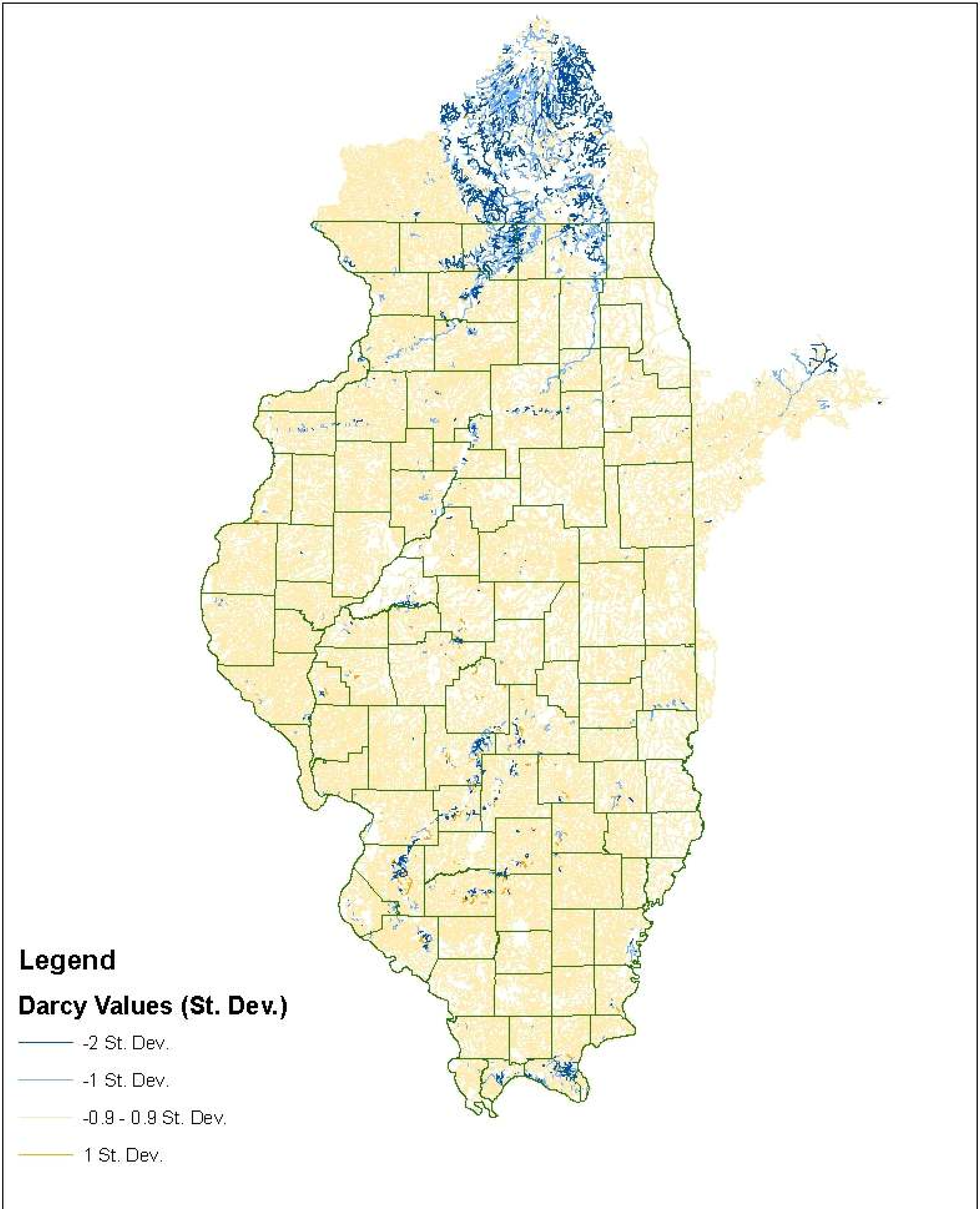


Figure 1. Darcy model output values

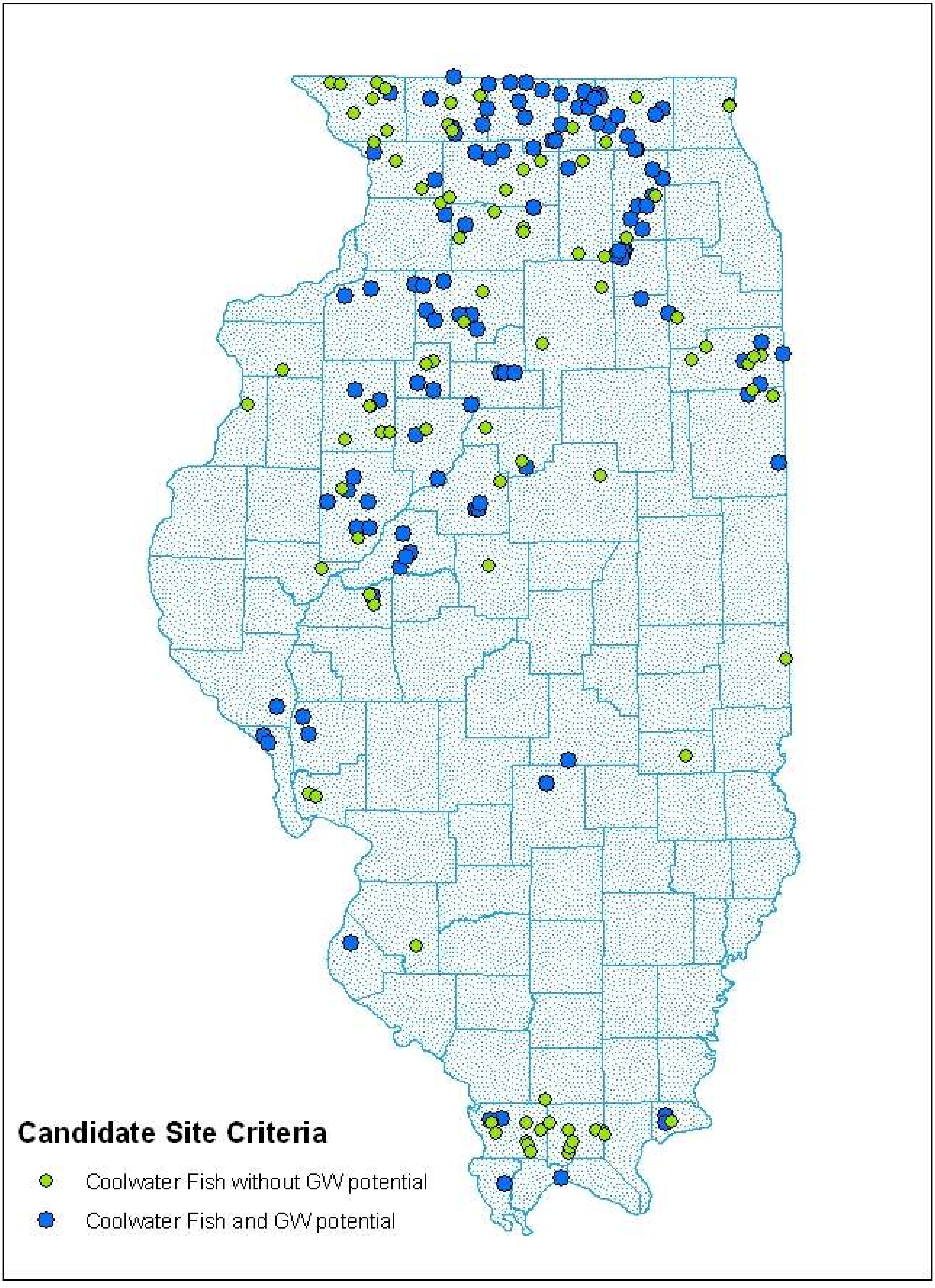


Figure 2. Candidate coolwater sites in Illinios streams.

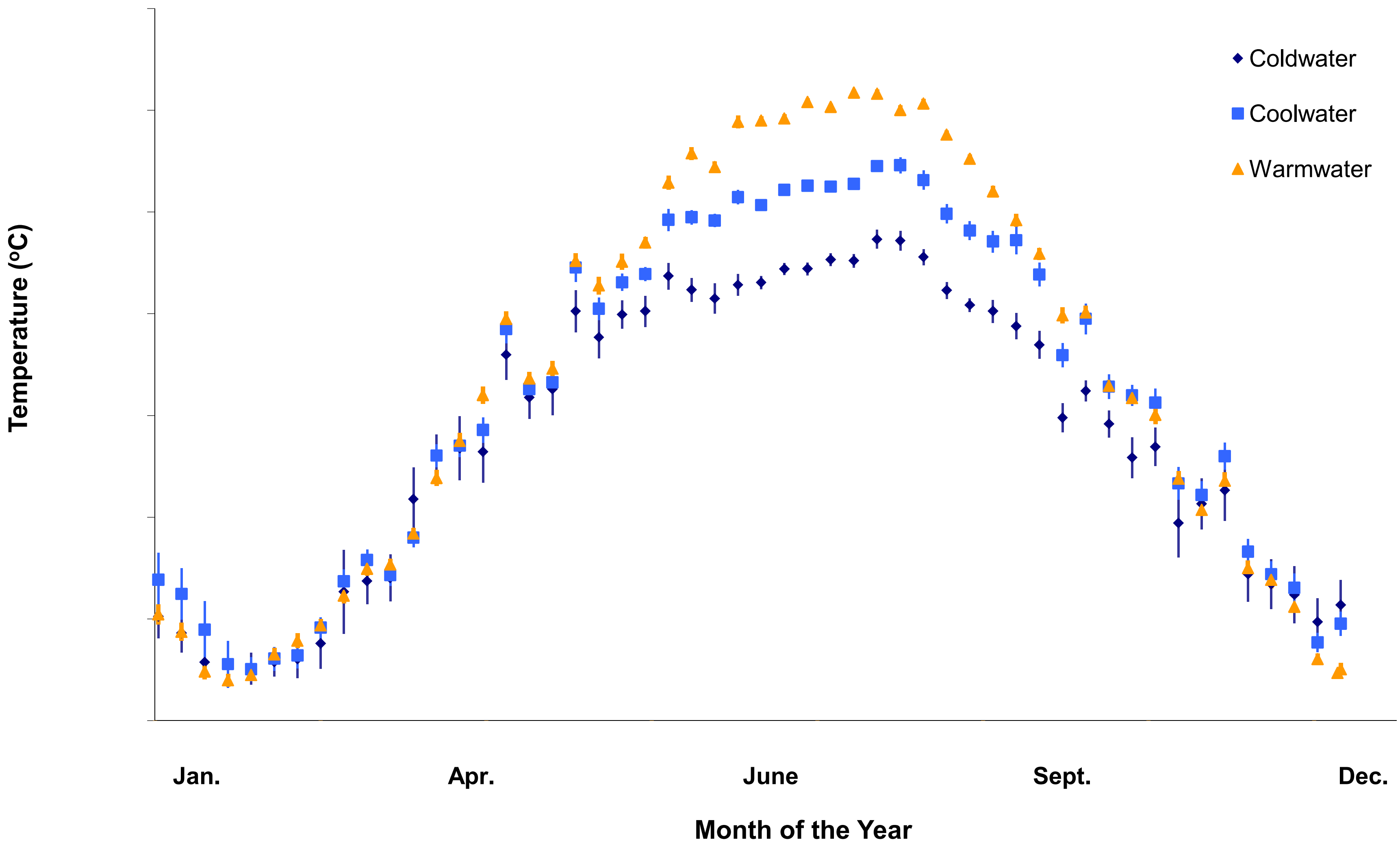


Figure 3. Weekly mean noon temperature with 95% confidence intervals for each thermal class.

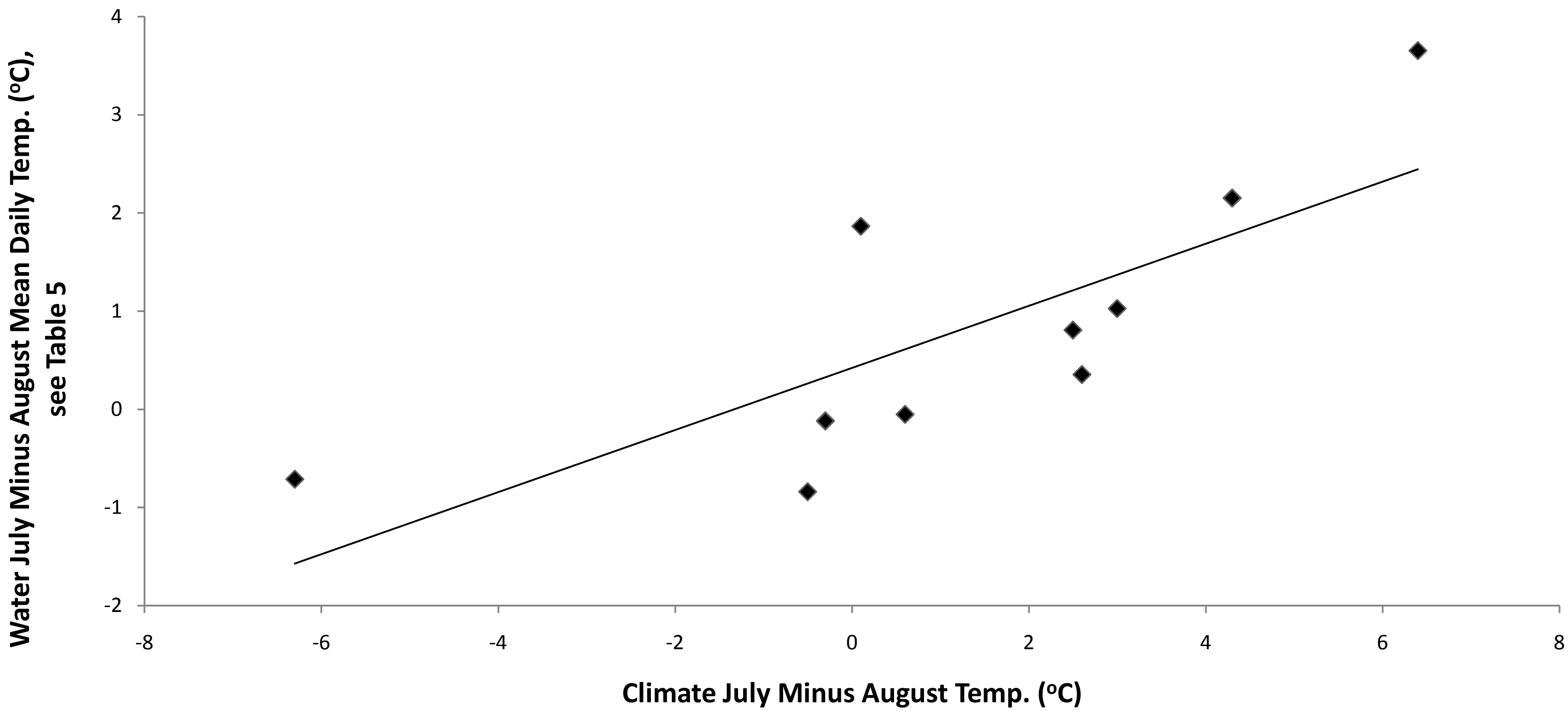


Figure 4. Comparison of mean change in monthly mean daily water

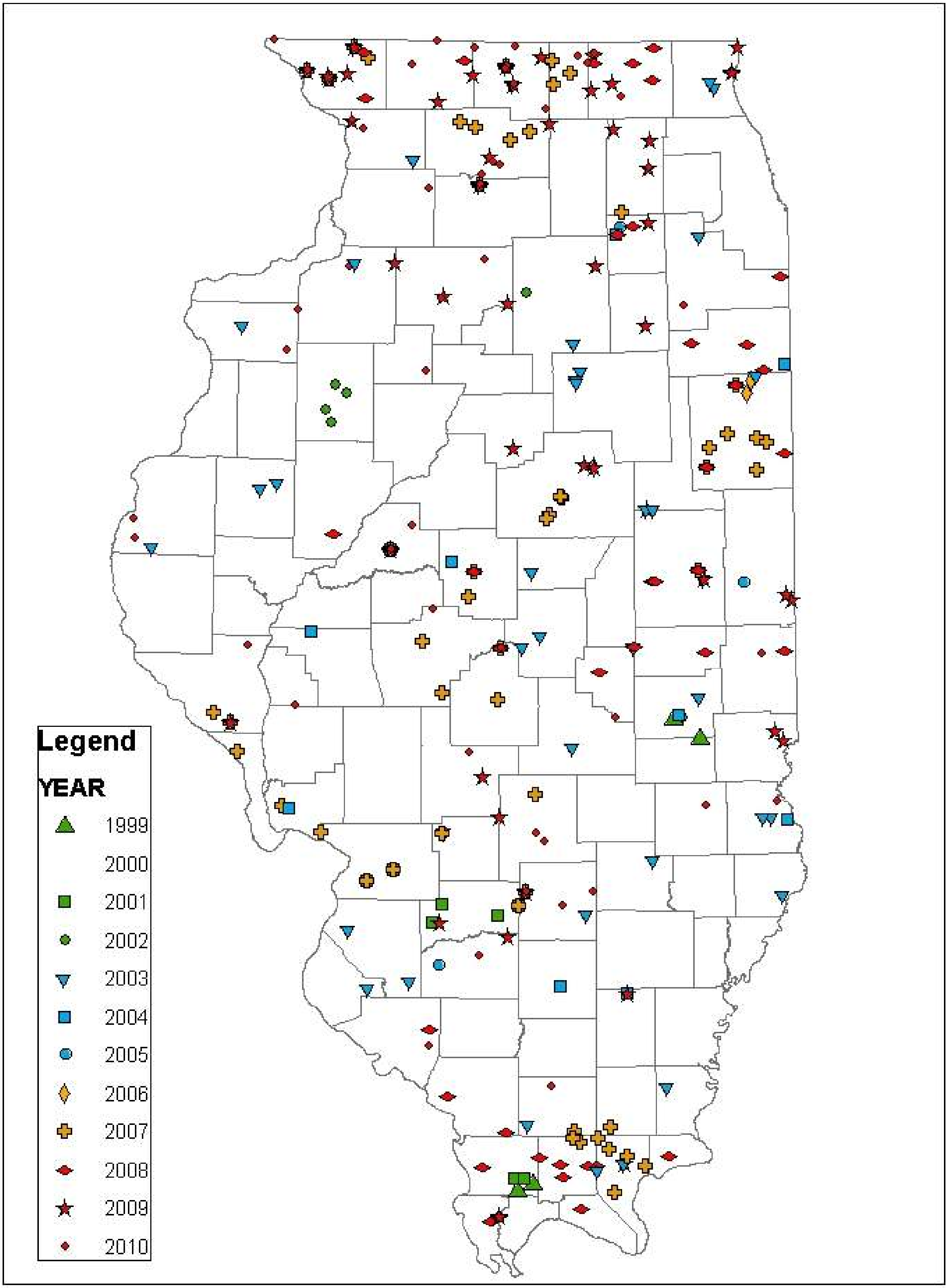


Figure 5. Logger deployment locations.

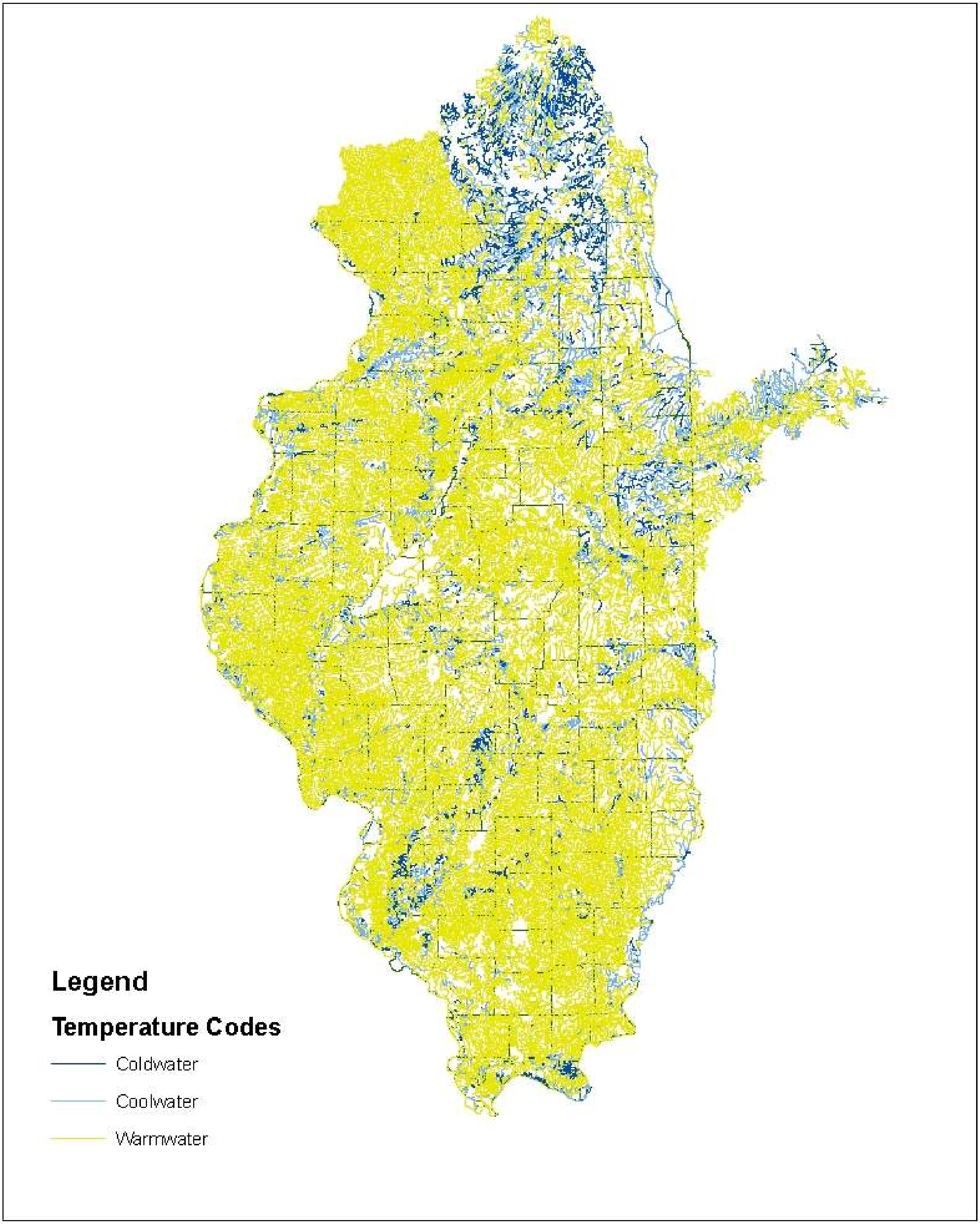


Figure 6. Temperature model results

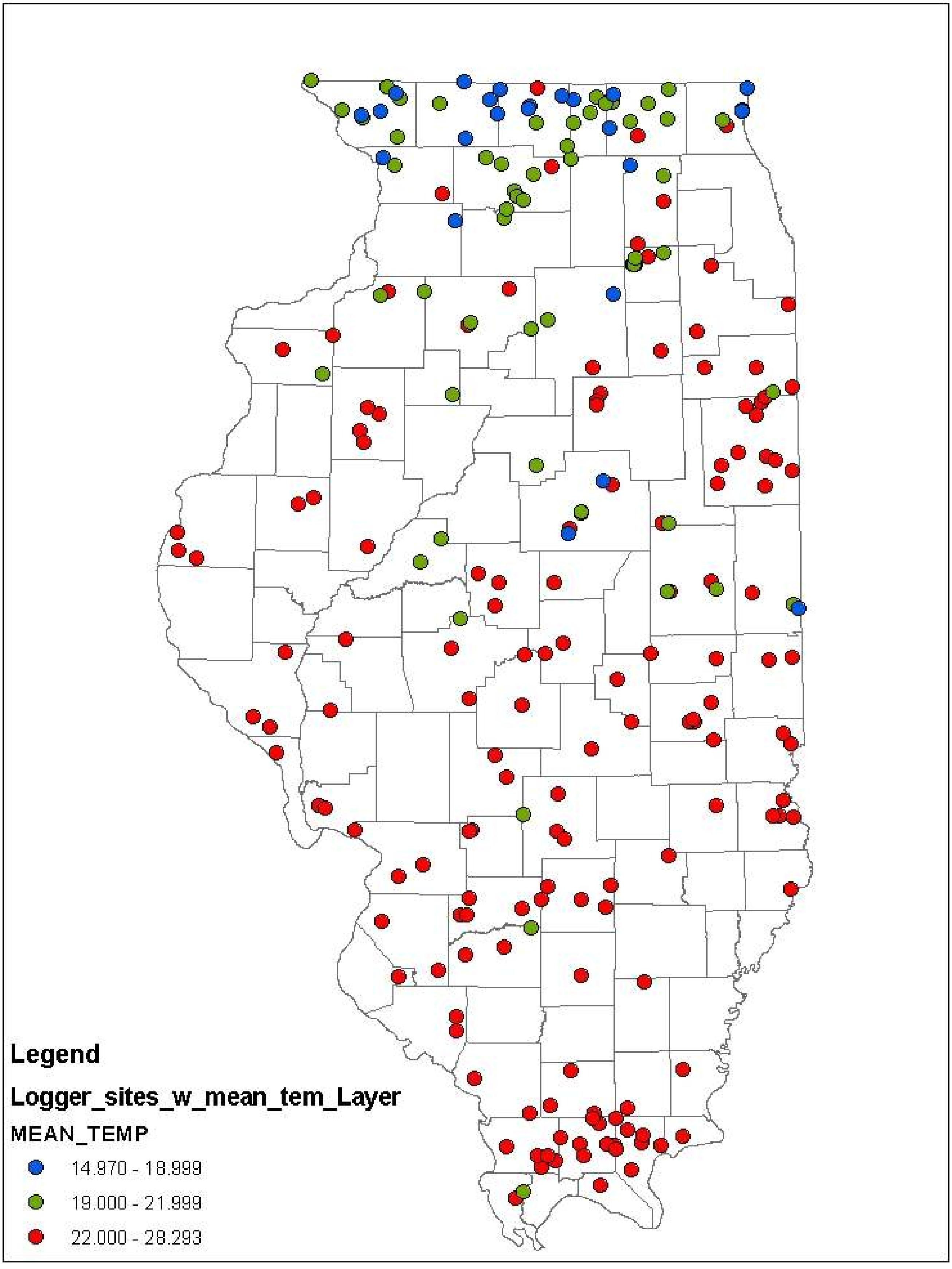


Figure 7. Logger locations color coded by mean thermal category.

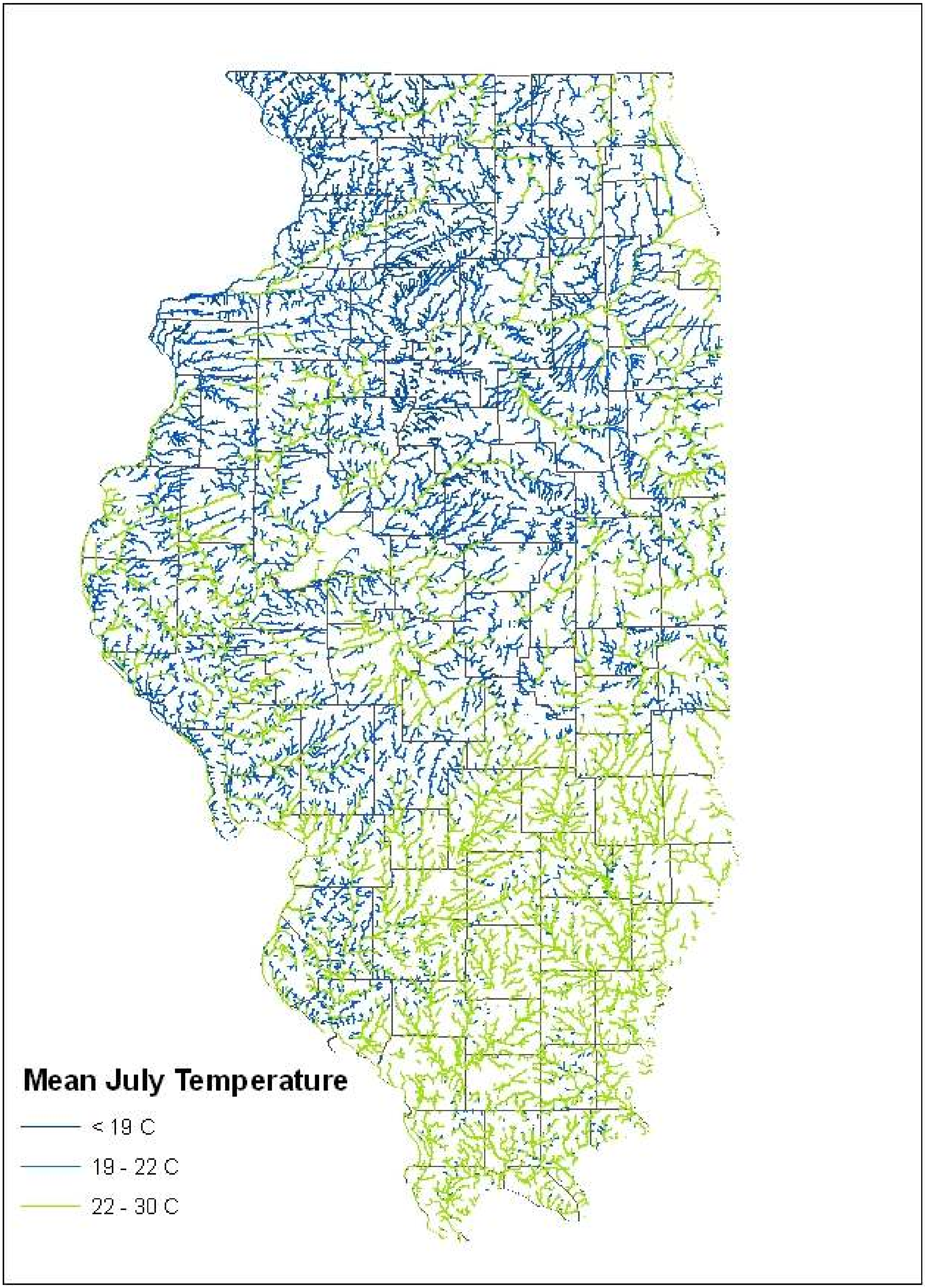


Figure 8. Revised stream temperature model for Illinois. Predicted temperatures of stream segments are presented as in Wehrly *et al.* 2003. Note: These results suggest expected thermal classes for relatively unimpacted watersheds and channels. Observed temperatures in these stream segments may be different.

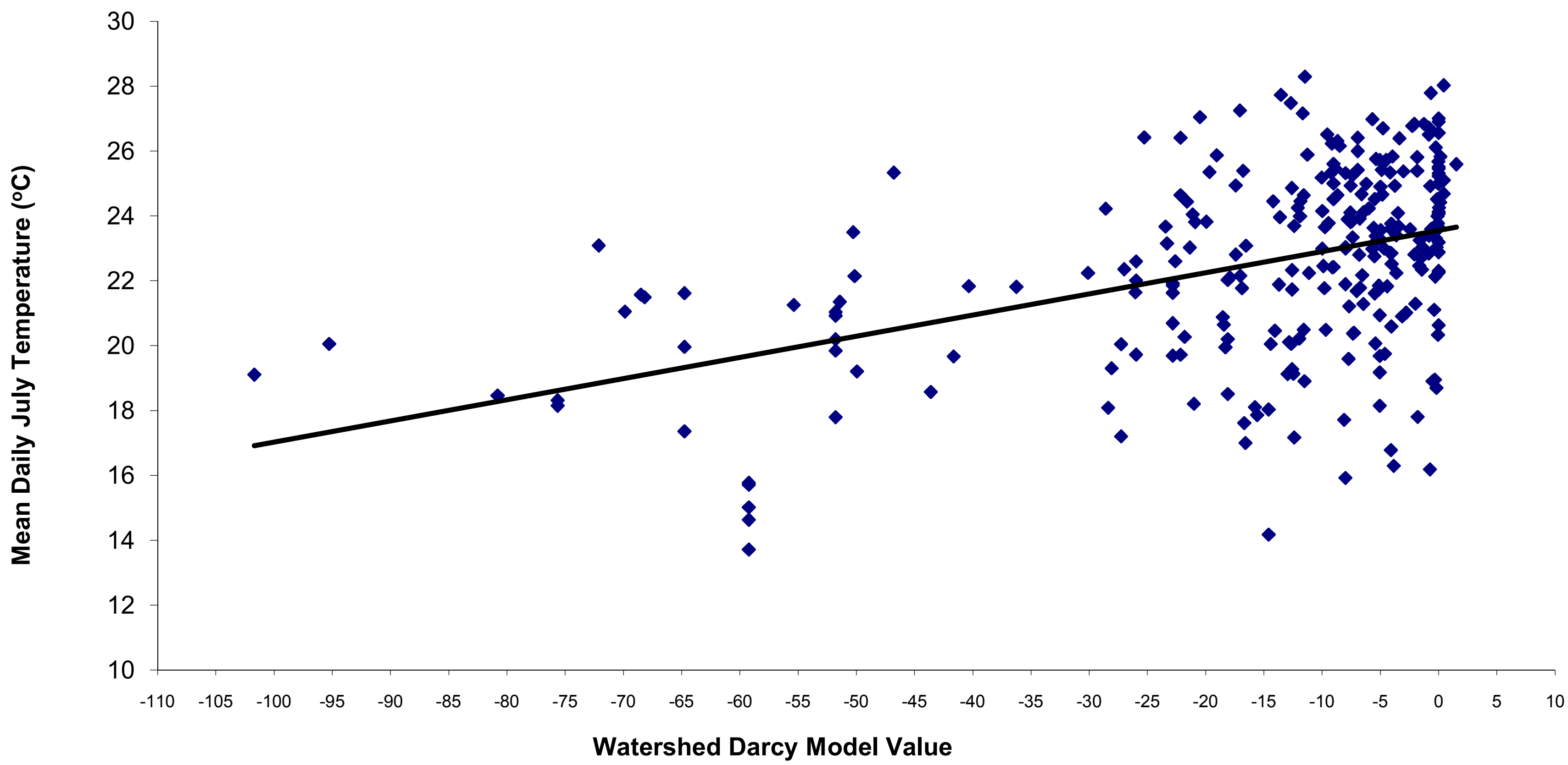


Figure 9. Comparison of measured temperature and modeled watershed Darcy value

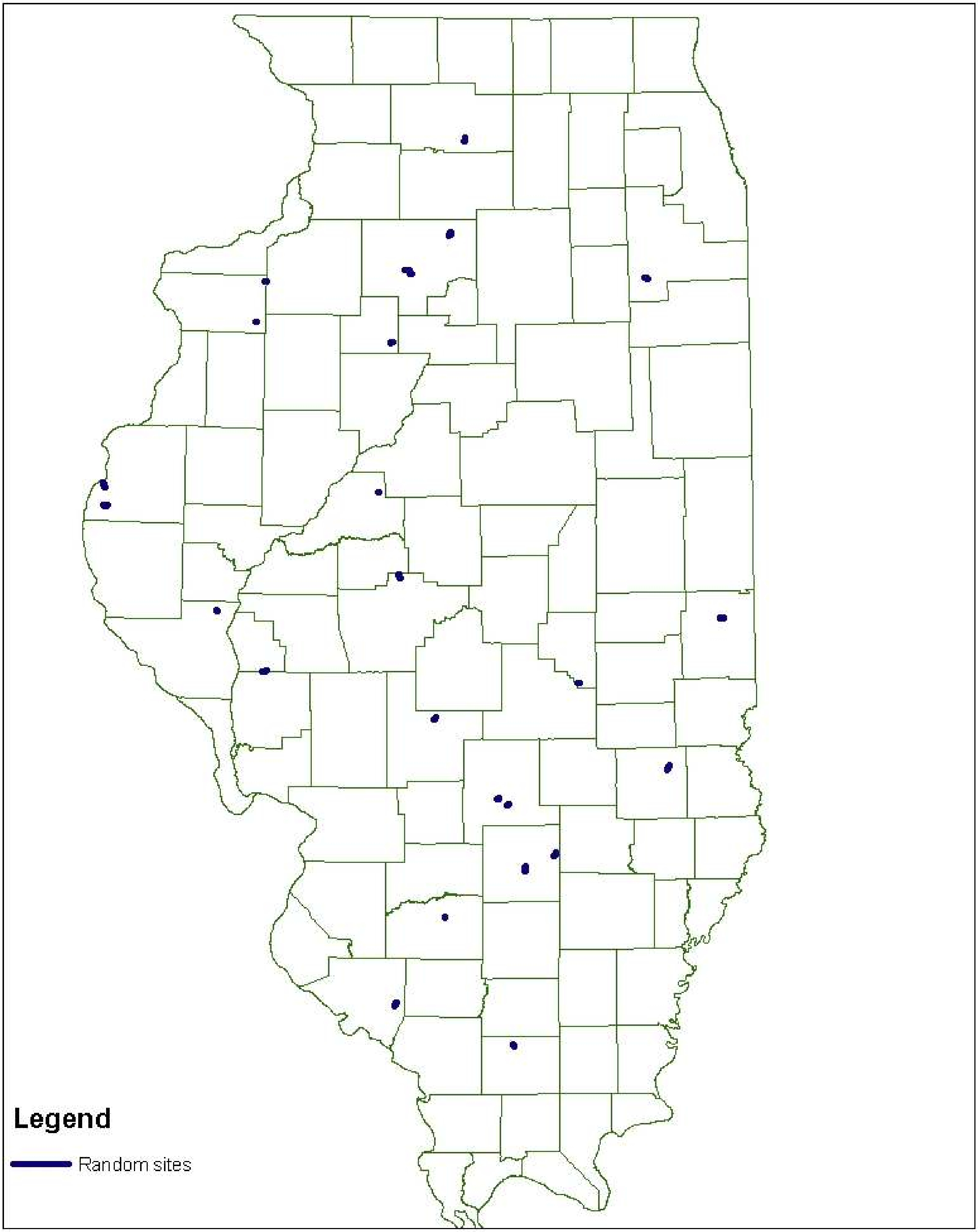


Figure 10. Random site locations.

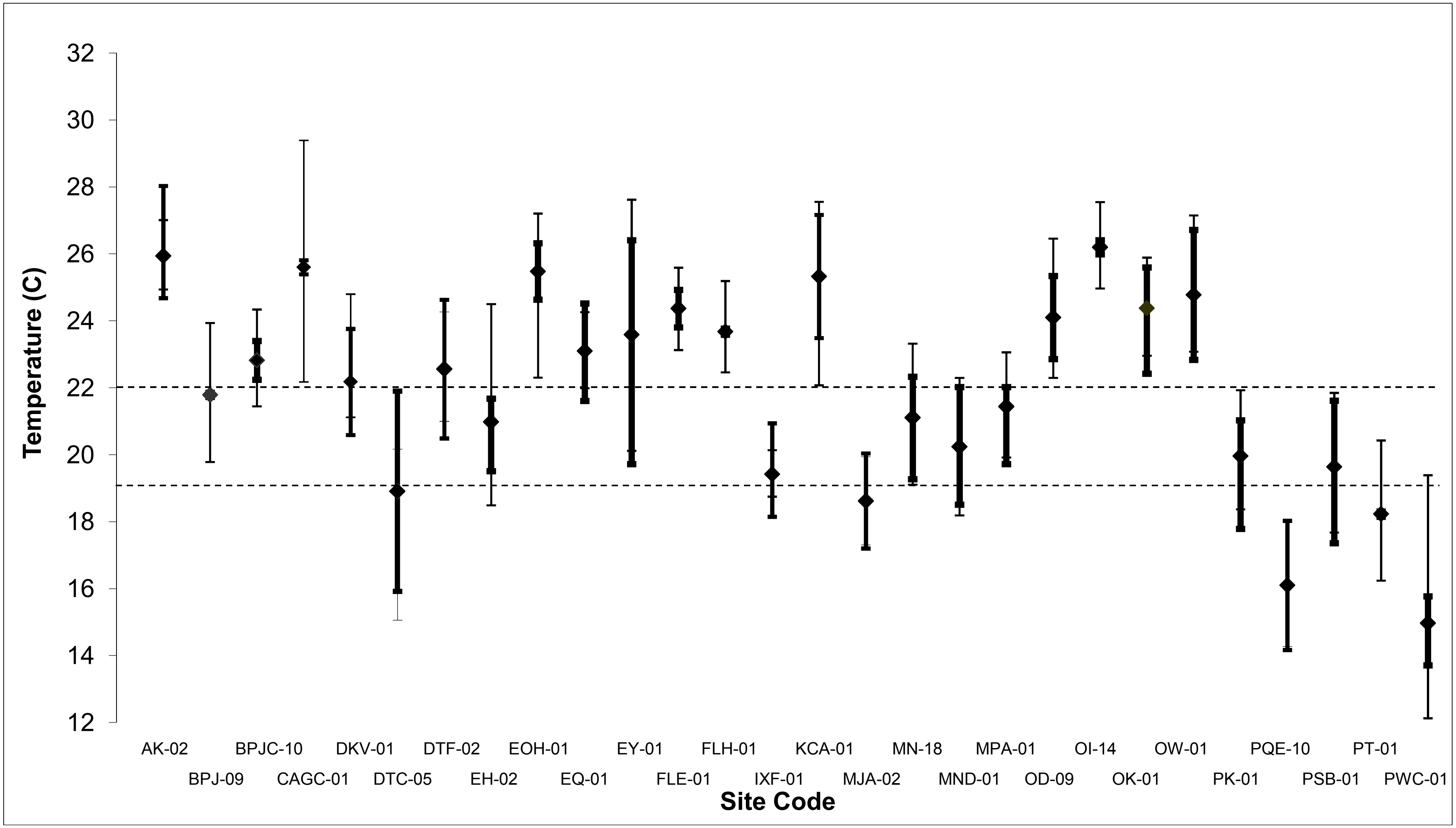


Figure 11. Summary of multiyear records.

◆ Mean of mean daily July temperature

Range of mean of maximum and minimum mean daily July temperature

Range of mean of mean daily July temperature

Figure 12. Network sampling locations.

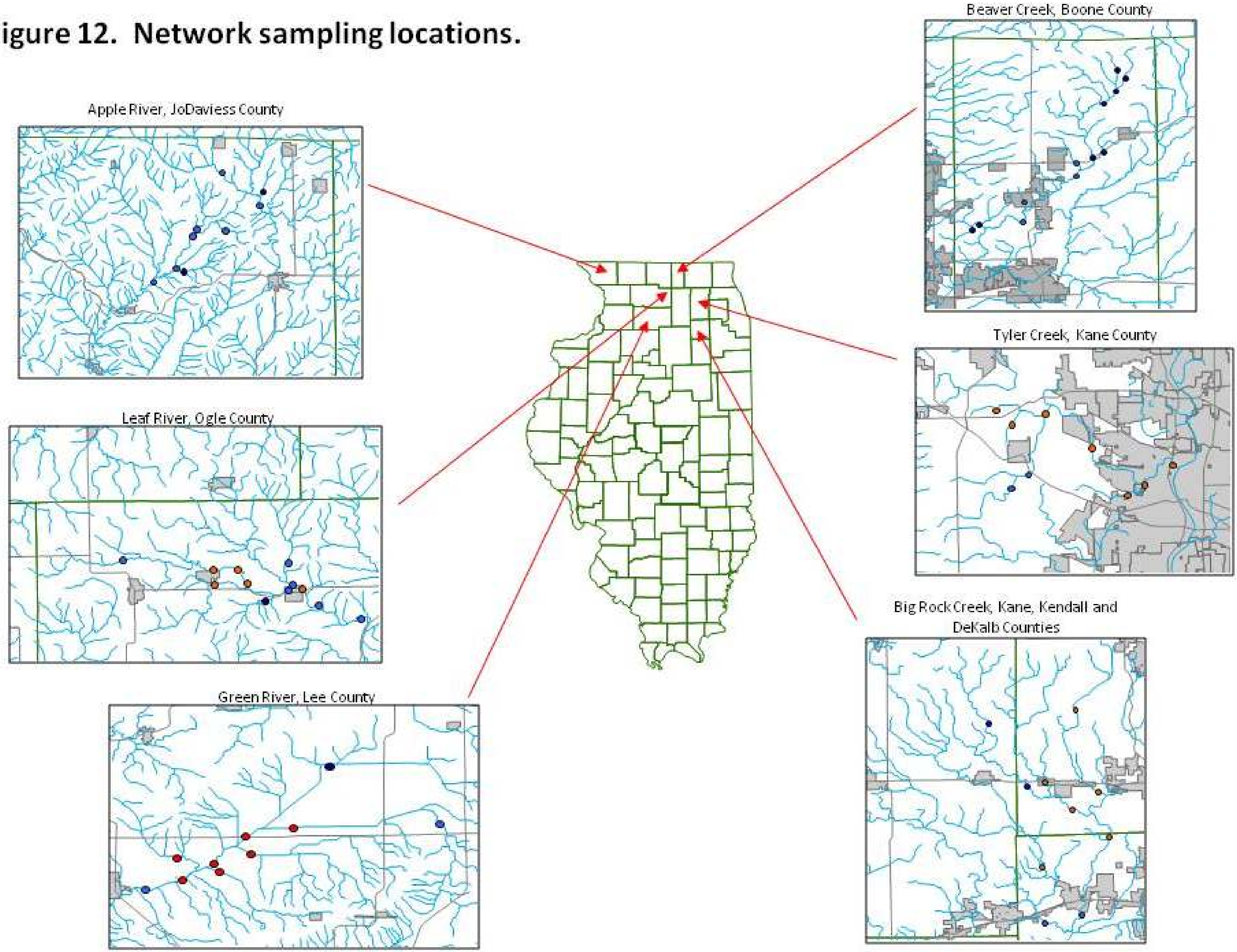


Figure 12 (continued). Network sampling locations.

