FINAL REPORT

As Required by

THE ENDANGERED SPECIES PROGRAM

TEXAS

TX E-136-R

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Endangered and Threatened Species Conservation

Data compilation, distribution models, conservation planning, and status survey for selected fishes of concern in Texas and region

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31 October 2013

FINAL REPORT

STATE: ____Texas_____ GRANT NUMBER: ___TX E-136-R-1__

GRANT TITLE: Data compilation, distribution models, conservation planning, and status survey for selected fishes of concern in Texas and region

REPORTING PERIOD: ____1 Sep 11 to 31 Aug 13_

OBJECTIVE(S). To supply i.) standardized and georeferenced range-wide occurrence data for federally listed *N. girardi, & H. amarus*, and 4 state-listed species (*P. gracilis, M. tetranema, P. hubbsi, & P. maculata*), ii.) a status survey for two federal candidates for listing, *N. oxyrhynchus* and *N. buccula*, and iii.) fish conservation decision support products.

Segment Objectives:

Tasks:
Year 1. Sept. 1, 2011 - Aug. 31, 2012: Data compilation, standardization, georeferencing - compile occurrence data for species in Table 1 (Project Statement) from online sources and regional museum databases. Then will parse them into appropriate fields, synonymize taxa names with current accepted taxonomy (American Fisheries Society) and georeference them according to accepted protocols used in other large-scale georeferencing projects (Fishes of Texas, HerpNet, Ornis, Manis).

Jun.- Aug. 2012: Status survey - conduct status survey in the Brazos River for *N. buccula* and *N. oxyrhynchus* to provide baseline data for future monitoring program. At least 20 sites will be sampled on the main-stem Brazos (sample siting dependent on accessibility, land ownership, and overall suitability for efficient sampling). Sites will be sampled one time each and voucher specimens of all species collected will be deposited in the Texas Natural History Collection at University of Texas at Austin.

Year 2. Sept. 1, 2012 - Jan. 1, 2013: Species Distribution Models - produce SDMs over the 8 species' respective ranges using the Maxent program. Additional hydrologic variables obtained from the National Hydrography Dataset (mean annual flow & velocity, cumulative drainage, stream segment slope) will also be incorporated to explicitly account for fish responses to differing hydrologic conditions. A newly created continuous geographic variable based on drainage network connectivity and distance will be tested and incorporated into these models to approximate, and simultaneously evaluate, species-specific biogeographic and dispersal constraints.

Jan. 1, 2013 - Aug. 31, 2013: Conservation Area Network Planning - SDMs created for these 8 species will be incorporated into existing, conservation area network planning analyses utilizing the Tabu search algorithm implemented in the ConsNet 2.0 software package for systematic conservation area planning. We will produce a minimum of two sets of results. The first will be a zonation of waterscapes of Texas with respect to their conservation value for fishes, produced achieving targeted representation of species in minimal area. Second, we will produce nominal management areas when species targets vary according to conservation status, as well as uniform targets of 20% and 30% for comparative purposes (e.g., see Figure 2). The second set of plans will incorporate compactness of shape and connectivity (unique to ConsNet) as additional criteria optimized for ease of planning and management.

Significant Deviations:

None.

Summary Of Progress:

Please see Attachment A. In addition, data from the project have been accepted and archived in the University of Texas Digital Repository (http://repositories.lib.utexas.edu/ - see **Location**, below), and it has been assigned the following identifier: http://hdl.handle.net/2152/21837. This identifier should be used when citing the submission.

> **Location:** *Data provision and modeling*: University of Texas, Texas Natural History Collections (TNHC), 10100 Burnet Rd., PRC176 EAST/R4000, Austin, Texas 78758-4445. *Status survey*: Brazos River watershed, Texas USA.

Cost: ___Costs were not available at time of this report, they will be available upon completion of the Final Report and conclusion of the project.__

Prepared by: _Craig Farquhar_____ Date: _31 October 2013

Approved by: _____ Date:_____31 October 2013____
C. Craig Farquhar

ATTACHMENT A

Final Report: Data compilation, distribution models, conservation planning, and status survey for selected fishes of concern in Texas and region

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Delivered to Texas Parks and Wildlife Department October 30, 2013

Permanently archived with all related data sets in the University of Texas Digital Repository (http://repositories.lib.utexas.edu/) with the permanent identifier http://hdl.handle.net/2152/21837

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ABSTRACT

The four primary objectives of this project were to: (1) compile a dataset of georeferenced range-wide occurrence records for 6 target fish species (*Notropis buccula*, *N. oxyrhynchus*, *N. girardi*, *Hybognathus amarus*, *Platygobio gracilis*, *Macrhybopsis tetranema*, *Pteronotropis hubbsi*, and *Percina maculata*); (2) use a high quality and geographically wide-ranging subset of those data to create species distribution models (SDM's), which convert point occurrences into a continuous probability coverage; (3) use those models in conjunction with 130 additional SDM's (previously created) to develop modeled conservation priority areas for Texas; and (4) complete a status survey for *N. oxyrhynchus* and *N. buccula* in the mainstem of the middle Brazos River. The dataset provided, derived from 51 original sources, includes 11,082 records, of which we were able to georeference 3,675 (33%). This number of records was sufficient for constructing SDM's for the six target species, with all models meeting quality assurance criteria. Using these models, conservation area prioritizations were developed for Texas under several guiding criteria for decision making. The field survey sampled the mainstem Brazos at 20 sites between Possum Kingdom Reservoir and Bryan, TX, collecting 65,840 fish specimens representing 46 species. Neither survey target species was collected, suggesting absence or extreme rarity of both in this reach of the Brazos at the time of sampling. Collection sites upstream of Waco, compared to those downstream of that city, were less diverse in cyprinids and more diverse in non-native species, suggesting more heavily impacted habitat upstream of Waco. All raw data used in analyses and results of analyses and the field survey are provided with the written report.

1 DATA PROCESSING

1.1 DATA COMPILATION FROM VARIOUS SOURCES

We queried large online multi-institution data providers as well as our smaller internally derived databases and made direct requests to museums to compile 495,101 North American fish occurrence records that include this project's target species (*Notropis buccula*, *N. oxyrhynchus*, *N. girardi*, *Hybognathus amarus*, *Platygobio gracilis*, *Macrhybopsis tetranema*, *Pteronotropis hubbsi*, and *Percina maculata*) as well as numerous other fish taxa. These data consist primarily of specimen-based records that are thus verifiable via examination of museum specimens and other documentation held in museum archives. We started with 15 separate queries of 11 databases (Appendix 1). Those data sources providing the greatest numbers of records were GBIF (Global Biodiversity Information Facility; http://www.gbif.org/), FishNet2 (http://www.fishnet2.net/) and FishBase (http://www.fishbase.org/), all major data providers of global occurrence data, and all queried via their online query engines specifically for occurrences of these target species across their full geographic distributions. The other eight sources are datasets derived by us for other projects or derived by affiliates working on their own projects, as well as museum databases. These other sources were queried to get additional comprehensive taxonomic coverage for fishes in Texas and neighboring states, including the US and Mexico. This larger and more taxonomically inclusive data gathering approach, which ultimately includes data from 119 independent contributing entities (Appendix 2), ensured a more comprehensive dataset maximizing the number of records for these target species from large, as well as smaller and lesser known databases that are typically little utilized, but that often hold valuable and sometimes rare occurrence records. This approach was in

part to fulfill our broader research objectives to document fish occurrences in Texas drainages (those shared with neighboring states in the US and Mexico) and the relevant data derived from this project will eventually be incorporated into the Fishes of Texas Project (www.fishesoftexas.org) for provision online to researchers around the world. We intend, pending funding, to continue work on verifying specimen identifications and further applying our quality control methods to as much of these data as possible.