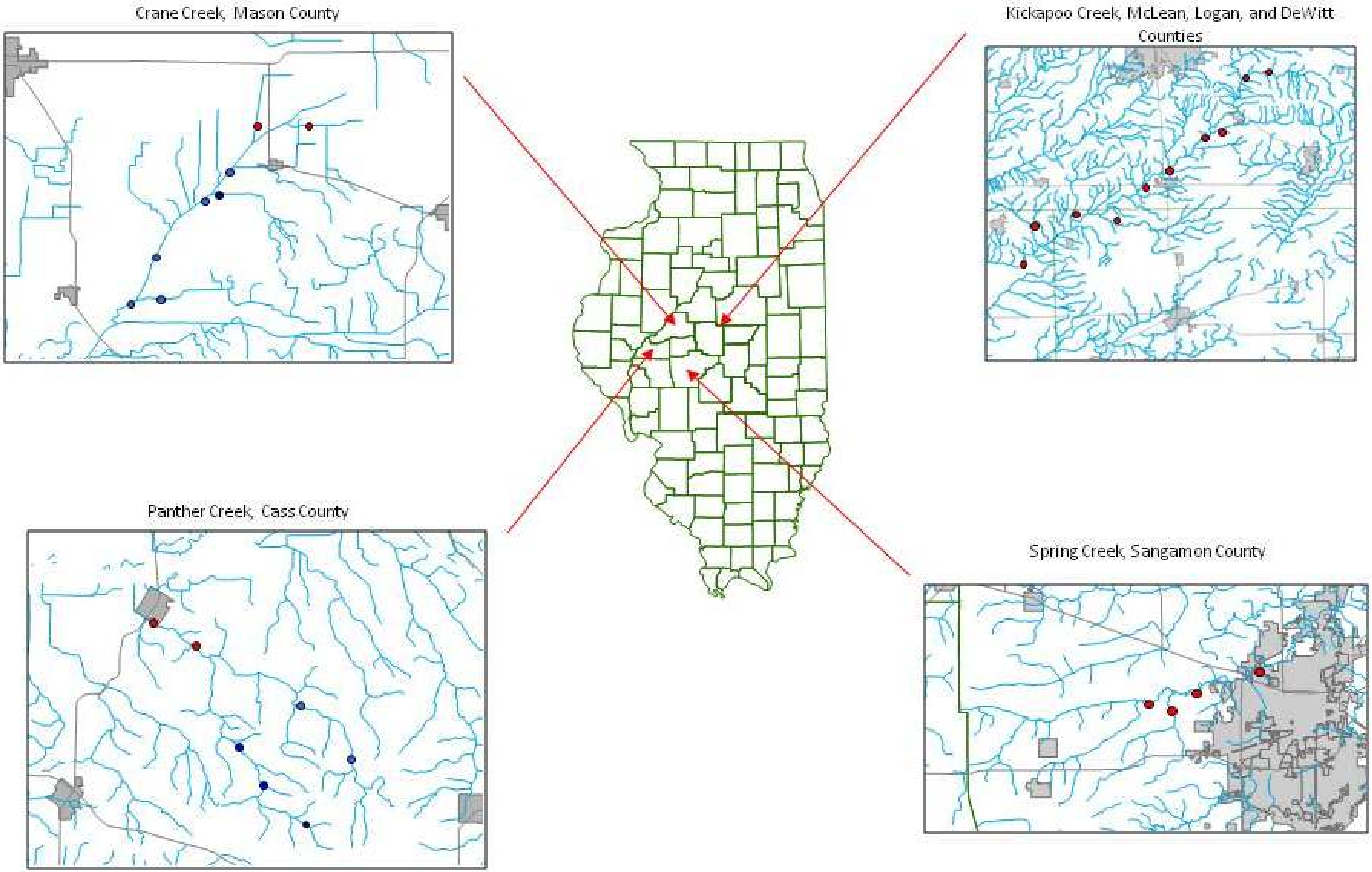
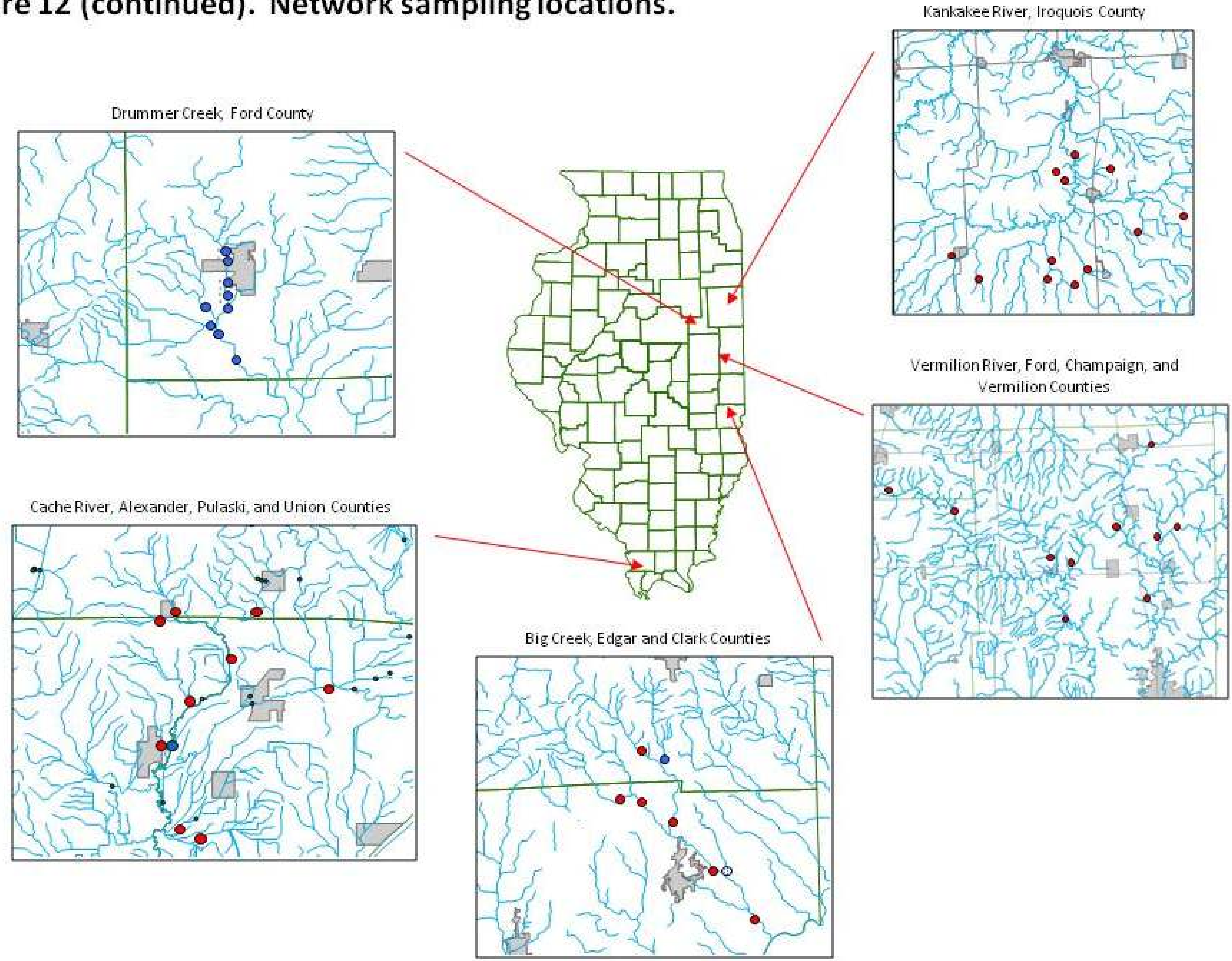


Figure 12 (continued). Network sampling locations.



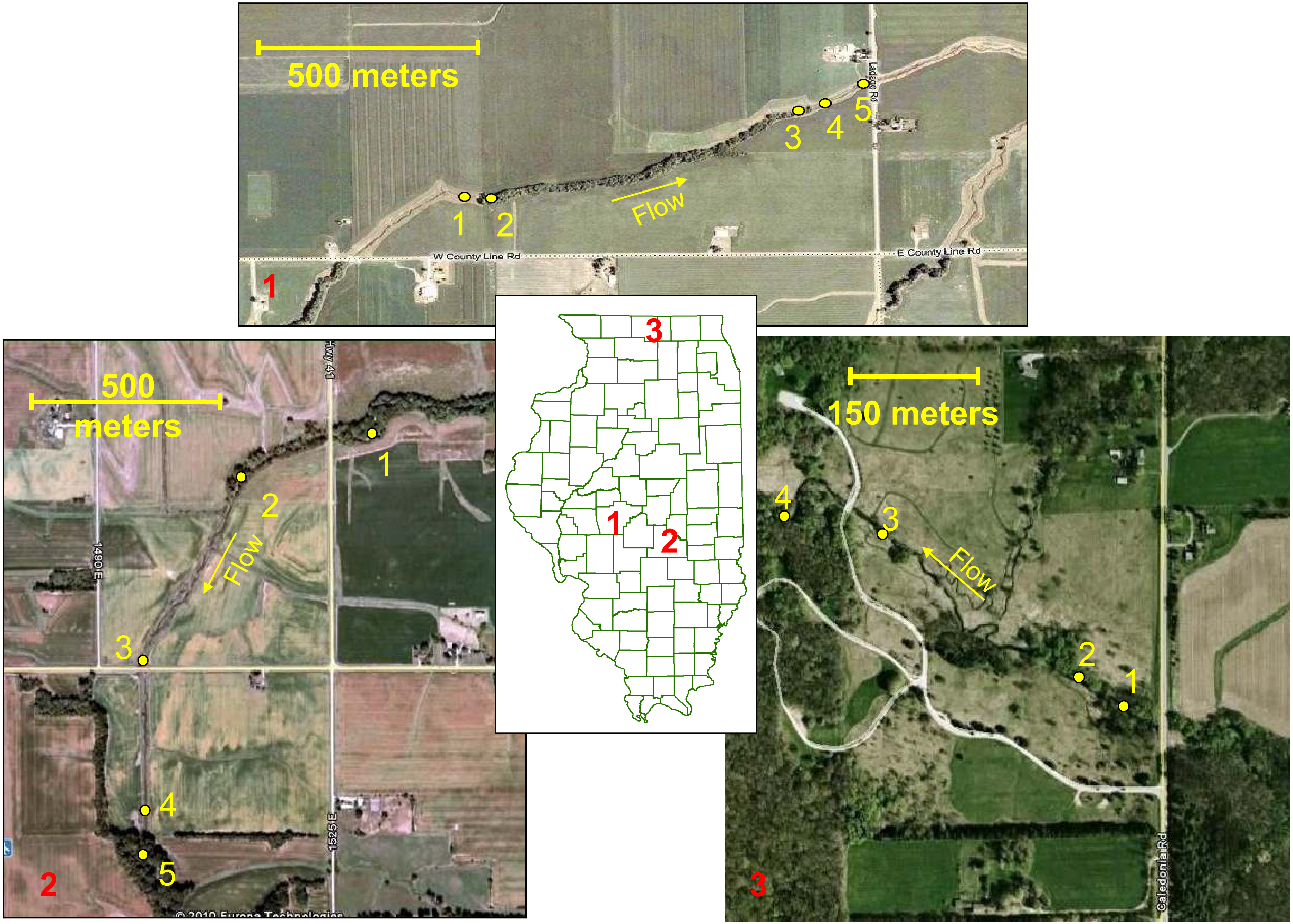


Figure 13. Satellite images of shading study sites.

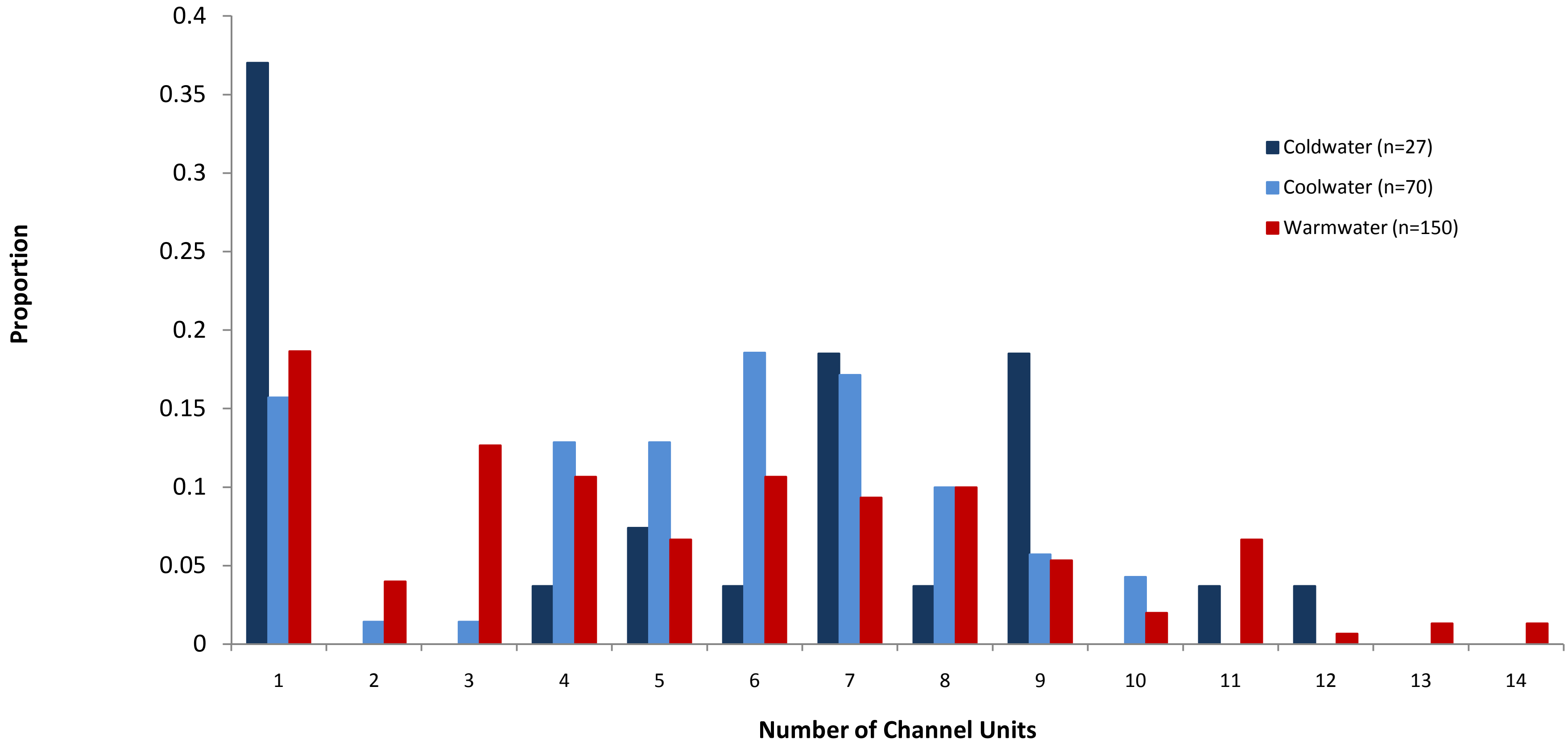


Figure 14. Proportion of Channel Unit Number

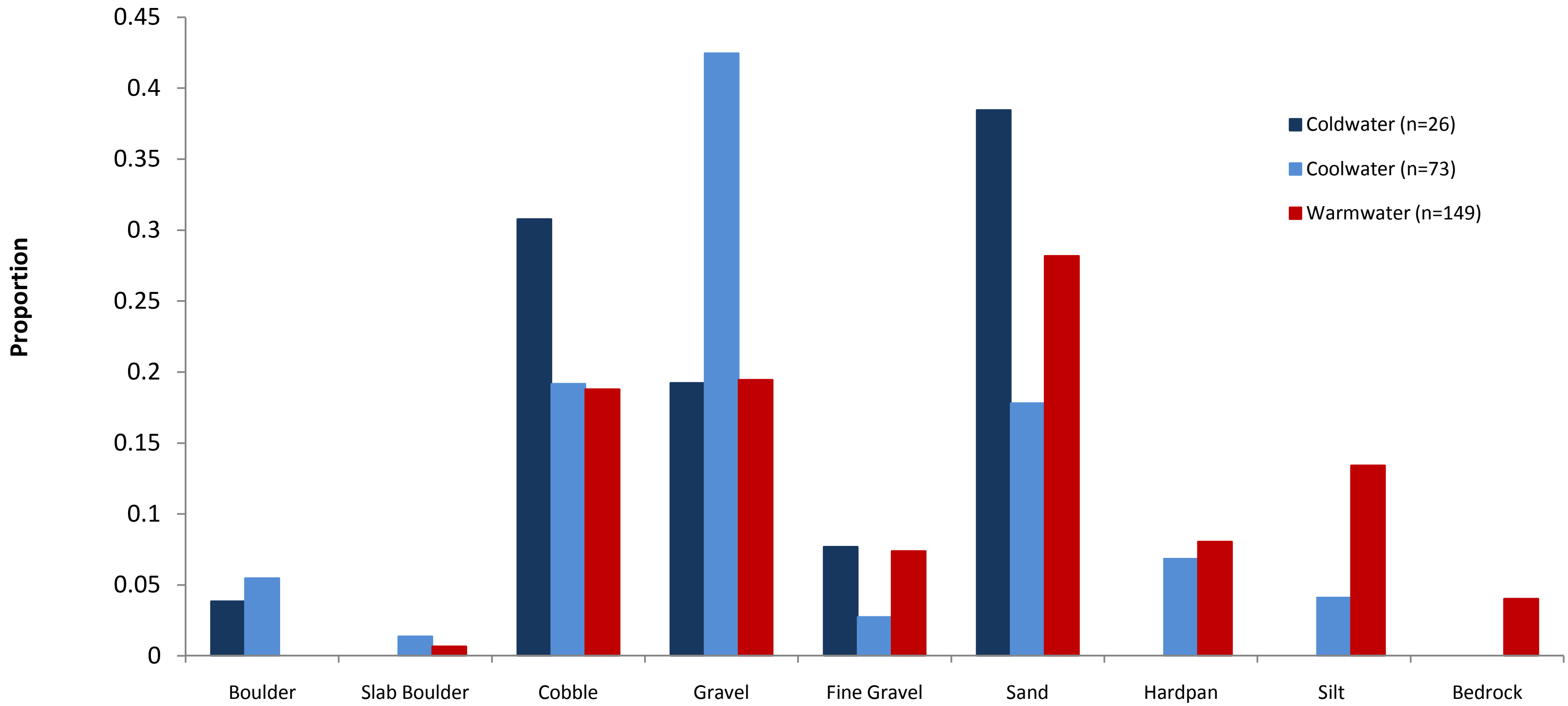


Figure 15. Proportion of Dominant Substrate Type

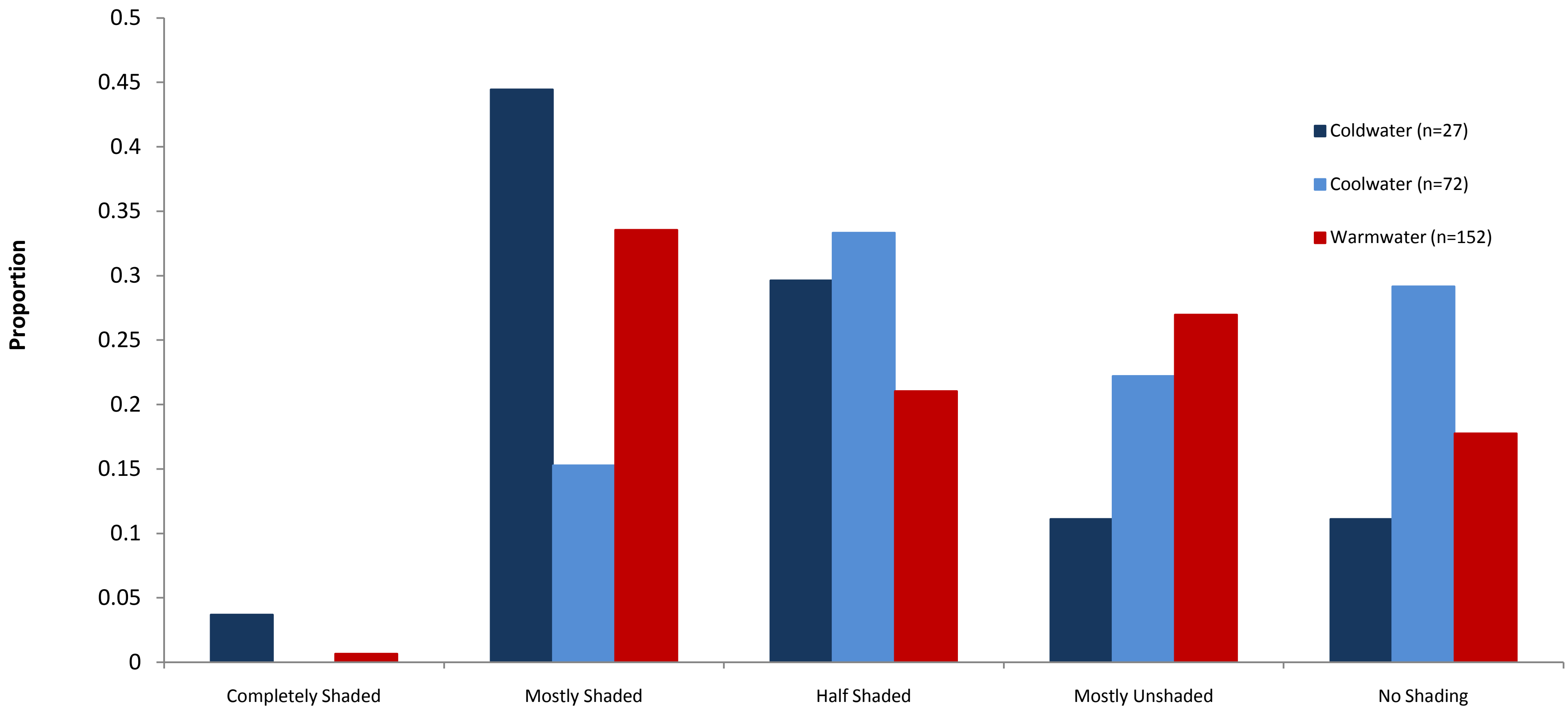


Figure 16. Proportion of Channel Shading Category

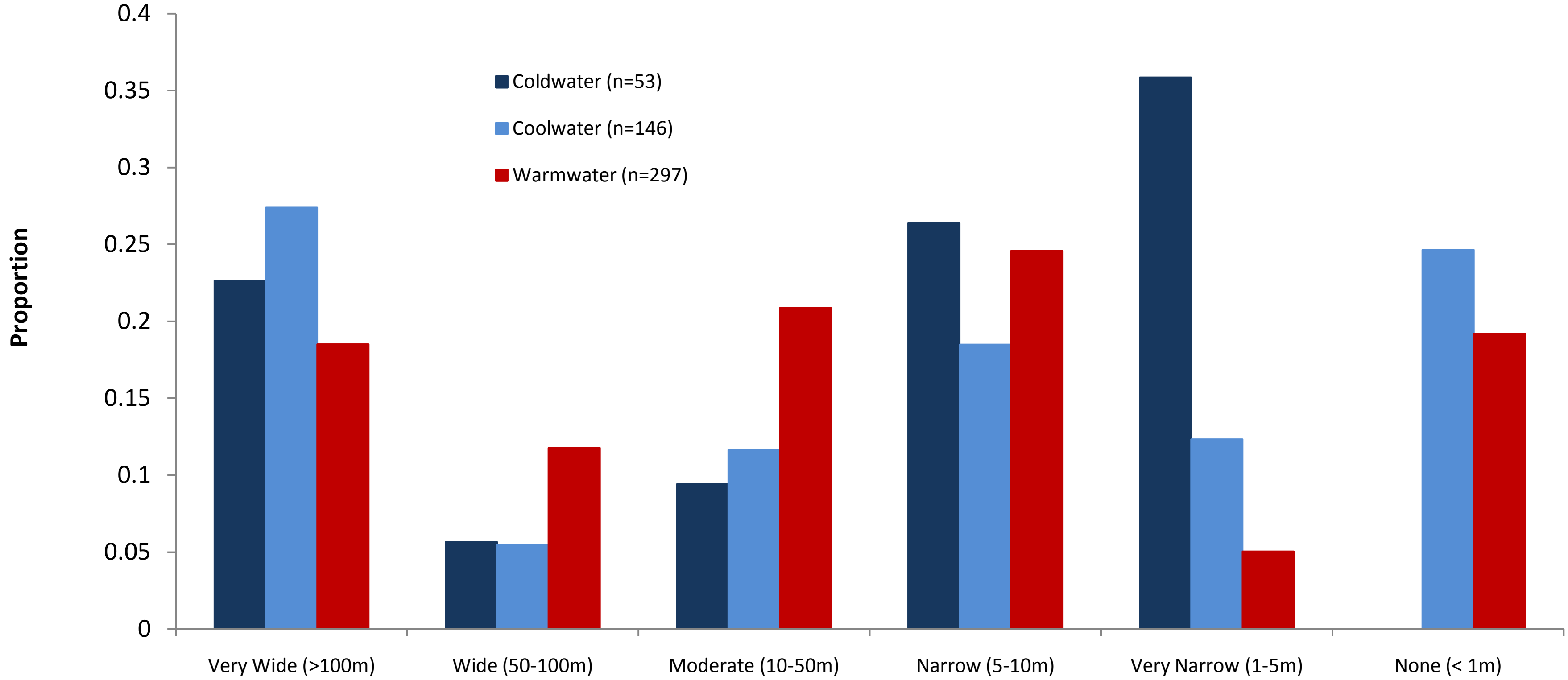


Figure 17. Proportion of Riparian Width Categories

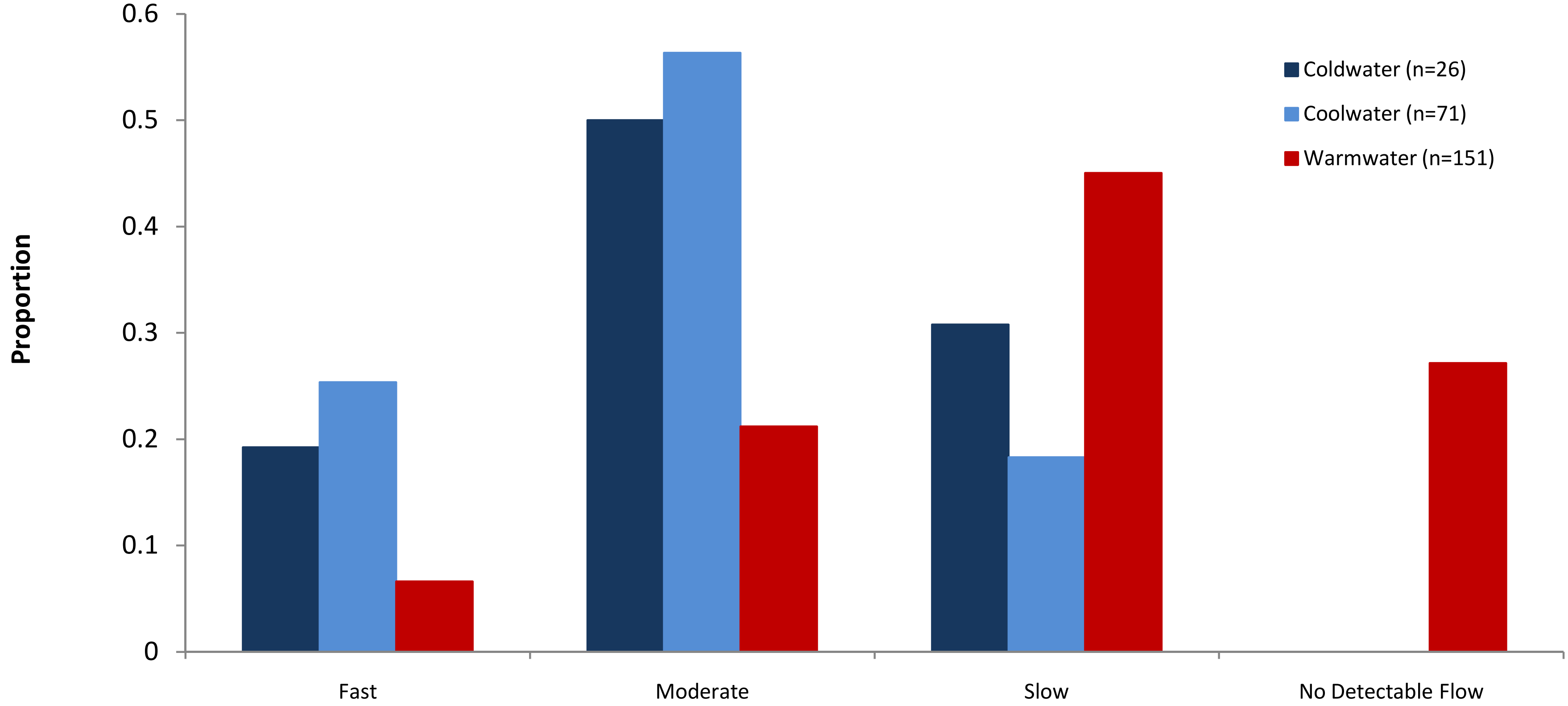


Figure 18. Proportion of Flow Category

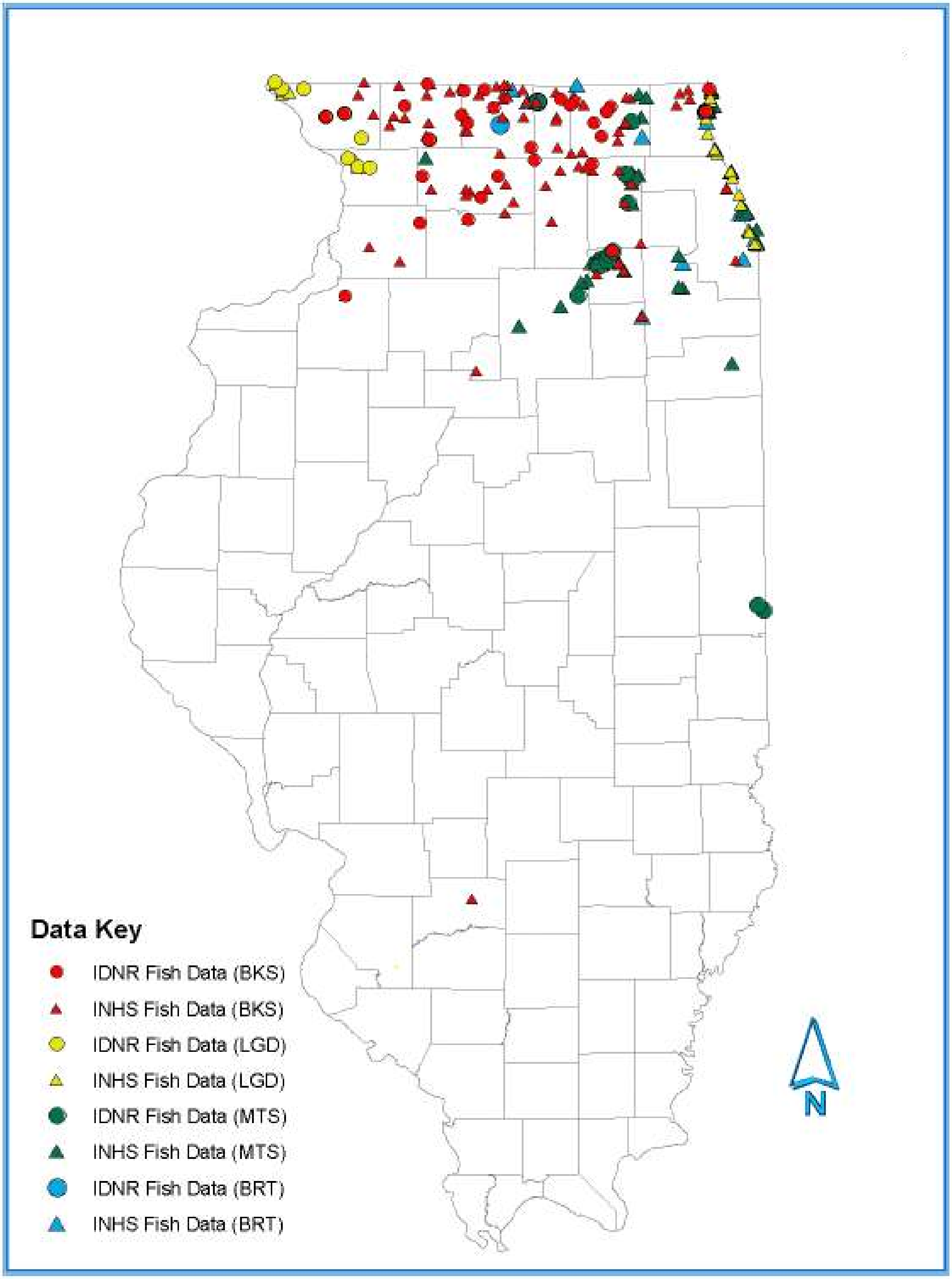


Figure 19. Collection locations for brook stickleback (BKS), longnose dace (LGD), mottled sculpin (MTS), and brown trout (BRT).

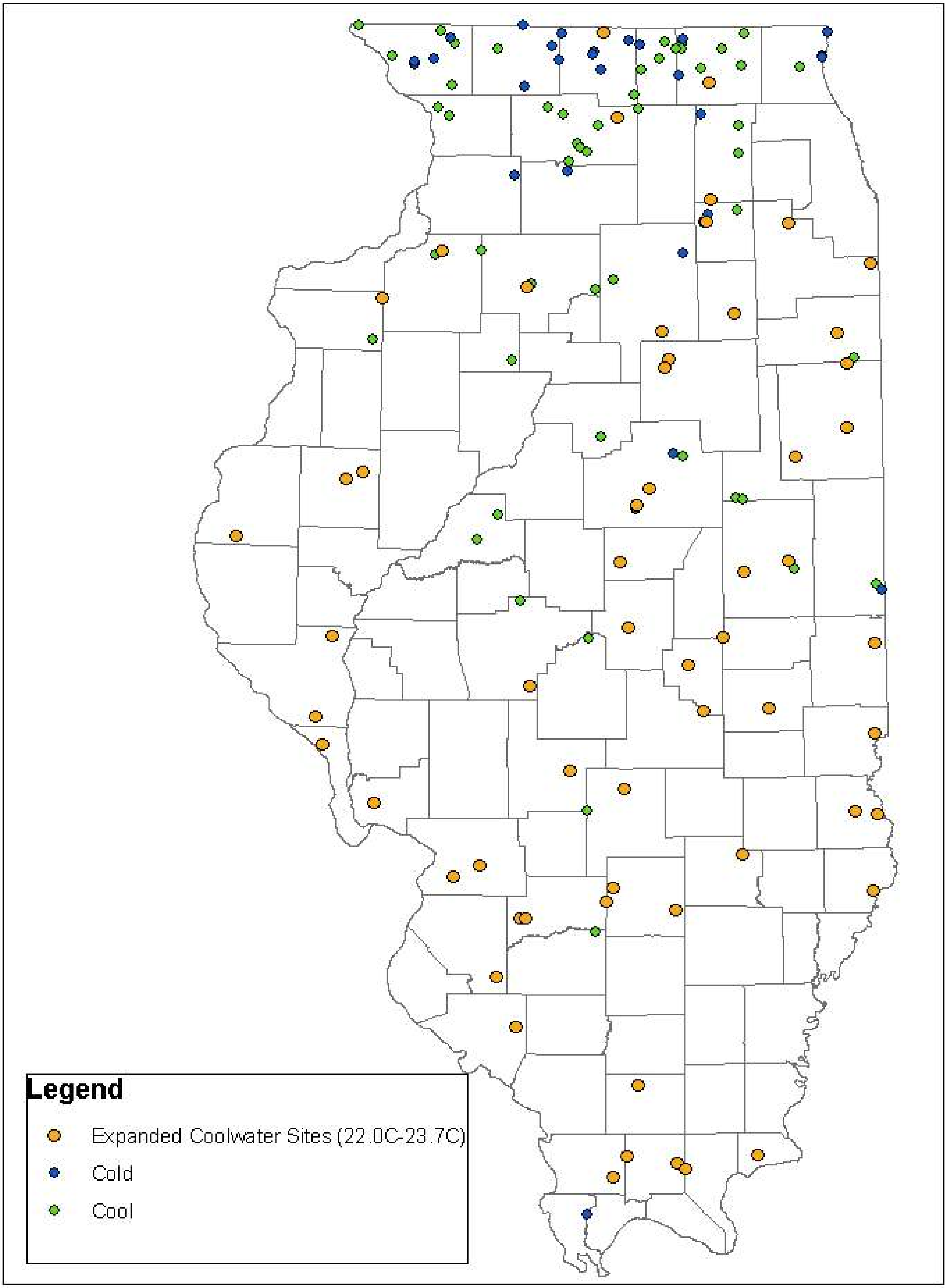
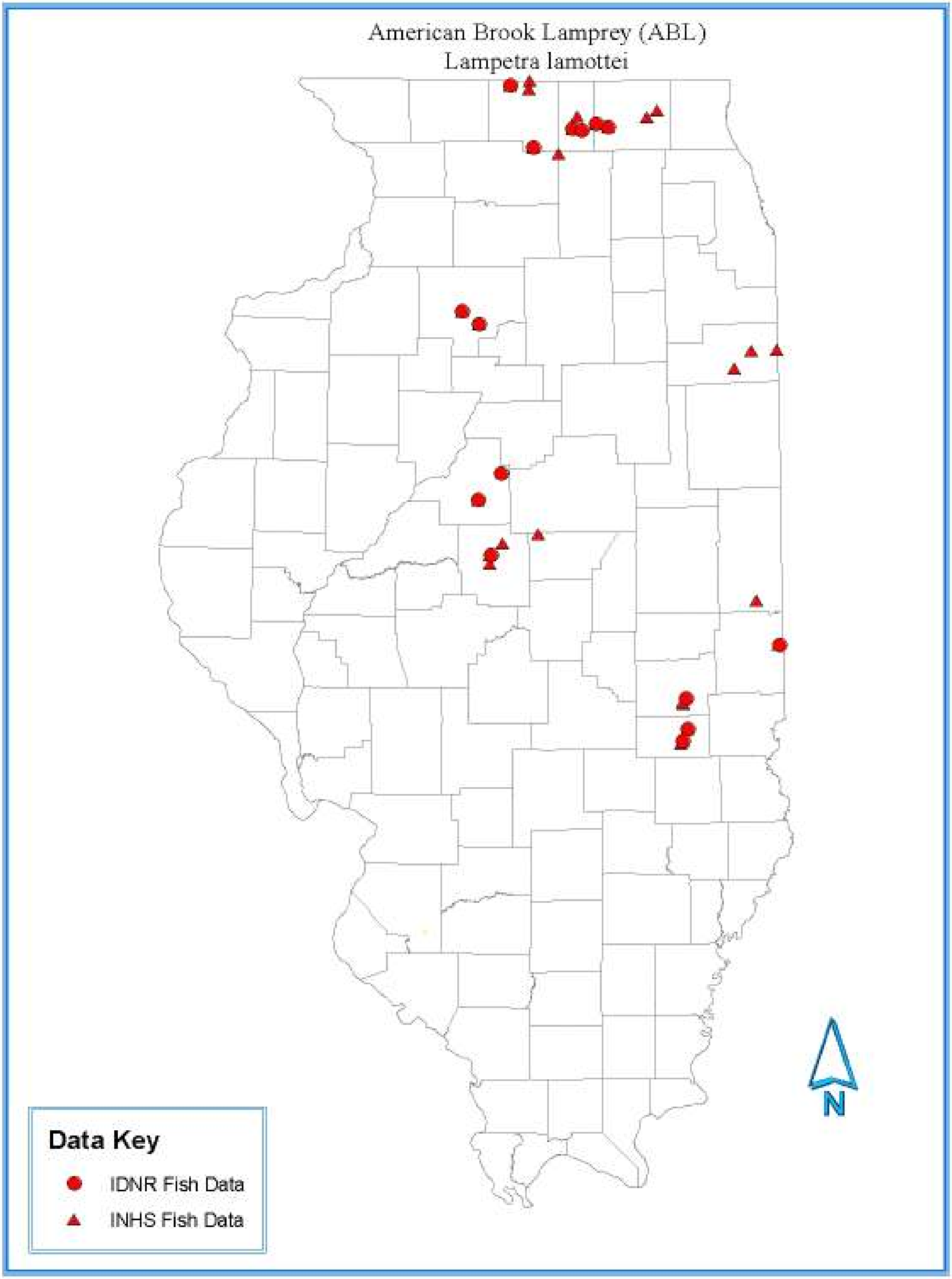
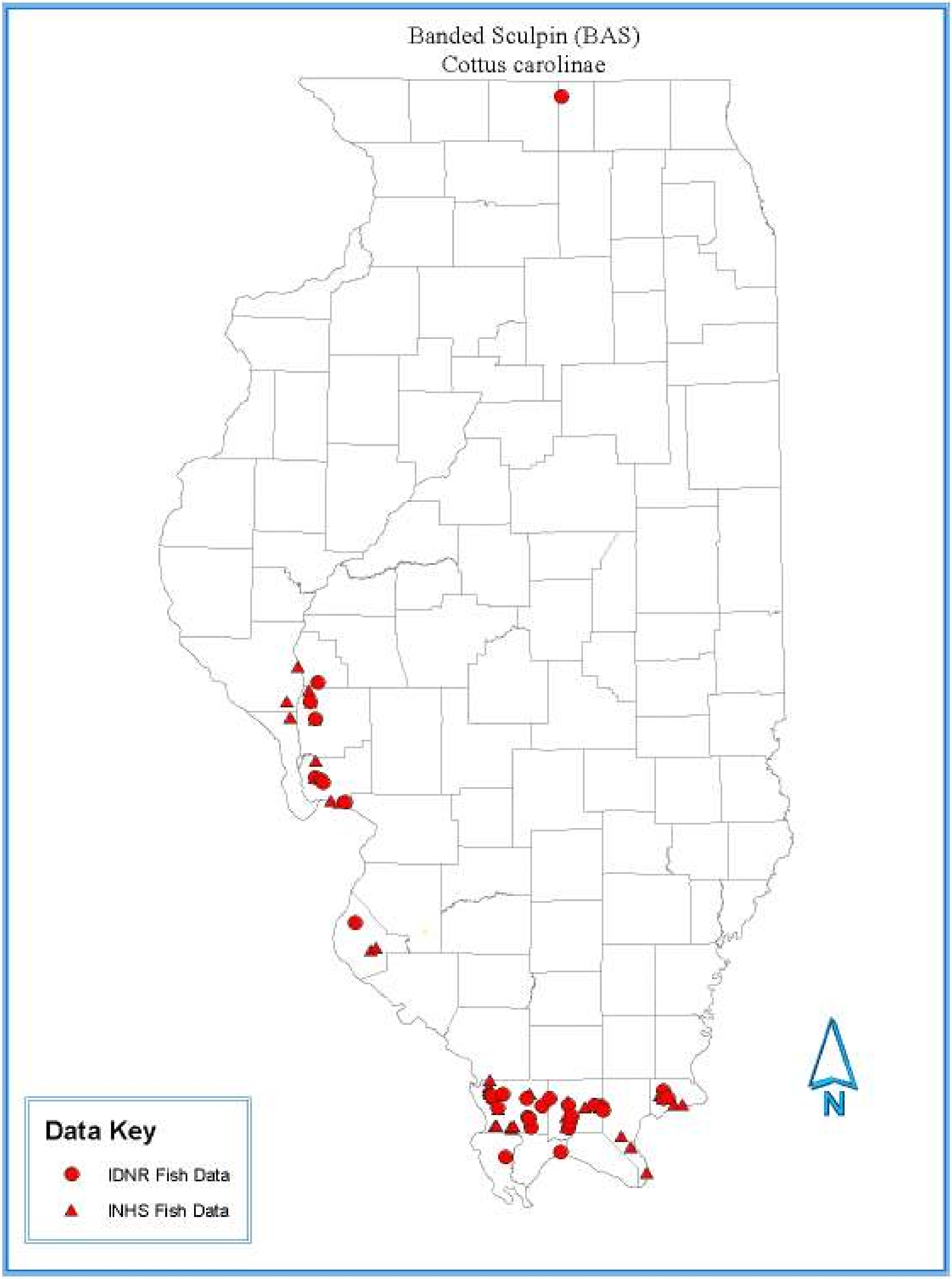
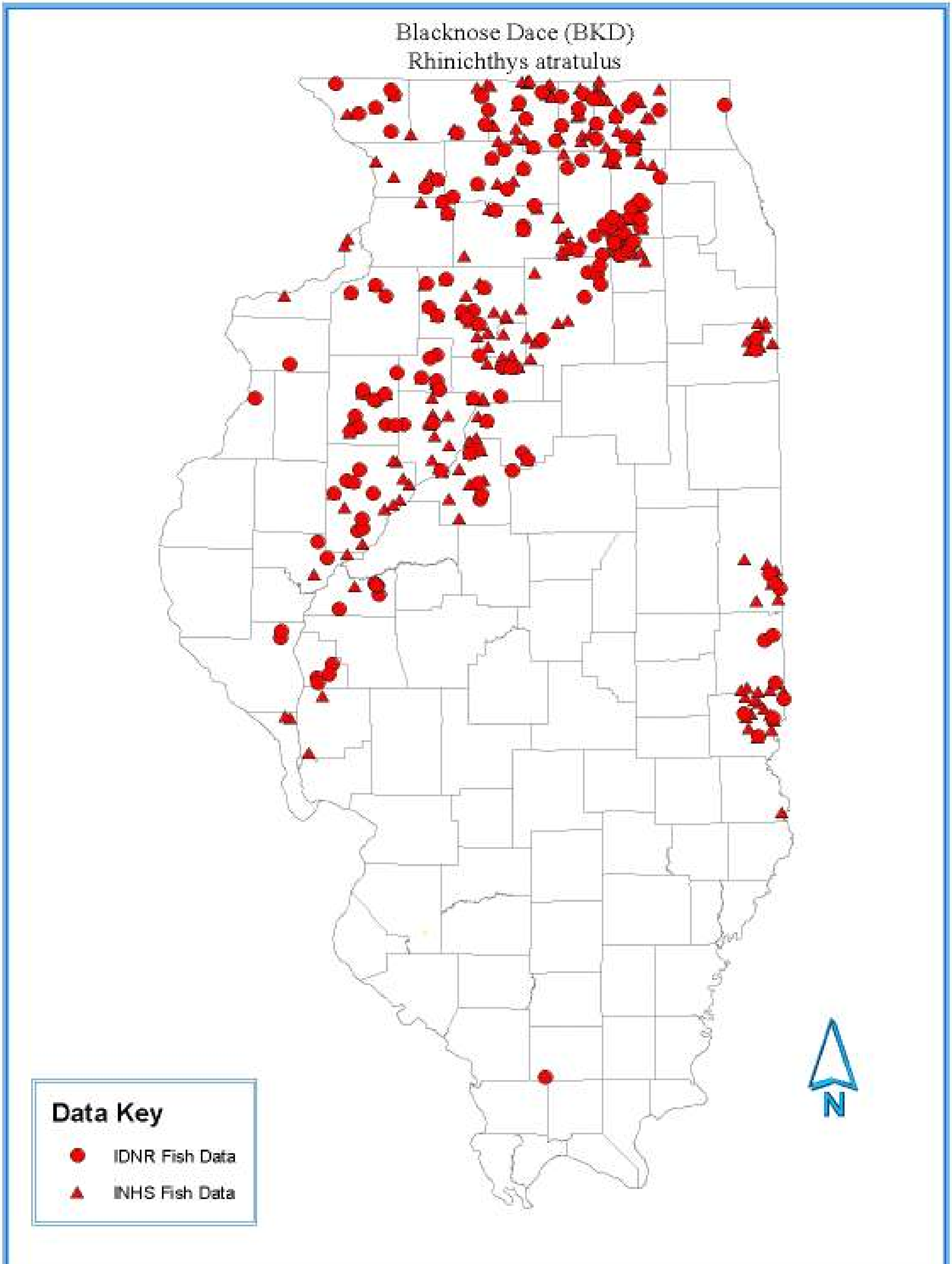


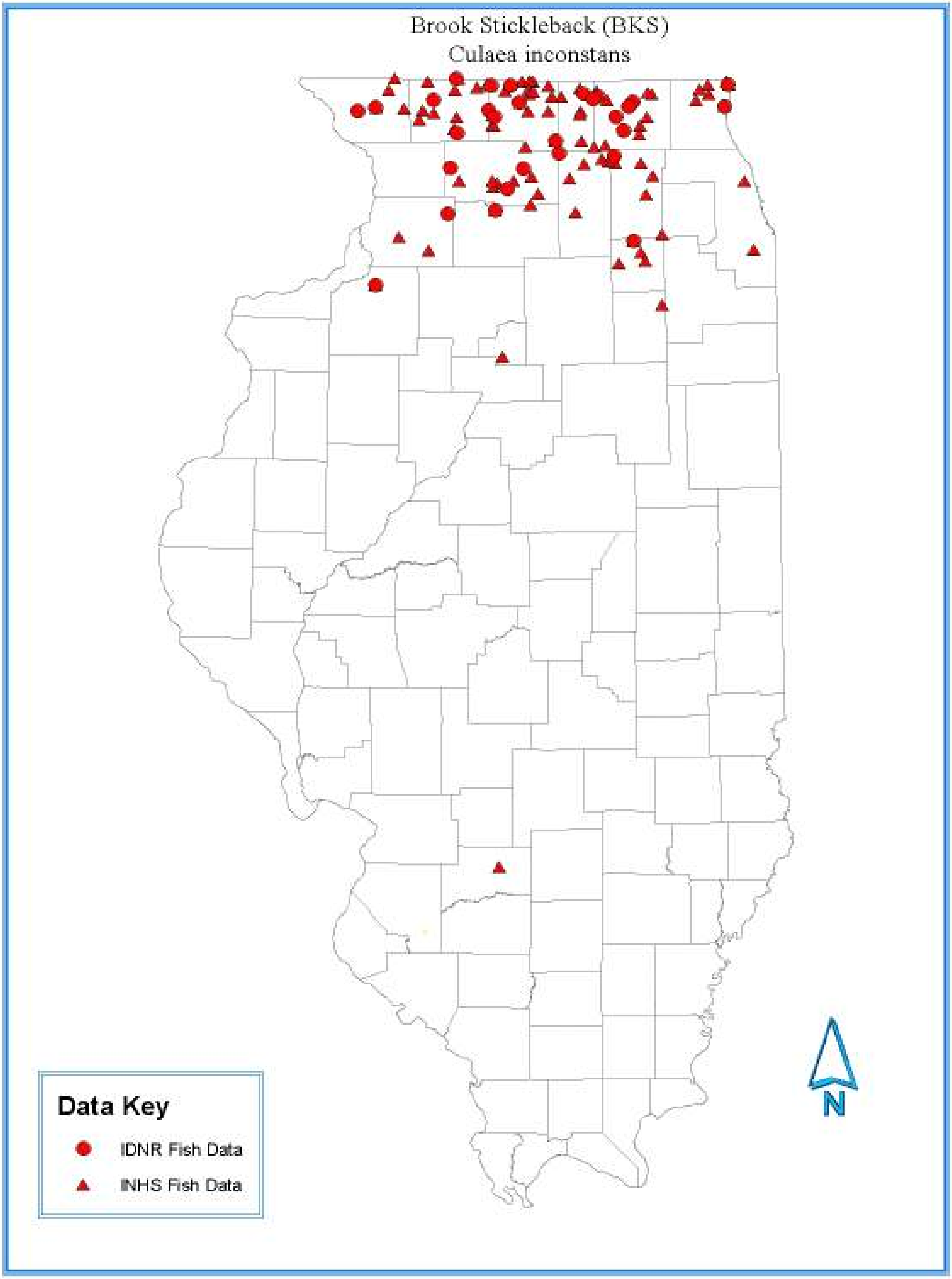
Figure 20. Locations of original coldwater and coolwater sites with expanded (23.7°C) coolwater sites.