The final dataset is smaller than what we downloaded directly from these data providers since we were surprised to find records of non-fish taxa in the query results, apparently due to errors in higher taxonomy. We removed those records, as well as records pertaining to what were indicated to be fossil specimens.

We estimate, based on unique combinations of our formatted "institution" and "catalog number" fields, that the dataset herein provided represents approximately 343,206 unique museum specimen lots, however, the actual number of records is greater. This is because we chose to retain near duplicate records that resulted from multiple queries to different providers that serve overlapping data. We felt it important to retain these near duplicates since they often differ in data completeness or content in sometimes subtle but potentially important ways, most often due to provision of different fields by different data servers. Removal of such near duplicates is not easily done with automated methods without compromising some level of data quality and we decided, therefore, to provide all records here. The record reformatting efforts, date parsing, taxa synonymization and georeferencing done for this project will potentially help us to more fully reconcile such duplicates in the future.

1.2 Normalization and synonymization

Typical of legacy museum data, the starting dataset for this project suffered from misspellings and inconsistent formatting resulting from independent handling by diverse institutions and individuals for sometimes over a century before becoming part of projects like this that strive to normalize such inconsistencies. Field names and data definitions varied across institutions but we were able to match incoming data fields to standard fields with little difficulty. Due to differences in data definitions, original data contents were "broken" apart into our pre-defined and separate fields (often with adjustments to date format and removal of special characters, e.g. diacritical marks), but the original "verbatim data", albeit sometimes reformatted, were always retained intact. This critical step of normalization of the data content in new, consistently formatted fields now allows the dataset to be searched as a single resource, but for any record any field can always be easily and quickly compared to the "verbatim" fields since our improvements and quality control corrections are in separate fields.

Institutional acronyms varied across data sources and were synonymized (Appendix 2) to each institution's American Society of Ichthyology and Herpetology standard (Sabaj Pérez 2013), when one existed in that source. If one did not exist we maintained the codon as received from the data donor.

Collector and determiner names have not been synonymized or standardized. Users must rely on the verbatim fields for that content. However, all records here that were extracted from our own Fishes of Texas project had been previously normalized by that project for most names.

Dates were typically received as a single field and had to be interpreted into a six field system (begin year, begin month, begin day, end year, end month, and end day) to facility managing dates. No editing of data content occurred in this step, only a strict transformation into these fields.

Verbatim taxa names were synonymized and brought into compliance with a modern standard taxonomy aided by use of Taxonome (Kluyver and Osborne 2013). This free downloadable tool allows verbatim taxa names to be compared, using "fuzzy" matching algorithms, to a list of accepted names. It scores matches for accuracy and that score can be used to aid the decision-making process and thus aid processing of large datasets such as this. Before matching we edited the verbatim names to remove text that was clearly not part of any formally accepted name (i.e. "sp., cf., "unidentified" and other variations of these, as well as what appeared to be stray key strokes). Then, using Taxonome software, our edited verbatim names were matched to the taxonomy of the American Fisheries Society (AFS - Nelson et al. 2004), and separately the taxonomy provided by the Integrated Taxonomic Information System (ITIS; http://www.itis.gov/; downloaded in parts Nov 15, 2012 and May 13, 2013). When an exact match (score =1) to both was found that name was accepted without examination. When the AFS taxonomy had no match, we accepted the ITIS name if the score was 0.8 or greater. Likewise, when the ITIS taxonomy had no match, we accepted the AFS name if the score was 0.8 or greater. When no match was made to either, we manually processed names (but only for those records from the Rio Grande drainage, because our larger research goals and funding require that we fully process those records). These non-matching names, however, were often attributed to spelling errors that once corrected, easily attributed to AFS or ITIS taxonomies. In some cases, names not in AFS or ITIS were found in FishBase (http://www.fishbase.org/search.php) or the Catalog of Fishes (http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp). Names not matching any of these taxonomies and from locations outside of the Rio Grande basin were not synonymized. Taxonomy provided by donors only to taxonomic levels above family were not synonymized and were simply labeled as that taxonomic level. Since we used Taxonome to match genus and species names, family names were associated later and were matched to genera following AFS, and records without matches were matched to the ITIS taxonomy. Some names were found not to represent any fish and were labeled as "Out of taxonomic scope".

Specimens were not examined for verification of ID's since that was outside of the scope of this project, so all determinations were derived from the verbatim fields. However, since *Macrhybopsis aestivalis* was recently split by Eisenhour (2004) into several species based primarily on geography, we assumed, based on that work, that all *M. aestivalis* records from the geographic distribution of *M. tetranema*, as defined in that publication, actually represent *M. tetranema*. We did not verify this by inspection of specimens, but adjusted the dataset as indicated and included those records in modeling (See "Species distribution models (SDMs)").

1.3 Georeferencing

Querying the dataset described above for the six target species retrieved 11,081 records from 51 unique entities (Appendix 3). Our georeferencing protocols are the same as those used in other large georeferencing projects such as HerpNet (http://herpnet2.org/) and MaNIS (http://manisnet.org/) and all locations receive coordinates with an associated error radius calculated using an online calculator (http://manisnet.org/gci2.html). For some records it was often obvious that vague locality descriptions, internal conflicts, or complete lack of locality detail would prevent unambiguous georeferencing, so we skipped these, as well as any record for which it was quickly obvious that the georeferenced locality error would be larger than the 1 kilometer prerequisite for species distribution modeling (see "Species distribution models (SDMs)"). The total of 3,675 precisely georeferenced occurrence records represent 1,162 unique locations (Table 1).

Table 1. Data summary for occurrence records of the six target species (see also Figures 1-6).

Row Labels	Records	Georeferenced records	Unique locations georeferenced	N states (georeferenced)	unique donor entities
Hybognathus amarus	300	138	73	2 USA; 4 Mex	13
Notropis girardi	2679	1209	167	5 USA	26
Platygobio gracilis	3315	781	327	11 USA; 3 Can	37
Pteronotropis hubbsi	203	73	29	4 USA	13
Percina maculata	4155	1316	536	23 USA; 2 Can	34
Macrhybopsis tetranema	429	158	30	4 USA	17
Grand Total	11081	3675	1162		51

After georeferencing, records that received coordinates were examined in a GIS environment and occurrences that were geographically disjunct and in conflict with distributions published by Page and Burr (2011) were flagged as suspect with a "1" and not used in modeling. Those records, however, are provided in the final dataset, which also includes all records that were not georeferenced (see "Supplemental Data" and georeferenced records mapped in Figures 1-6).

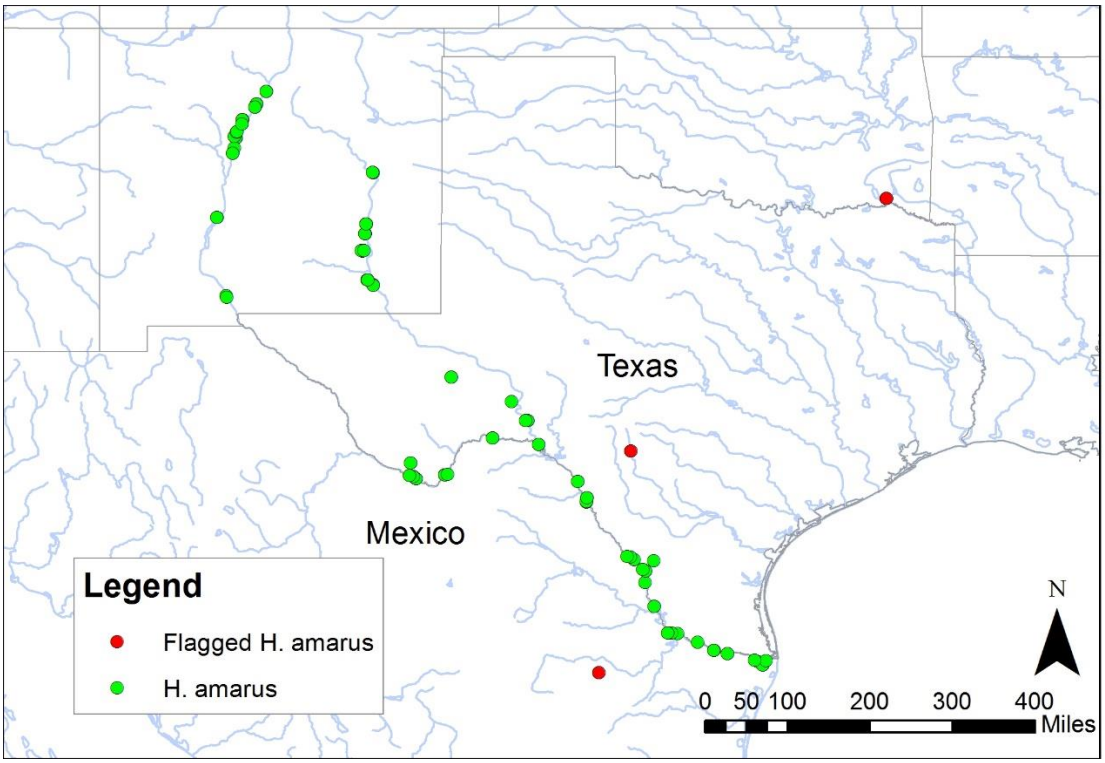

Figure 1. Georeferenced occurrence records of Hybognathus amarus

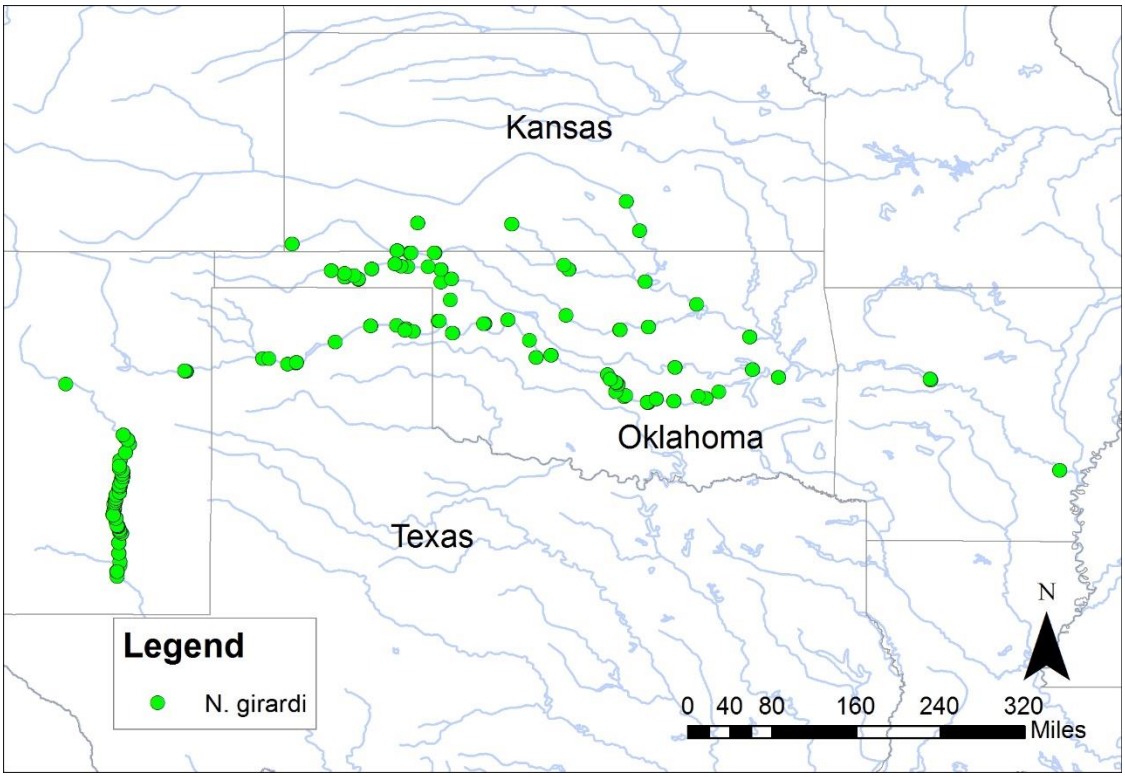

Figure 2. Georeferenced records of Notropis girardi

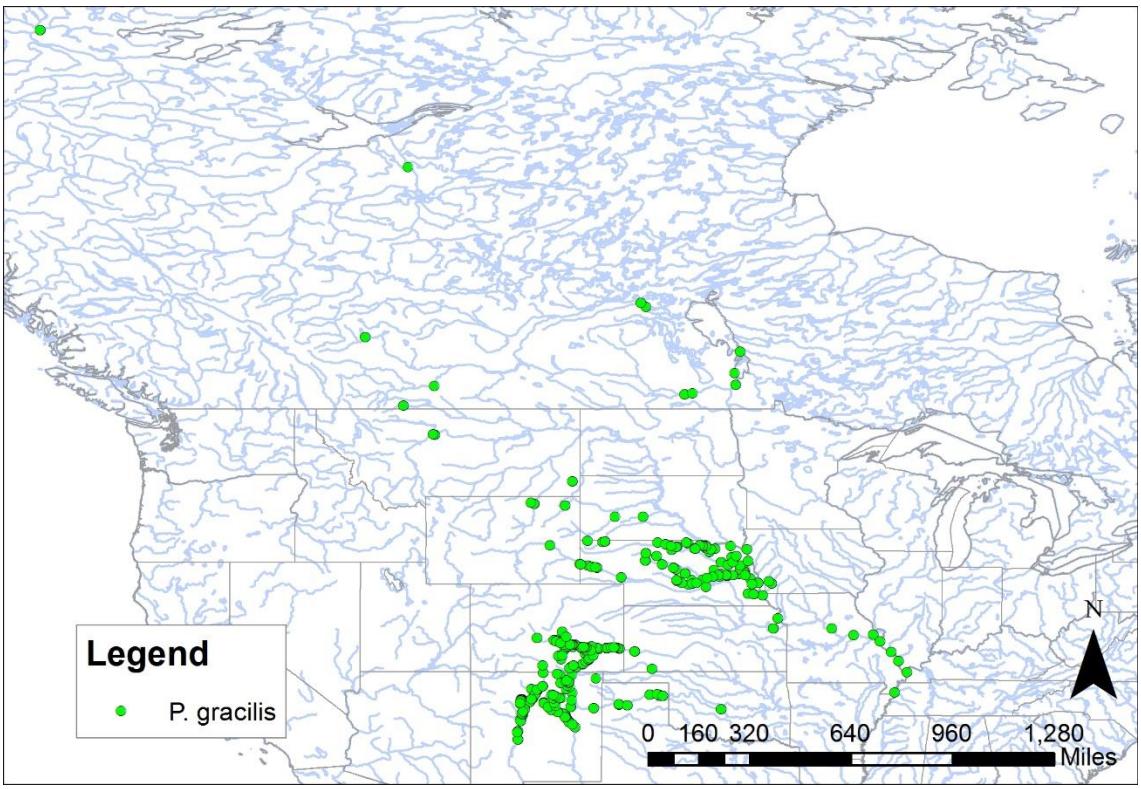

Figure 3. Georeferenced records of Platygobio gracilis.