Appendix A

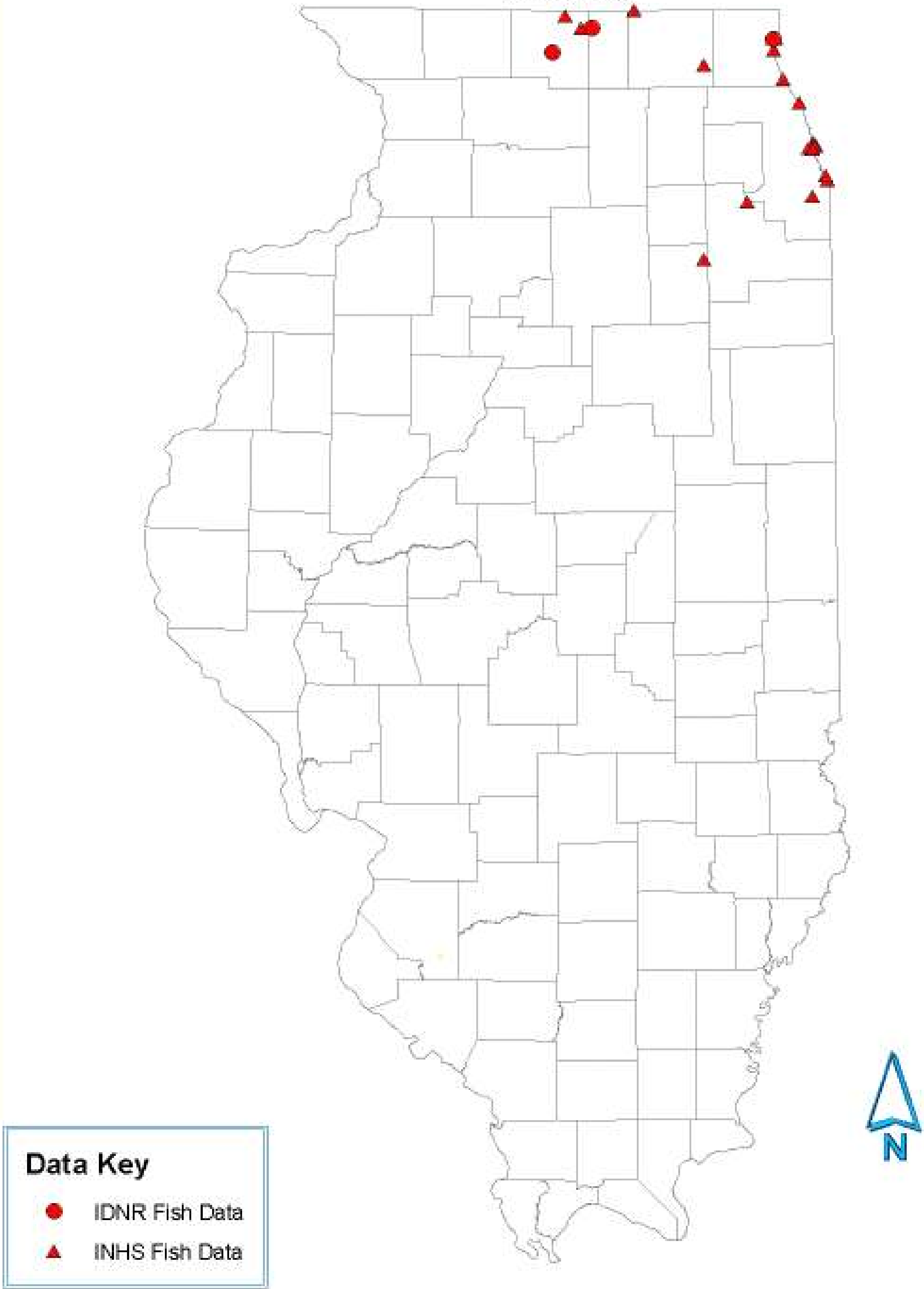

American Brook Lamprey (ABL)
Lampetra lamottei
Data Key
IDNR Fish Data
INHS Fish Data
N


Banded Sculpin (BAS)
Cottus carolinae
Data Key
IDNR Fish Data
INHS Fish Data
N

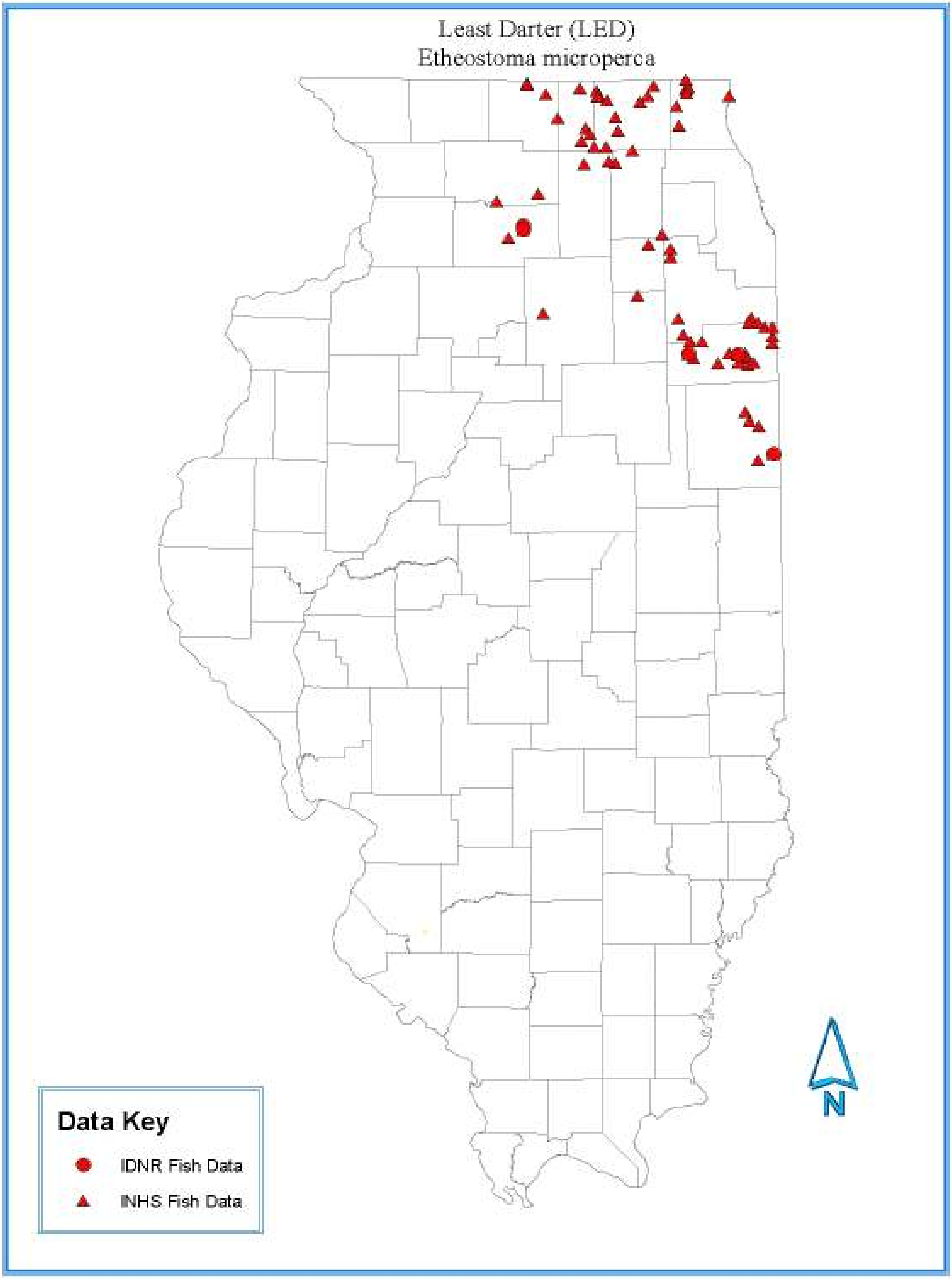

Blacknose Dace (BKD)
Rhinichthys atratulus
Data Key
IDNR Fish Data
INHS Fish Data
N

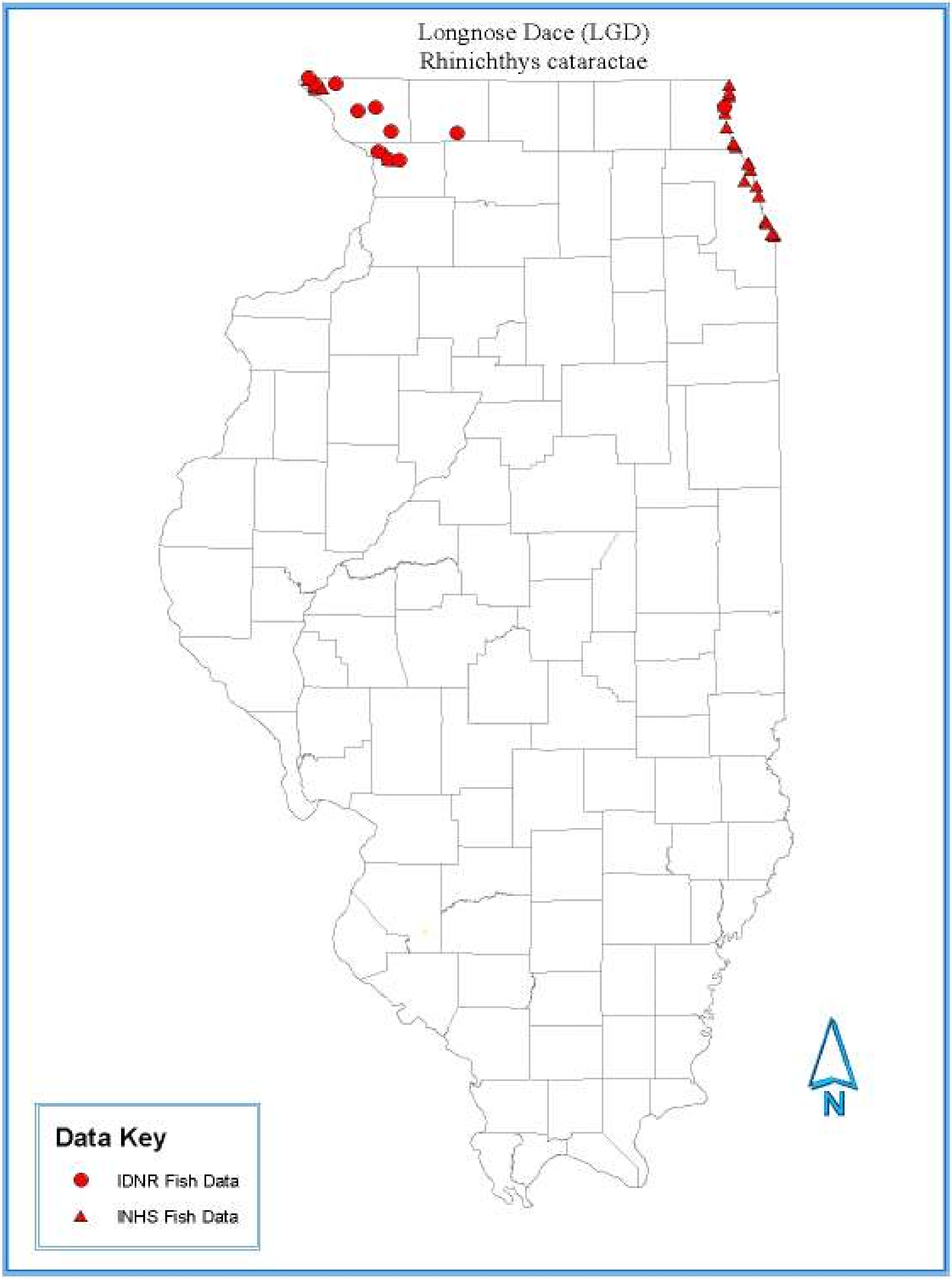

Brook Stickleback (BKS)
Culaea inconstans
Data Key
IDNR Fish Data
INHS Fish Data
N

Brown Trout (BRT)
Salmo trutta

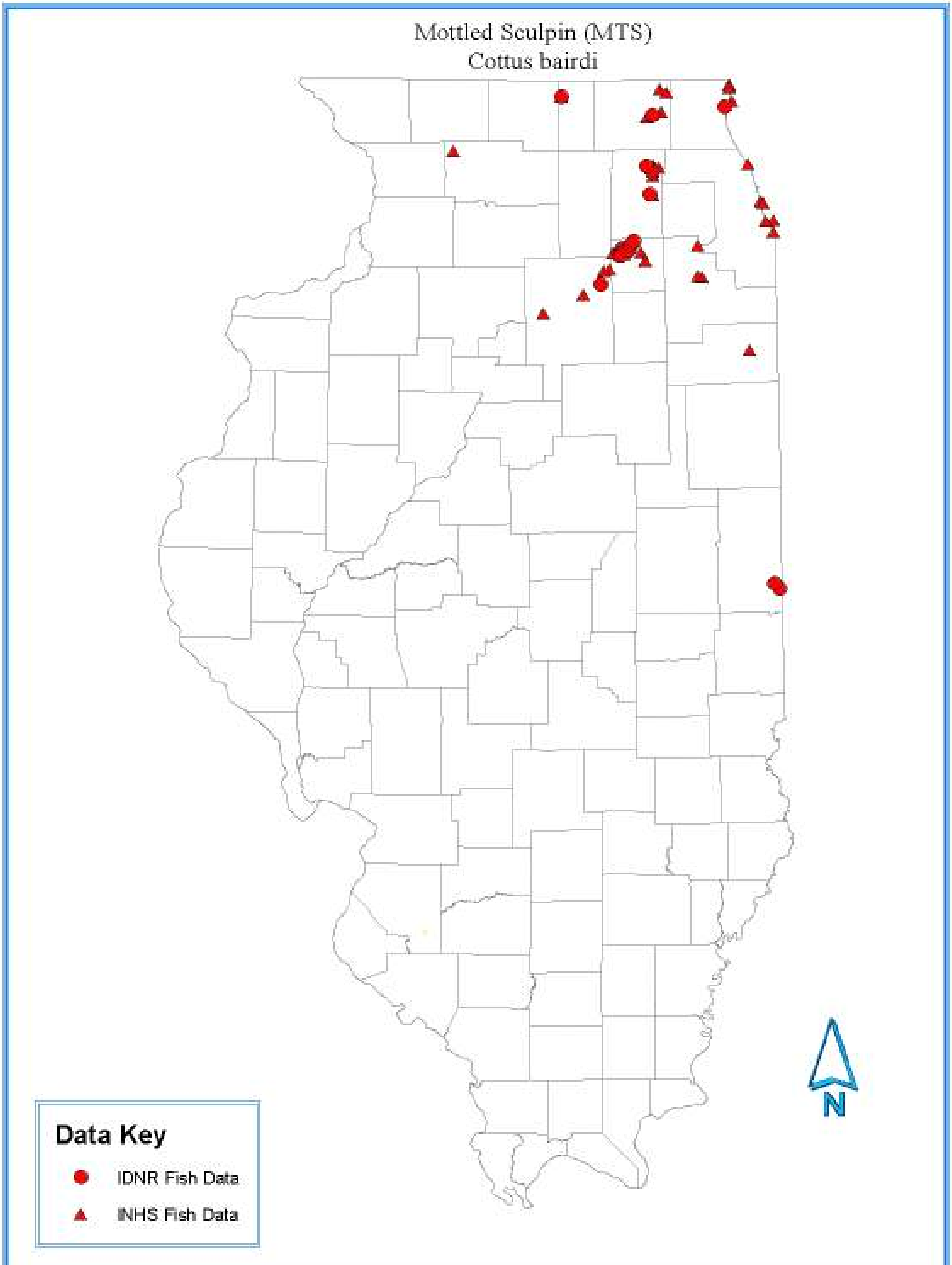


Least Brook Lamprey (LBL)
Lampetra aepyptera


Least Darter (LED)
Etheostoma microperca
Data Key
IDNR Fish Data
INHS Fish Data
N



Longnose Dace (LGD)
Rhinichthys cataractae
Data Key
IDNR Fish Data
INHS Fish Data
N


Mottled Sculpin (MTS)
Cottus bairdi
Data Key
IDNR Fish Data
INHS Fish Data
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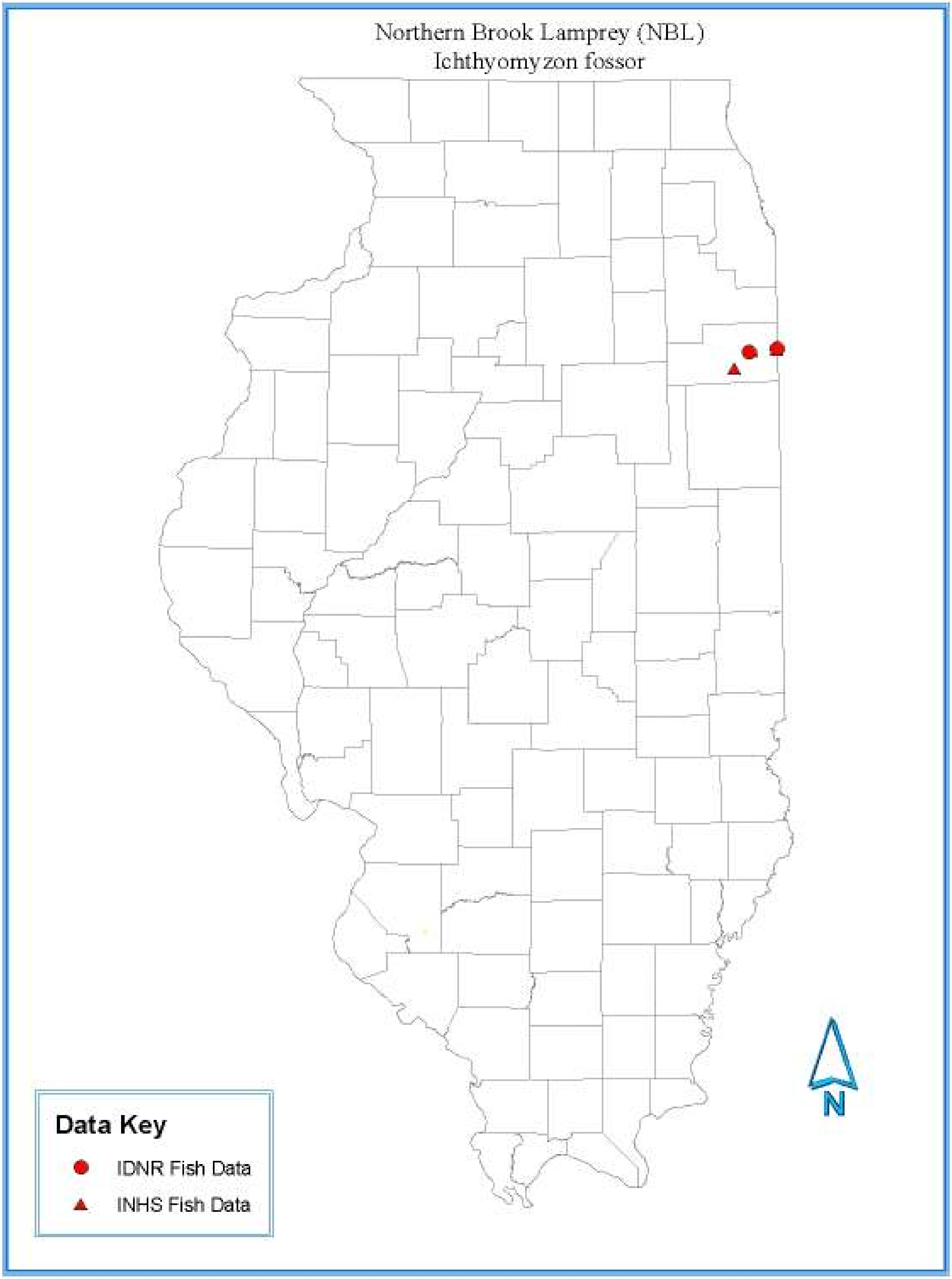
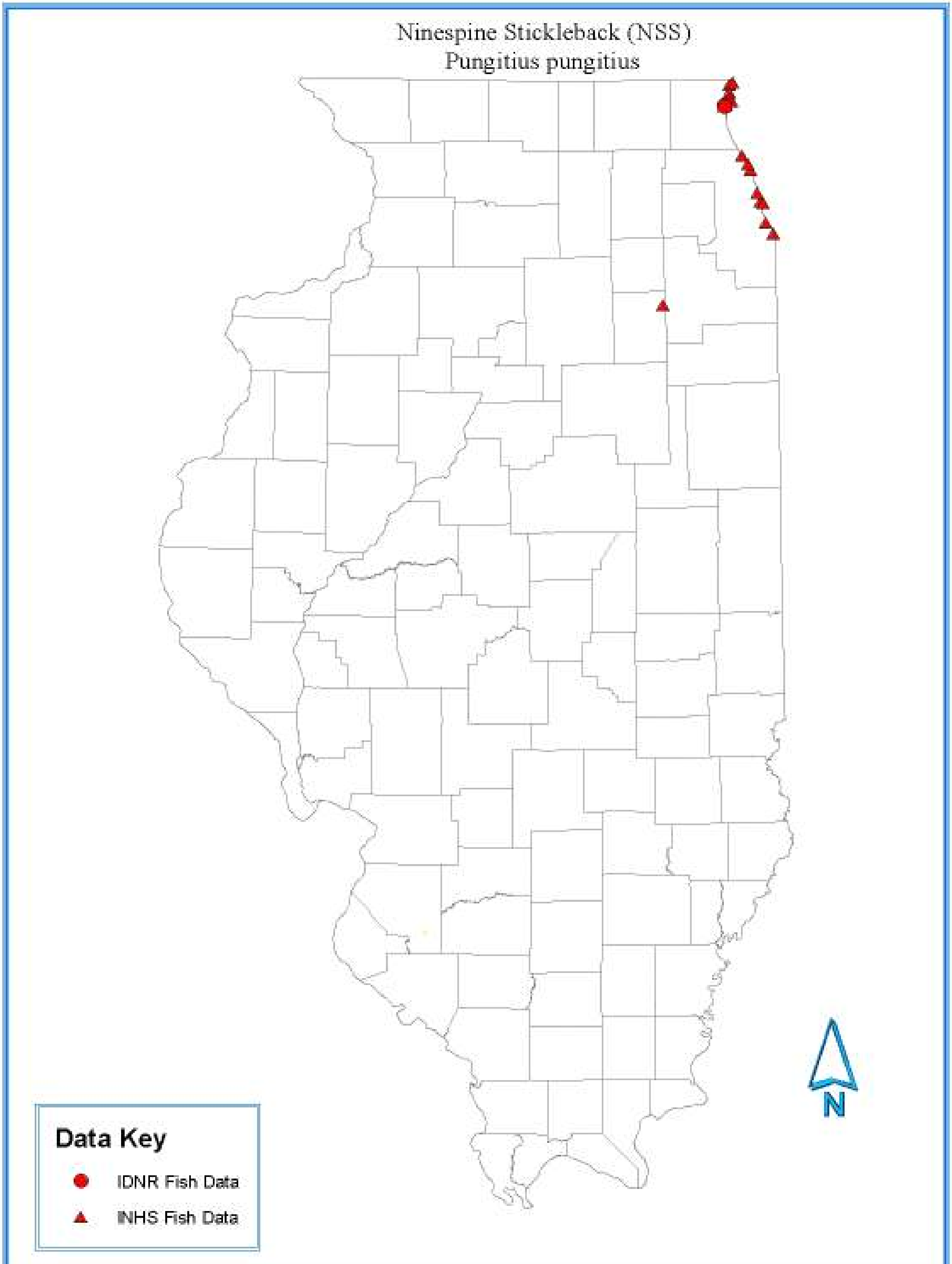
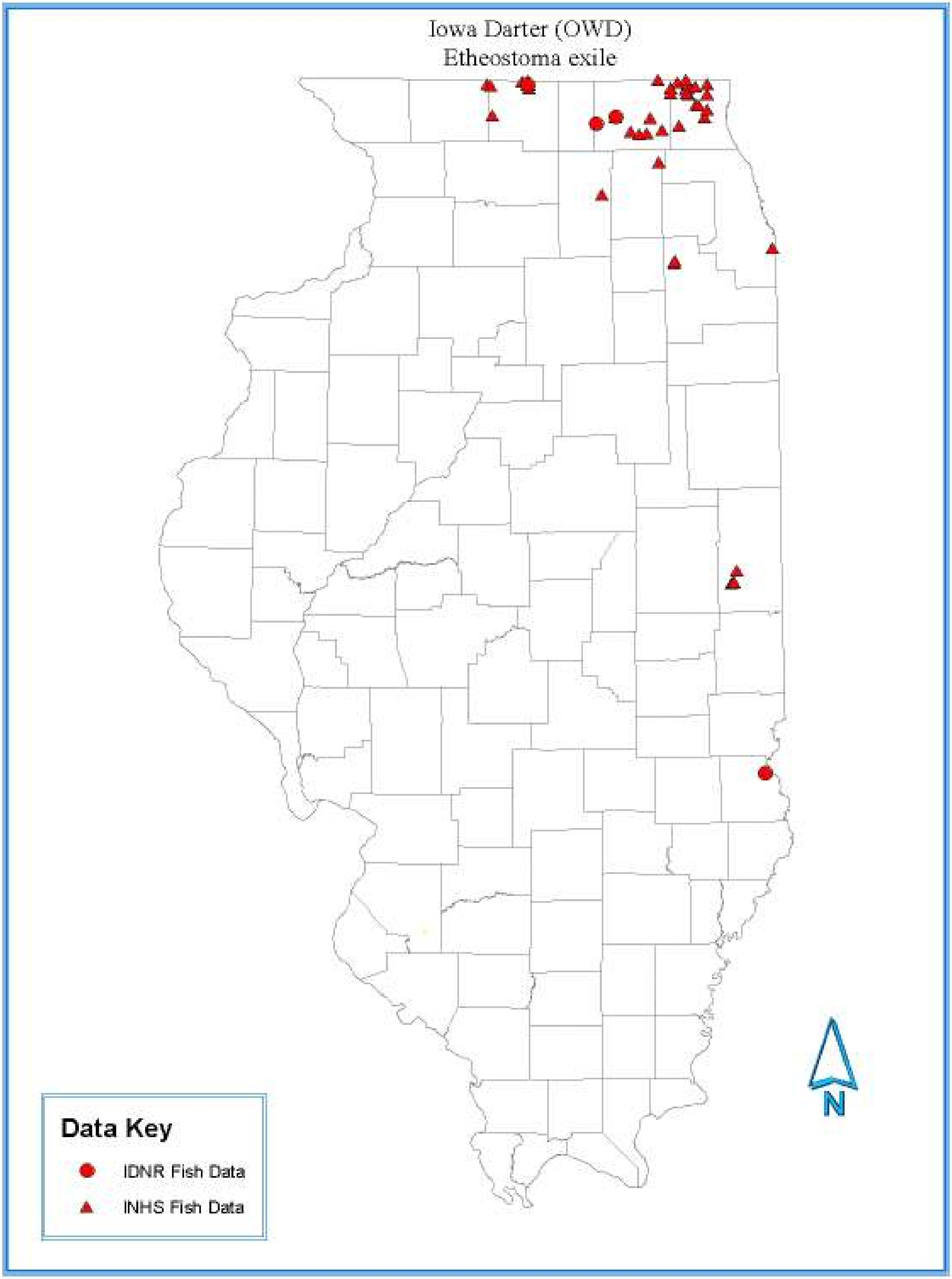

Northern Brook Lamprey (NBL)
Ichthyomyzon fossor
Data Key
IDNR Fish Data
INHS Fish Data
N



Ninespine Stickleback (NSS)
Pungitius pungitius
Data Key
IDNR Fish Data
INHS Fish Data
N


Iowa Darter (OWD)
Etheostoma exile
Data Key
IDNR Fish Data
INHS Fish Data
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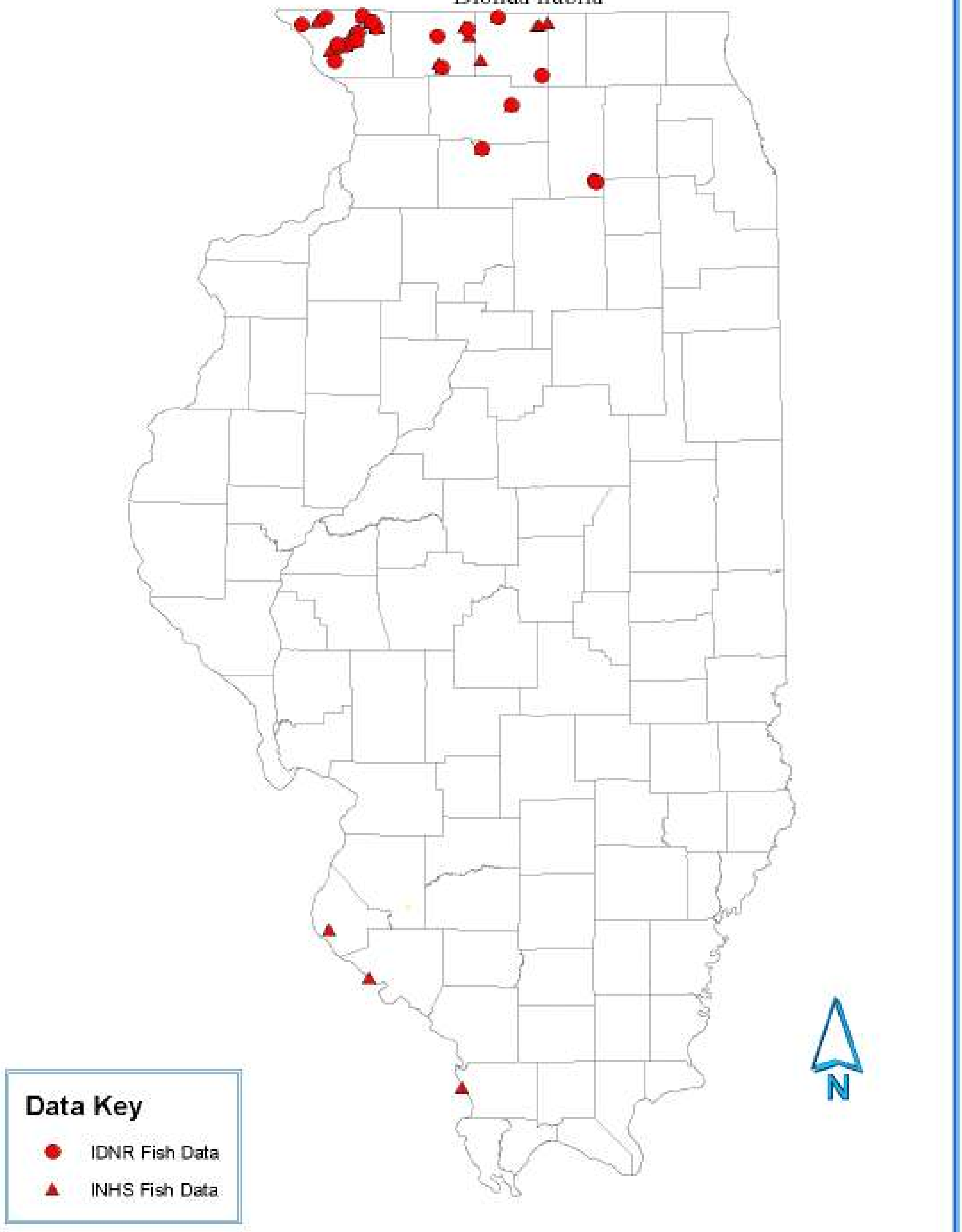
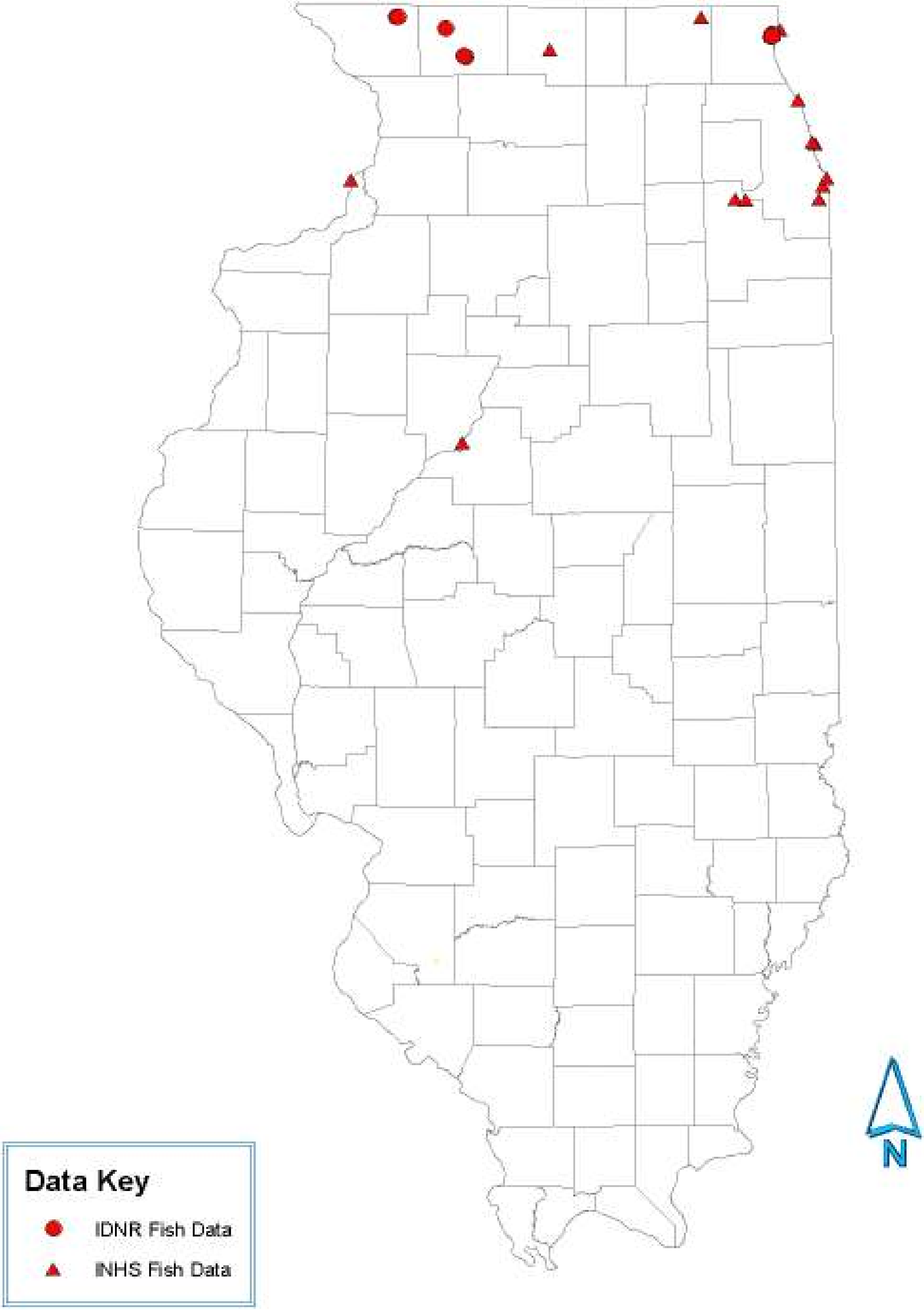
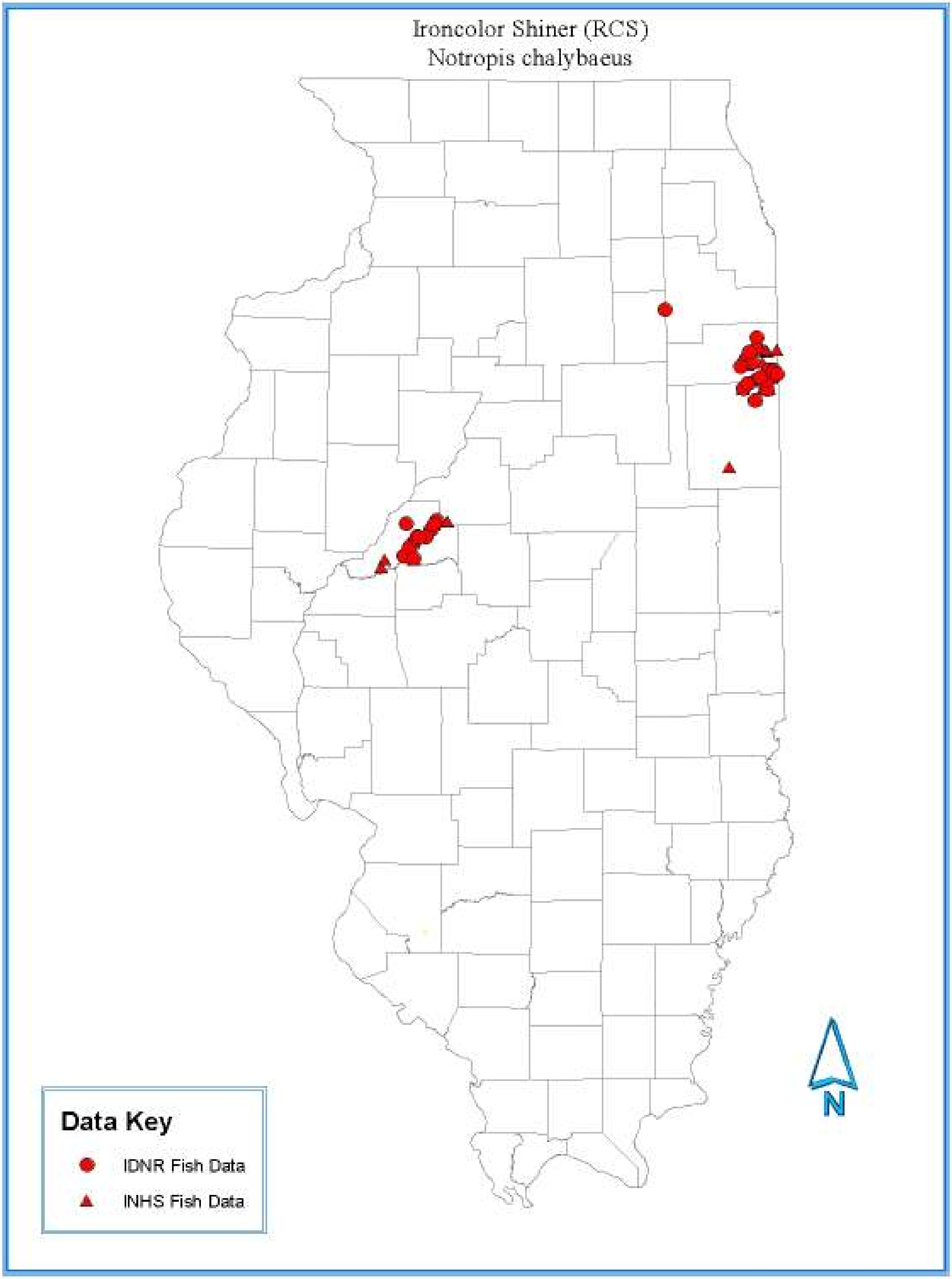
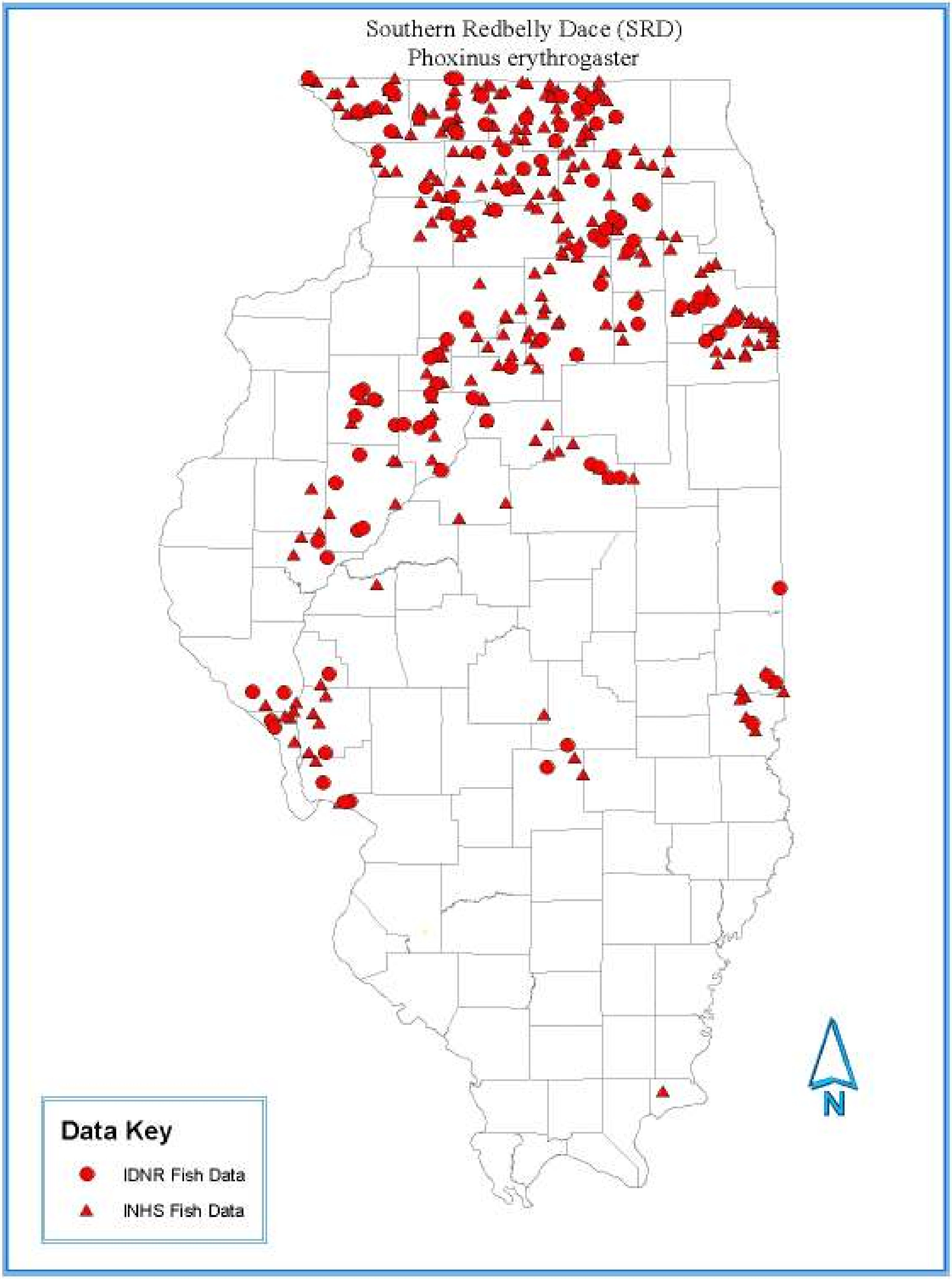
Ozark Minnow (OZM)
Dionda nubila



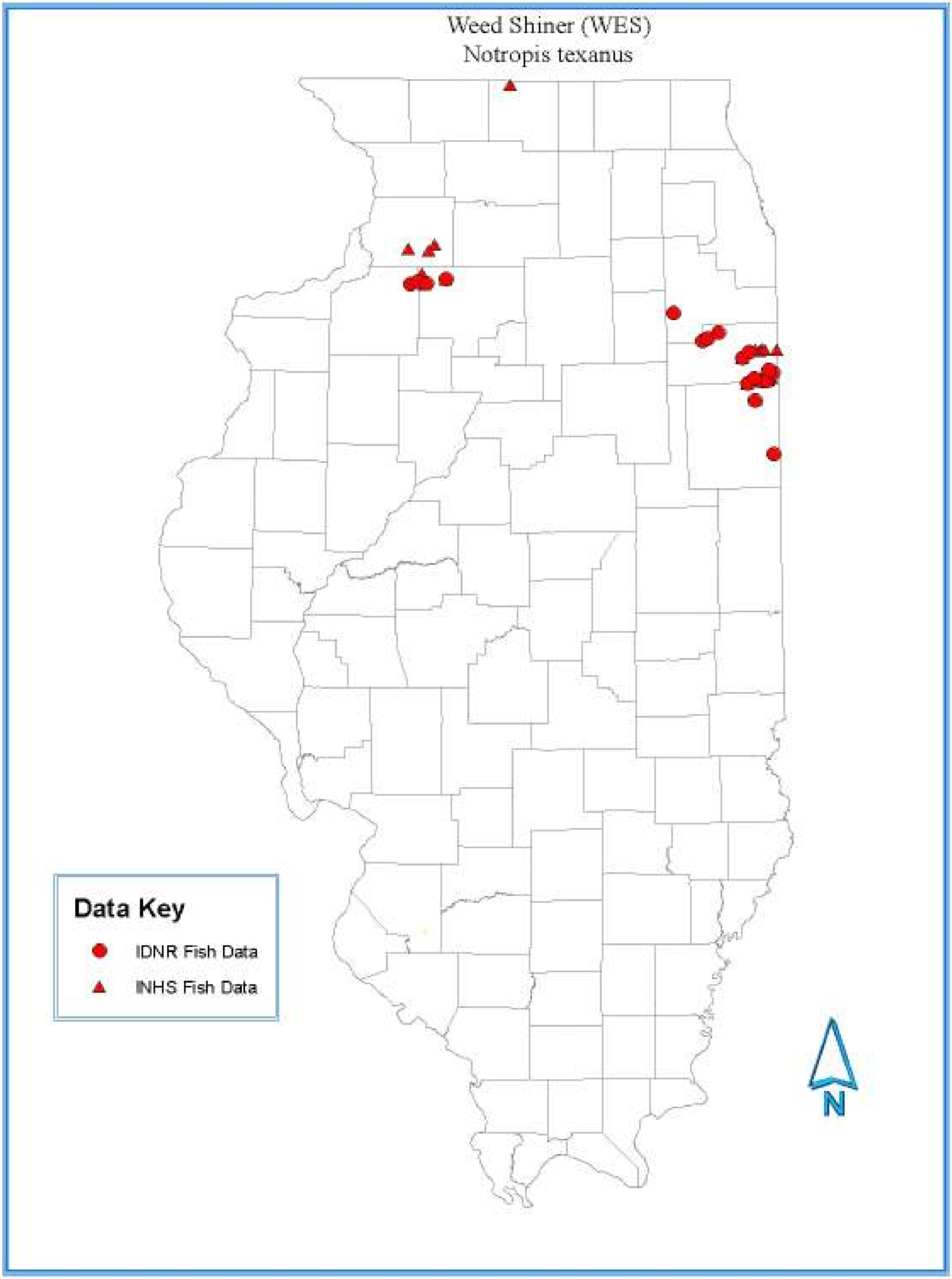
Rainbow Trout (RBT)
Salmo gairdneri




Ironcolor Shiner (RCS)
Notropis chalybaeus
Data Key
IDNR Fish Data
INHS Fish Data
N



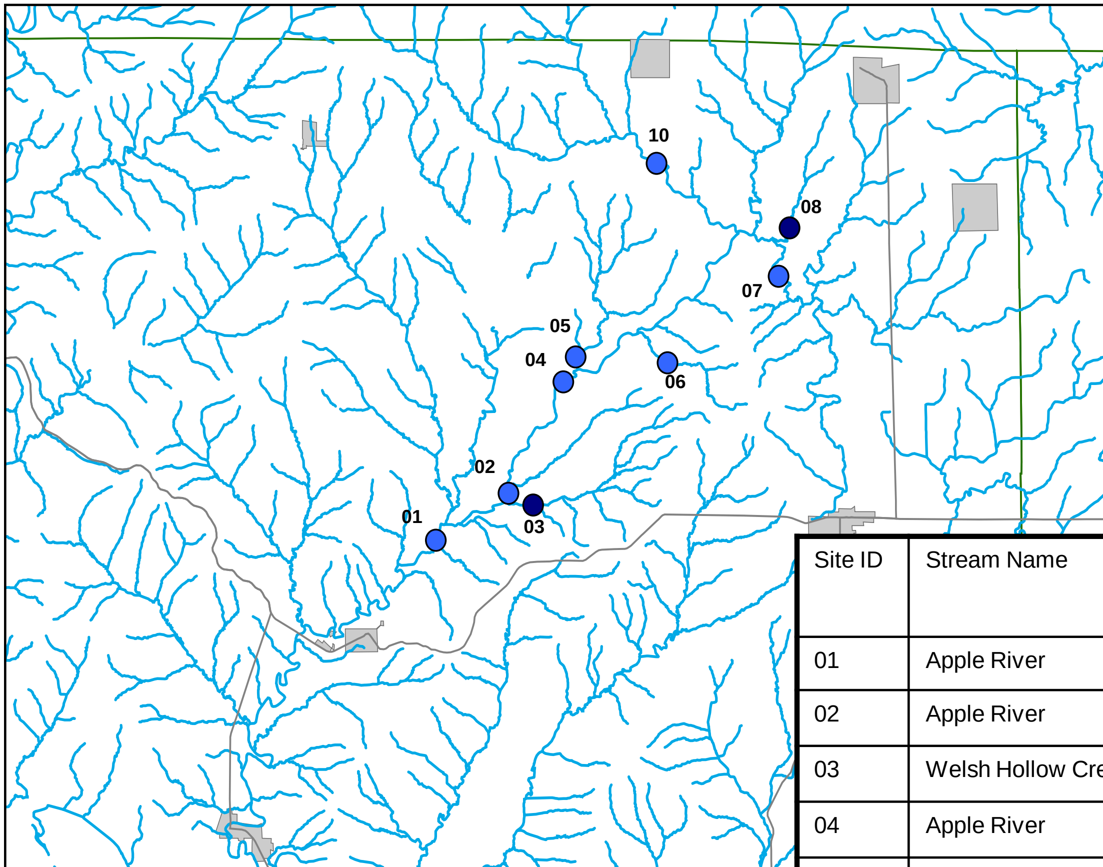
Southern Redbelly Dace (SRD)
Phoxinus erythrogaster
Data Key
IDNR Fish Data
INHS Fish Data
N



Weed Shiner (WES)
Notropis texanus
Data Key
IDNR Fish Data
INHS Fish Data
N

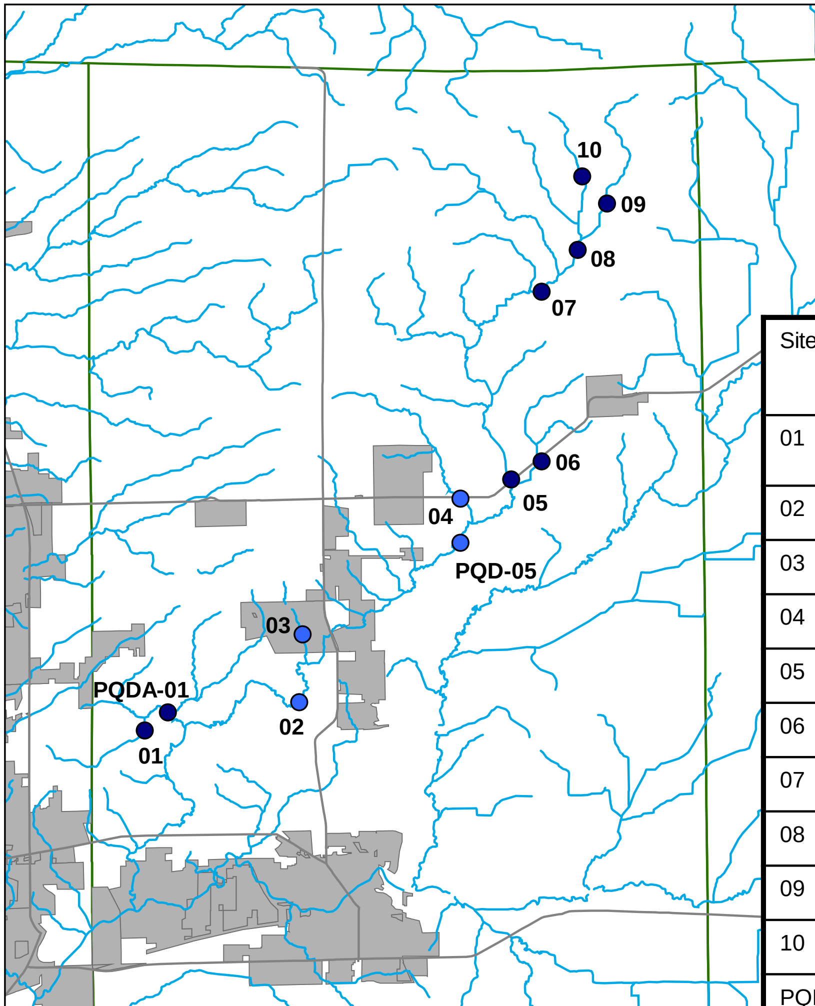
Appendix B

Apple River Network Results (July-August, 2008)



Site ID	Stream Name	Mean Daily Temperature	Mean Daily Temperature Range
01	Apple River	20.65	4.56
02	Apple River	21.12	4.65
03	Welsh Hollow Creek	18.33	4.52
04	Apple River	21.03	3.94
05	Coon Creek	19.35	3.85
06	Lilly Branch	20.93	7.41
07	S. Fork Apple River	20.62	3.24
08	Birch Creek	17.91	3.12
10	Apple River	21.46	3.89

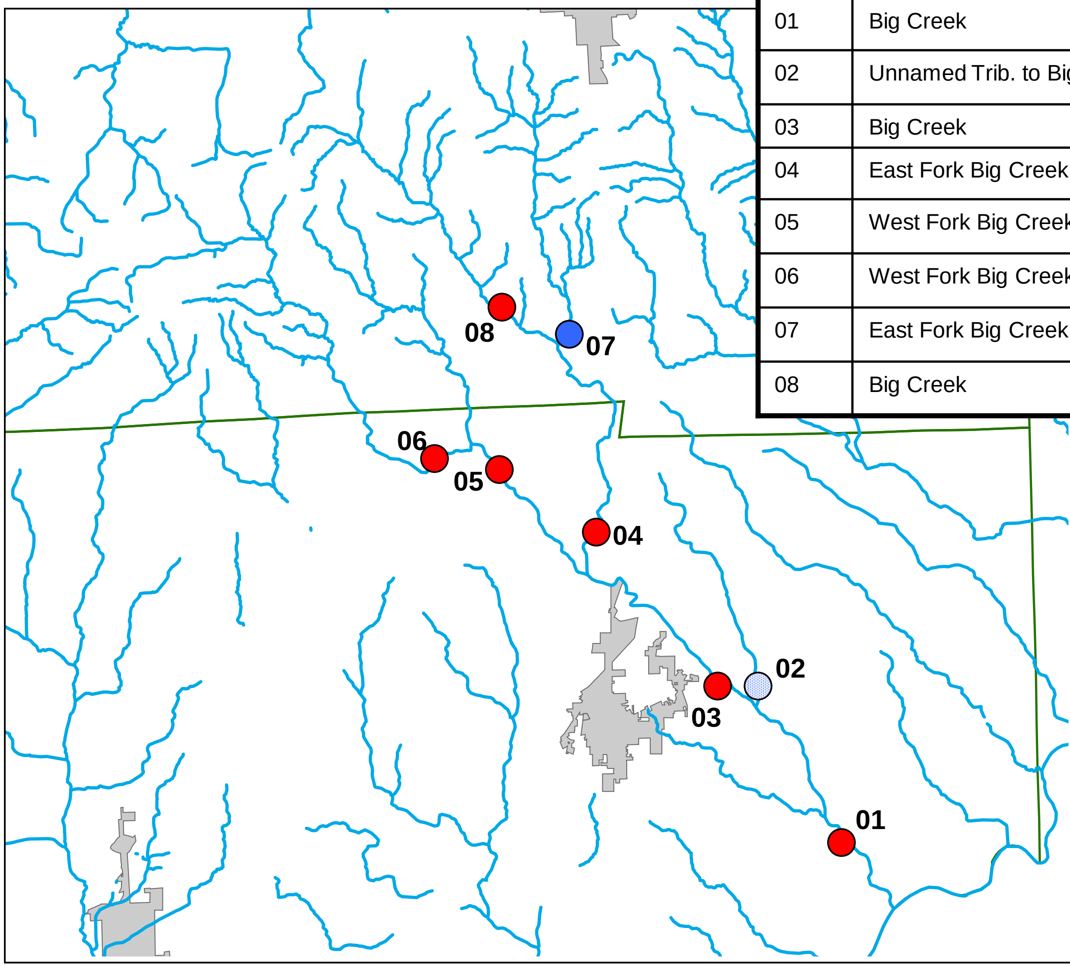
Beaver Creek Network Results (August-September, 2007)



Site ID	Stream Name	Mean Daily Temperature	Mean Daily Temperature Range
01	Trib. to Mosquito Creek	17.21	0.83
02	Beaver Creek	20.44	2.88
03	Trib. to Beaver Creek	21.48	3.05
04	Trib. to Beaver Creek	19.13	2.94
05	Beaver Creek	18.87	2.97
06	Trib. to Beaver Creek	18.03	5.86
07	Beaver Creek	18.99	2.92
08	Trib. to Beaver Creek	18.52	3.26
09	Trib. to Beaver Creek	18.57	3.72
10	Trib. to Beaver Creek	18.29	3.41
PQDA-01	Mosquito Creek	18.84	2.99
PQD-05	Beaver Creek	19.12	3.29

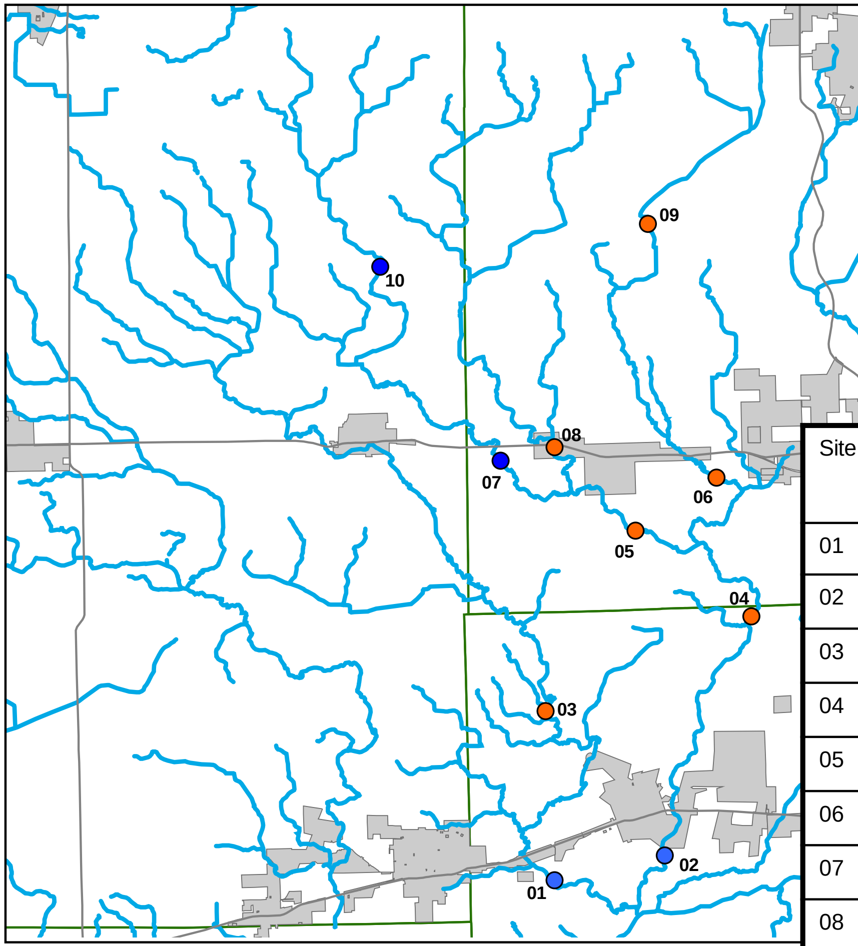
Big Creek Network Results (July-September, 2009)

Site ID	Stream Name	Mean Daily Temperature	Mean Daily Temperature Range
01	Big Creek	23.67	9.91
02	Unnamed Trib. to Big Creek	21.39	6.64
03	Big Creek	24.22	9.84
04	East Fork Big Creek	23.45	8.29
05	West Fork Big Creek	23.41	11.63
06	West Fork Big Creek	22.26	8.32
07	East Fork Big Creek	21.02	10.95
08	Big Creek	22.12	8.61



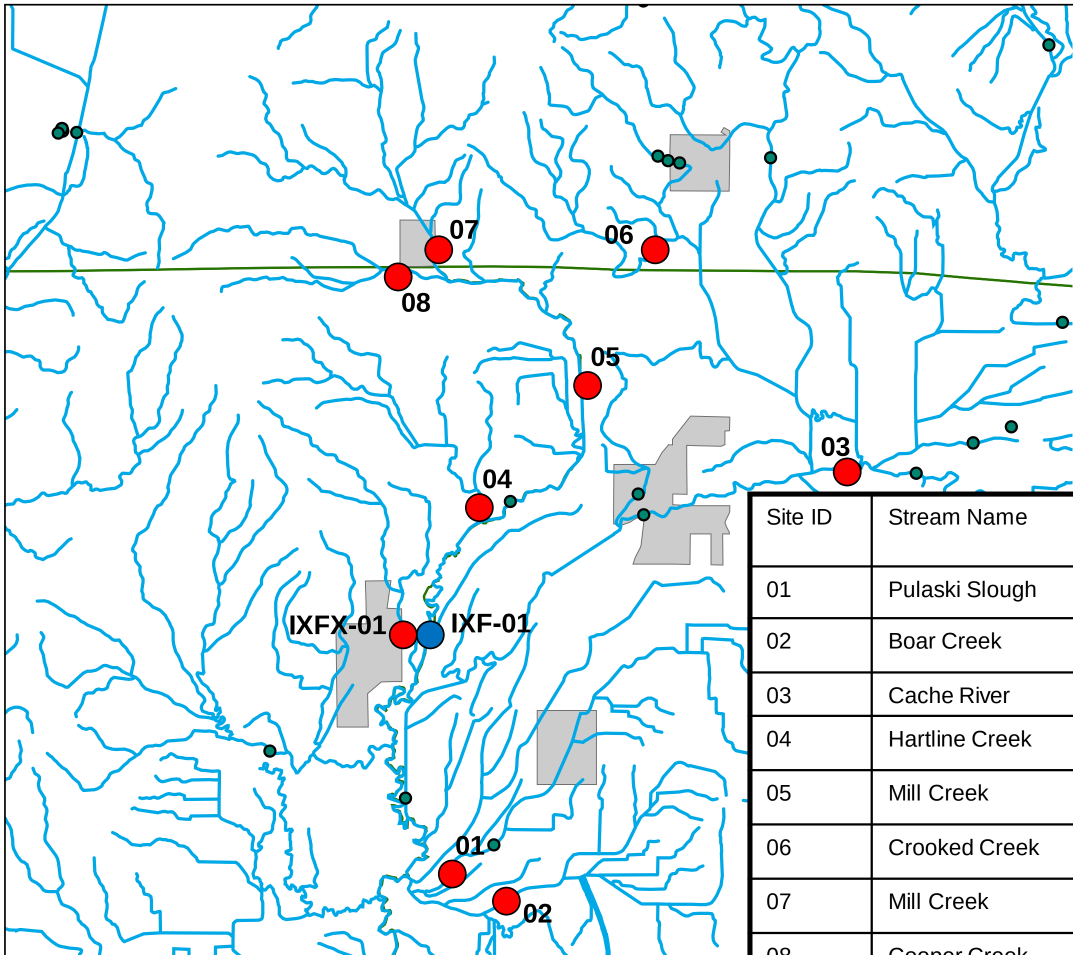
Note: Site 02 was dry for most of sample period, but when water was present, site was cool

Big Rock Creek Network Results (July-August, 2008)



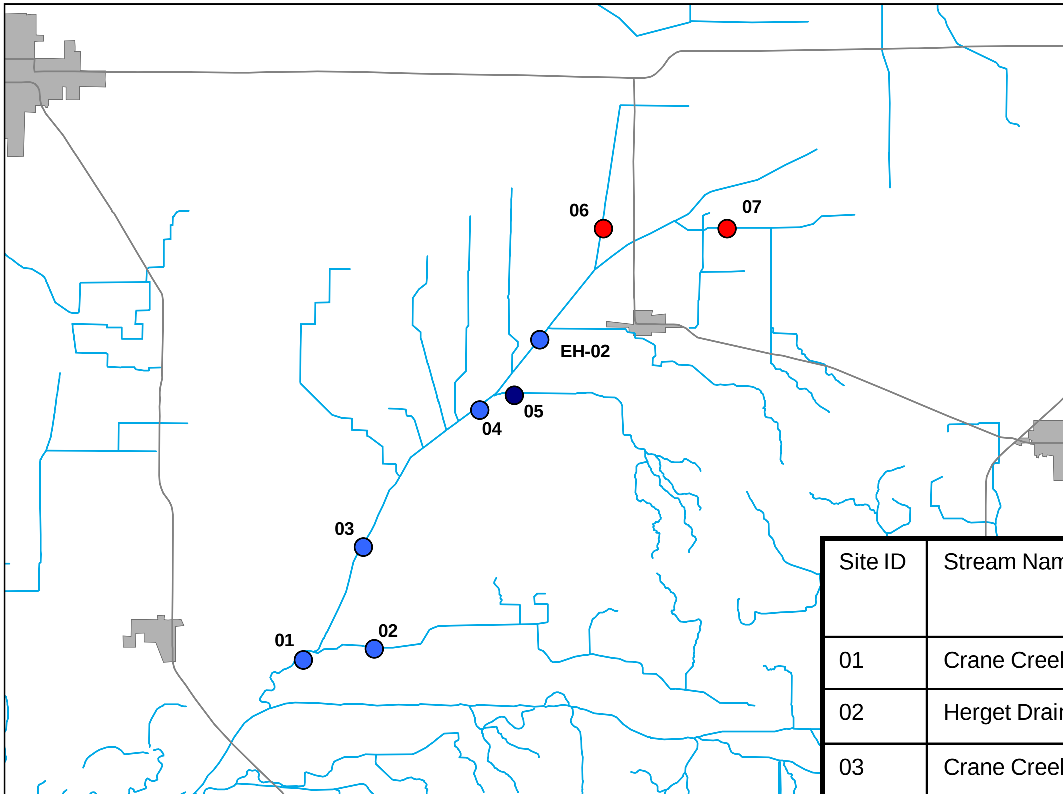
Site ID	Stream Name	Mean Daily Temperature	Mean Daily Temperature Range
01	Little Rock Creek	19.49	3.00
02	Big Rock Creek	21.04	9.30
03	Little Rock Creek	22.49	3.40
04	Big Rock Creek	23.12	3.42
05	Big Rock Creek	23.24	5.57
06	Welch Creek	22.19	4.26
07	Big Rock Creek	19.59	3.22
08	E. Branch Big Rock Creek	22.42	4.40
09	Welch Creek	22.92	5.30
10	W. Branch Big Rock Creek	20.78	4.87

Cache River Network Results (June-July, 2009)



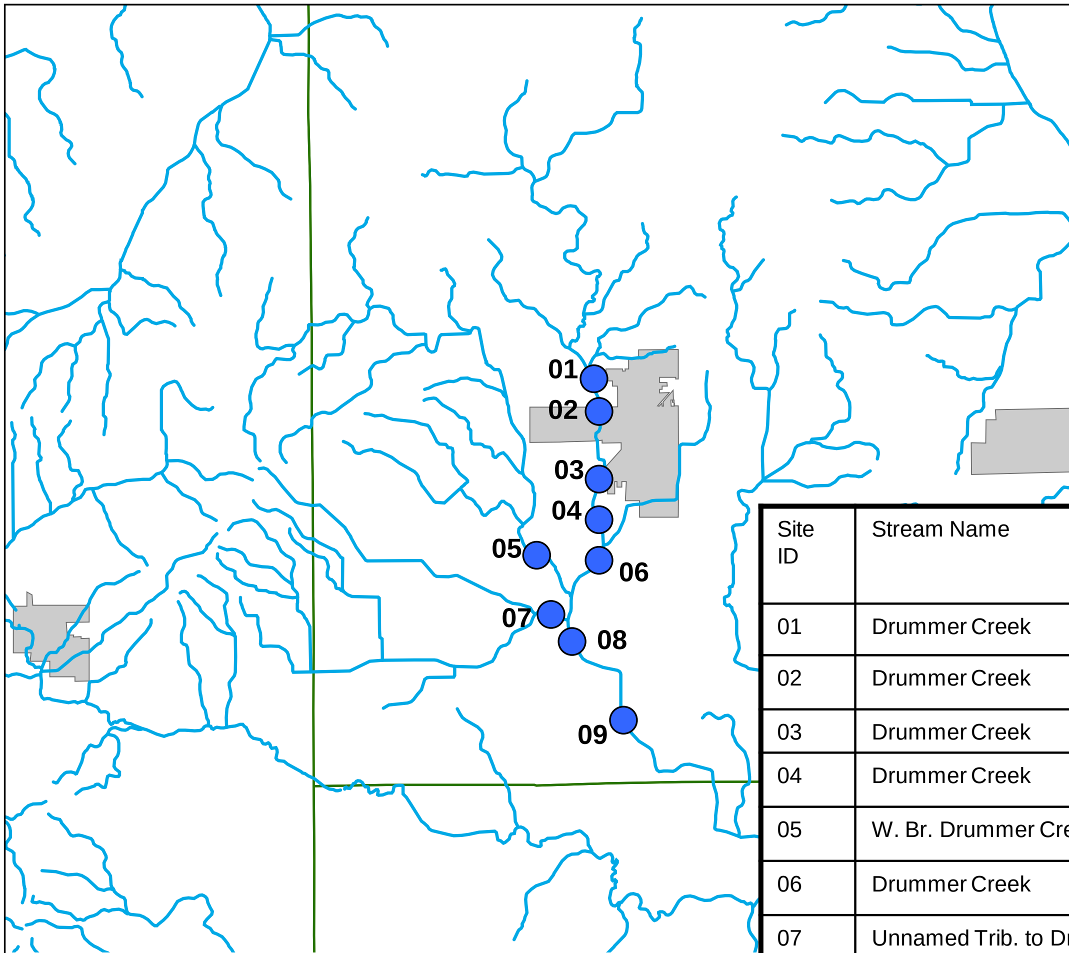
Site ID	Stream Name	Mean Daily Temperature	Mean Daily Temperature Range
01	Pulaski Slough	26.90	6.68
02	Boar Creek	25.66	1.83
03	Cache River	26.89	1.27
04	Hartline Creek	23.32	2.83
05	Mill Creek	25.62	2.23
06	Crooked Creek	23.65	3.09
07	Mill Creek	22.40	2.84
08	Cooper Creek	23.68	2.46
IXF-01	Mill Creek	19.17	3.66
IXFX-01	Jackson Creek	24.04	3.98

Crane Creek Network Results (July, 2008)



Site ID	Stream Name	Mean Daily Temperature	Mean Daily Temperature Range
01	Crane Creek	21.68	6.15
02	Herget Drainage Ditch	21.59	6.22
03	Crane Creek	20.31	5.01
04	Crane Creek	20.83	4.25
05	Hall Ditch	15.04	3.55
06	Hardin Ditch	23.05	3.82
07	Furrer Ditch	22.16	4.35
EH-02	Crane Creek	21.85	4.24

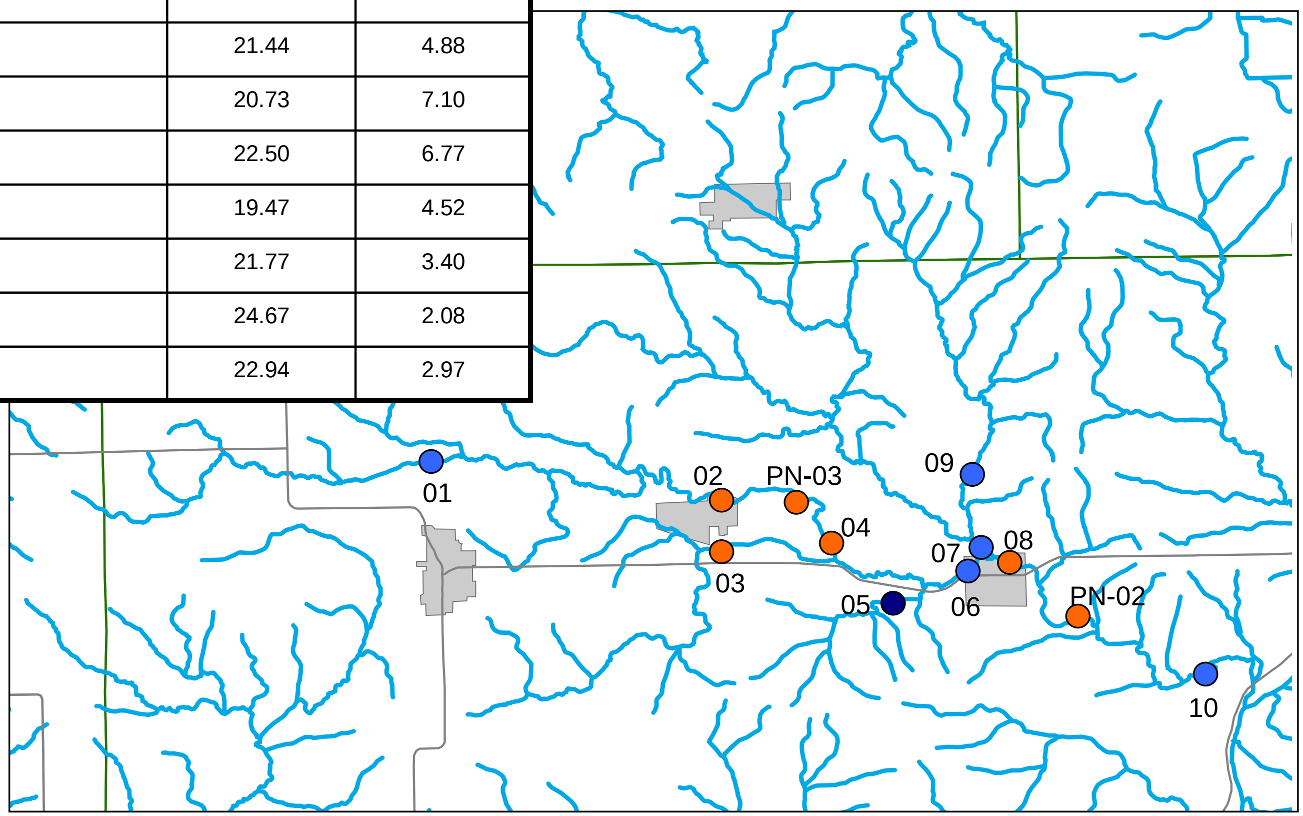
Drummer Creek Network Results (May-September, 2009)



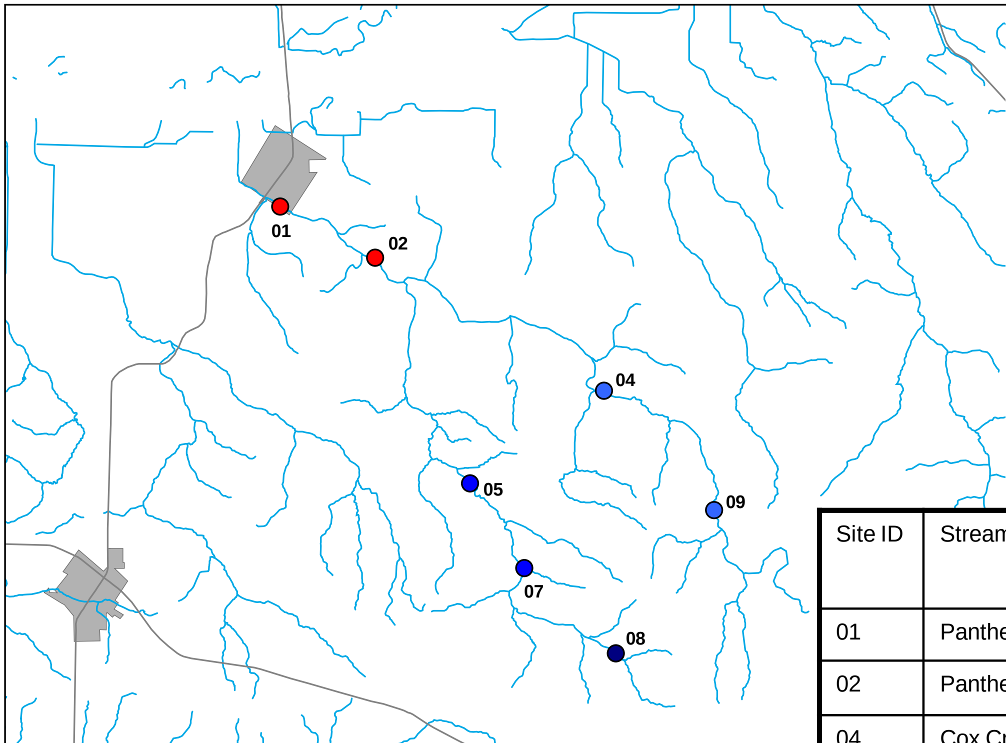
Site ID	Stream Name	Mean Daily Temperature	Mean Daily Temperature Range
01	Drummer Creek	20.99	7.67
02	Drummer Creek	20.60	6.86
03	Drummer Creek	20.50	8.50
04	Drummer Creek	20.33	7.09
05	W. Br. Drummer Creek	19.46	7.66
06	Drummer Creek	20.88	11.43
07	Unnamed Trib. to Drummer Creek	19.67	10.82
08	Drummer Creek	20.82	11.65
09	Drummer Creek (EY-01)	19.72	9.45

Site ID	Stream Name	Mean Daily Temperature	Mean Daily Temp. Range
01	Leaf River	21.21	4.77
02	Leaf River	23.05	4.88
03	Unnamed Trib. to Leaf River	23.04	5.41
04	Leaf River	23.12	5.29
05	Unnamed Trib. to Leaf River	17.36	7.90
06	Leaf River	21.44	4.88
07	Mud Creek	20.73	7.10
08	Leaf River	22.50	6.77
09	Otter Creek	19.47	4.52
10	Leaf River	21.77	3.40
PN-03	Leaf River	24.67	2.08
PN-02	Leaf River	22.94	2.97

Leaf River Network Results (August, 2007)

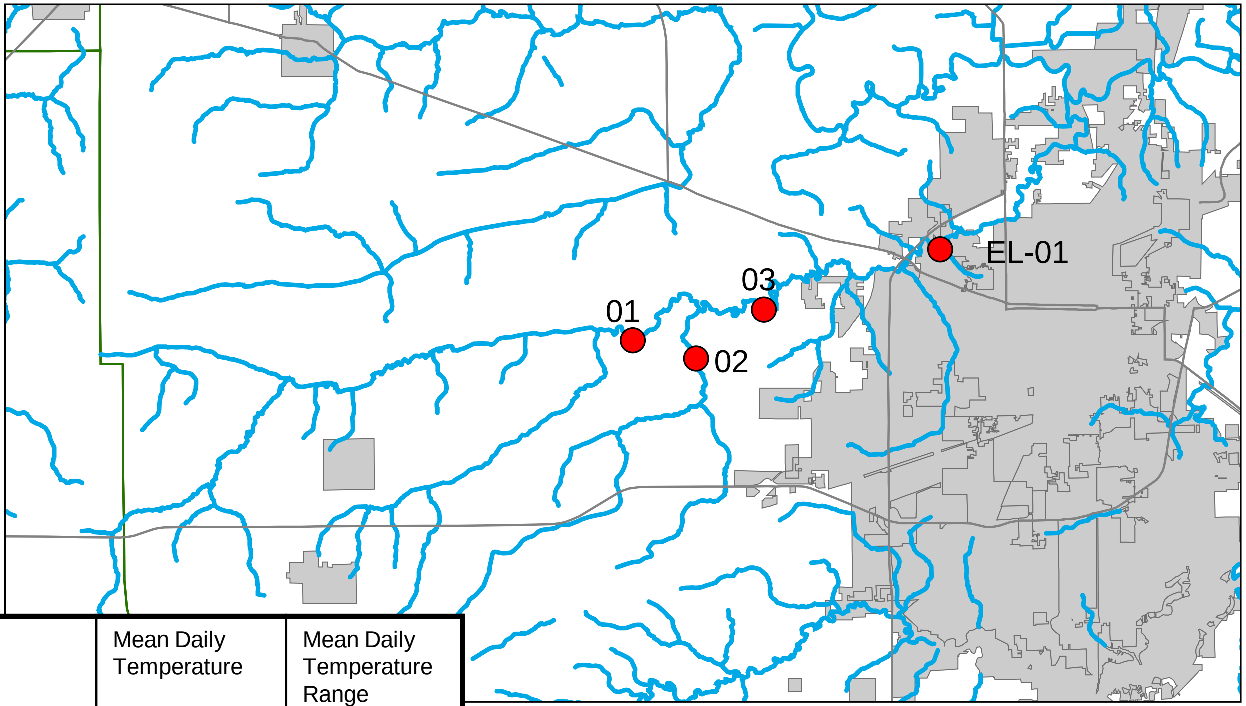


Panther Creek Network Results (July, 2008)



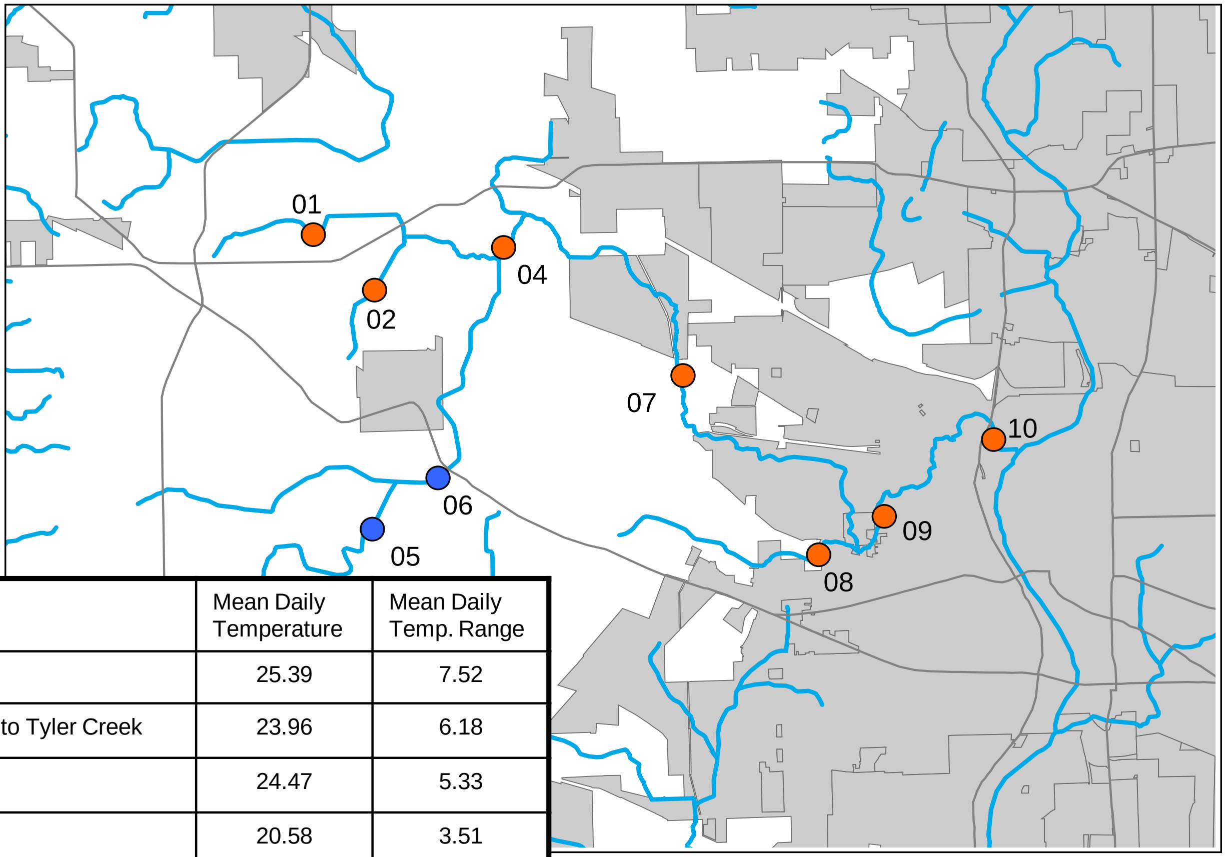
Site ID	Stream Name	Mean Daily Temperature	Mean Daily Temperature Range
01	Panther Creek	23.52	3.76
02	Panther Creek	23.25	3.50
04	Cox Creek	20.99	2.48
05	Panther Creek	21.20	3.74
07	Panther Creek	20.68	3.00
08	Panther Creek	18.21	2.38
09	Cox Creek	20.31	3.97

Spring Creek Network Results (August-September, 2007)



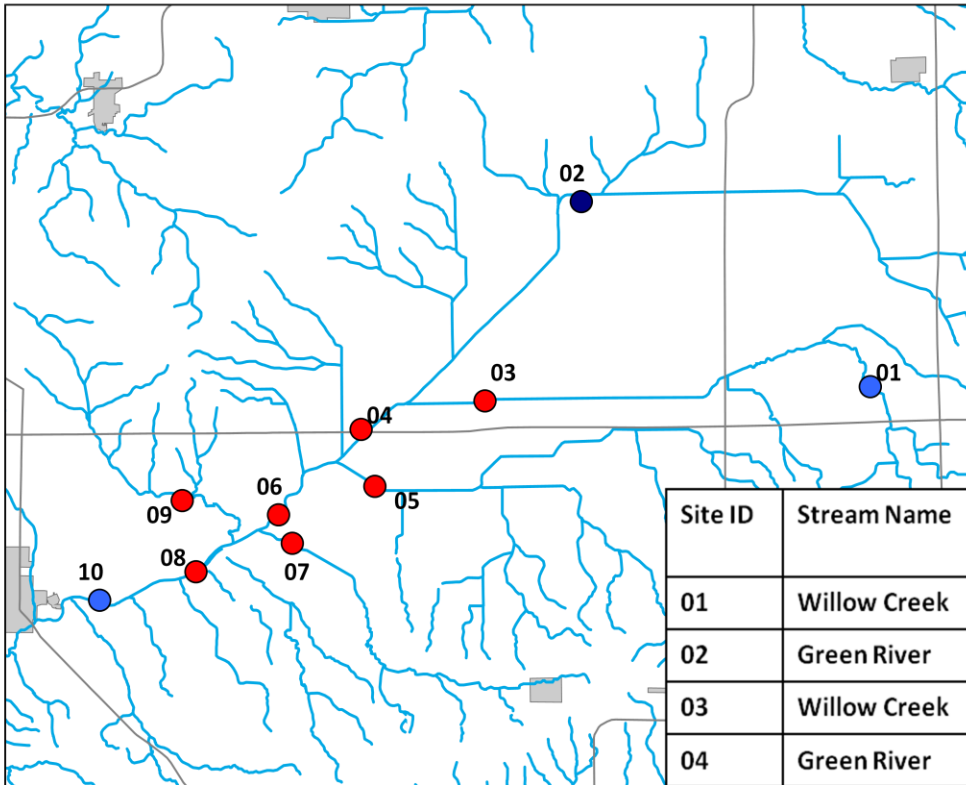
Site ID	Stream Name	Mean Daily Temperature	Mean Daily Temperature Range
01	Spring Creek	26.37	9.73
02	Little Spring Creek	24.73	3.43
03	Spring Creek	25.57	7.35
EL-01	Spring Creek	26.04	5.33

Tyler Creek Network Results (August, 2007)



Site ID	Stream Name	Mean Daily Temperature	Mean Daily Temp. Range
01	Tyler Creek	25.39	7.52
02	Unnamed Trib. to Tyler Creek	23.96	6.18
04	Tyler Creek	24.47	5.33
05	Tyler Creek	20.58	3.51
06	Tyler Creek	20.83	3.76
07	Tyler Creek	23.57	4.38
08	Unnamed Trib. to Tyler Creek	23.62	7.35
09	Tyler Creek	23.60	4.14
10	Tyler Creek	23.55	3.71

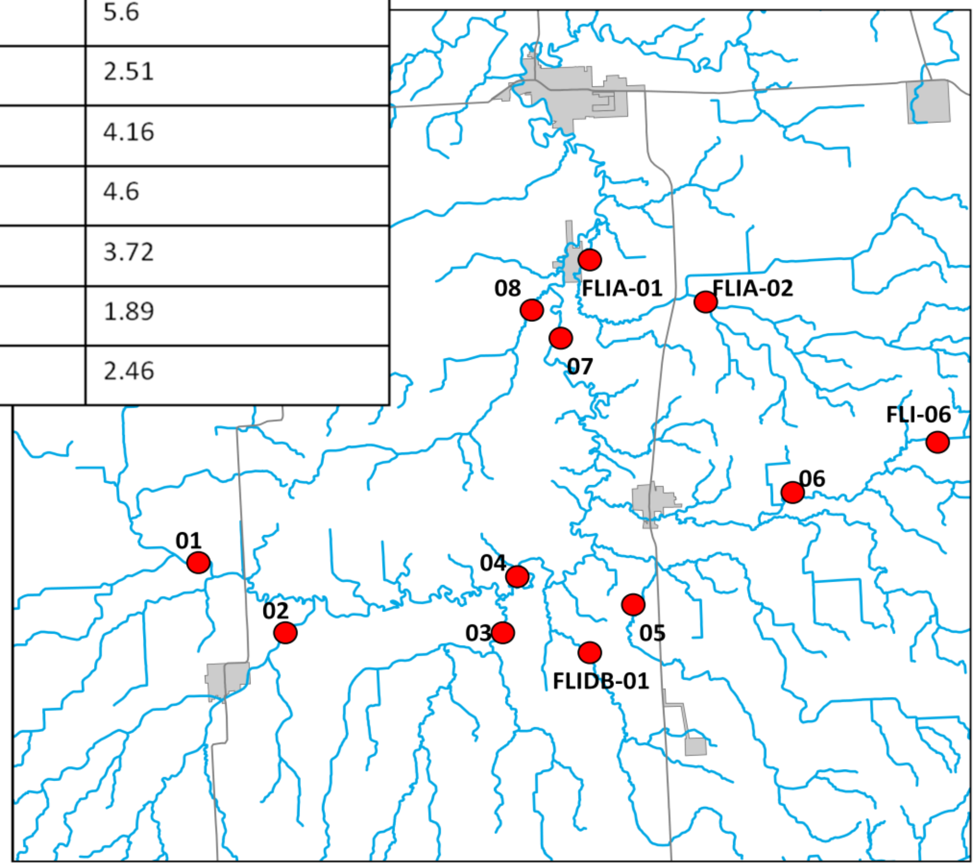
Green River Network Temperature Results (July, 2010)



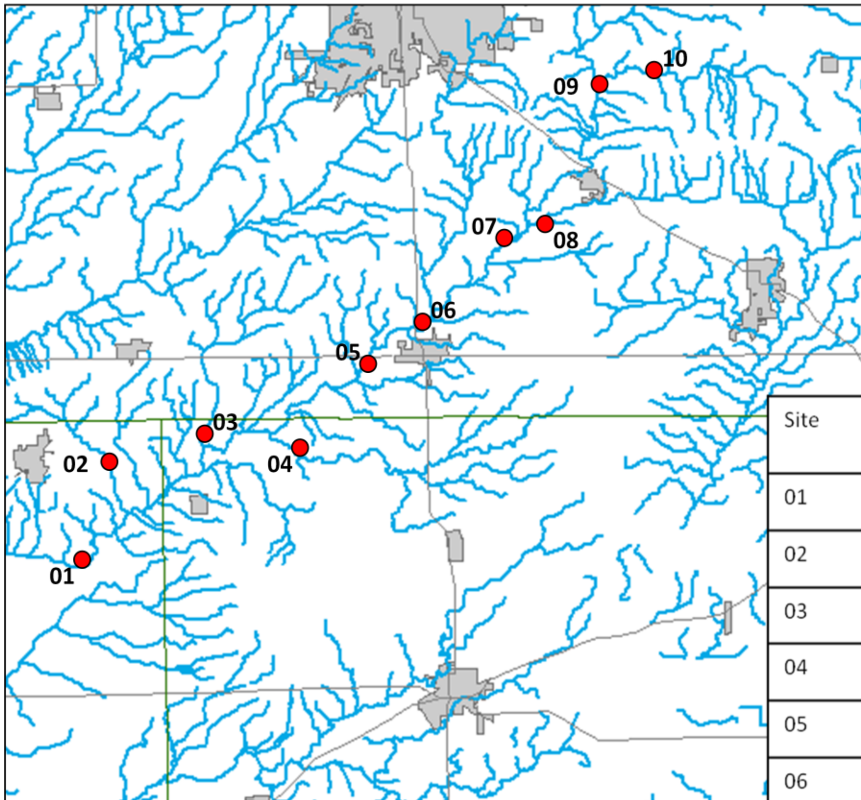
Site ID	Stream Name	Mean Daily Temperature	Mean Daily Temperature Range
01	Willow Creek	21.74	3.42
02	Green River	18.49	7.6
03	Willow Creek	22.1	8.96
04	Green River	22.1	7.74
05	Tributary to Green River	22.5	8.27
06	Green River	22.66	6.6
07	Tributary to Green River	23.3	7.35
08	Green River	22.89	5.42
09	Tributary to Green River	22.12	6.1
10	Tributary to Green River	21.68	4.24

Kankakee River Network Temperature Results (July, 2010)

Site ID	Stream Name	Mean Daily Temperature	Mean Daily Temperature Range
01	Mud Creek	24.68	5.41
02	Pigeon Creek	27.48	5.6
03	Fountain Creek	26.51	2.51
04	Mud Creek	27.22	4.16
05	Tributary to Mud Creek	25.32	4.6
06	Sugar Creek	25.61	3.72
07	Sugar Creek	26.29	1.89
08	Tributary to Sugar Creek	24.93	2.46