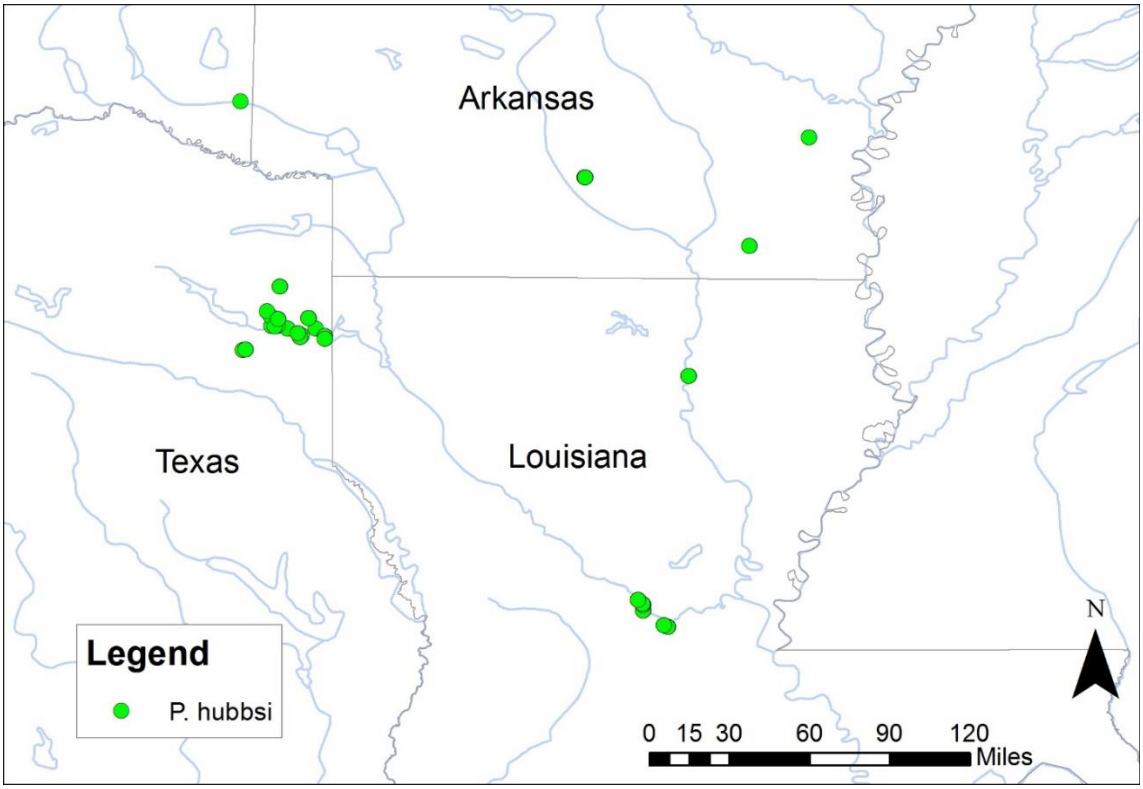

Figure 4. Georeferenced records of Pteronotropis hubbsi

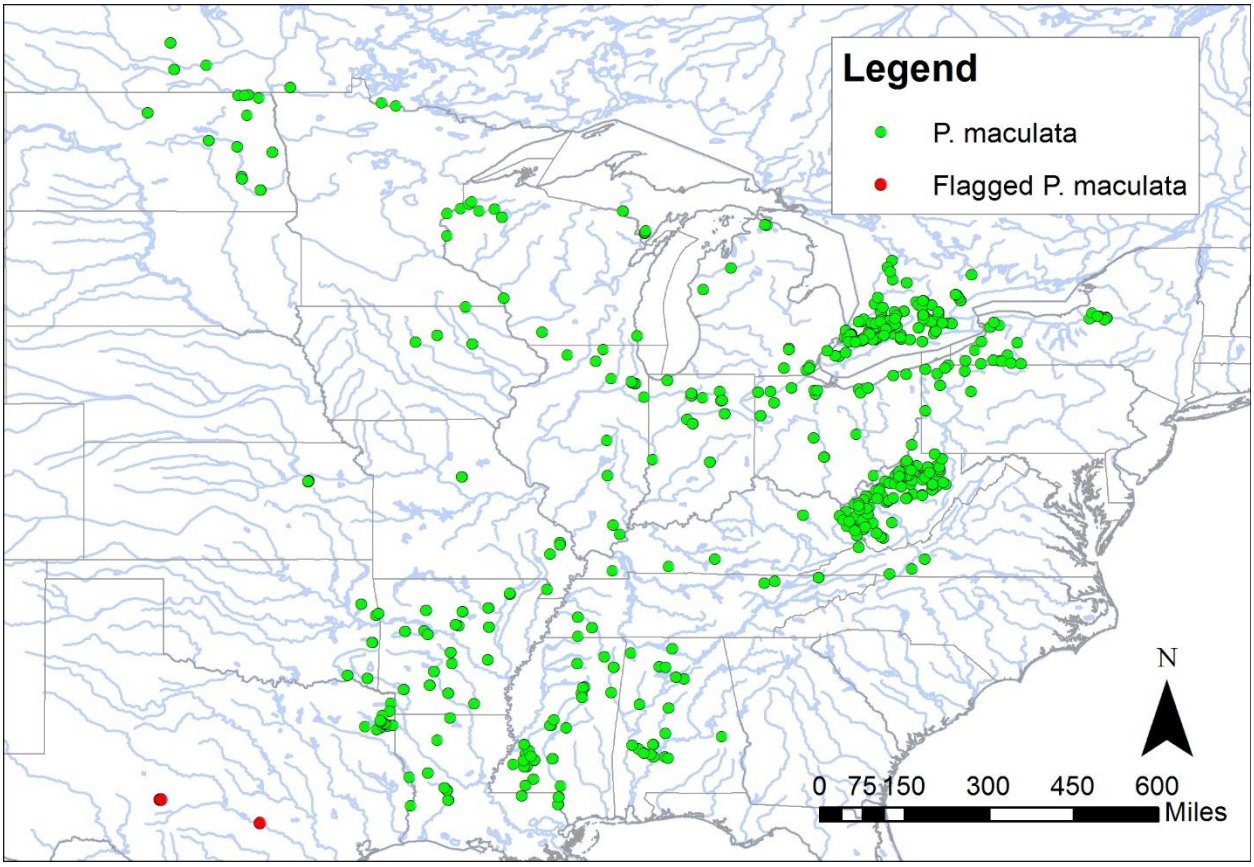

Figure 5. Georeferenced records of Percina maculata.

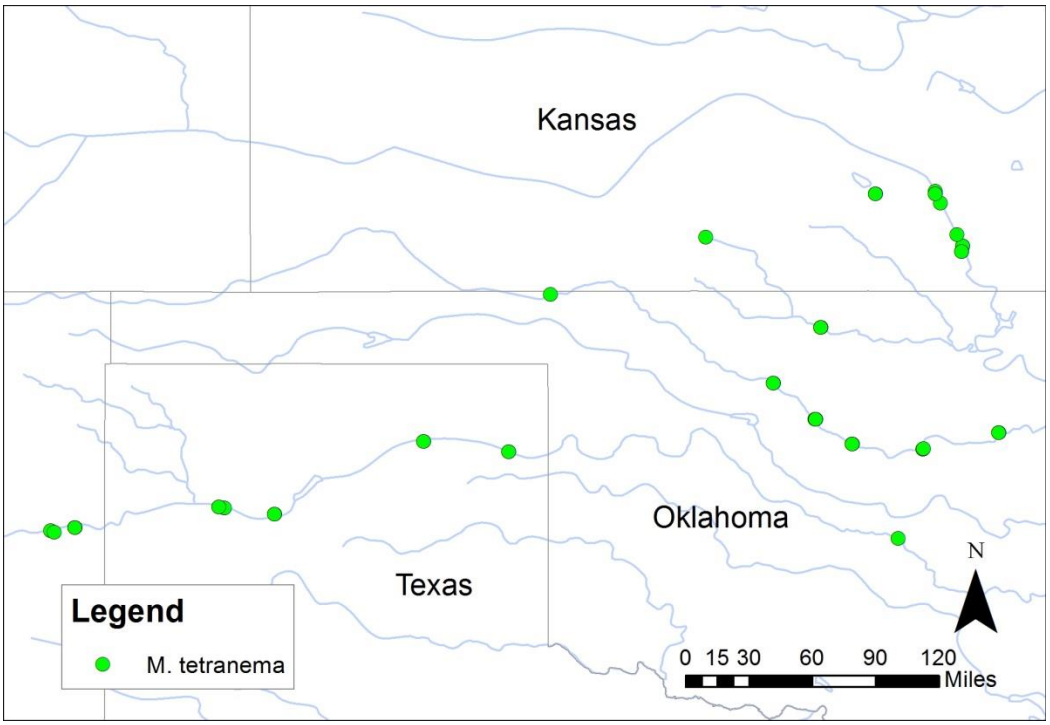

Figure 6. Georeferenced records of Macrhybopsis tetranema.

2 SPECIES DISTRIBUTION MODELS (SDMS)

2.1 SDM BACKGROUND

Species distribution models (SDMs) are an increasingly popular tool for conversion of point occurrence data into range-wide continuous probability coverages useful for a great diversity of management-relevant applications (Guisan et al. 2013). This transformation is achieved through powerful software packages that evaluate statistical relationships between species occurrences and environmental variables. Here we use SDMs to prioritize conservation areas (see Conservation area network planning). Figure 7 provides a conceptual guide for how SDMs (and other spatial products such as those provided in this report) should be incorporated into conservation planning and decision support (Guisan et al. 2013).

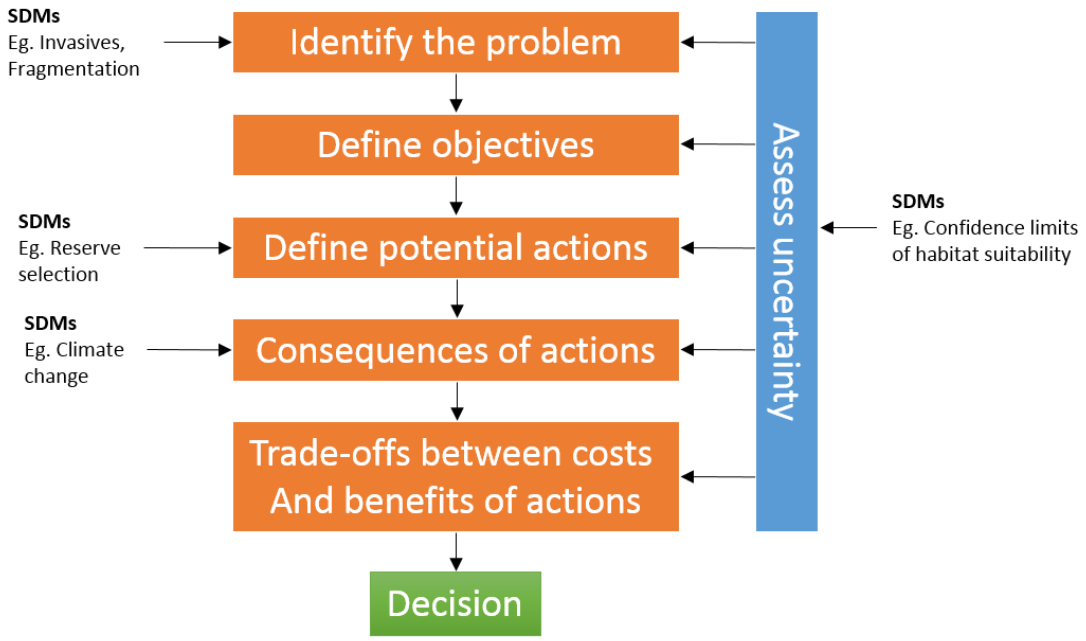

Figure 7. A decision-making process with indication of potential entry points for the use of SDMs in influencing conservation planning work. Adapted from Guisan et al., 2013.

2.2 ENVIRONMENTAL VARIABLES

The environmental variables used in SDM construction (Table 2) were selected in part on the basis of expert evaluation of models created from subsets of variables for a set of species with well-known distributions (see Labay et al. 2011 for a detailed description). The climatic, hydrologic, and topographic variables were used to attempt to account for broad-scale physiological constraints as determinants of distribution (Graham and Hijmans 2006), and the two hydrology-based geographic variables control for historical zoogeography by categorically constraining predictions of species presence/absence to watersheds from which they are documented. Appendix 5 contains Maxent's jackknife test of variable importance for each species.

For each of the six priority species we produced two sets of models, one set that included the categorical geographic variables (huc4_raster & huc8_raster; see Table 2) in model production, and a second set that

excluded these variables. Comparison of these allows for identification of suitable environmental conditions that are currently not documented by the occurrence information from which the models were created to be utilized by the species. The utility of an SDM for decision makers is highly context sensitive. Thus, providing the two sets of results, one geographically conservative based on occurrence data and the second relatively liberal, allows for flexibility in application. For example, the second result that excludes categorical geographic variables, and thus loosens predictions from occurrence points, might provide insights regarding potential repatriation or translocation sites.