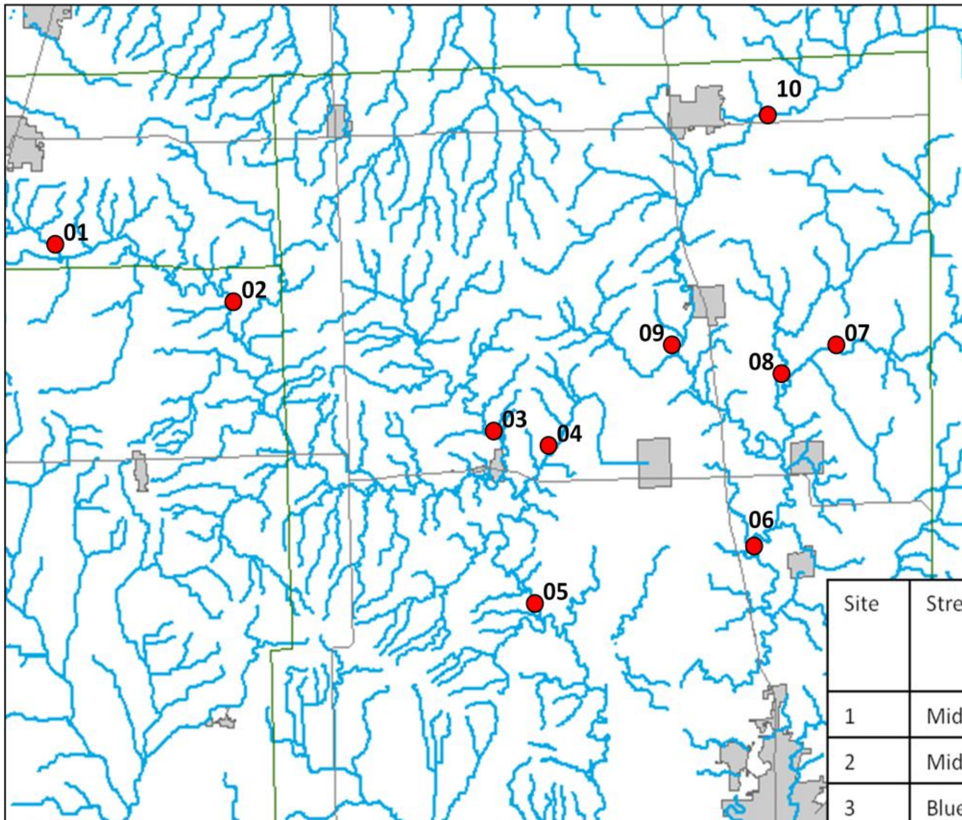


Kickapoo Creek Network Temperature Results (August, 2010)



Site	Stream Name	Mean Daily Temperature	Mean Daily Temperature Range
01	Kickapoo Creek	27.49625	3.9565
02	Clear Creek	25.45791	2.807846
03	Prairie Creek	26.40778	6.0575
04	Long Point Creek	27.06597	5.1935
05	Kickapoo Creek	26.03017	3.225071
06	Kickapoo Creek	26.08552	3.655571
07	Kickapoo Creek	26.12889	3.032643
08	Kickapoo Creek	24.38878	3.003857
09	Kickapoo Creek	25.74481	4.262714
10	Kickapoo Creek	26.15651	5.643929

Vermillion Network Temperature Results (July-August, 2010)



Site	Stream Name	Mean Daily Temperature	Mean Daily Temperature Range
1	Middle Fork Vermillion	27.09509	7.072182
2	Middle Fork Vermillion	23.21548	2.917091
3	Bluegrass Creek	25.35106	3.404727
4	Bean Creek	22.62158	3.345364
5	Middle Fork Vermillion	26.97034	3.208545
6	North Fork Vermillion	25.99641	2.823182
7	Jordan Creel	26.43356	3.826
8	Middle Branch	25.12312	4.487273
9	North Fork Vermillion	24.74529	5.044273
10	North Fork Vermillion	24.68466	4.195364

Appendix C

General Information

Site ID	AO-03
Stream Name	Big Creek
Location	upstream of marked location of AO-03, 150' upstream of 600N ?bridge
Sample Date	8/29/2007
Sample Time	1400
Sample Method	Backpack
Sample Reach Length	~ 200'
Sample Effort	841 sec. 14.02 min
Water Temp.	26.5 C

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Northern hog sucker	12	22.5/123; 22.0/117; 20.0/82; 14.0/27; 14.5/28
Orangespotted sunfish	10	11.5/27; 12.0/34; 12.5/39/ 8.0/9; 12.0/28
Rock bass	3	12.5/30; 11.5/28
Central stoneroller	30	
Bluegill	7	
Banded sculpin	11	
Bluntnose minnow	3	
Blackspotted topminnow	2	
White sucker	4	
Redfin shiner	22	
Johnny darter	5	
Stripetail darter	1	
() darter	18	

Summary

Total Fish Collected	128
Total Species Collected	13
CPUE (#/hour)	547

General Information

Site ID	AJ-09
Stream Name	Bay Creek
Location	just north of route 147, upstream of bridge ~20 feet
Sample Date	8/30/2007
Sample Time	1030
Sample Method	Backpack
Sample Reach Length	~150'
Sample Effort	907 sec. 15.12 min
Water Temp.	23.5 C

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Orangespotted sunfish	14	9.0/11; 13.0/41; 12.0/31; 10.0/20; 9.5/14; 9.5/19
Yellow bullhead	12	13.0/28; 12.0/18
Blackspotted topminnow	2	
Bluegill	16	
Creek chub	16	
Central stoneroller	5	
Bluntnose minnow	2	
Blackstripped topminnow	2	
Mosquito fish	1	
Freckled madtom	8	
Banded sculpin	25	
Johnny darter	2	
Pirate perch	2	

Summary

Total Fish Collected	107
Total Species Collected	13
CPUE (#/hour)	425

General Information

Site ID	AJG-18	
Stream Name	Hayes Creek	
Location	upstream and downstream of bridge	
Sample Date	8/29/2007	
Sample Time	1700	
Sample Method	Backpack	
Sample Reach Length	~100 total feet	
Sample Effort	690 sec.	11.50 min
Water Temp.	23.0 C	at 0900

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Pirate perch	17	
Banded sculpin	21	
Creek chub	37	
Bluntnose minnow	1	
Central stoneroller	7	
Blackside darter	1	
Blugill	4	
Orangespotted sunfish	1	
() minnow	4	
Mosquito fish	3	
Freckled madtom	2	
() darter	2	

Summary

Total Fish Collected	100
Total Species Collected	12
CPUE (#/hour)	521

General Information

Site ID	PWC-01
Stream Name	Rhule Creek
Location	upstream of bridge
Sample Date	9/11/2007
Sample Time	0800
Sample Method	Backpack
Sample Reach Length	~200 total feet
Sample Effort	868 sec 14.47 min
Water Temp.	11.5 C

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Bluegill	6	
Creek Chub	80	
Bluntnose minnow	8	
Largemouth bass	4	
Orangespotted sunfish	18	
Brook stickleback	32	
Common carp	1	
Johnny darter	2	

Summary

Total Fish Collected	151
Total Species Collected	8
CPUE (#/hour)	627

General Information

Site ID	PQDA-01
Stream Name	Mosquito Creek
Location	upstream and downstream of culvert
Sample Date	9/10/2007
Sample Time	1700
Sample Method	Backpack
Sample Reach Length	~300 total feet
Sample Effort	1093 sec 18.22 min
Water Temp.	15.5 C

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Creek chub	77	
White sucker	13	
Bluntnose minnow	63	
Orangespotted sunfish	3	
Largescale stoneroller	35	
Fathead minnow	9	
Bluegill	35	
Common shiner	4	
Blacknose dace	4	
Largemouth bass	2	
Smallmouth bass	2	
Johnny darter	6	

Summary

Total Fish Collected	253
Total Species Collected	12
CPUE (#/hour)	832

General Information

Site ID	DZP-03
Stream Name	Spring Creek
Location	upstream of bridge
Sample Date	9/25/2007
Sample Time	1100
Sample Method	Backpack
Sample Reach Length	~300 total feet
Sample Effort	1551 sec 25.85 min
Water Temp.	23.0 C

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Common shiner	2	
Gizzard shad	1	
Creek chub	6	
Central stoneroller	77	
Horneyhead chub	18	
Bluegill	20	
Yellow bullhead	4	
Green sunfish	32	
() Sunfish	2	
Smallmouth bass	3	
Bluntnose minnow	8	
White sucker	1	
Log perch	3	
Orangespotted sunfish	1	
Stonecat	2	

Summary

Total Fish Collected	180
Total Species Collected	15
CPUE (#/hour)	418

General Information

Site ID	ADD-02
Stream Name	Dutchman Creek
Location	upstream of crossing
Sample Date	8/13/2007
Sample Time	1000
Sample Method	Backpack
Sample Reach Length	~150 total feet
Sample Effort	1315 sec 21.92 min
Water Temp.	

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Bluegill	29	
Largemouth bass	1	
Gizzard shad	1	
Grass pickerel	1	
Longear sunfish	5	
Bluntnose minnow	6	
Green sunfish	3	
Yellow bullhead	1	
Orangespotted sunfish	2	
Blackspotted topminnow	1	
Blackside darter	3	
Banded sculpin	1	
Spotted sucker	1	
Golden redhorse	1	

Summary

Total Fish Collected	56
Total Species Collected	14
CPUE (#/hour)	153

General Information

Site ID	AOA-01
Stream Name	Hogthief Creek
Location	upstream of bridge
Sample Date	8/12/2007
Sample Time	1300
Sample Method	Backpack
Sample Reach Length	~150 total feet
Sample Effort	1658 sec 27.63 min
Water Temp.	

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Creek chub	28	
Striped shiner	16	
Central stoneroller	98	
Northern hogsucker	1	
Blackspotted topminnow	3	
Orangspotted sunfish	5	
Bluegill	2	
Longear sunfish	2	
White sucker	1	
Green sunfish	2	
Rock bass	1	
Banded sculpin	28	
Rainbow darter	35	
Golden redhorse	2	
Spottail darter	9	

Summary

Total Fish Collected	233
Total Species Collected	15
CPUE (#/hour)	505

General Information

Site ID	AJF-16
Stream Name	Cedar Creek
Location	upstream of bridge
Sample Date	8/12/2007
Sample Time	1600
Sample Method	Backpack
Sample Reach Length	~100 total feet
Sample Effort	1085 sce 18.08 min
Water Temp.	

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Bluegill	7	
Golden redhorse	2	
Orangespotted sunfish	4	
Pirate perch	3	
Longear sunfish	1	
Blackspotted topminnow	1	
Blackside darter	1	
Bluntnose minnow	3	

Summary

Total Fish Collected	22
Total Species Collected	8
CPUE (#/hour)	73

General Information

Site ID	ADDB-01
Stream Name	Little Cache Creek
Location	upstream of park bridge
Sample Date	8/13/2007
Sample Time	0800
Sample Method	Backpack
Sample Reach Length	~150 total feet
Sample Effort	1164 sec 19.40 min
Water Temp.	

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Bluegill	39	
Orangespotted sunfish	5	
Longear sunfish	4	
Banded sculpin	1	
Blackside darter	3	
Green sunfish	3	
Largemouth bass	1	
Pirate perch	7	
Bluntnose minnow	1	
Carp	2	
Tadpole madtom	1	

Summary

Total Fish Collected	67
Total Species Collected	11
CPUE (#/hour)	207

General Information

Site ID	DZA-03
Stream Name	Otter Creek
Location	upstream of bridge
Sample Date	9/2/2007
Sample Time	1115
Sample Method	Backpack
Sample Reach Length	~200 total feet
Sample Effort	1419 sec 23.65 min
Water Temp.	

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Channel catfish	1	22/140
Yellow bullhead	11	18/115; 17/75; 15/45; 17/75; 17.5/82; 13/39; 15/48; 14/34; 19.5/90; 17/NA
Freshwater drum	3	21/137; 20/90; 19/67
Common Carp	1	43/930
Bluntnose minnow	76	
Largemouth bass	4	11/20; 10/17; 12/21; 11/18
Bluegill	20	14/59
White sucker	1	20/67
Golden redhorse	10	21/92; 91/37; 37/558; 21/105; 32/314; 19/72; 20/93; 22/124; 19.5/81; 24.5/169
Horneyhead chub	1	
Smallmouth bass	6	17.5/66; 10/12; 10.5/44
Green sunfish	5	
Blackstripe topminnow	3	
Log perch	10	
Sand shiner	55	
Mosquitofish	1	
Redfin shiner	2	
Johnny darter	6	
Central stoneroller	2	

Summary

Total Fish Collected	218
Total Species Collected	19
CPUE (#/hour)	553

General Information

Site ID	FLDAE-01
Stream Name	Little Beaver Creek
Location	downstream of bridge
Sample Date	8/21/2008
Sample Time	1130
Sample Method	Backpack
Sample Reach Length	~300 total feet
Sample Effort	1725 sec 28.75 min
Water Temp.	19.5

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Common shiner	2	
Striped shiner	8	
White sucker	7	33/440; 22/130; 22/120; 23/140; 25/170
Grass pickerel	3	
Black bullhead	3	27/300
River redhorse	1	28/340
Longear sunfish	4	
Largemouth bass	1	21/140
Creek chub	1	
Bluntnose minnow	2	
Green sunfish	4	
Yellow bullhead	4	
Bluegill	1	
Johnny darter	10	
Rock bass	3	24/220

Summary

Total Fish Collected	54
Total Species Collected	15
CPUE (#/hour)	113

General Information

Site ID	PWIA-01
Stream Name	Pink Creek
Location	upstream of bridge
Sample Date	8/19/2008
Sample Time	1300
Sample Method	Backpack
Sample Reach Length	~300 total feet
Sample Effort	1633 sec 27.22 min
Water Temp.	19

Fish Collection

Common Name	# Collected	Length/Weight Measurements
White sucker	23	35/325; 28/240; 25/170; 27/270; 30/280; 27/190; 22/140; 21/110; 33/400; 24/140; 31/360; 30/320; 29/290; 22/130; 18/70; 23/120; 24/150; 25/200; 20/100
Northern pike	6	25/90; 20/40; 21/50; 21/50; 23/70; 22/60; 21/100; 19/90; 14/40
Green sunfish	1	15/80
Largemouth bass	1	15/40
Grass pickerel	1	
Black redhorse	1	
Johnny darter	2	

Summary

Total Fish Collected	35
Total Species Collected	7
CPUE (#/hour)	77

General Information

Site ID	PWI-01
Stream Name	Rock Run
Location	upstream of bridge
Sample Date	8/19/2008
Sample Time	1500
Sample Method	Backpack
Sample Reach Length	~150 total feet
Sample Effort	1717 sec 28.62 min
Water Temp.	20

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Smallmouth bass	3	10/16; 38/720; 14/40
White sucker	26	27/200; 26/230; 30/310; 26/180; 22/100; 22/110; 22/110; 25/170; 30/280; 30/290; 30/270; 22/120; 19/70; 16/40; 23/150; 23/130; 18/60; 21/100; 18/120; 28/260; 26/180; 18/50; 18/70
Hornyhead chub	44	
Bluntnose minnow	47	
Common shiner	3	
Bigmouth shiner	5	
Northern pike	1	
Central stoneroller	5	
Fathead minnow	1	
Creek chub	3	
Fantail darter	146	
Johnny darter	19	
Bluegill	1	
Stonecat	3	
Carp	2	0.71m/NA; >0.50m/NA

Summary

Total Fish Collected	309
Total Species Collected	15
CPUE (#/hour)	648

General Information

Site ID	PU-01
Stream Name	North Kinnikinnik Creek
Location	upstream of bridge
Sample Date	8/20/2008
Sample Time	1000
Sample Method	Backpack
Sample Reach Length	~300 total feet
Sample Effort	2086 sec 34.77 min
Water Temp.	19

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Carp	1	46/1100
White sucker	19	32/360; 23/110; 20/70; 18/60; 24/140; 18/80; 21/120; 21/90; 21/90; 19/80; 18/70; 18/70; 19/80; 24/140; 20/90
Creek chub	11	
Bluegill	5	
Common shiner	2	
Green sunfish	1	
Northern pike	2	32/240; 20/40
Hornyhead chub	14	
Grass pickerel	4	
Northern hogsucker	13	
Bluntnose minnow	10	
Stonecat	1	
Yellow bullhead	1	
Central stoneroller	10	
Fantail darter	13	
Johnny darter	4	

Summary

Total Fish Collected	111
Total Species Collected	16
CPUE (#/hour)	198

General Information

Site ID	PQE-10
Stream Name	Piscasaw Creek
Location	upstream of bridge
Sample Date	8/20/2008
Sample Time	1300
Sample Method	Backpack
Sample Reach Length	~200 total feet
Sample Effort	1826 sec 30.43 min
Water Temp.	18

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Creek chub	31	
White sucker	22	25/190; 34/450; 21/90; 41/770; 23/170; 24/170; 26/200; 20/110; 28/240; 23/130; 29/250; 18/70; 22/110; 24/130; 21/100; 20/80
Common shiner	2	
Central stoneroller	12	
Blacknose dace	31	
Sothern redbelly dace	1	
Brook stickleback	3	
Bluegill	3	
Green sunfish	12	
Johnny darter	20	
Rainbow darter	40	
Fantail darter	10	
Minnow	9	

Summary

Total Fish Collected	196
Total Species Collected	?
CPUE (#/hour)	387

General Information

Site ID	HBE-02
Stream Name	Plum Creek
Location	upstream of bridge
Sample Date	8/21/2008
Sample Time	900
Sample Method	Backpack
Sample Reach Length	~200 total feet
Sample Effort	1748 sec 29.13 min
Water Temp.	20

Fish Collection

Common Name	# Collected	Length/Weight Measurements
White sucker	16	34/390; 24/140; 19/60; 29/220; 33/290; 21/90; 18/60; 22/90; 16/40
Creek chub	27	
Grass pickerel	1	
Common shiner	7	
Bluegill	3	
Bluntnose minnow	26	
Largemouth bass	1	17/60
Hornyhead chub	15	
Green sunfish	20	
Yellow bullhead	1	17/80
Johnny darter	16	
Largescale stoneroller	17	
Blackside darter	4	

Summary

Total Fish Collected	154
Total Species Collected	13
CPUE (#/hour)	317

General Information

Site ID	DH-03
Stream Name	Sugar Creek
Location	upstream of bridge
Sample Date	8/25/2008
Sample Time	1000
Sample Method	Backpack
Sample Reach Length	~200 total feet
Sample Effort	1454 sec 24.23 min
Water Temp.	19.5

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Bluntnose minnow	105	
Creek chub	59	
Central stoneroller	101	
Striped shiner	5	
Bluegill	22	
White sucker	15	
Eastern mosquitofish	1	
Black bullhead	14	
Green sunfish	3	
Largemouth bass	7	
Blackside darter	6	
Yellow bullhead	1	
Johnny darter	8	
Orangethroat darter	18	

Summary

Total Fish Collected	365
Total Species Collected	14
CPUE (#/hour)	903

General Information

Site ID	PQCK-01
Stream Name	Rosseter Farm Creek
Location	upstream of bridge
Sample Date	7/20/2010
Sample Time	13:00
Sample Method	Backpack
Sample Reach Length	~200 total feet
Sample Effort	1390 sec 23.17 min
Water Temp.	21

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Bluntnose minnow	6	
Creek chub	15	
Central stoneroller	17	
Bigmouth shiner	6	
Bluegill	2	
White sucker	10	
Sand shiner	5	
Orangespotted sunfish	2	
Green sunfish	4	
Largemouth bass	12	
Johnny darter	17	
Largescale stoneroller	1	

Summary

Total Fish Collected	97
Total Species Collected	12
CPUE (#/hour)	251

General Information

Site ID	PW?-??
Stream Name	Tunnison Creek
Location	upstream of bridge
Sample Date	7/20/2010
Sample Time	15:00
Sample Method	Backpack
Sample Reach Length	~200 total feet
Sample Effort	sec min
Water Temp.	

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Creek chub	30	18 cm, 14, 17, 13.5, 20, 17
White sucker	20	26 cm, 26.5, 25, 28.5
Johnny darter	8	
Southern redbelly dace	1	
Blacknose dace	11	
Blackside darter	4	
Central stoneroller	1	
Brook stickleback	1	

Summary

Total Fish Collected	76
Total Species Collected	8
CPUE (#/hour)	

General Information

Site ID	PWPC-01
Stream Name	East Branch Richland Creek
Location	upstream of bridge
Sample Date	7/21/2010
Sample Time	
Sample Method	Backpack
Sample Reach Length	~200 total feet
Sample Effort	sec 1499 min 24.98
Water Temp.	

Fish Collection

Common Name	# Collected	Length/Weight Measurements
Creek chub	26	
White sucker	13	
Johnny darter	16	
Bluntnose minnow	4	
Fantail darter	38	
Largescale stoneroller	9	

Summary

Total Fish Collected	106
Total Species Collected	6
CPUE (#/hour)	262

General Information

Site ID	MJA-02
Stream Name	Camp Creek
Location	upstream of bridge
Sample Date	7/21/2010
Sample Time	
Sample Method	Backpack
Sample Reach Length	~200 total feet
Sample Effort	sec min
Water Temp.	

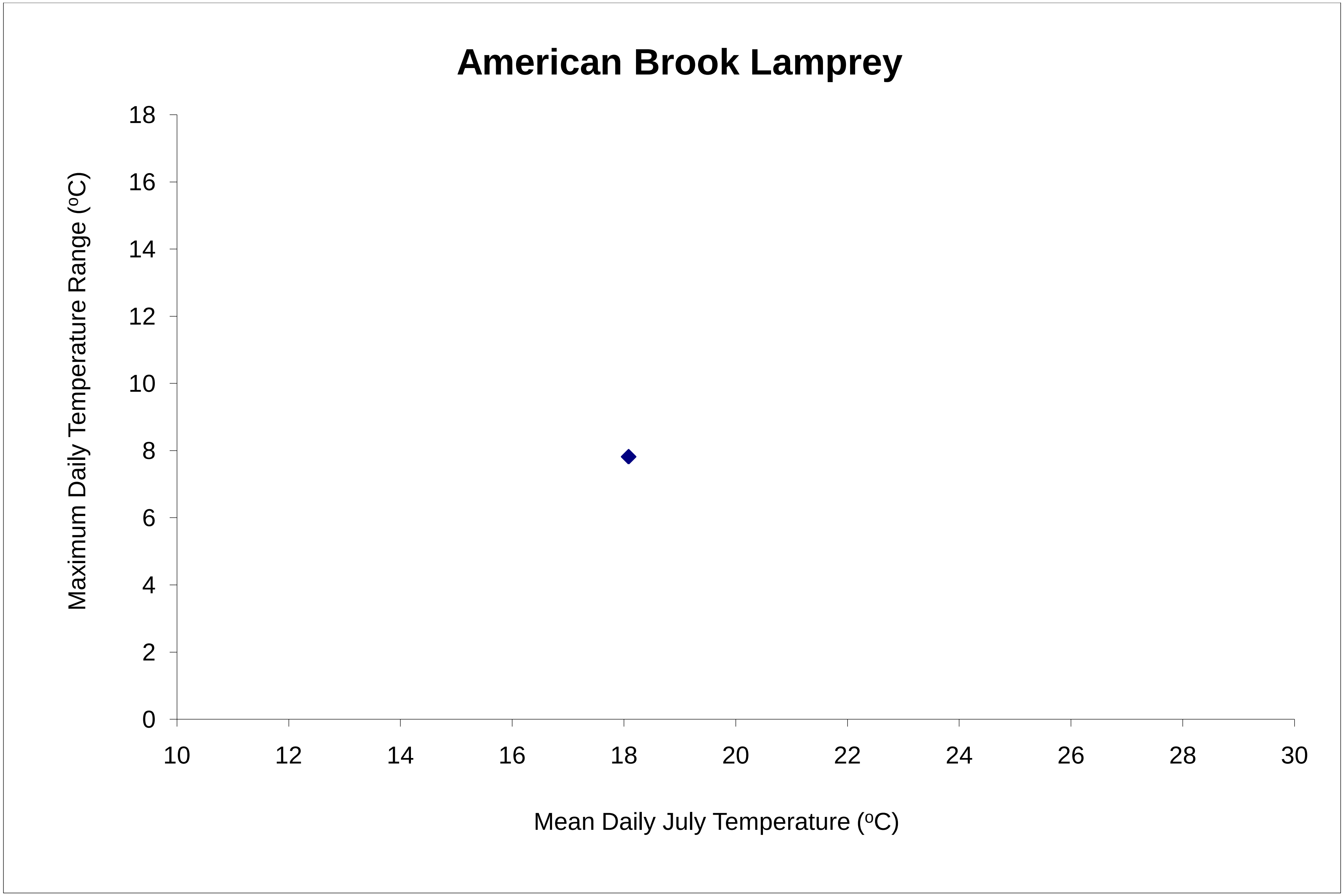
Fish Collection

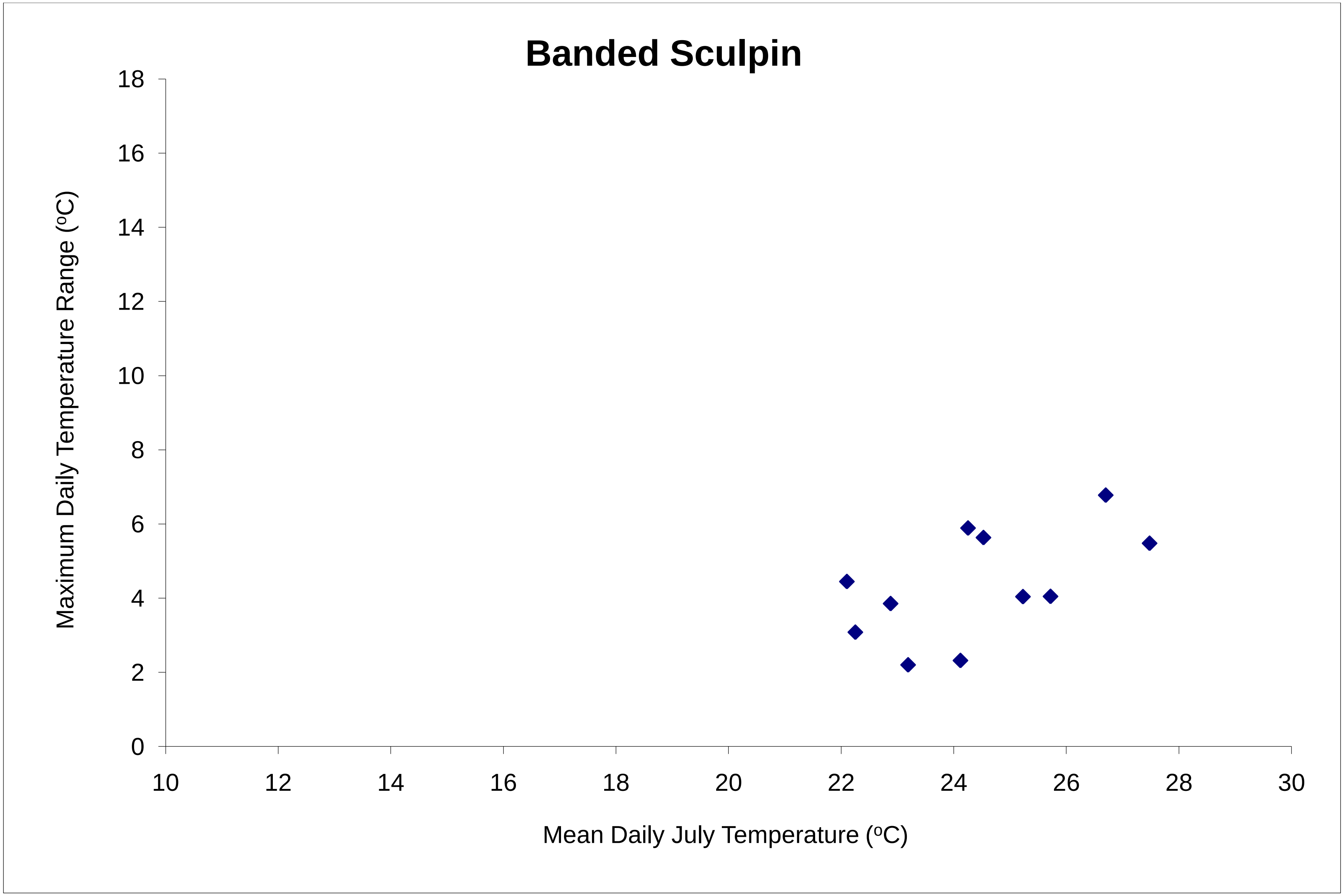
Common Name	# Collected	Length/Weight Measurements
Creek chub	1	
White sucker	9	
Johnny darter	3	
Bluntnose minnow	1	
Fantail darter	100	
Largescale stoneroller	1	
Madtom	1	
Longnose dace	29	
Green sunfish	1	
Central mudminnow	1	

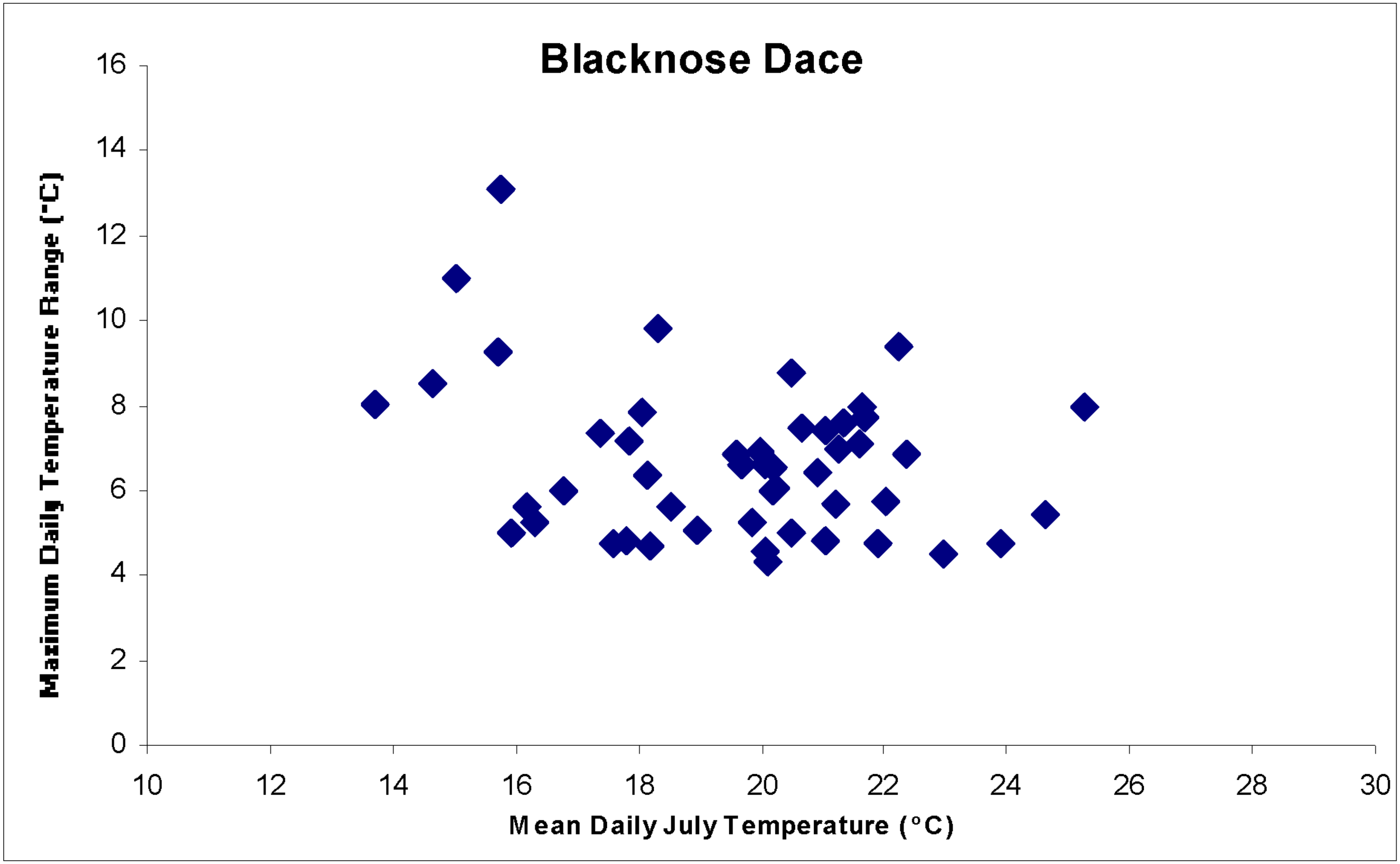
Summary

Total Fish Collected	147
Total Species Collected	10
CPUE (#/hour)	

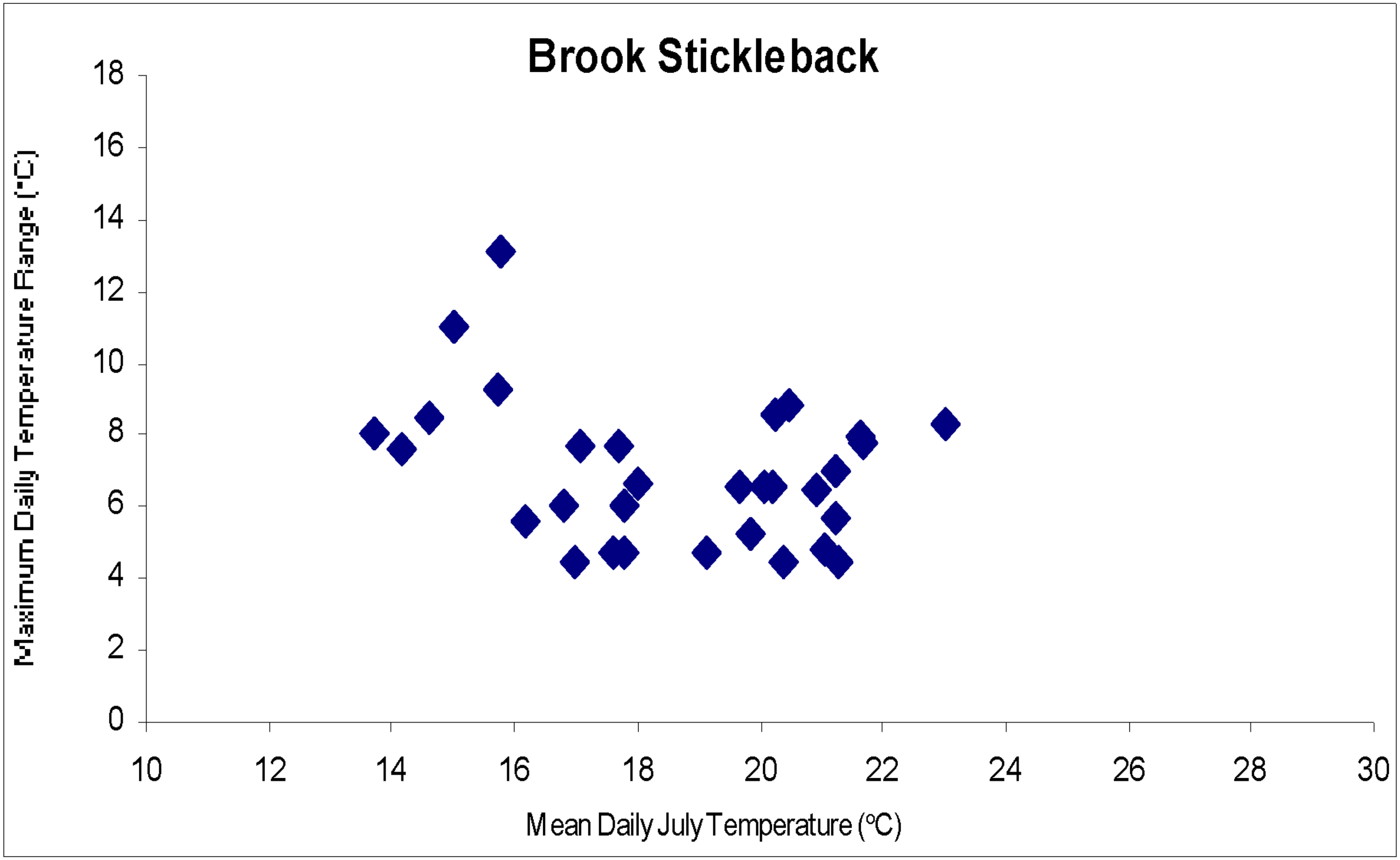
Appendix D


American Brook Lamprey
Maximum Daily Temperature Range (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)

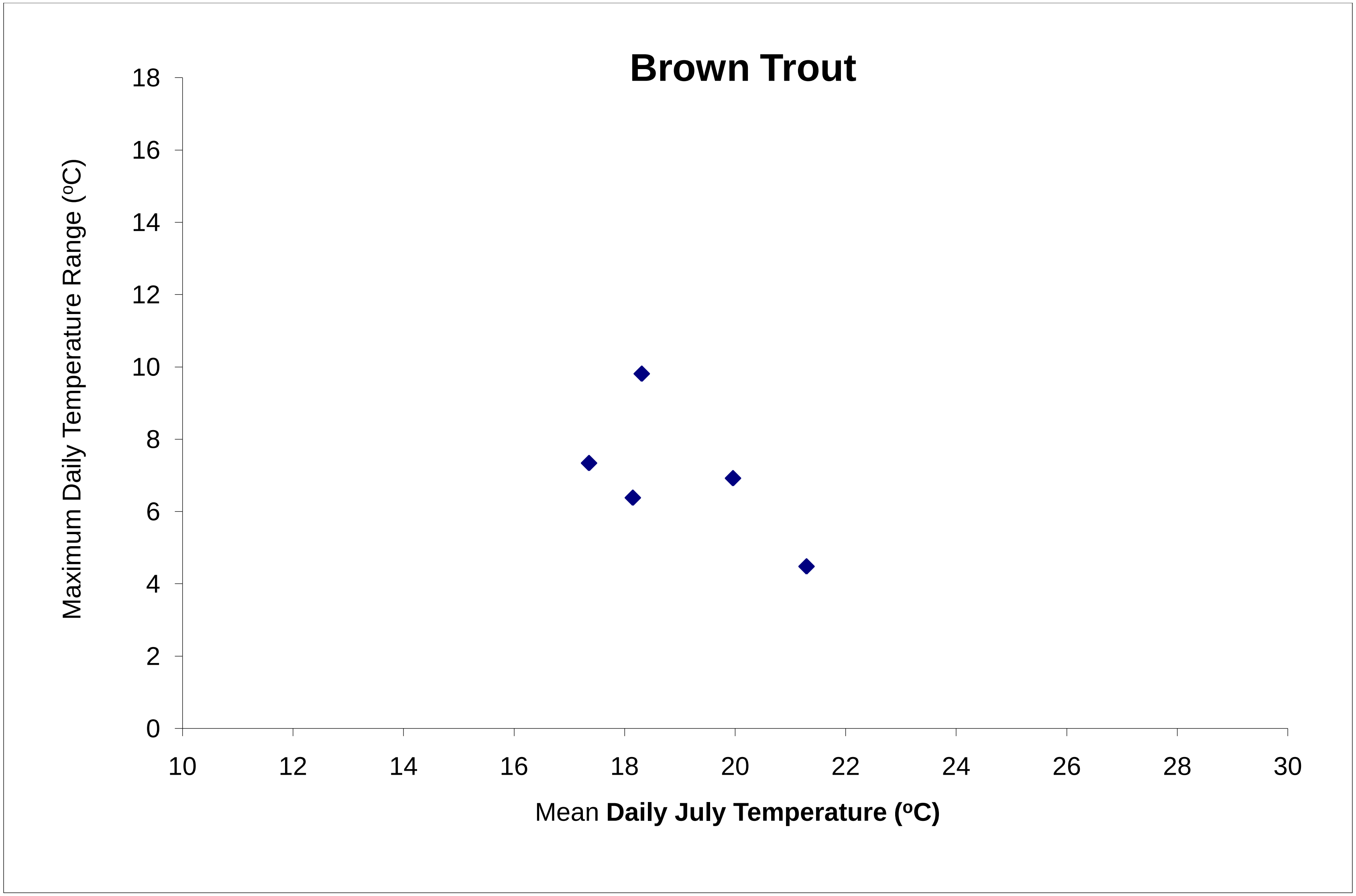

Banded Sculpin
Maximum Daily Temperature Range (ºC)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (ºC)

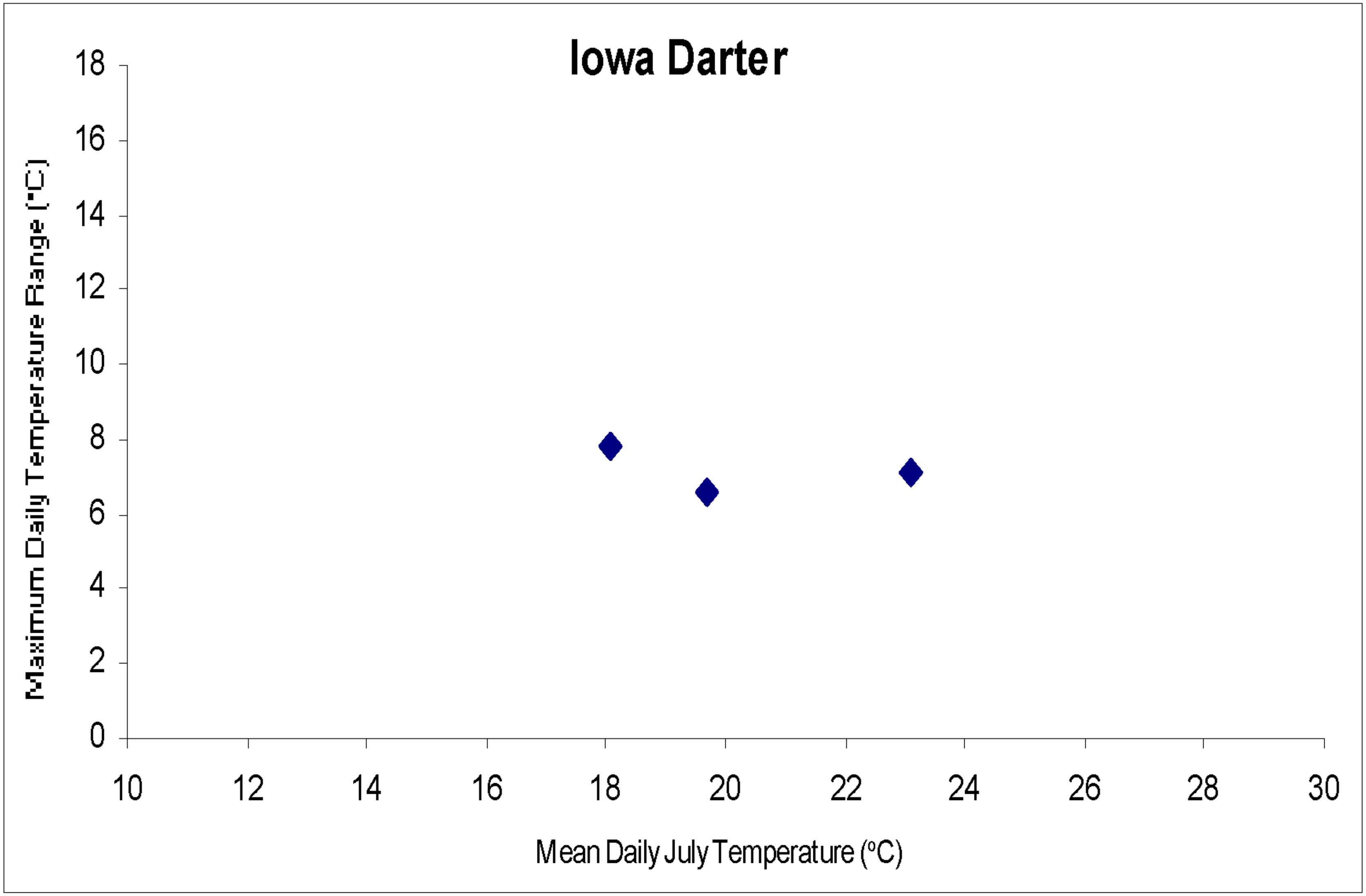


Blacknose Dace
Maximum Daily Temperature Range (°C)
0
2
4
6
8
10
12
14
16
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)

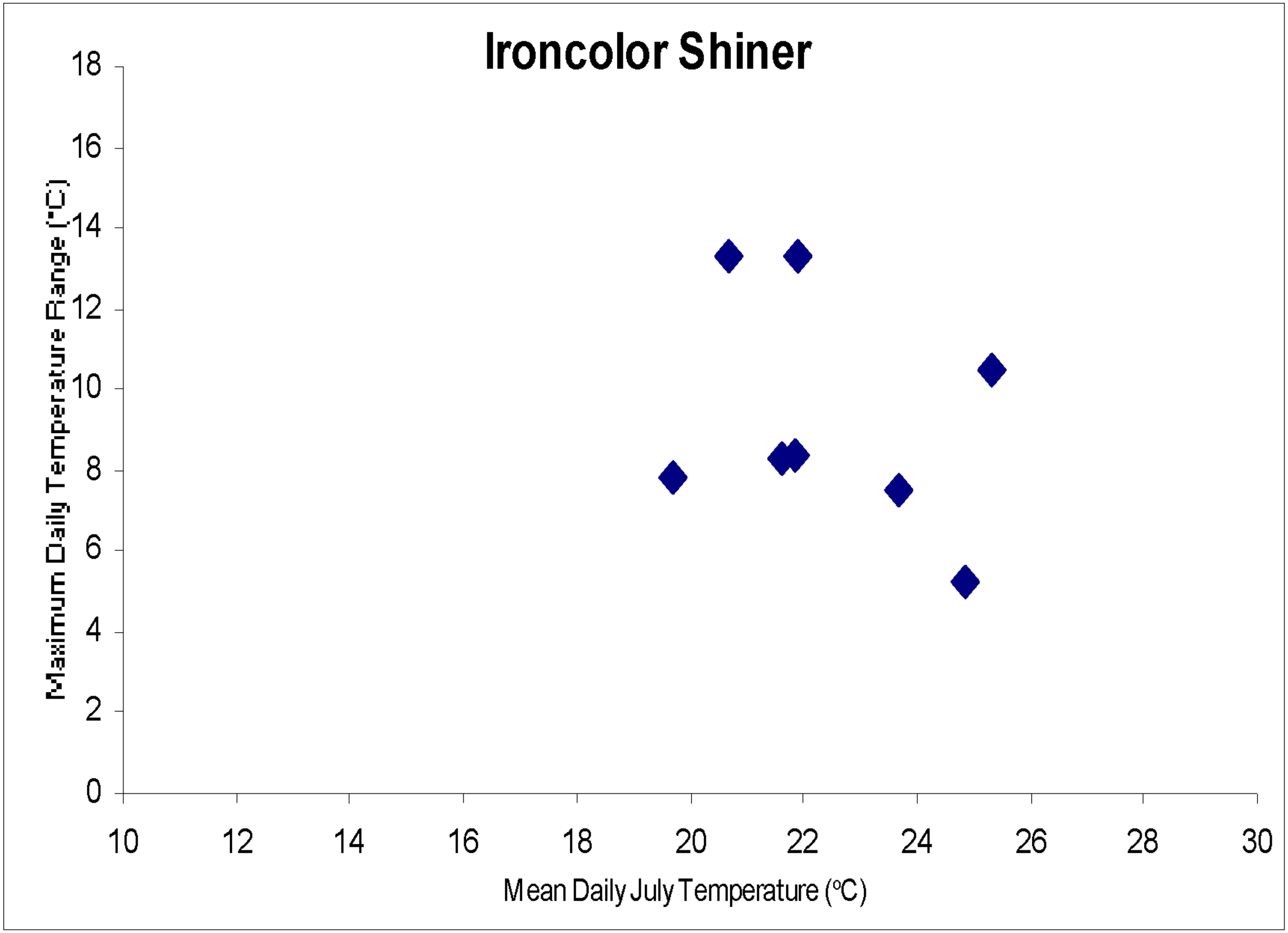


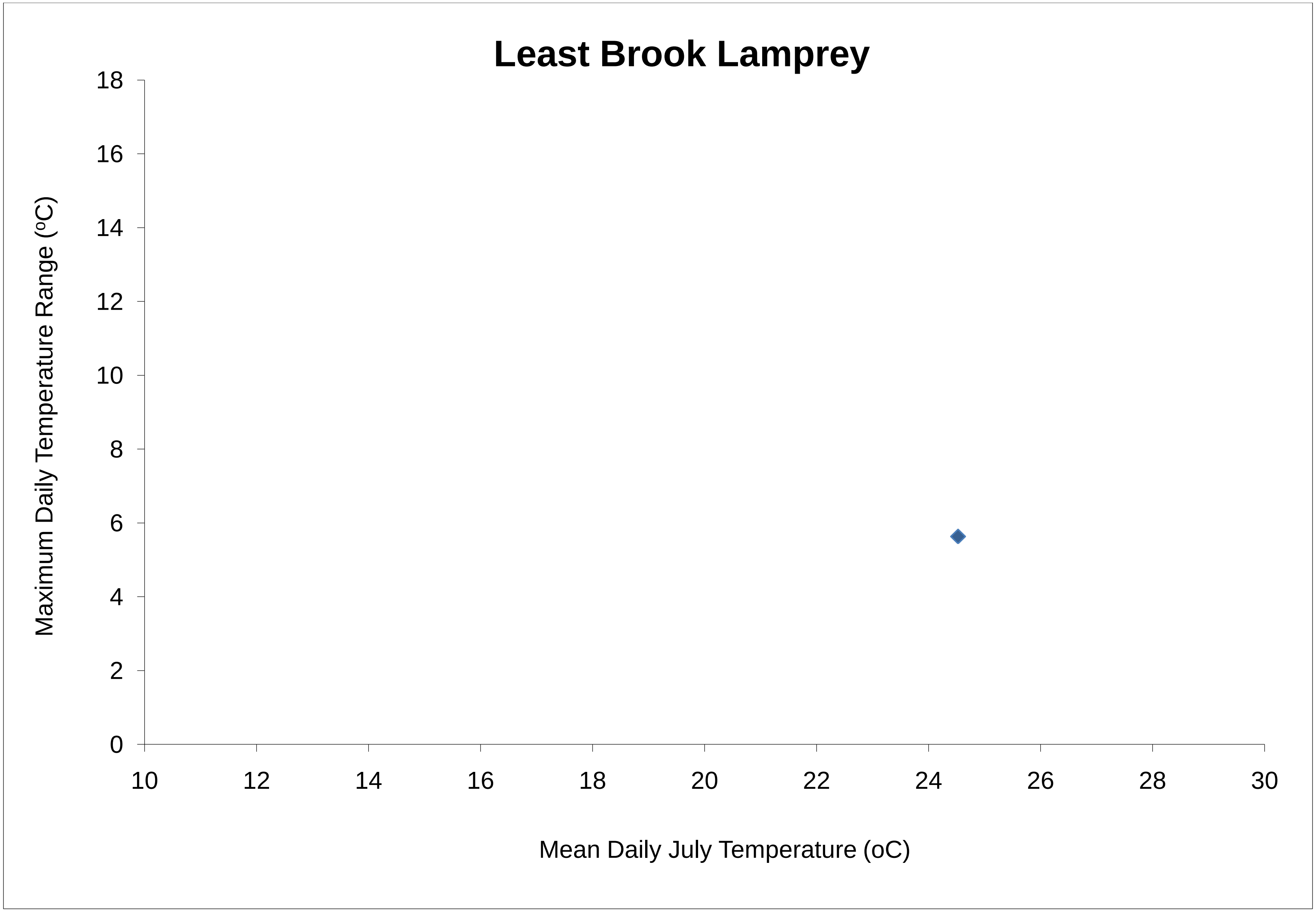
Brook Stickleback
Maximum Daily Temperature Range (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)