2.3 SDM CONSTRUCTION AND EVALUATION

To best match the resolution and time of the geographic/environmental layers used in modeling, occurrence data used were restricted to locations having error radii less than 1 km and observation dates after 1950. Records previously flagged as suspicious (see Georeferencing) were not used in modeling. Species distribution models were constructed using the maximum entropy algorithm encoded in the Maxent software package (Version 3.3.4; Phillips, Anderson, and Schapire 2006), known to be robust for species distribution modeling with presence-only records (Elith et al. 2006). We implemented Maxent following default parameterization recommendations (Phillips and Dudík 2008), with models cross-validated with 10 replicates (Elith et al. 2011). Individual species' model performance was evaluated using a receiver operating characteristic (ROC) analysis. The ROC analysis characterizes model performance at all possible thresholds using the area under the curve (AUC). An optimal model with perfect discrimination would have an AUC of one while a model that predicted species occurrences at random would have an AUC of 0.5 (Hanley and McNeil 1982).

2.4 SDM PRODUCTS

We provide model products in various formats. Appendix 4 contains images of both model runs for each species as well as a map of occurrence records used in modeling. These maps are useful for visual inspection and interpretation. Model images are displayed as symbolized rasters layered over a shapefile of major streams. Only modeled probabilities > 0.5 are shown to aid in visual interpretation and to illustrate what we suggest be interpreted as prime suitable habitat based on the high quality occupancy data used. Complete raw models are provided in supporting documents as GIS ready grid data layers. This format provides continuous probability estimates over species' ranges (unlike point occurrence data), and can be deployed in a great diversity of mathematical and GIS analyses that are of considerable utility to managers attempting to understand factors affecting distributions and suitability over broad scales.

Additionally we provide, in supporting documents, the Maxent results log, containing model parameterization and result details, and html files of each model's Maxent model summary for the individual 10 replicates as well as the average run. The summary includes plots of individual variable importance. Note that models do not directly account for anthropogenic influences such as dams or land use, and should thus be considered to estimate a species' potential, not necessarily actual, distribution, but they can thus serve as a benchmark for the species distribution based on the best available occurrence data.

Table 2. Environmental variables used in species distribution models.

Layer category	Description	Source	Variable code
Topological	Aspect	1km DEM	aspect
Topological	Slope	1km DEM	slope
Topological	compound topological index (ln(acc.flow/tan[slope]))	1km DEM	cti
Topological	Altitude	1km DEM	alt
Climate	annual mean temperature	Wordclim variable 1	bio_1
Climate	mean diurnal range (mean of monthly (max temp - min temp))	Wordclim variable 2	bio_2
Climate	isothermality (P2/P7)(*100)	Wordclim variable 3	bio_3
Climate	(temperature seasonality (sd *100)	Wordclim variable 4	bio_4
Climate	max temperature of warmest month	Wordclim variable 5	bio_5
Climate	min temperature of coldest month	Wordclim variable 6	bio_6
Climate	temperature annual range (P5-P6)	Wordclim variable 7	bio_7
Climate	annual precipitation	Wordclim variable 12	bio_12
Climate	precipitation of wettest month	Wordclim variable 13	bio_13
Climate	precipitation of driest month	Wordclim variable 14	bio_14
Climate	precipitation seasonality (coefficient of variation)	Wordclim variable 15	bio_15
Climate	precipitation of wettest quarter	Wordclim variable 16	bio_16
Climate	precipitation of driest quarter	Wordclim variable 17	bio_17
Climate	precipitation of warmest quarter	Wordclim variable 18	bio_18
Climate	precipitation of coldest quarter	Wordclim variable 19	bio_19
Geographic	major river basins	Texas Water Development Board	huc4_raster
Geographic	8-digit hydrologic unit code (HUC)	United States Geologic Survey	huc8_raster
Hydrologic	cumulative drainage	National Hydrology Dataset plus	cumdrainag
Hydrologic	mean annual flow	National Hydrology Dataset plus	maflowu
Hydrologic	mean annual velocity	National Hydrology Dataset plus	mavelu

3 CONSERVATION AREA NETWORK PLANNING

We incorporated the newly created SDMs for the six priority taxa along with previously created SDMs for 130 other freshwater fishes of Texas (all derived from occurrence data extracted from the Fishes of Texas project database (www.fishesoftexas.org), available in the products section of the Fishes of Texas website documentation, with model construction detailed in Labay et al., (2011) into a conservation area prioritization analysis designed to identify potential management areas and areas of high species representation. We utilized the Tabu search algorithm implemented in the ConsNet 2.0 software package (Ciarleglio, Wesley Barnes, and Sarkar 2009; Ciarleglio, Barnes, and Sarkar 2010) for systematic conservation area planning. As is done for the SDMs, area prioritization products are delivered as images and GIS-ready grid layers in supporting documents.

We produced two sets of results aimed to serve as baseline decision support tools for policy makers and resource managers. These products are meant to be a scientifically defendable starting point for identifying areas of fish diversity. More sophisticated, multi-criteria and cost-benefit analyses can leverage these initial products by incorporating additional features such as land cost, implementation impediments, habitat condition, stakeholder feedback, or any spatial product or feature desired to support sustainability of taxa.

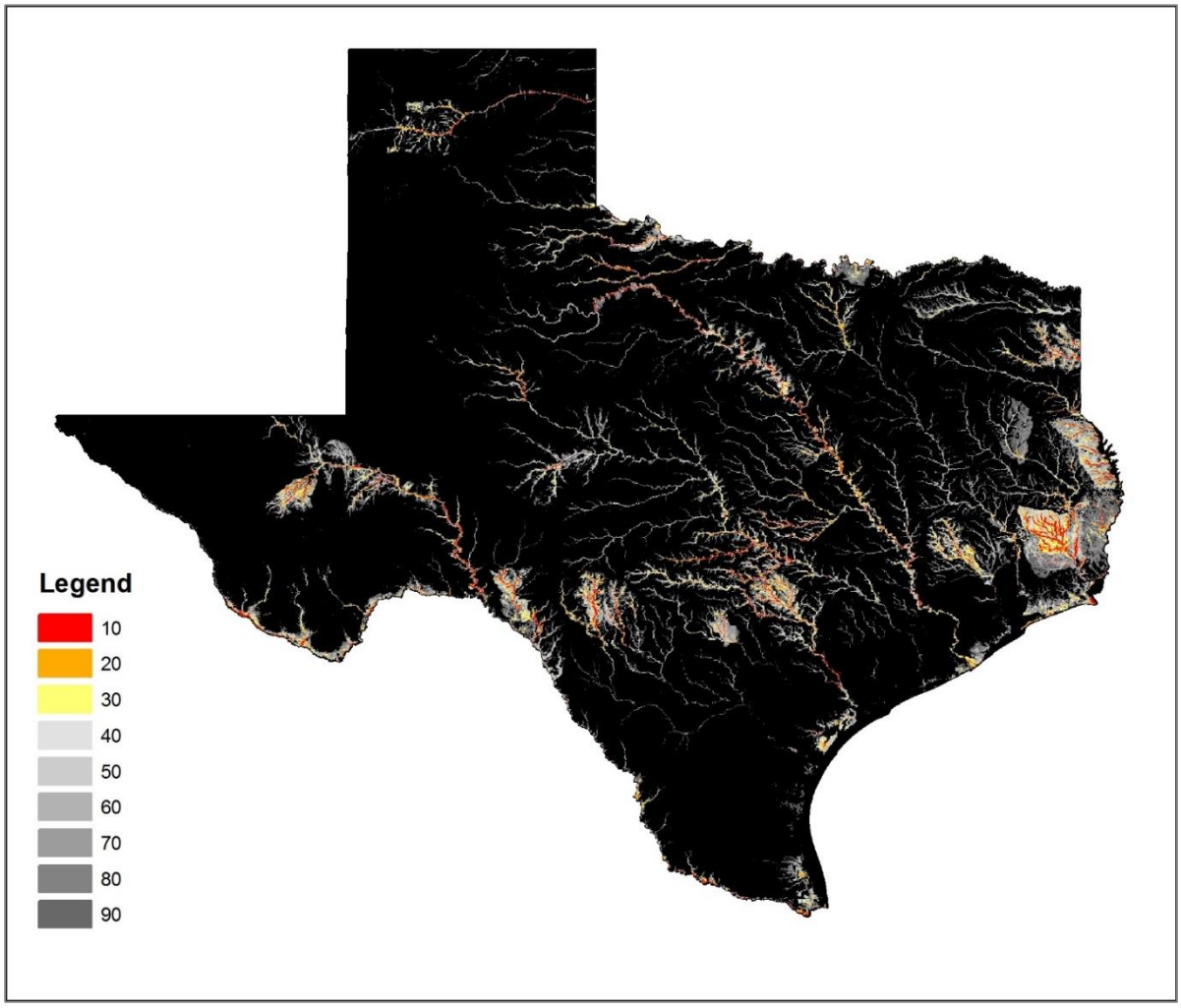

Figure 8. Map of priority areas required for the protection of 10 to 90 percent of the modeled habitat of the selected species. This was done to achieve targeted representation of the species in minimal area while maintaining as much connectivity as possible by minimizing clustering.

The first results produced are a prioritization of aquatic habitats of Texas with respect to their conservation value for fishes. These were produced with the goal of achieving targeted representation of species in minimal area (Figure 8) by identifying the top 10%, 20%, 30%,..etc. of habitat suitability for all species as measured by their aggregate probabilities in their respective SDMs. This product considers spatial representation of all taxa (via SDMs as input), and is intended to identify taxonomic diversity at various representation levels across species (all species had same representation target). This provides a map of fish diversity across the state; sort of a diversity 'hot-spot' approach to identifying areas that represent the top 10 (or 20 or 30 and so on) percent of modeled habitat for all species combined.

Second, we produced a set of management areas with species targets varying according to conservation status (Figure 9), as well as uniform targets of 20% (Figure 10) and 30% (Figure 11) for comparative purposes. The second set of areas incorporates compactness of shape and connectivity as additional criteria to help optimize planning and management practice. Note that these plans are simplistic in their results in that they do not account for aspects such as habitat condition, land use, or fragmentation, and we therefore reiterate that these map products are meant as a broad-scale starting point for discussion and more advanced planning.

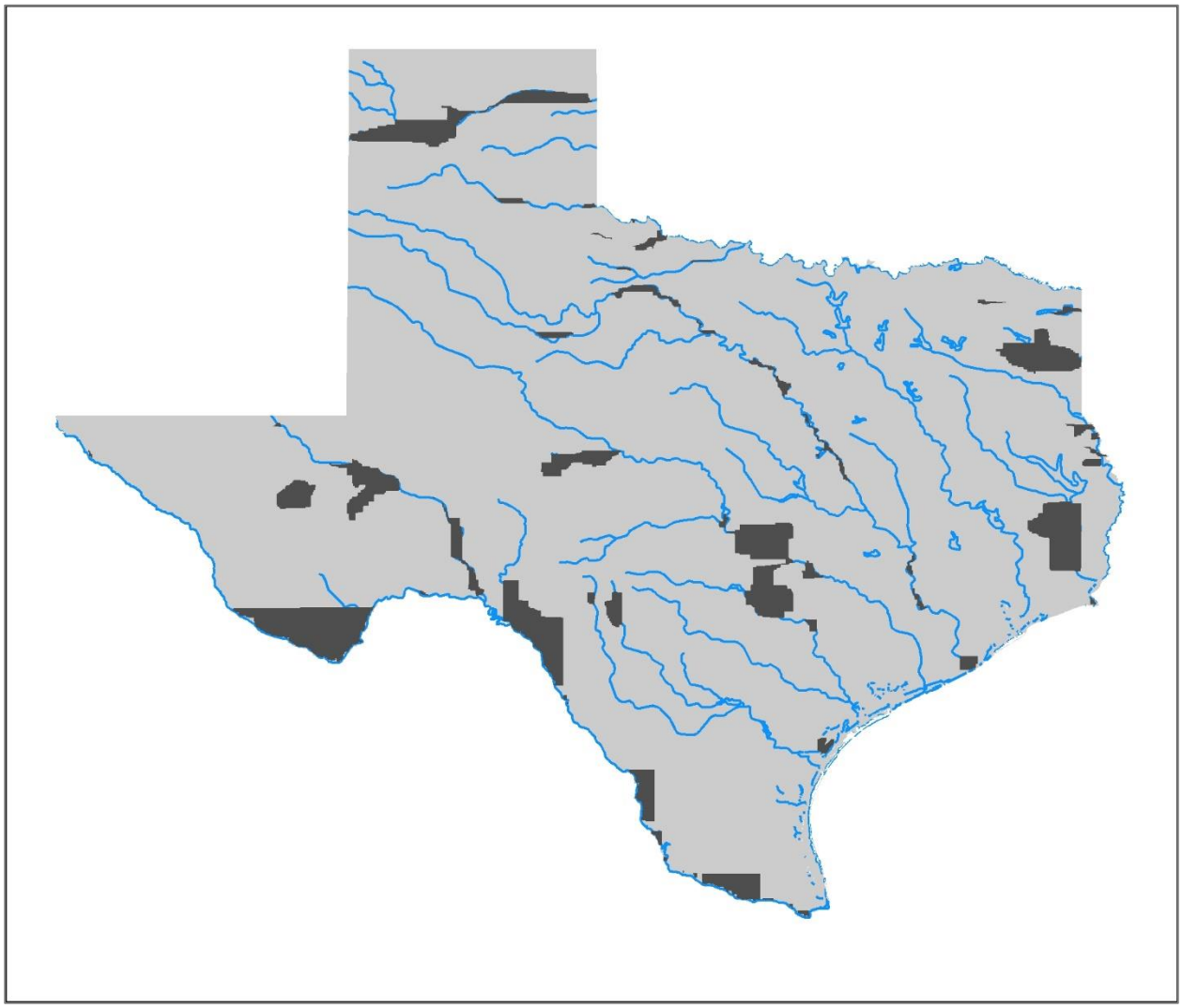

Figure 9. Map of the management areas when species targets vary according to conservation status. Species with federal status of endangered had a 90% target level, federally threatened = 67%, federal candidates for listing as well as state listed species = 50%, and all other species = 20%.