Brown Trout
Maximum Daily Temperature Range (ºC)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (ºC)

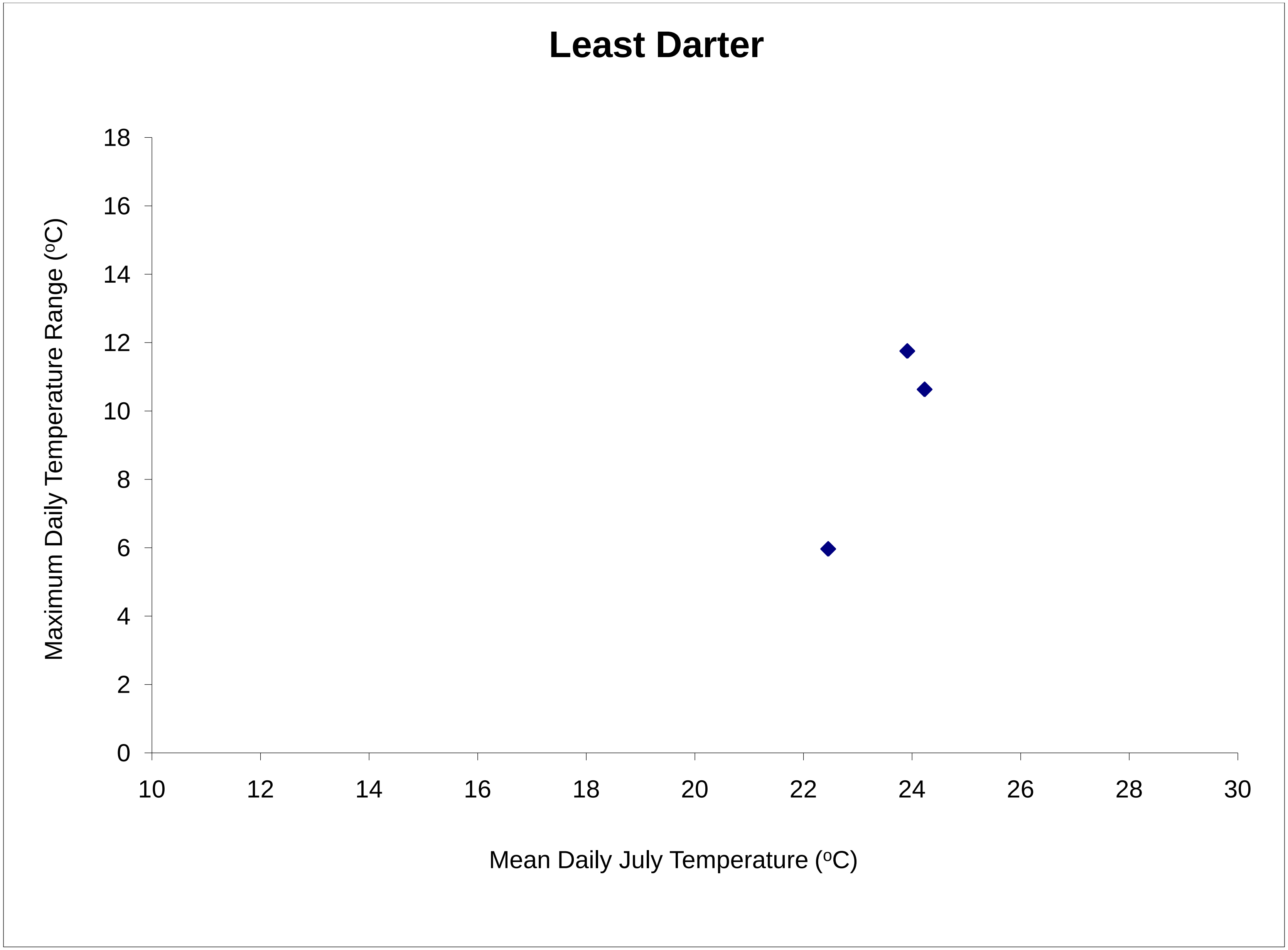


Iowa Darter
Maximum Daily Temperature Range (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)

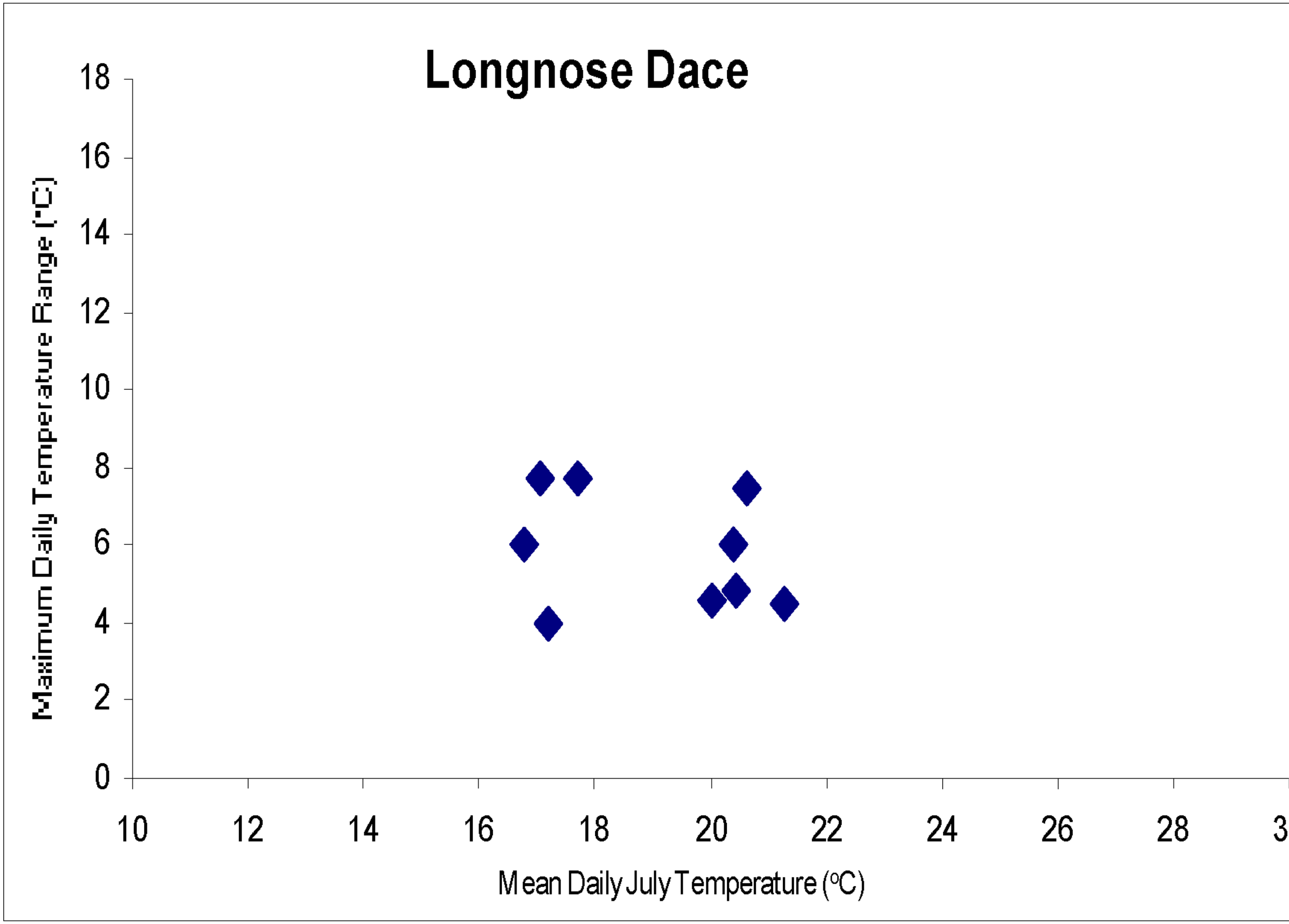

Ironcolor Shiner
Maximum Daily Temperature Range (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)

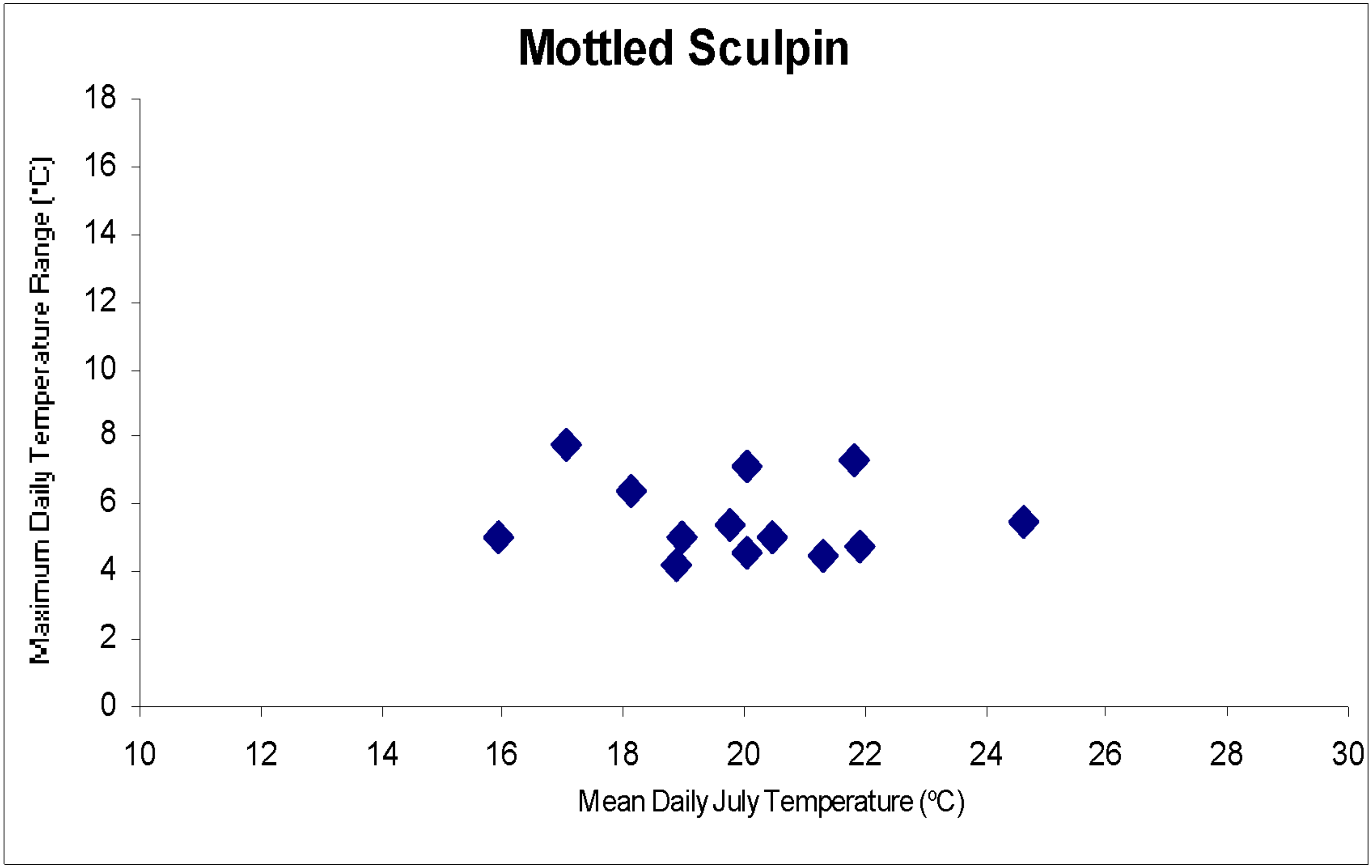


Least Brook Lamprey
Maximum Daily Temperature Range (ºC)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (oC)

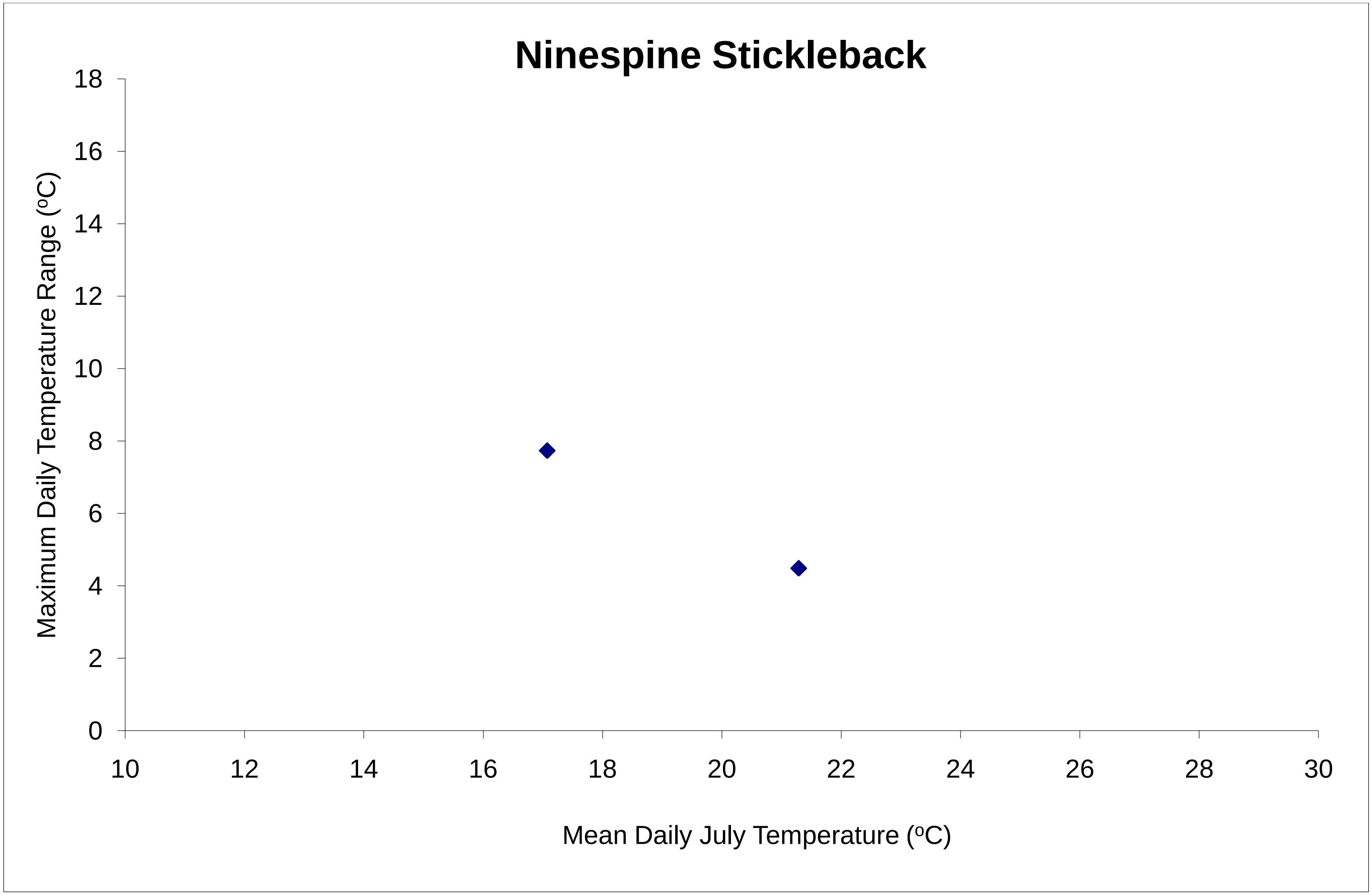


Least Darter
Maximum Daily Temperature Range (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)

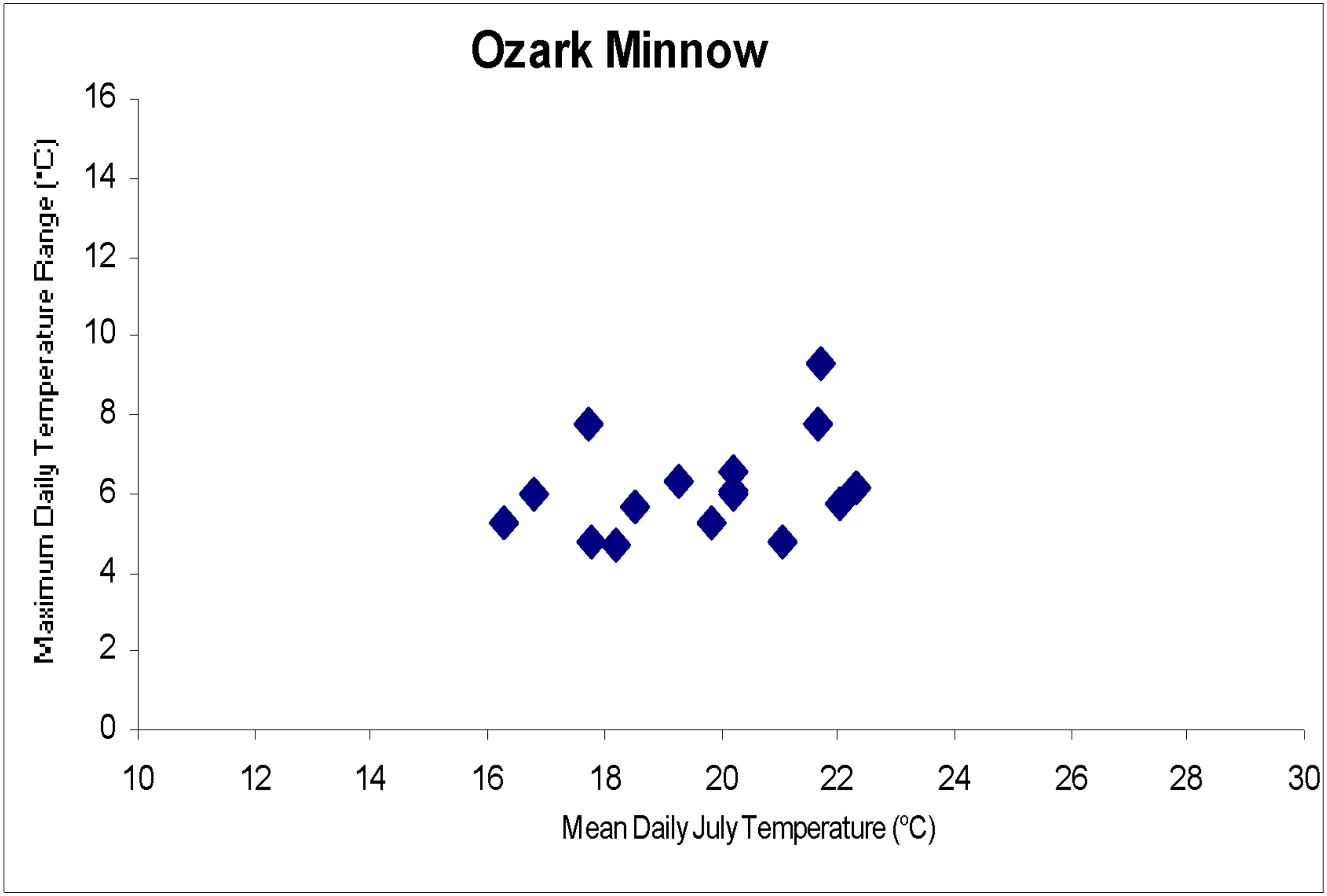

Longnose Dace
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30



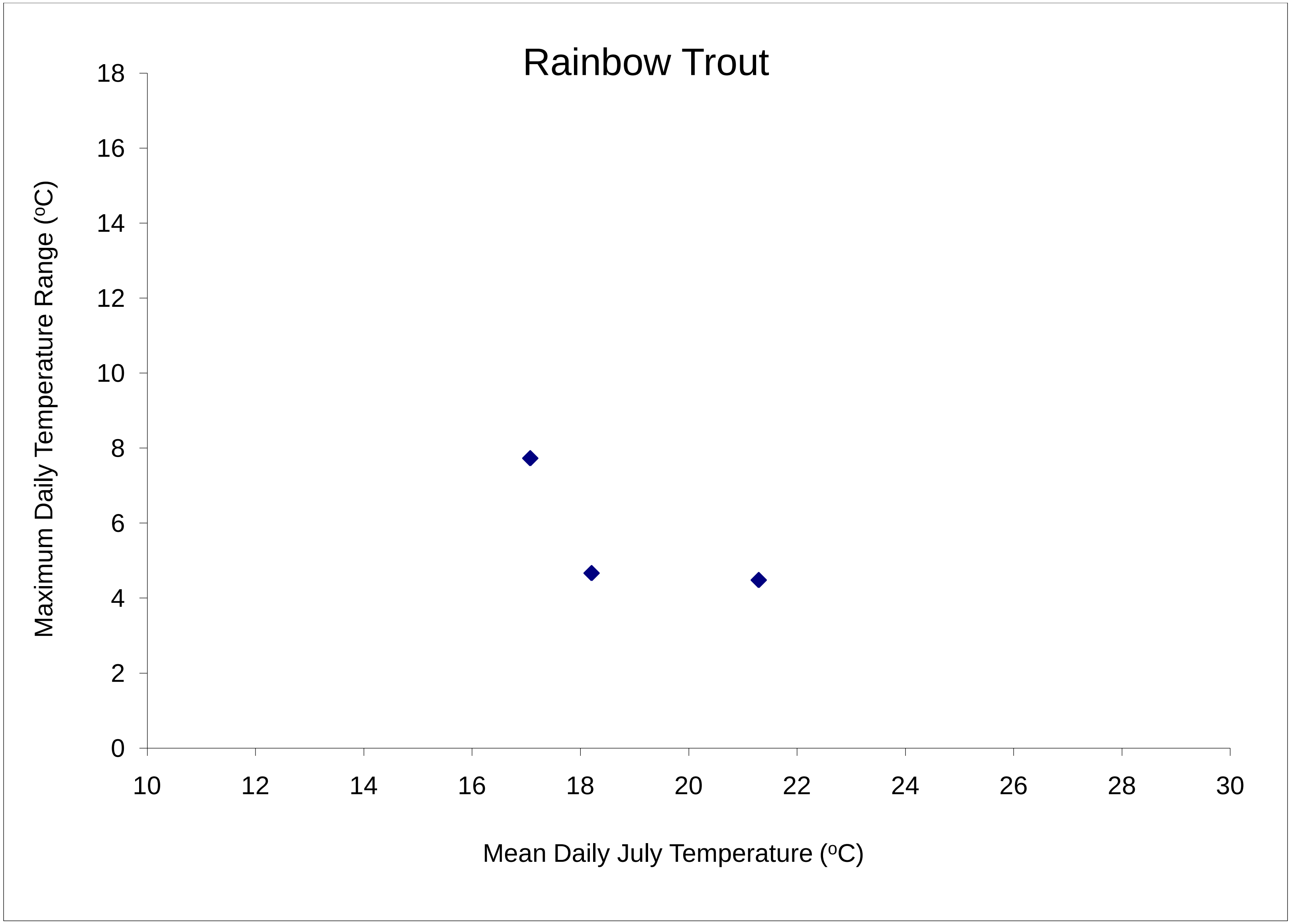
Mottled Sculpin
Maximum Daily Temperature Range (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (ºC)

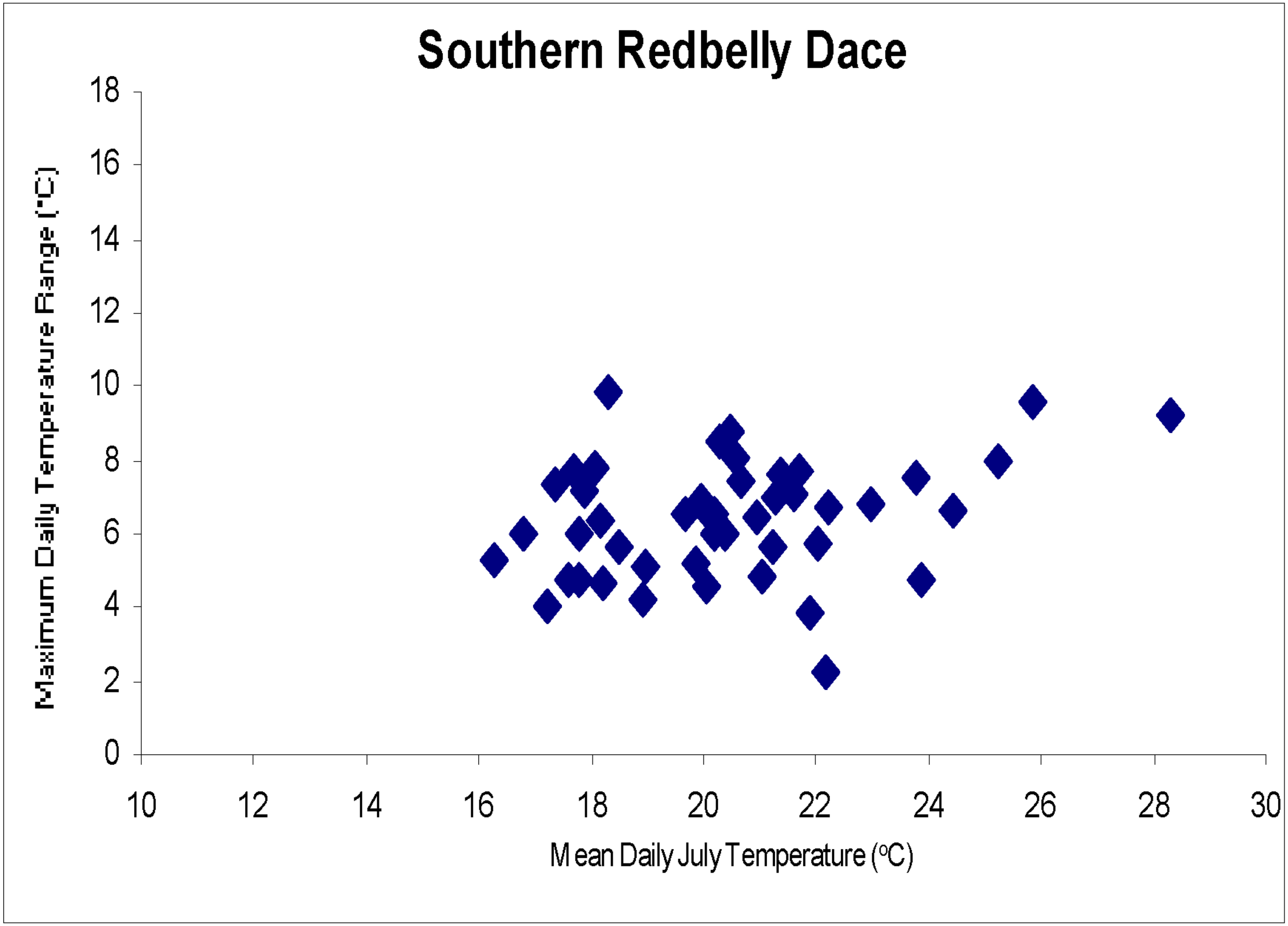


Ninespine Stickleback
Maximum Daily Temperature Range (oC)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (oC)

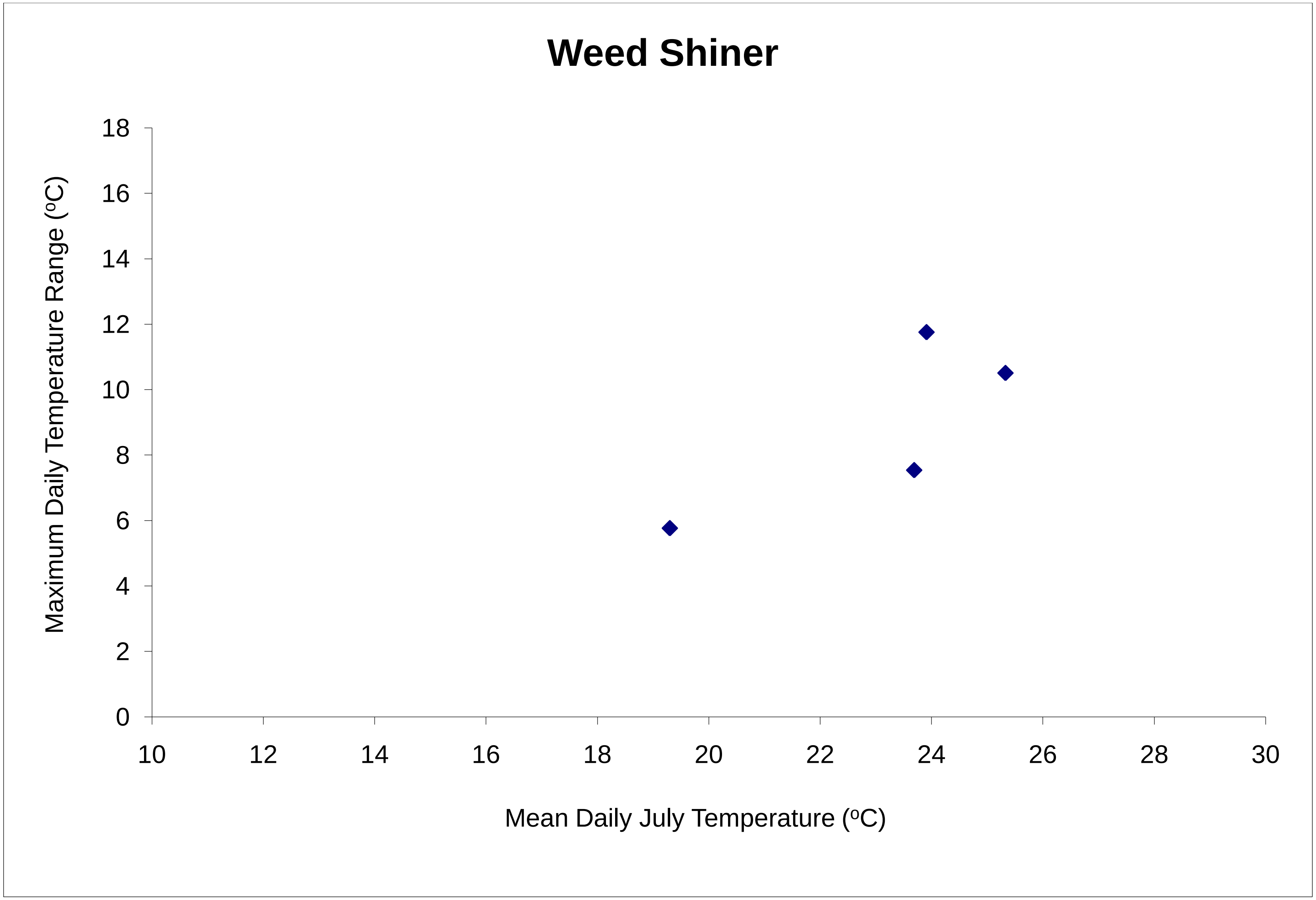


Ozark Minnow
Maximum Daily Temperature Range (°C)
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (ºC)

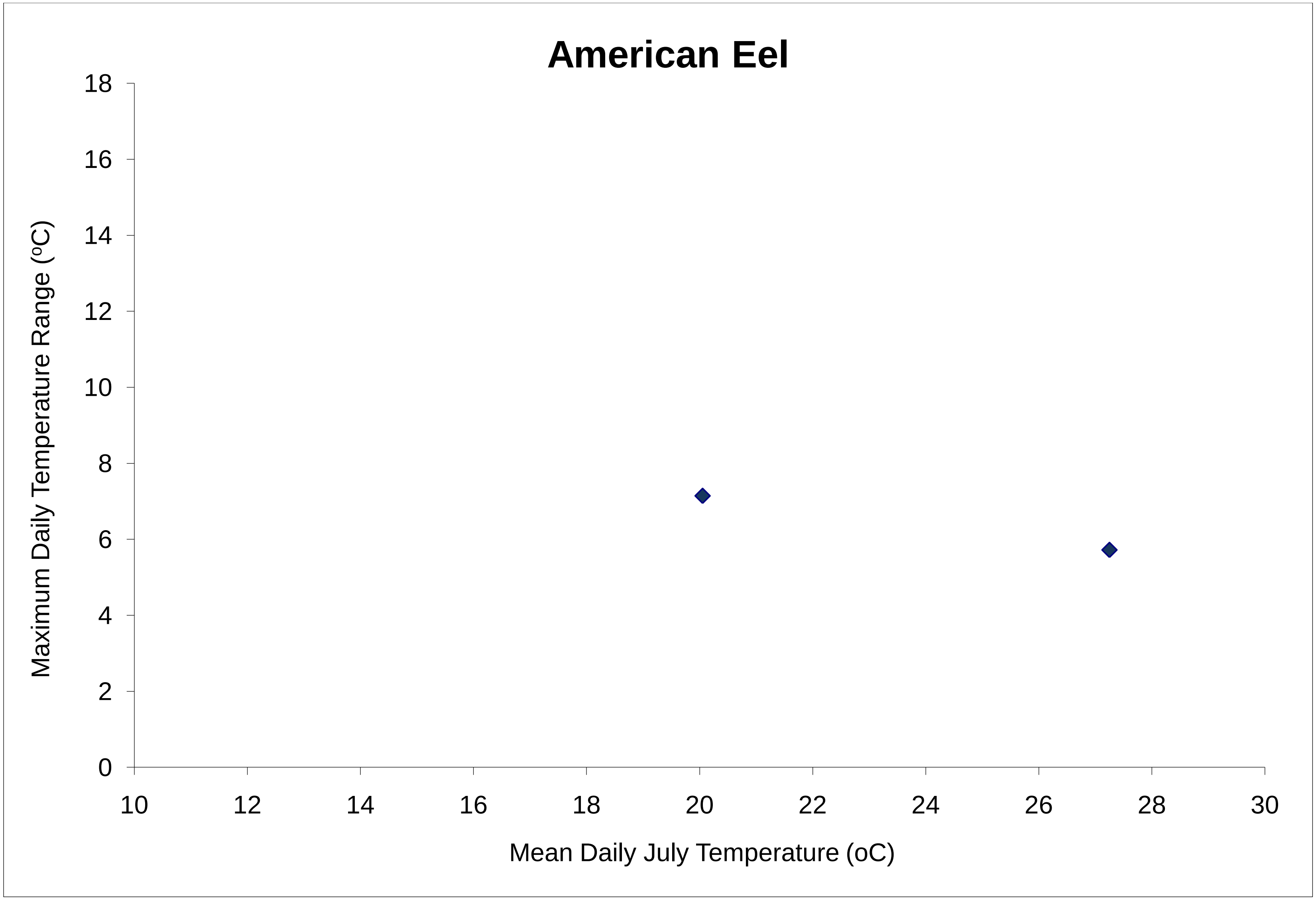

Rainbow Trout
Maximum Daily Temperature Range (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)

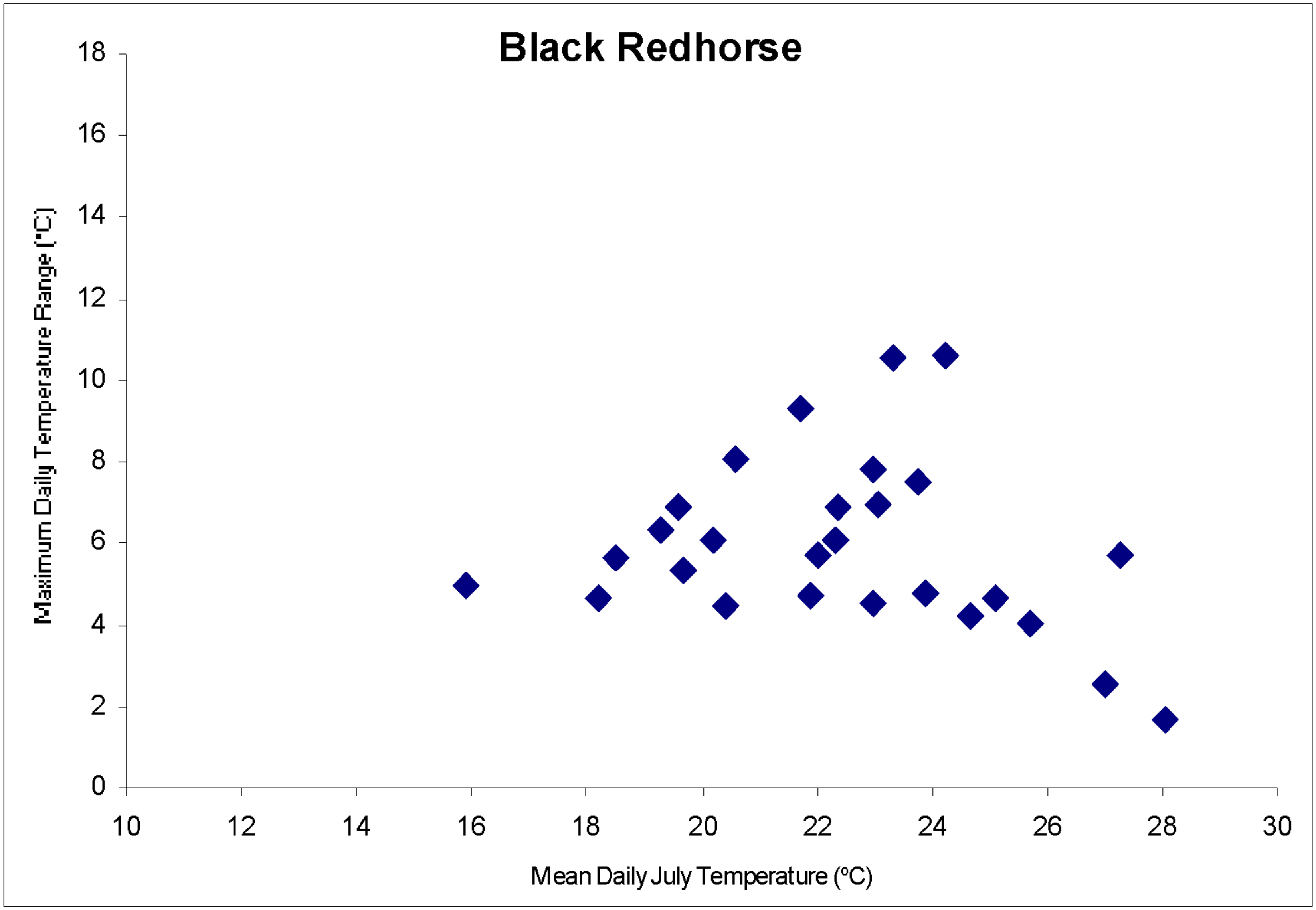


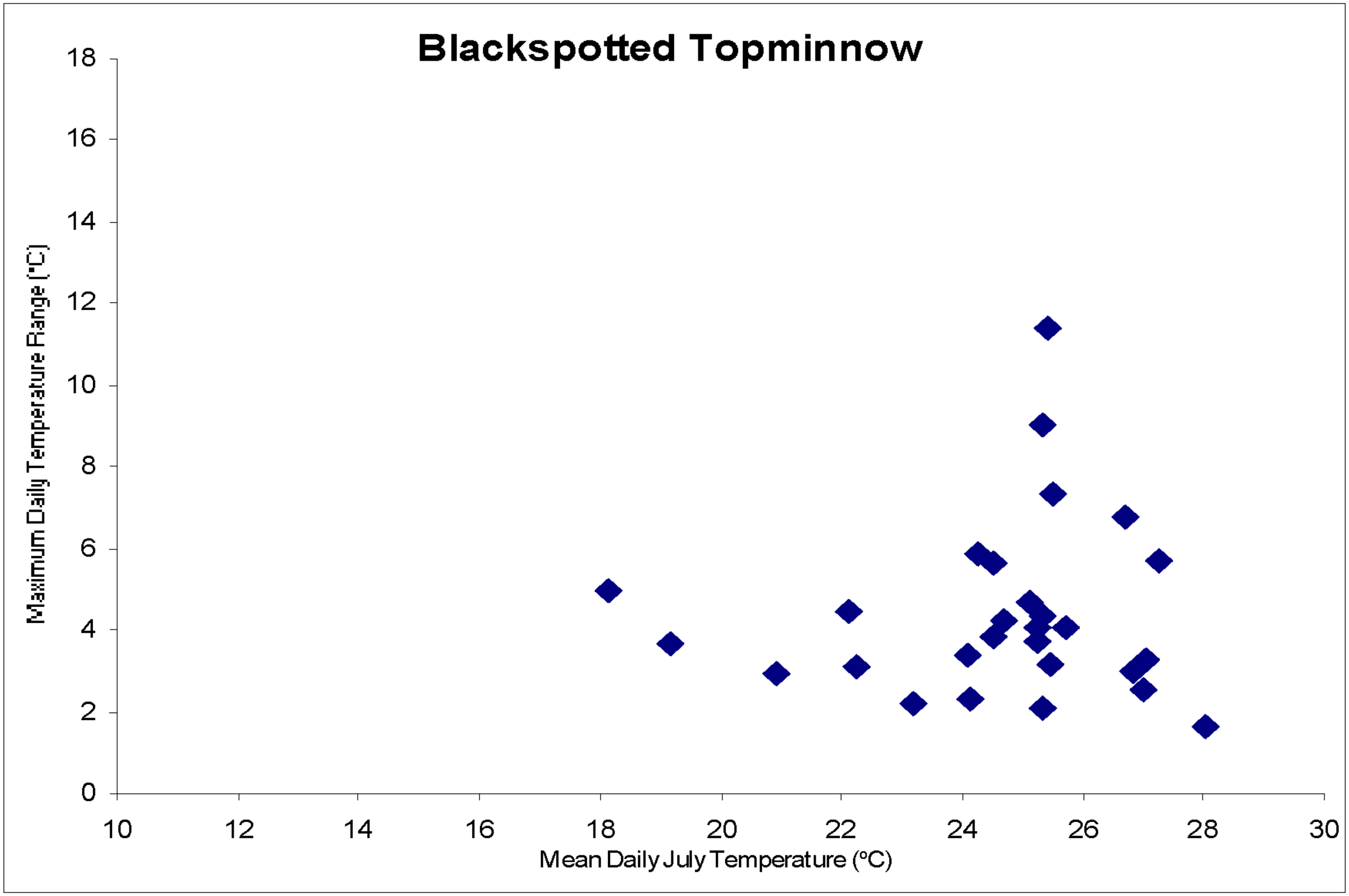
Southern Redbelly Dace
Maximum Daily Temperature Range (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)



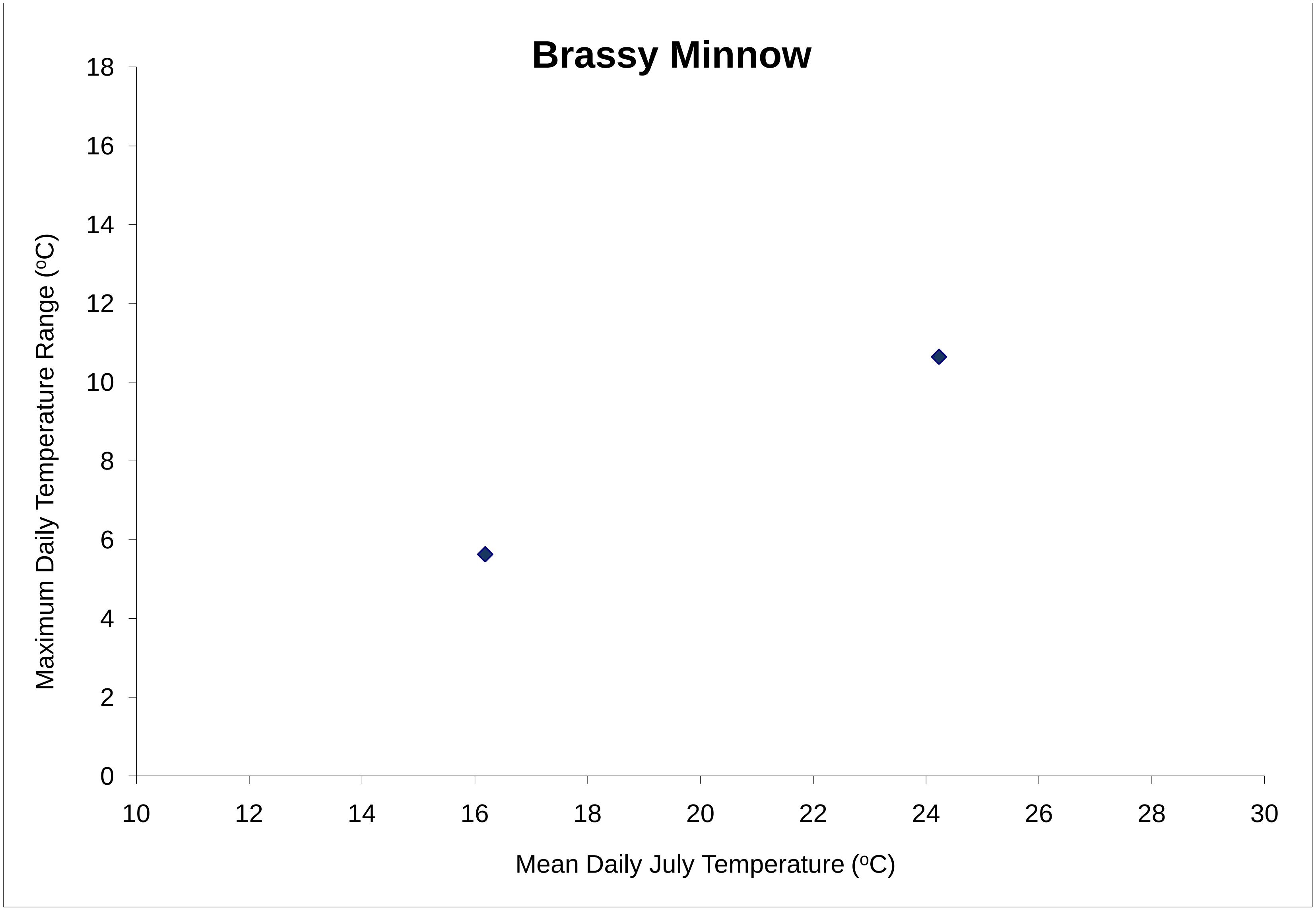
Weed Shiner
Maximum Daily Temperature Range (ºC)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (ºC)

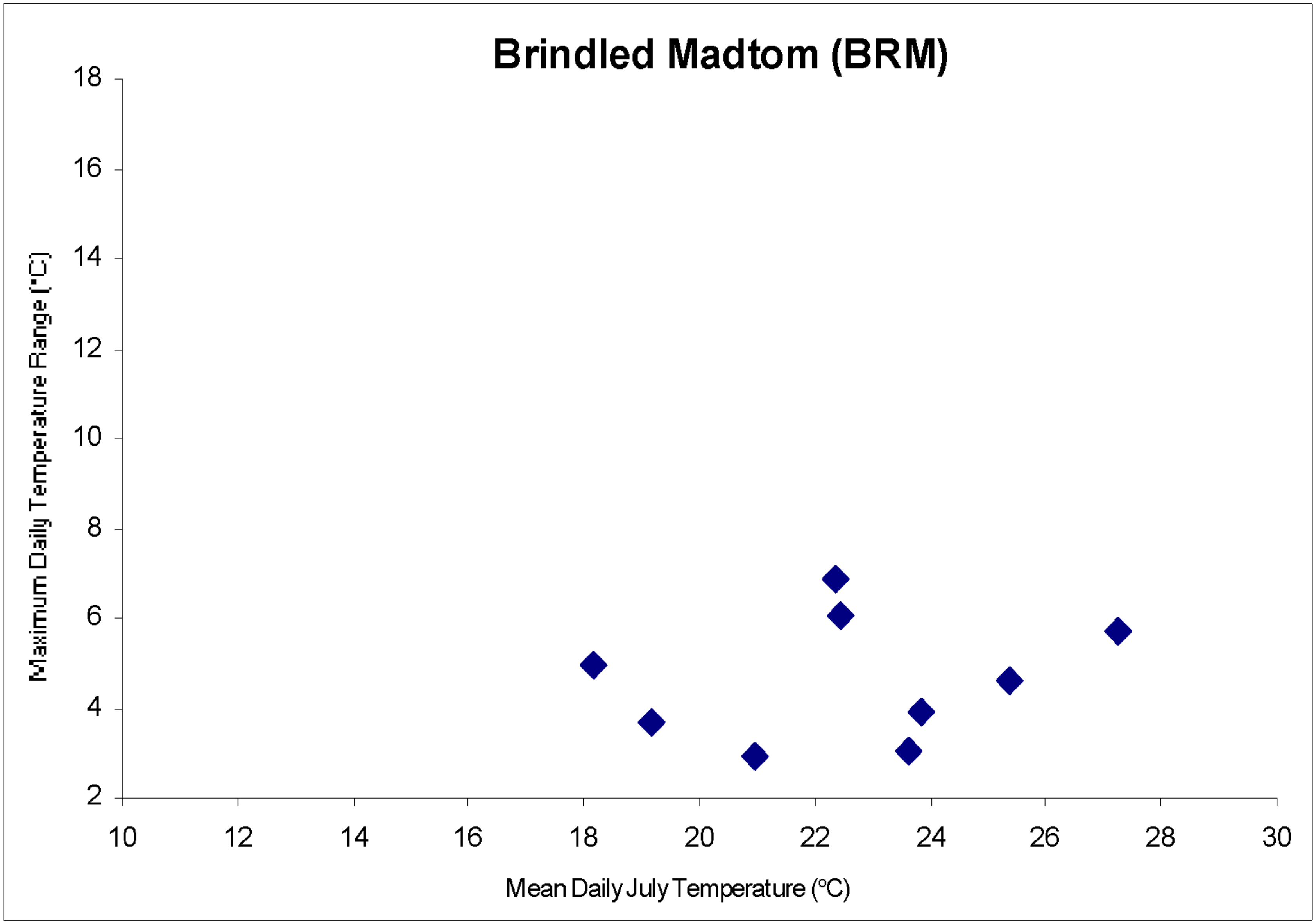

American Eel
Maximum Daily Temperature Range (oC)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (oC)

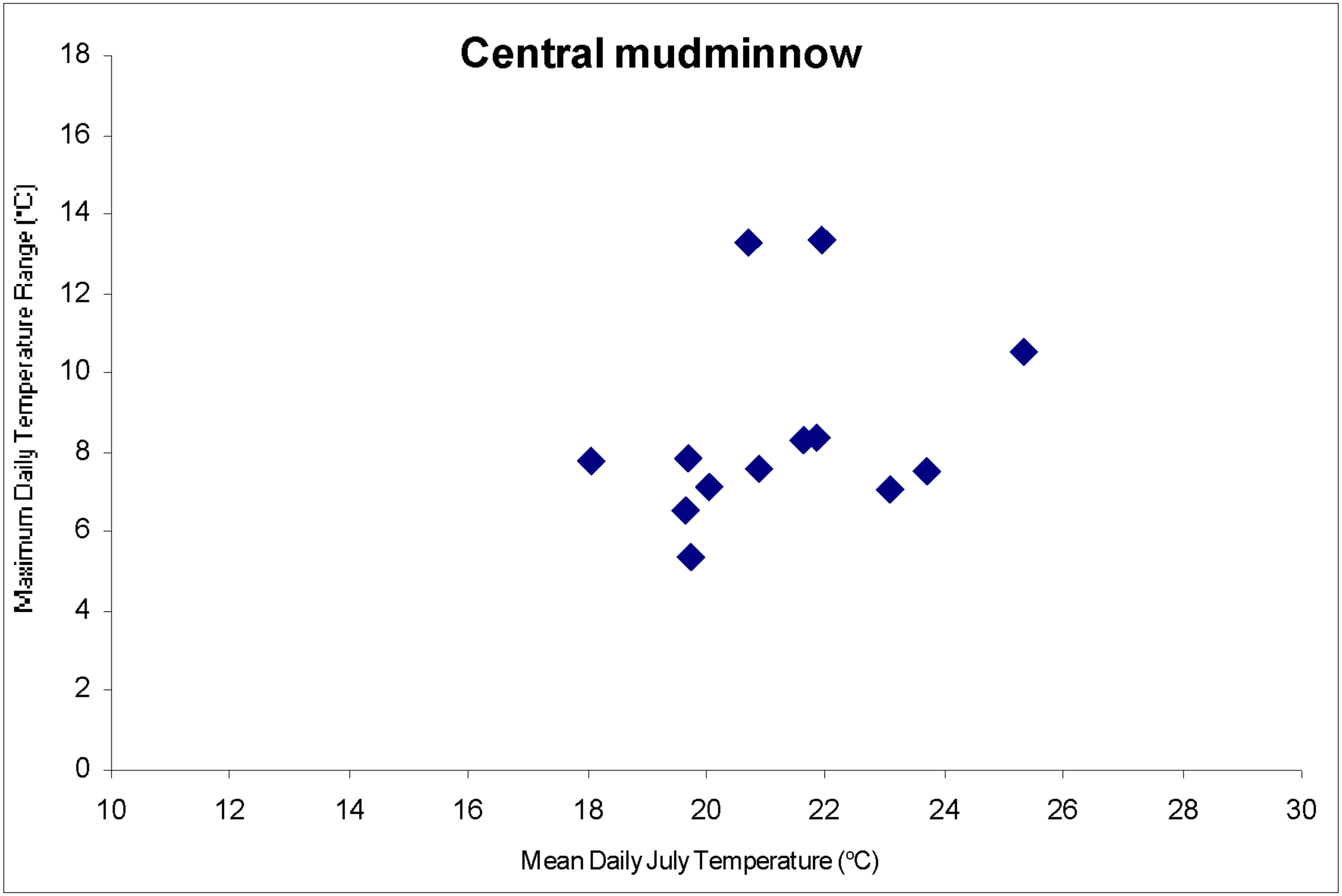

Black Redhorse
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30



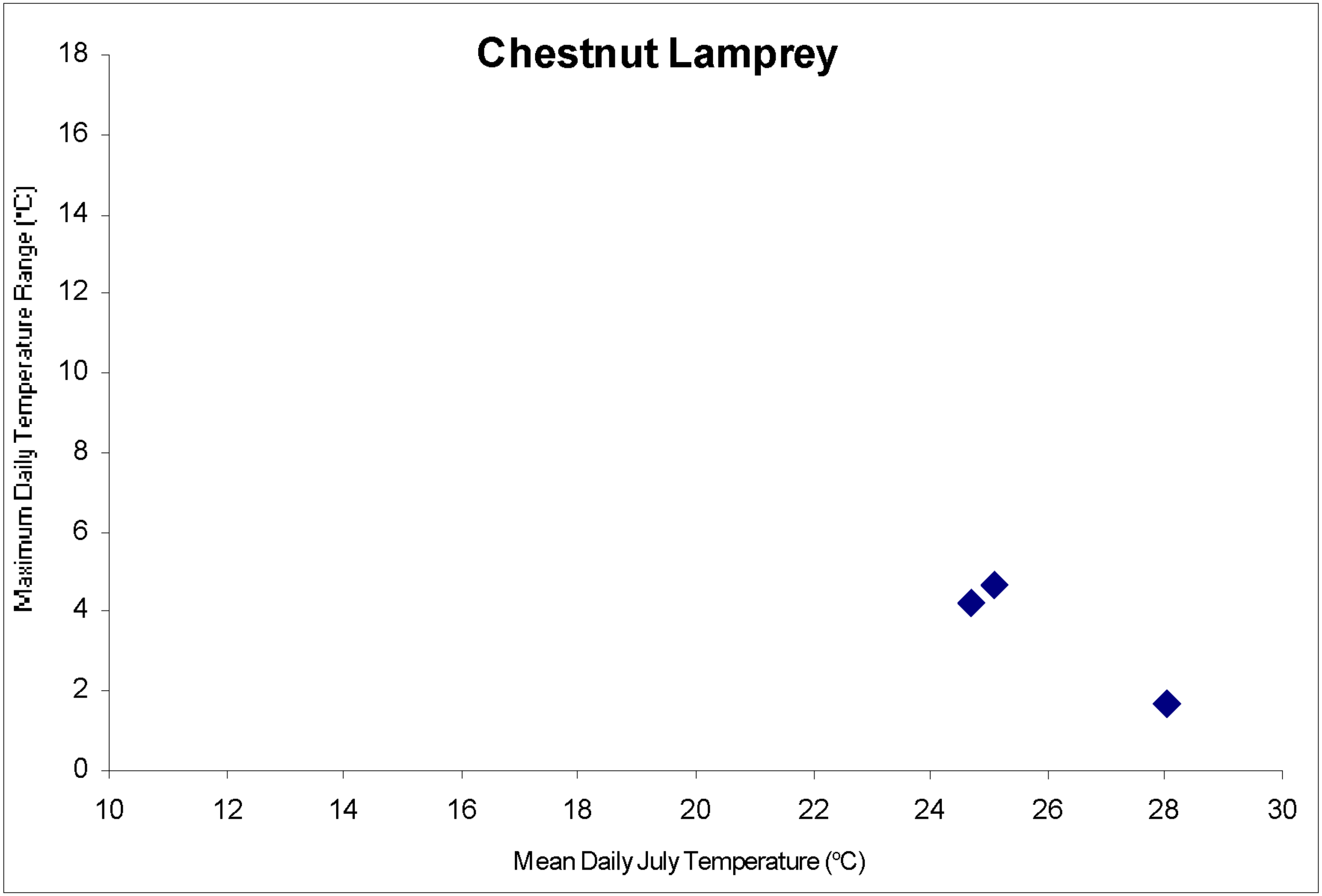
Blackspotted Topminnow
Maximum Daily Temperature Range (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)


Brassy Minnow
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30

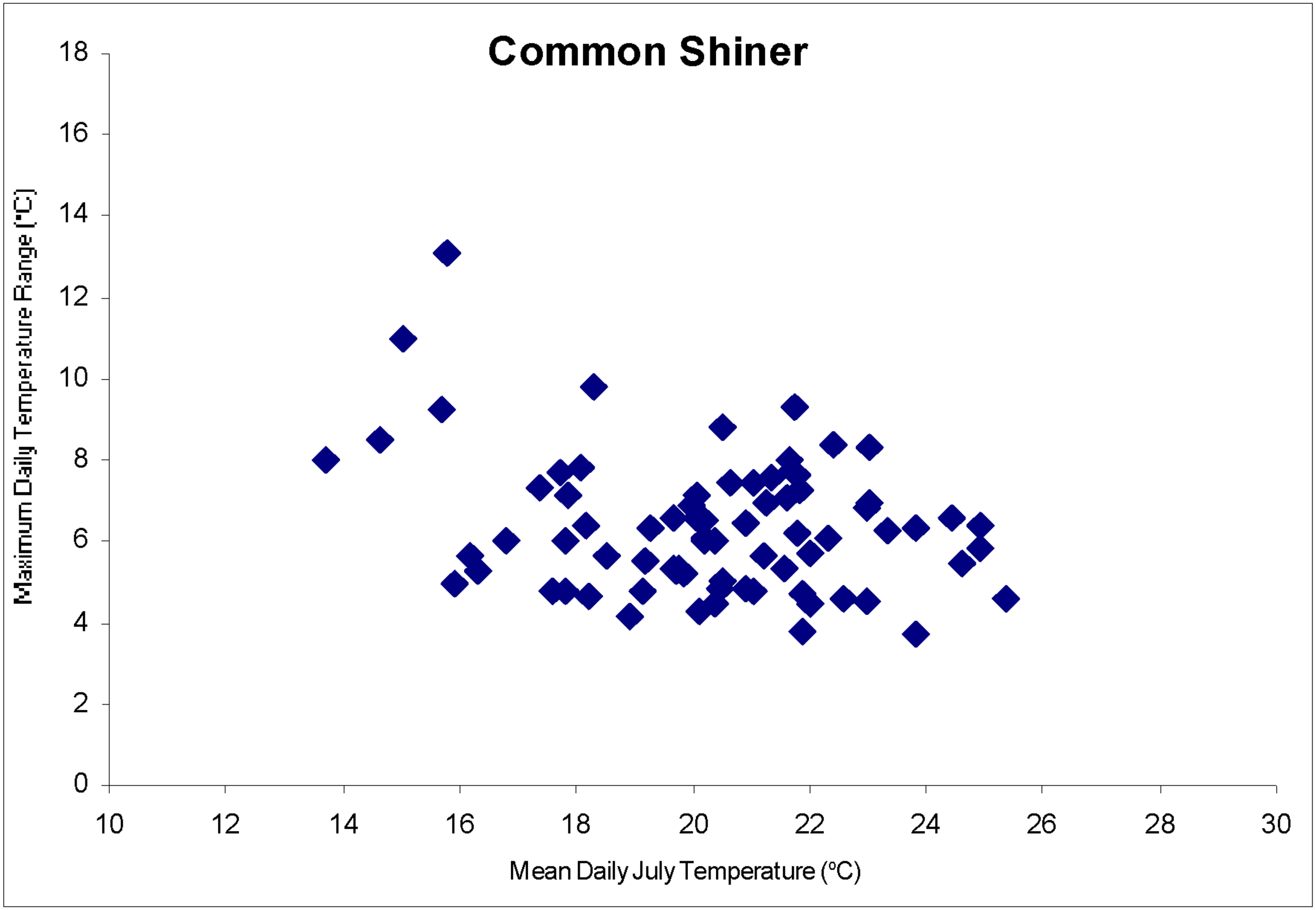

Brindled Madtom (BRM)
Maximum Daily Temperature Range (°C)
18
16
14
12
10
8
6
4
2
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)

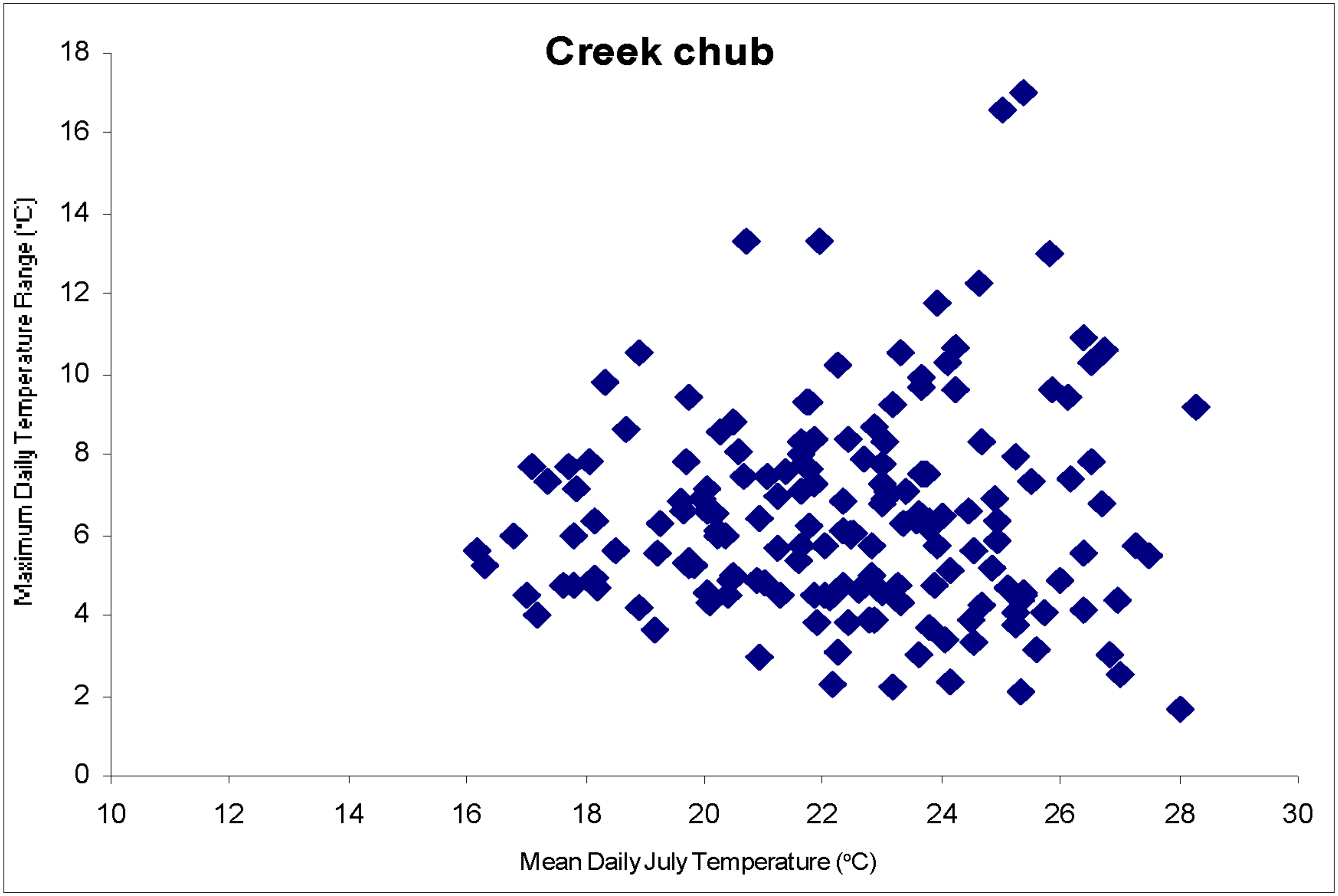


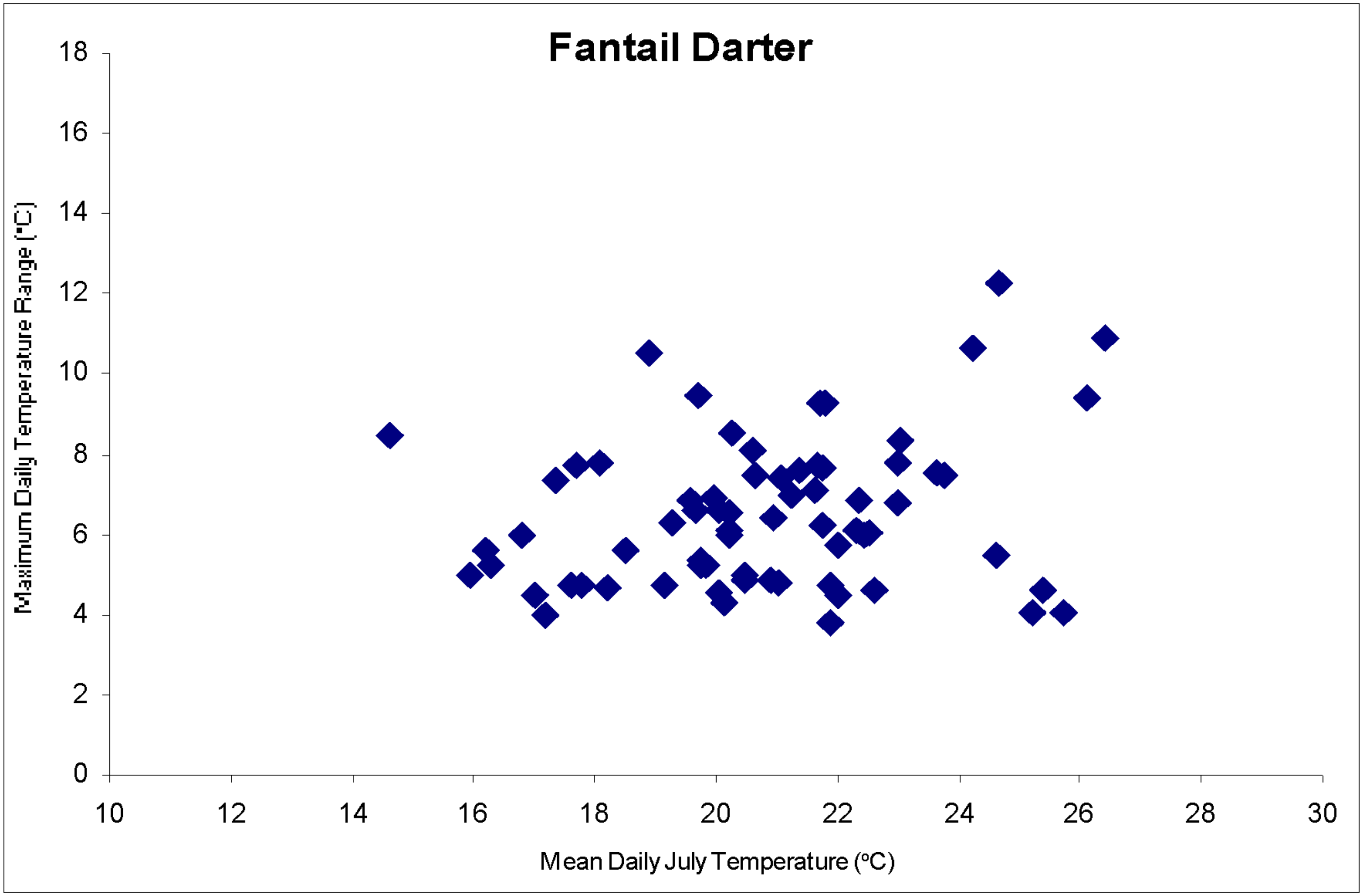
Central mudminnow
Maximum Daily Temperature Range (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)



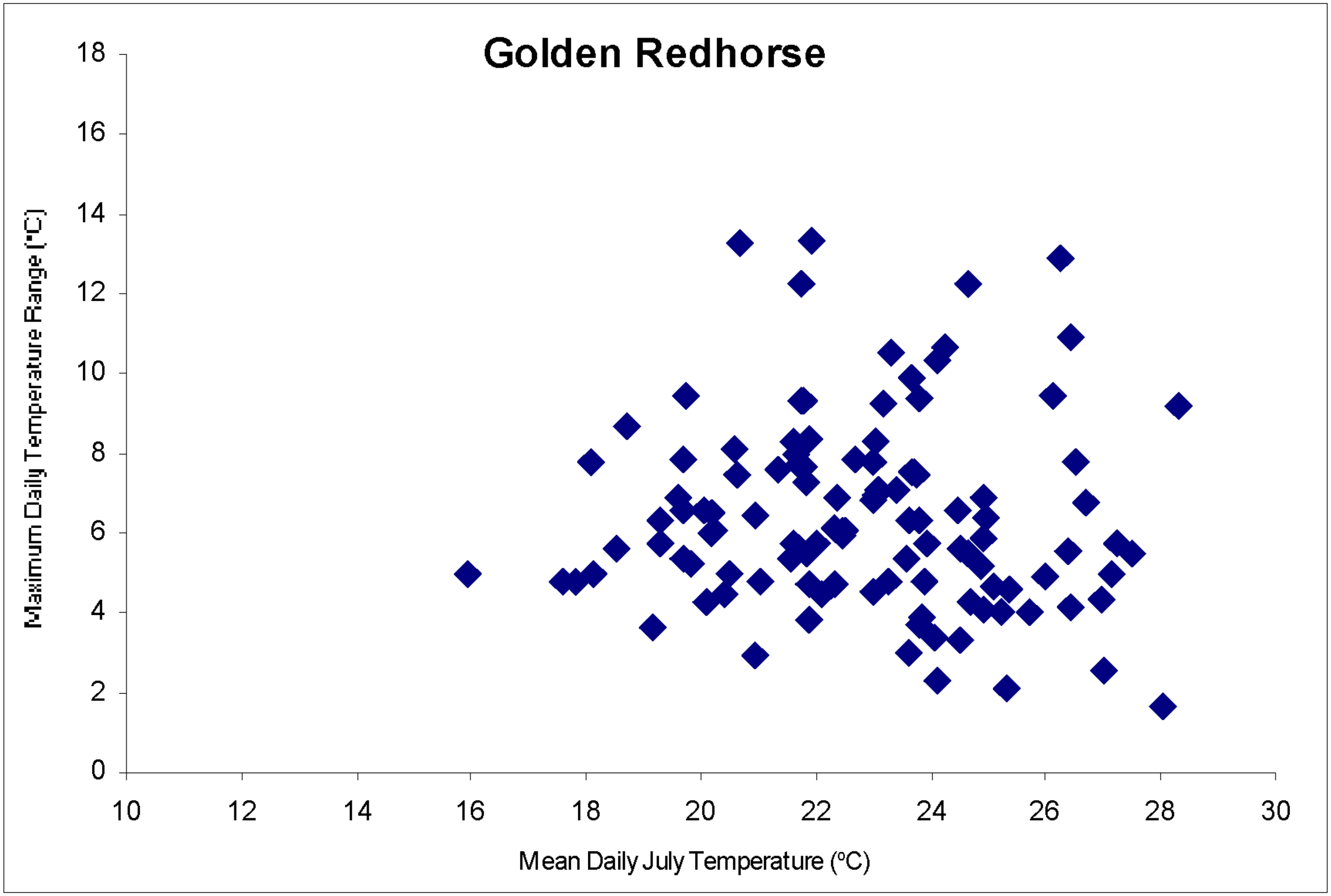
Chestnut Lamprey
Maximum Daily Temperature Range (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)

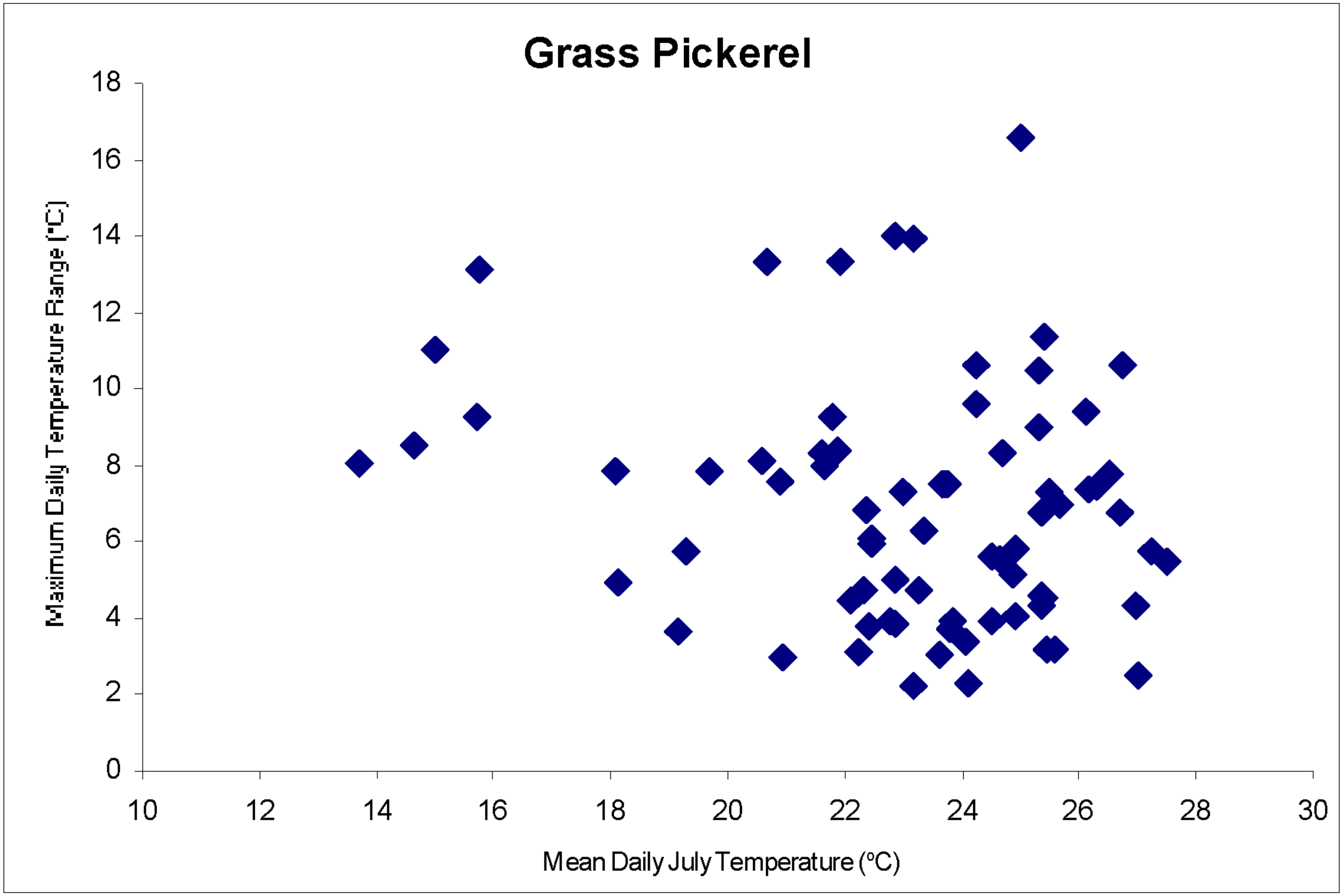

Common Shiner
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30


Creek chub
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30

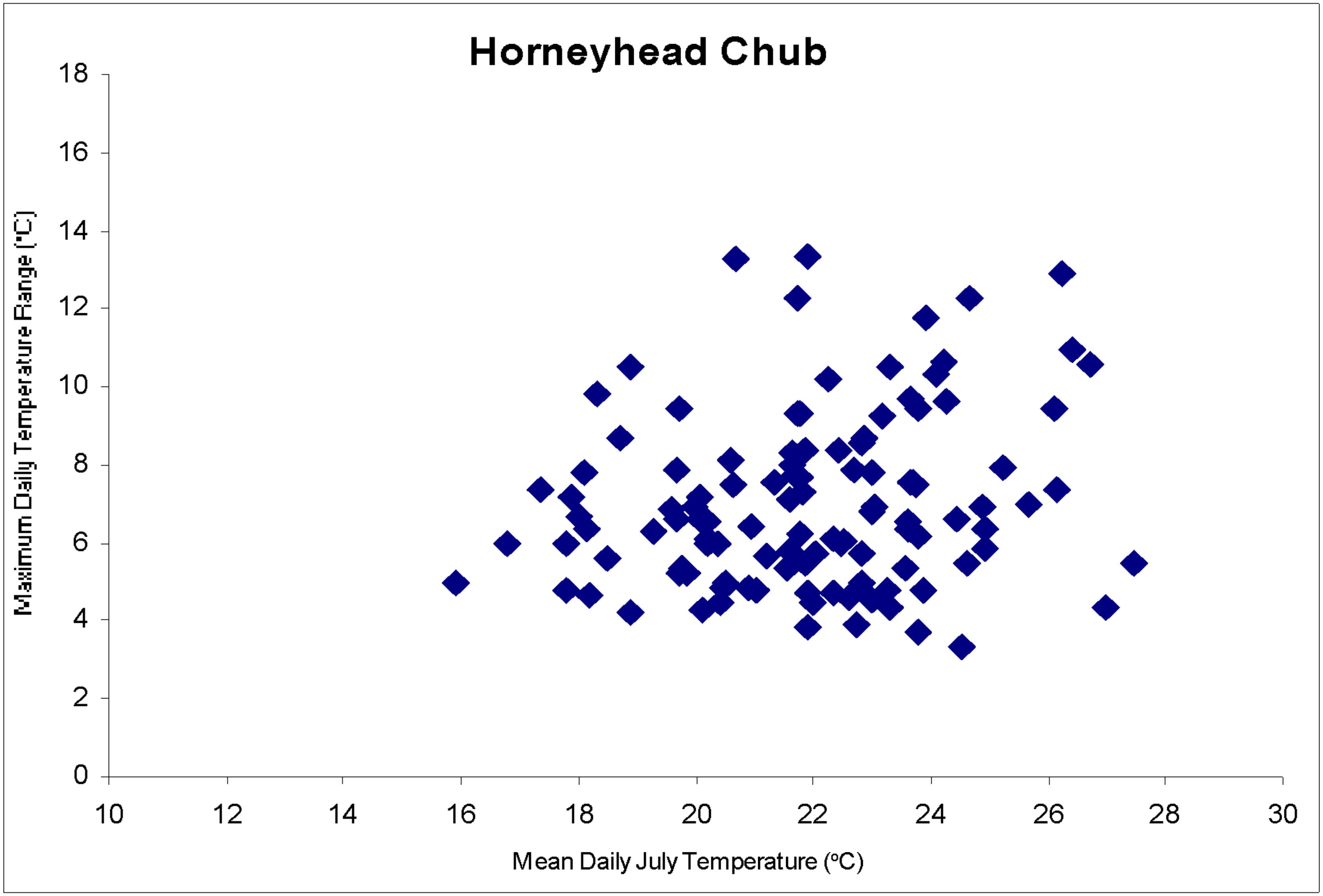


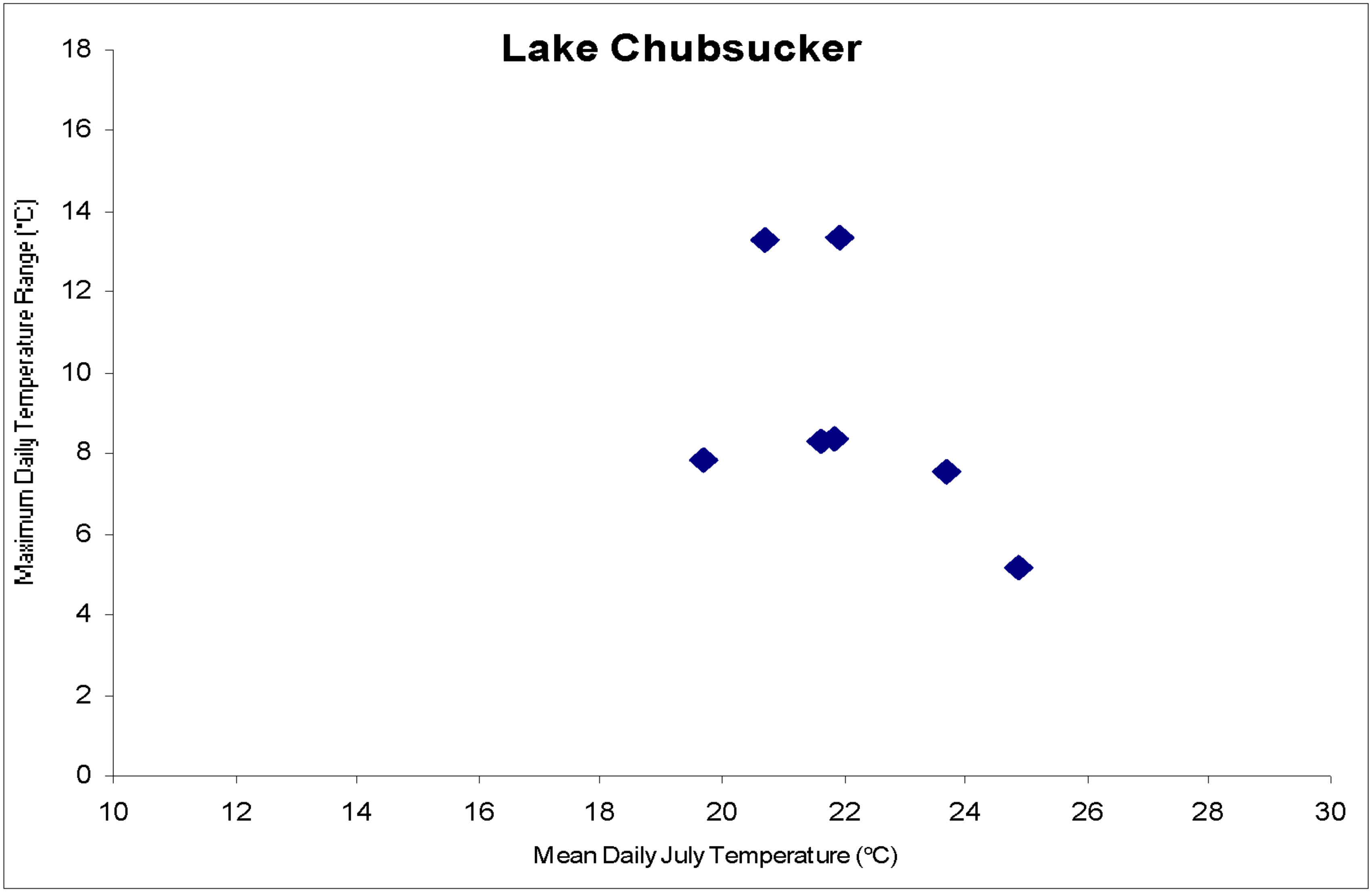
Fantail Darter
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30


Golden Redhorse
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30

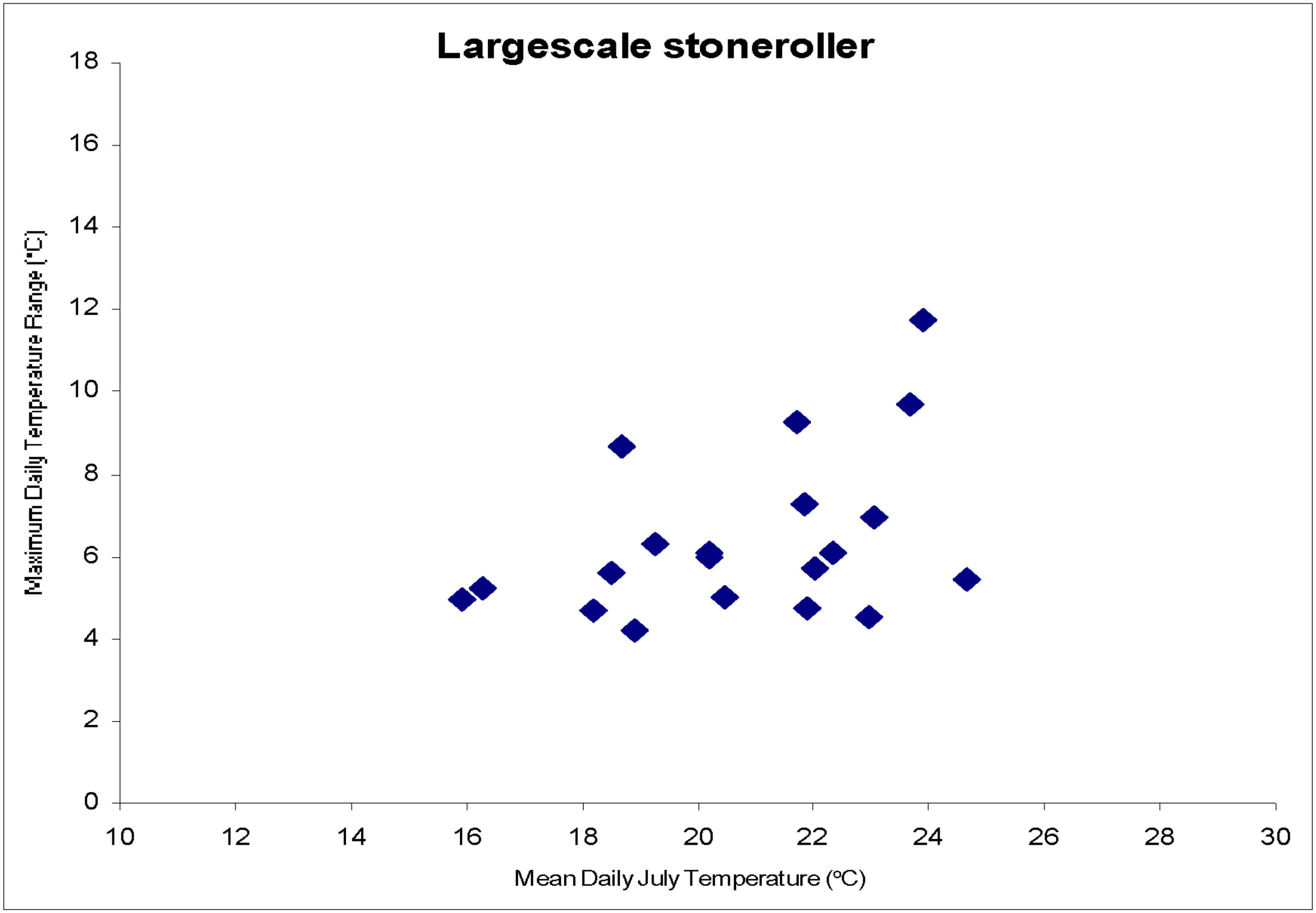


Grass Pickerel
Maximum Daily Temperature Range (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)

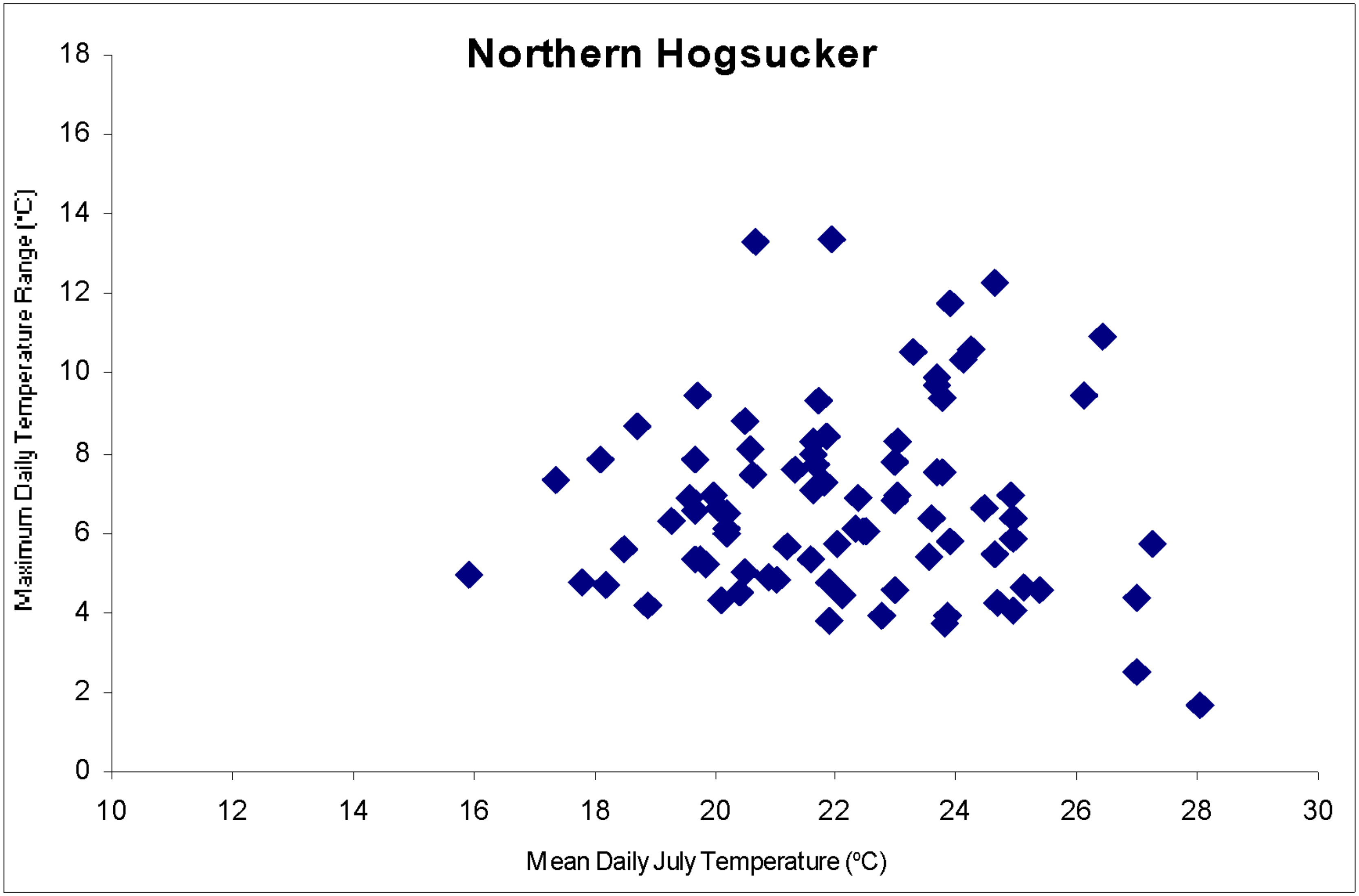

Horneyhead Chub
Maximum Daily Temperature Range (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)

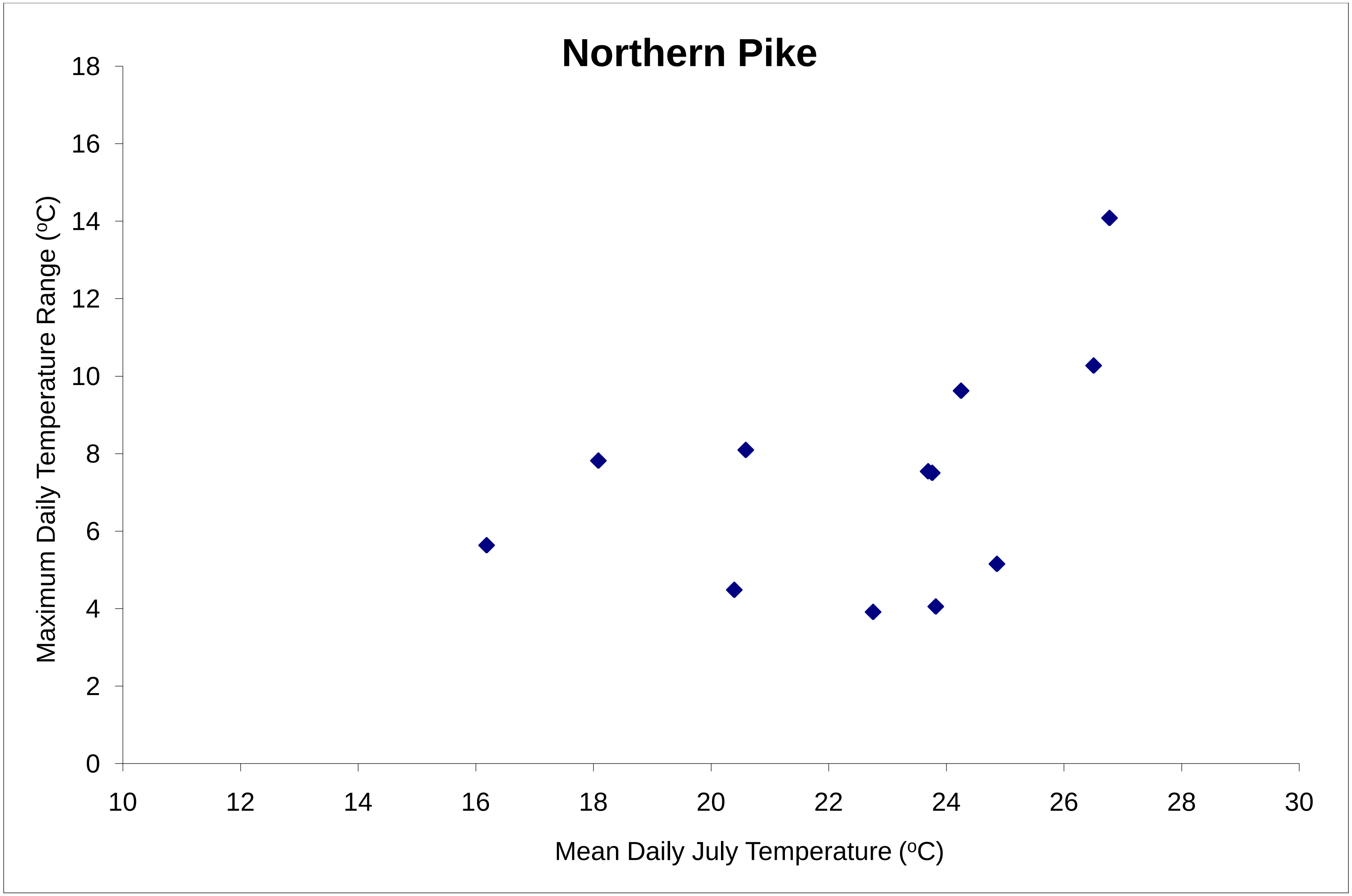


Lake Chubsucker
Maximum Daily Temperature Range (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)

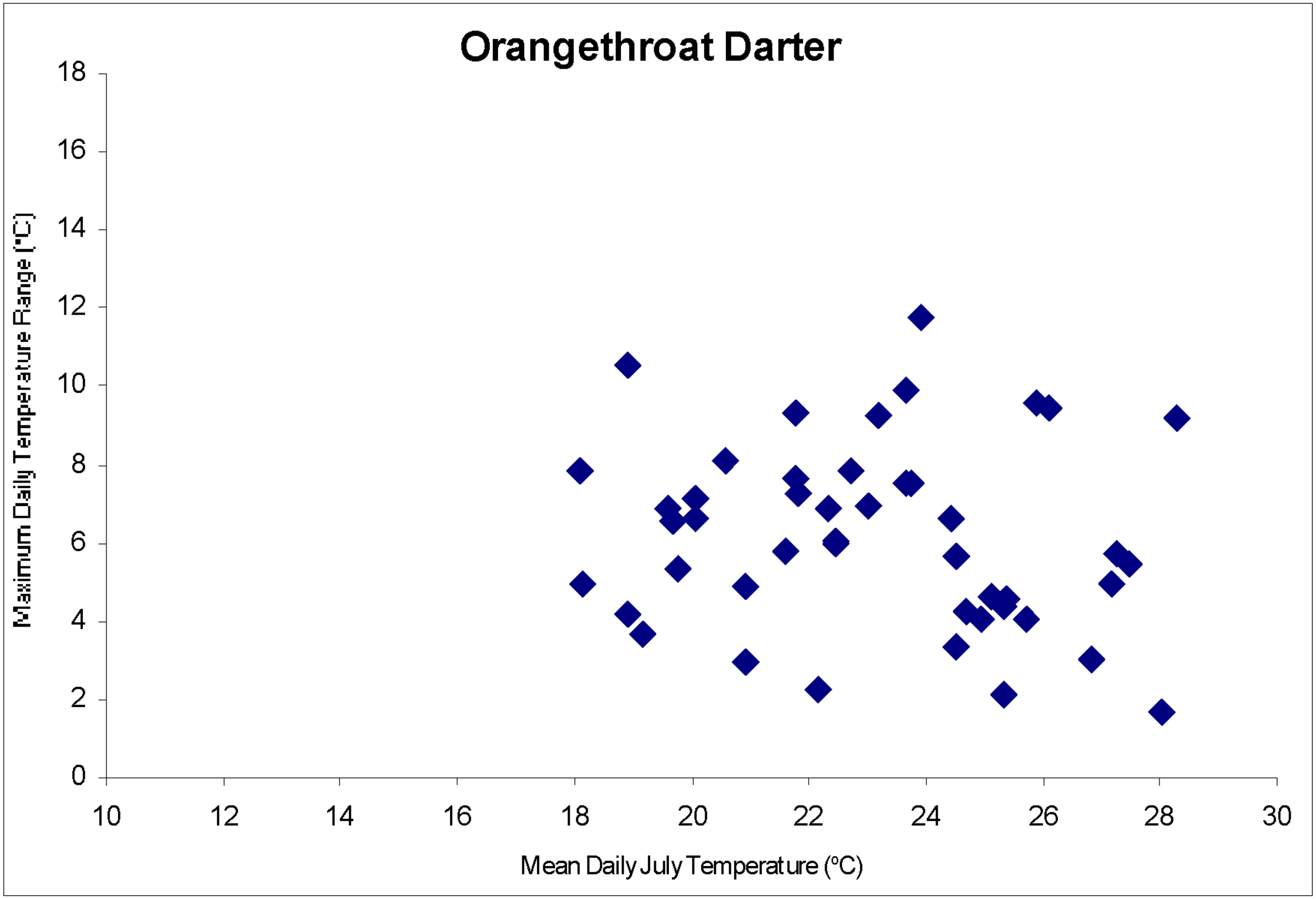


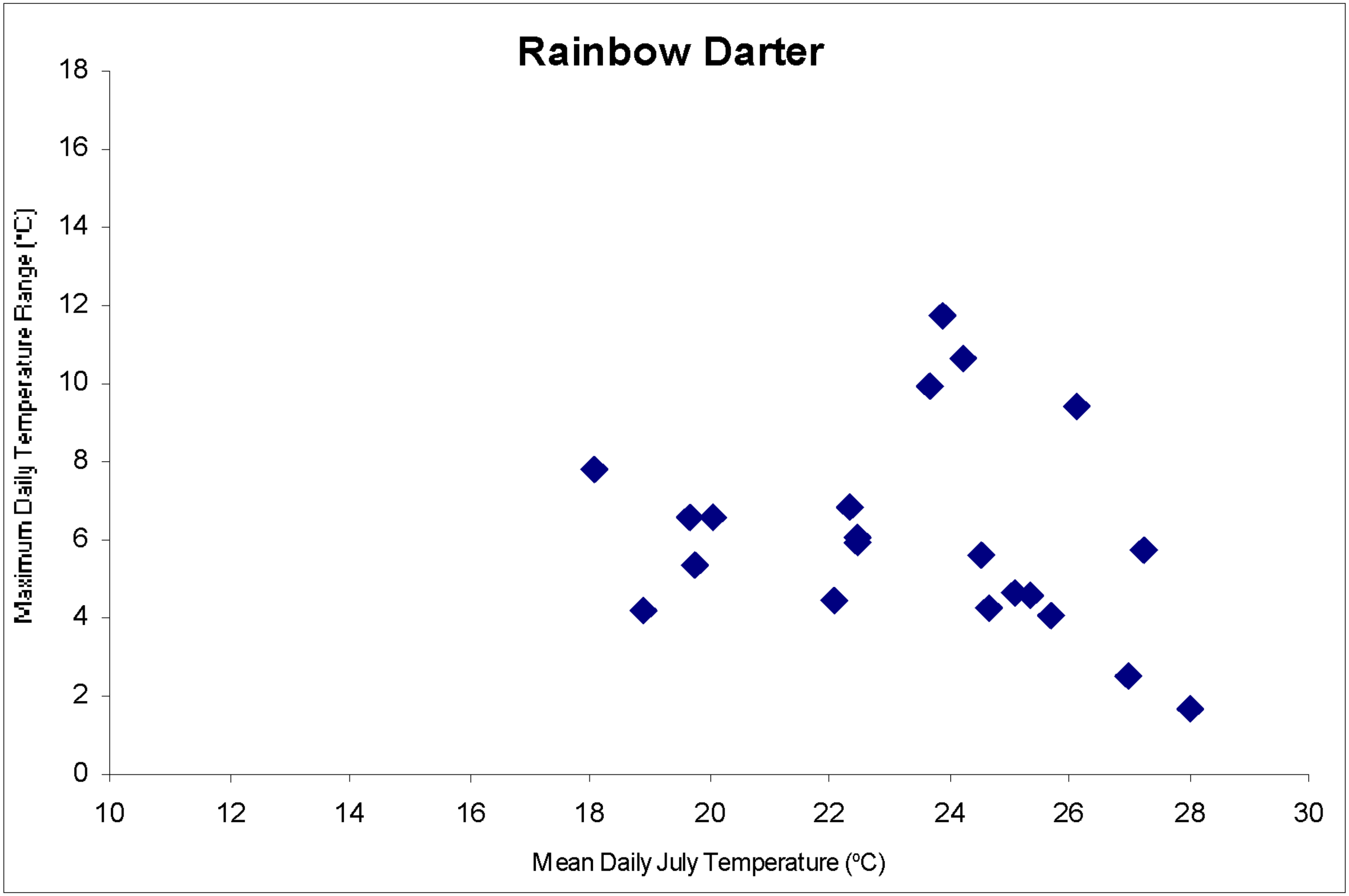
Largescale stoneroller
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (ºC)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30

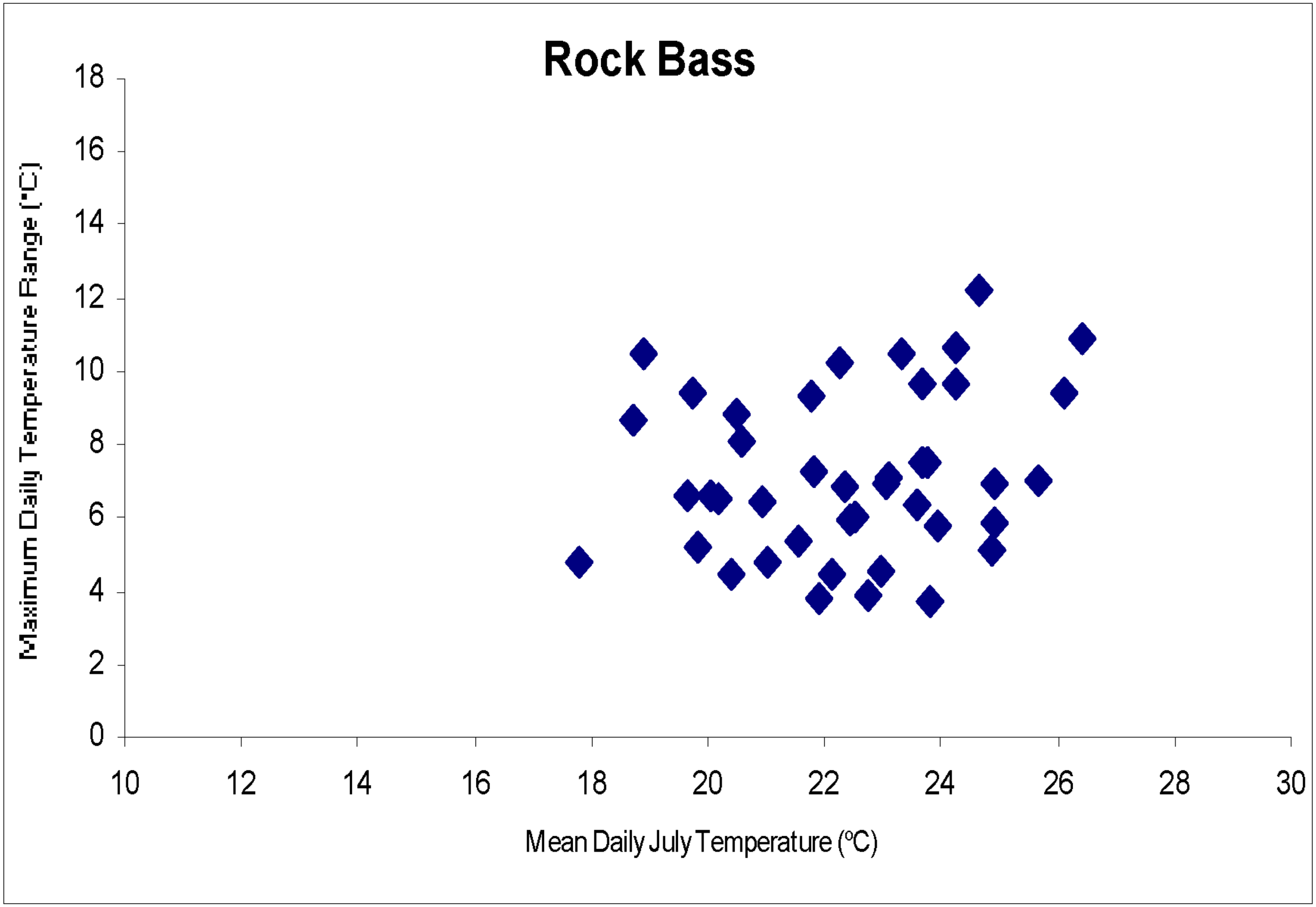

Northern Hogsucker
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30



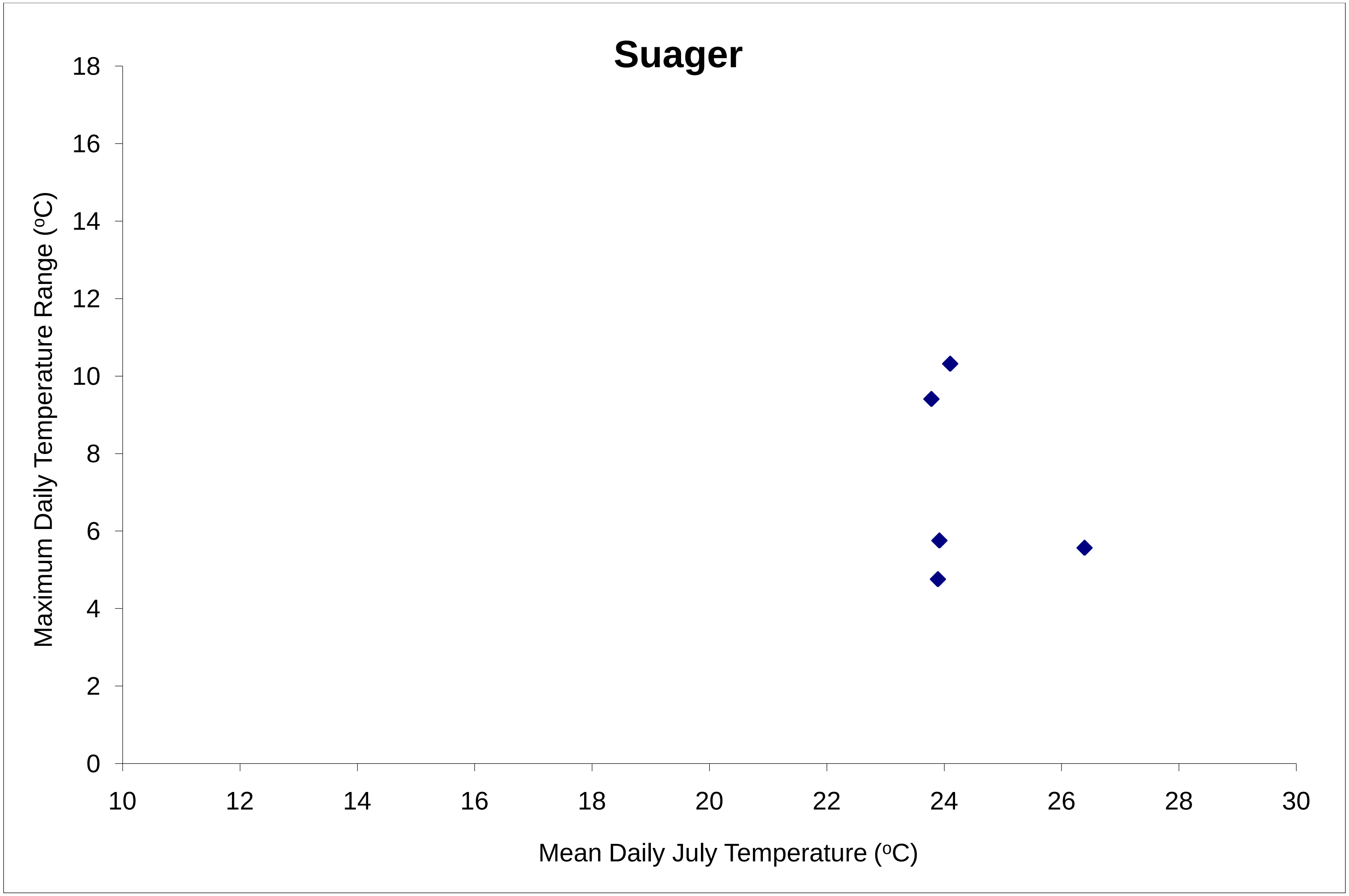
Northern Pike
Maximum Daily Temperature Range (oC)
Mean Daily July Temperature (oC)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30


Orangethroat Darter
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30

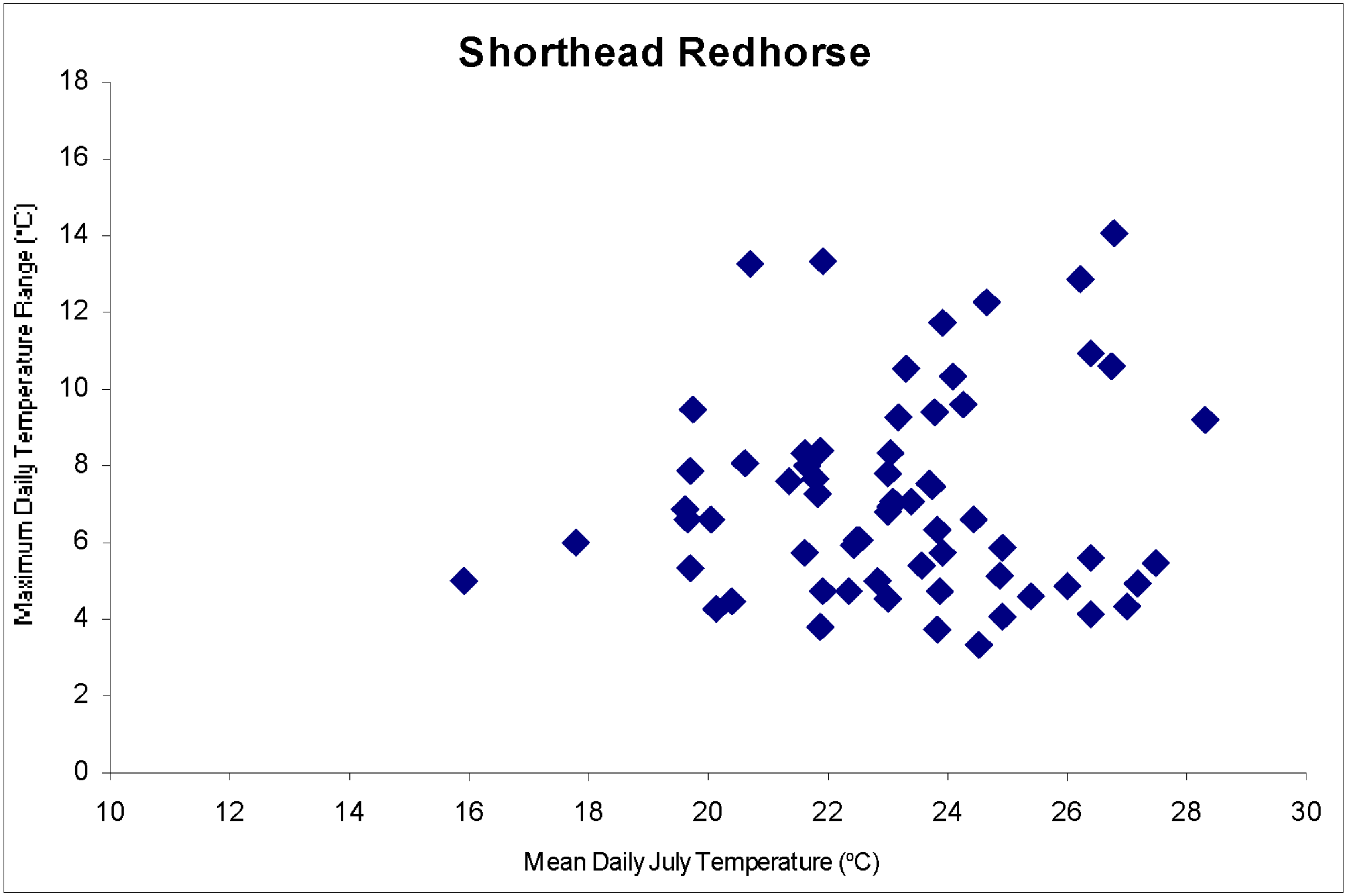

Rainbow Darter
Maximum Daily Temperature Range (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)



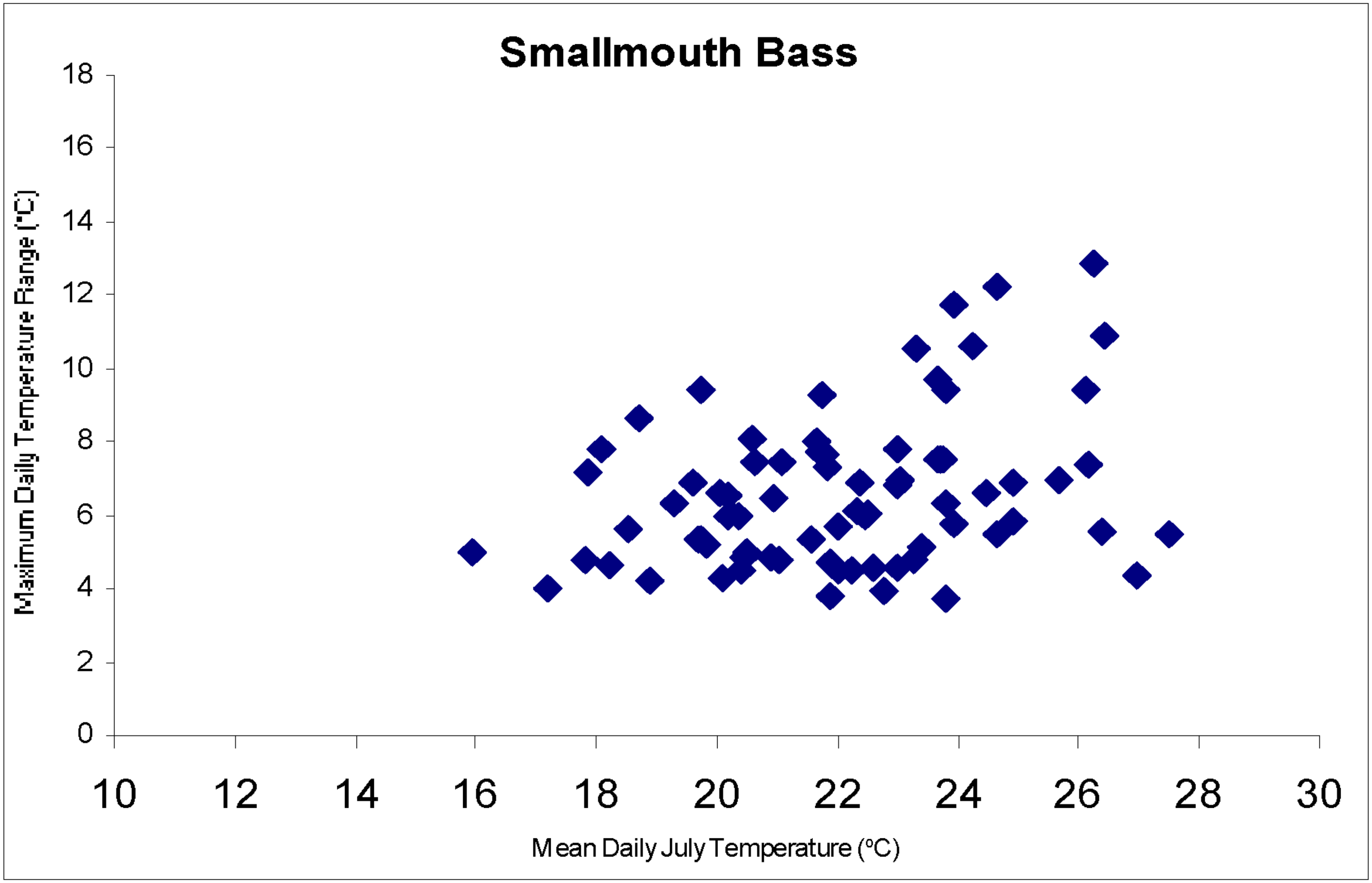
Rock Bass
Maximum Daily Temperature Range (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)

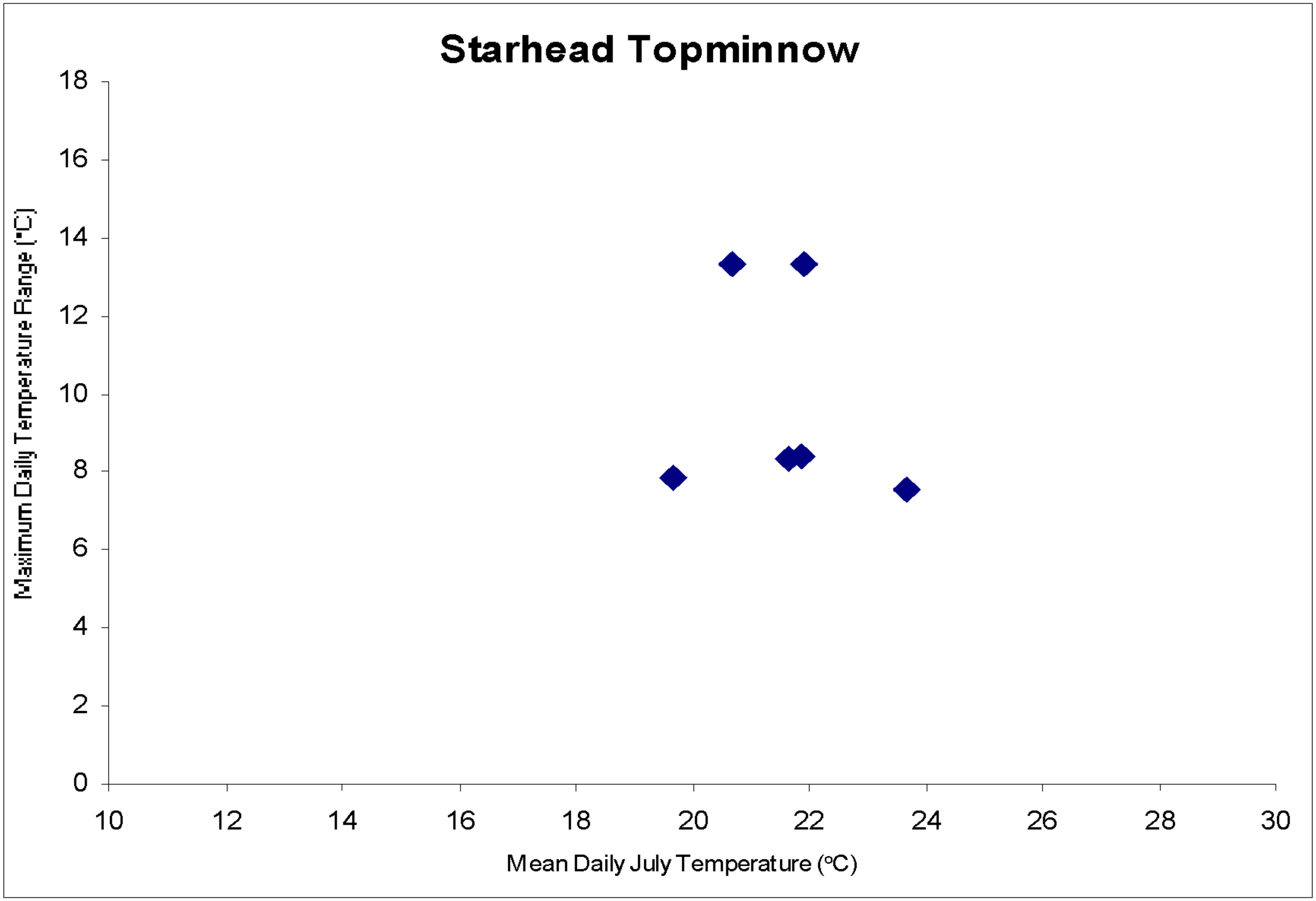


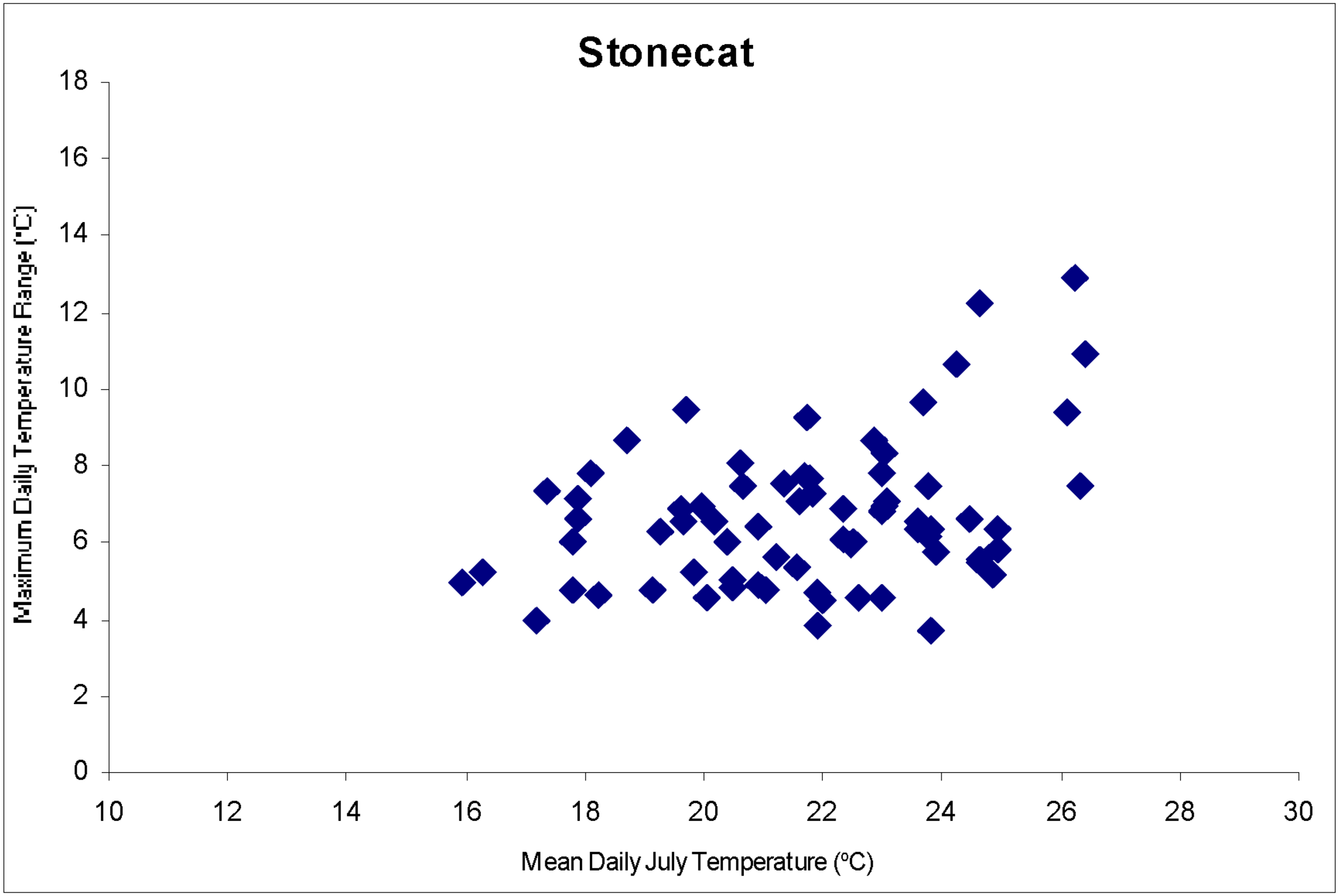
Suager
Maximum Daily Temperature Range (oC)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (oC)

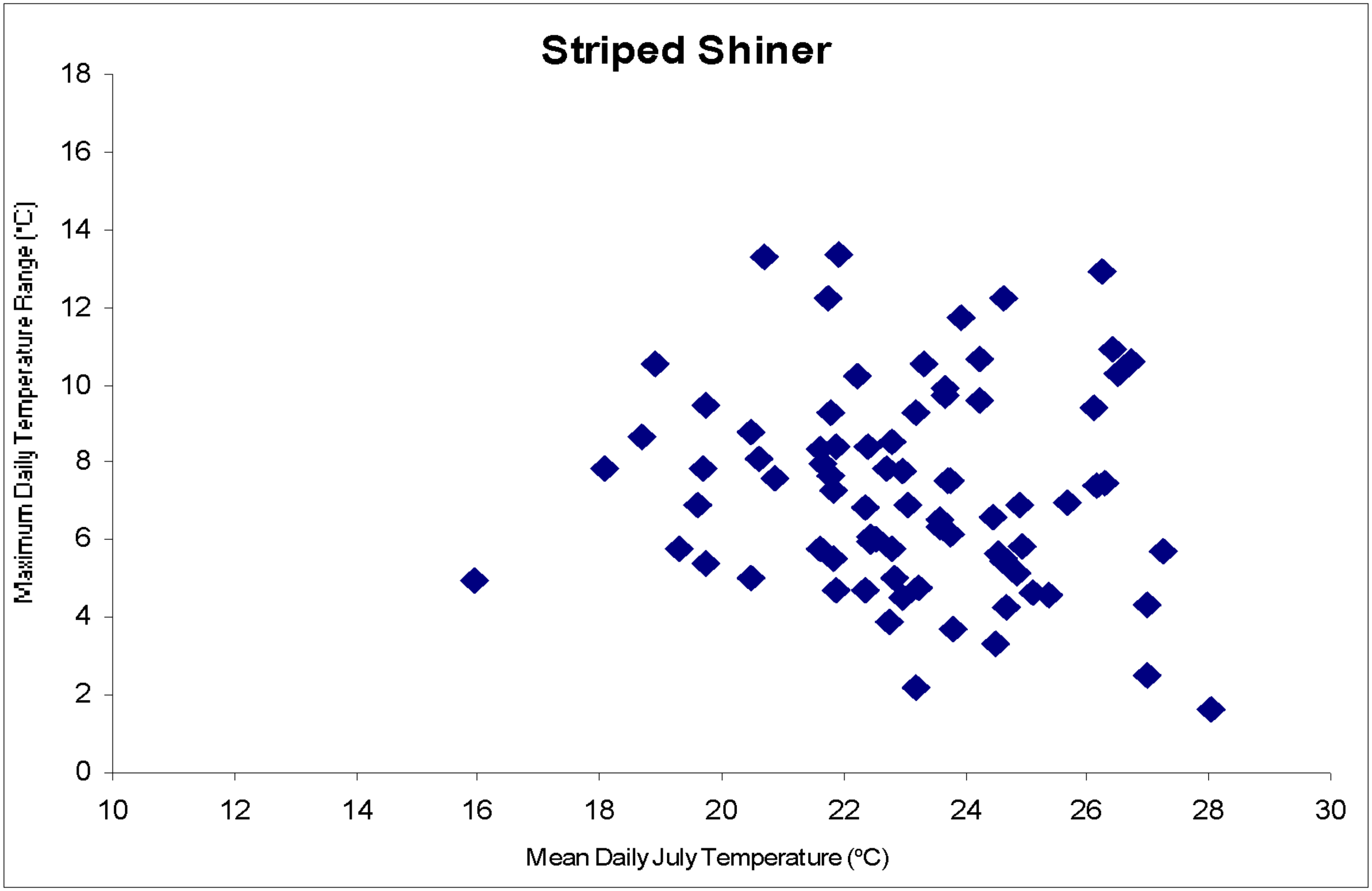


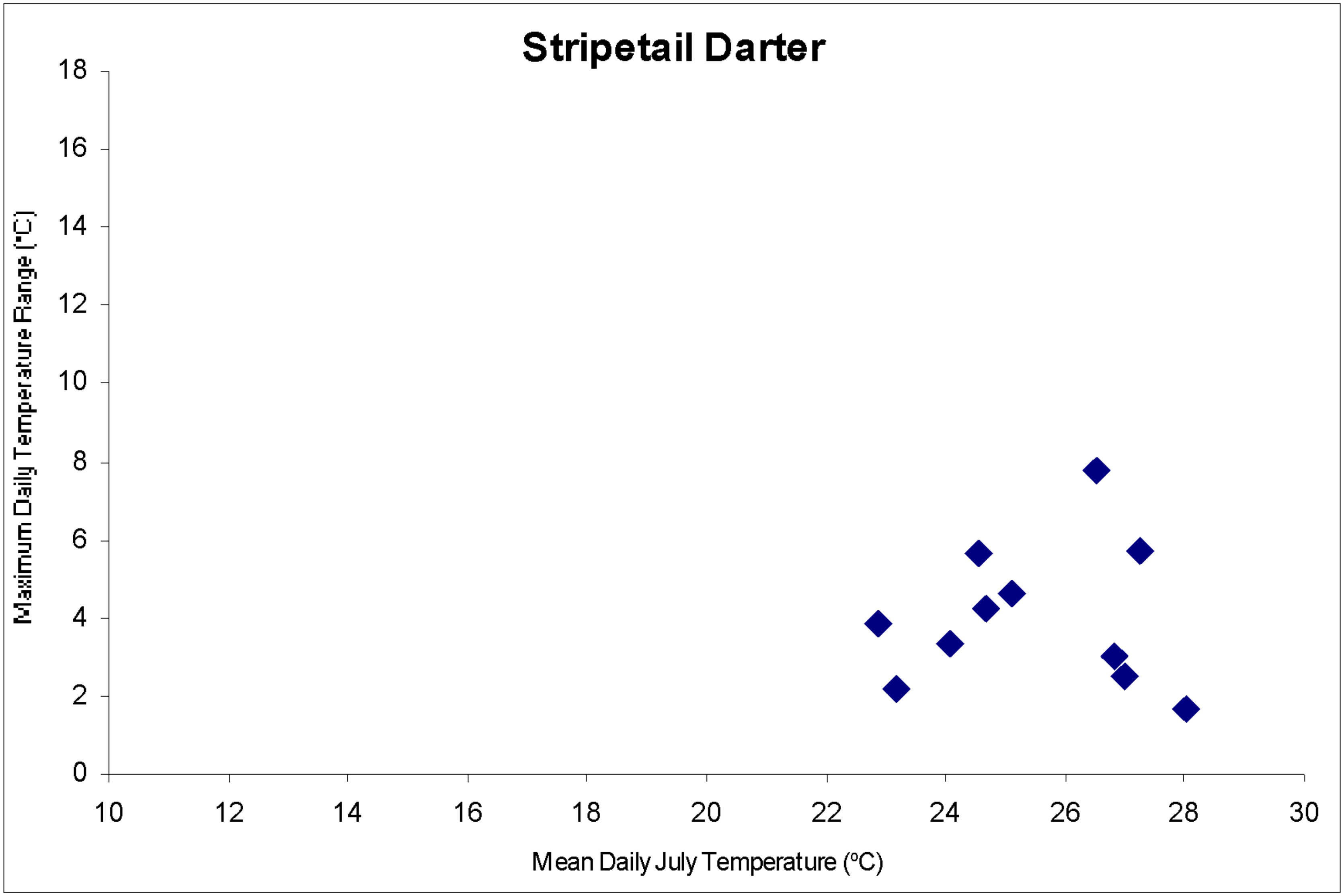
Shorthead Redhorse
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (ºC)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30

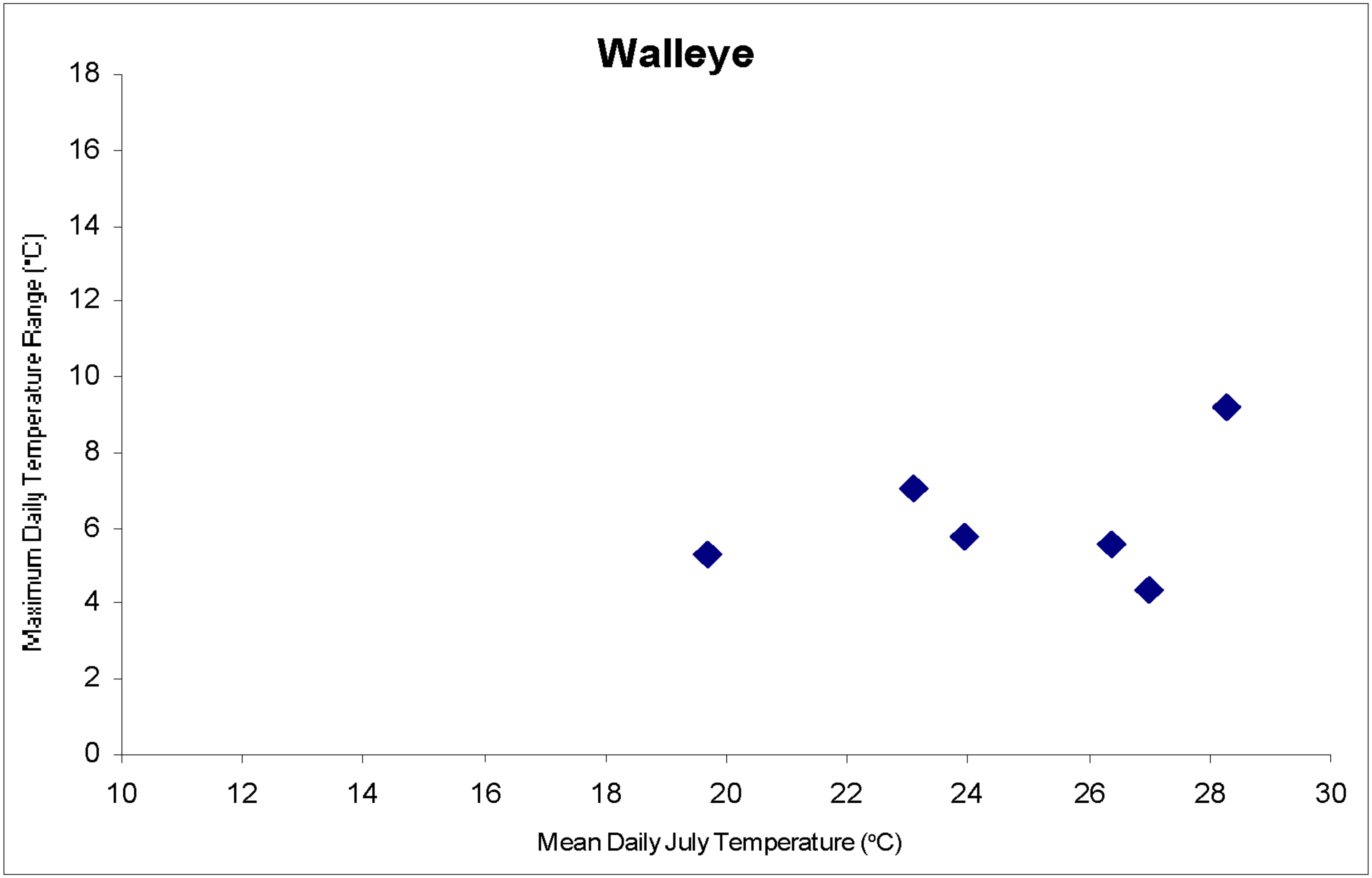

Smallmouth Bass
Maximum Daily Temperature Range (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)


Starhead Topminnow
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30

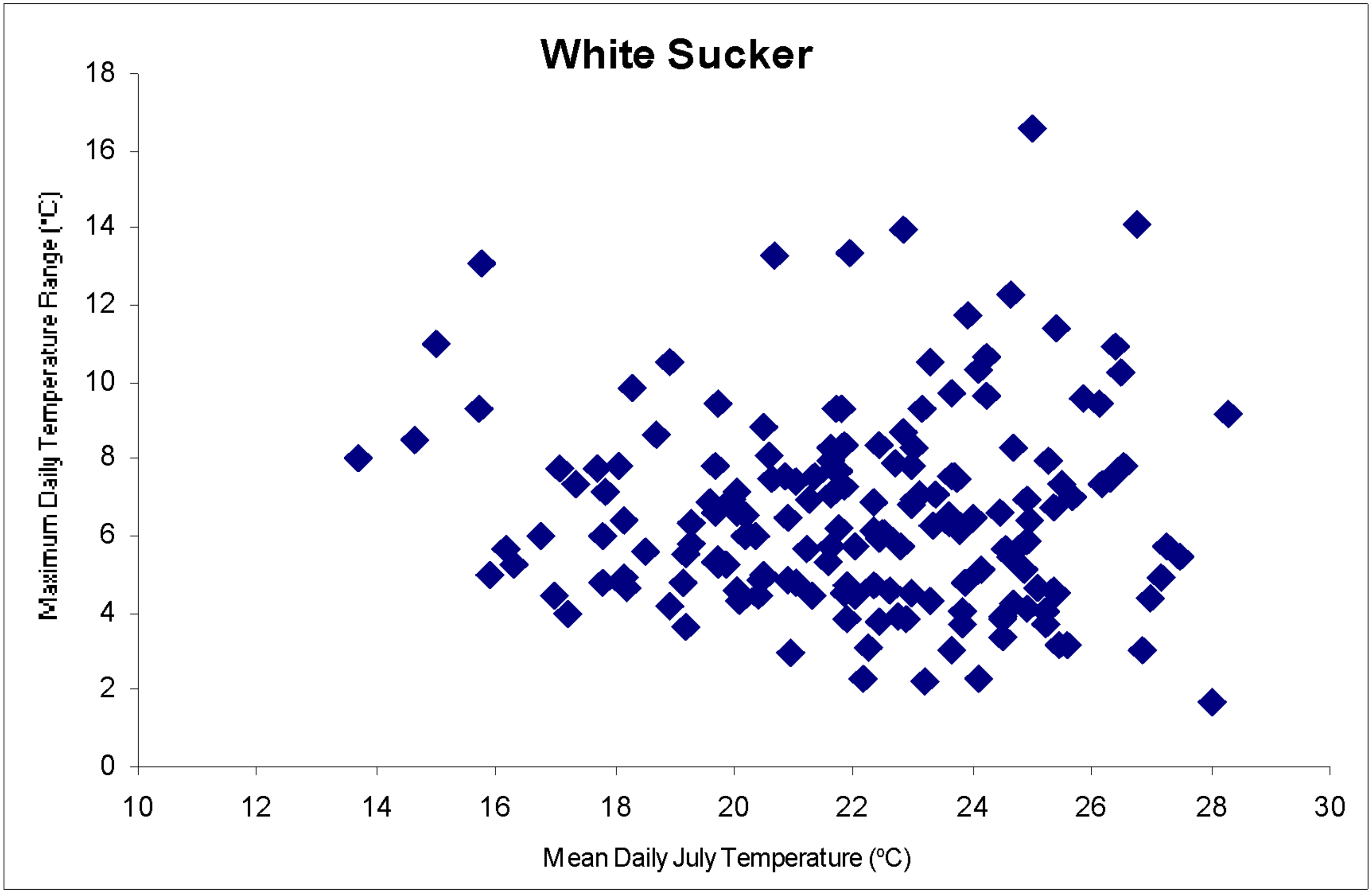

Stonecat
Maximum Daily Temperature Range (°C)
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)


Striped Shiner
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30


Stripetail Darter
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30



Walleye
18
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
Maximum Daily Temperature Range (°C)
Mean Daily July Temperature (ºC)


White Sucker
Maximum Daily Temperature Range (°C)
0
2
4
6
8
10
12
14
16
18
10
12
14
16
18
20
22
24
26
28
30
Mean Daily July Temperature (°C)