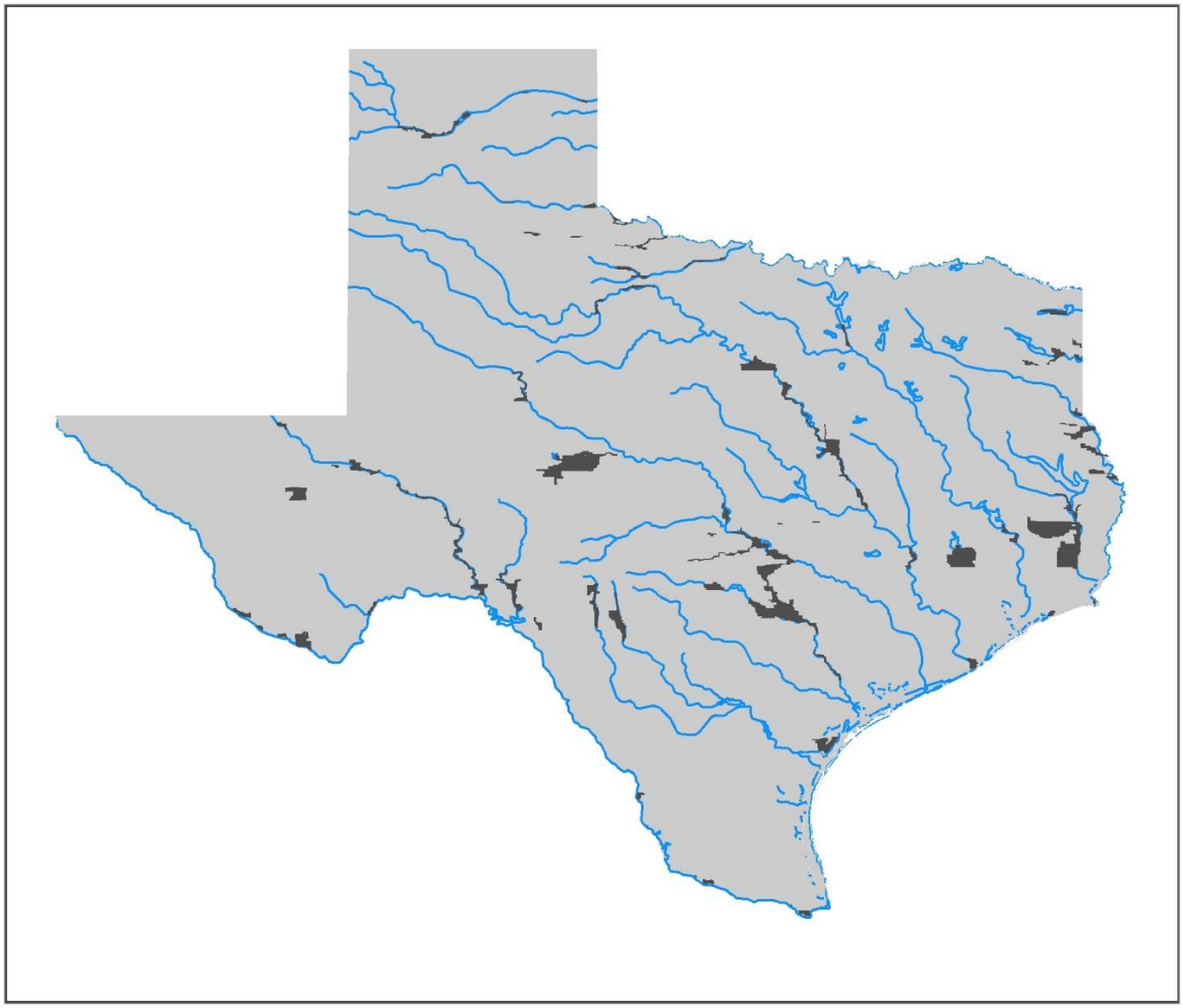

Figure 10. Map of the management areas when the targets of representation were 20 percent.

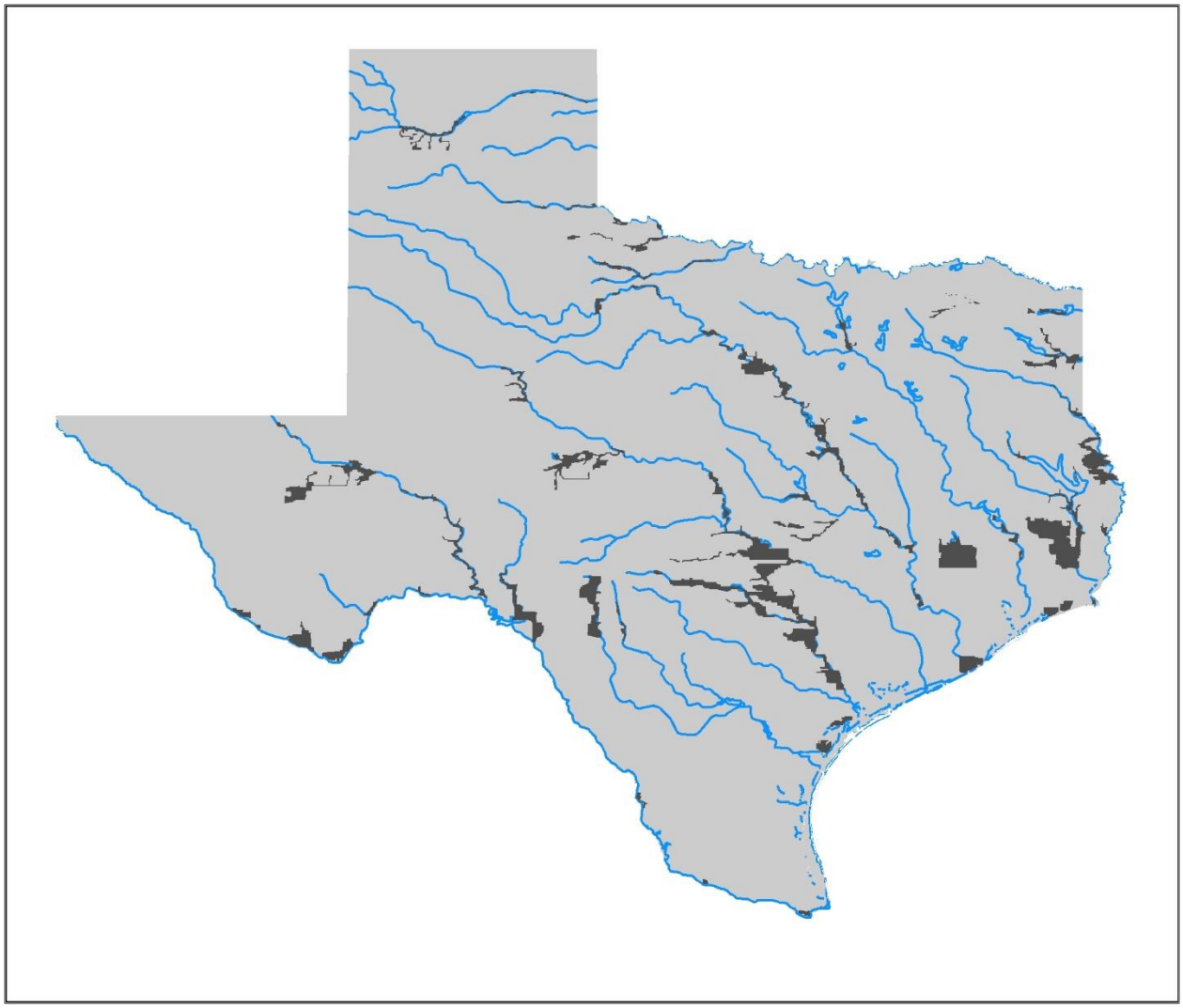

Figure 11. Map of the management areas when the targets of representation were 30 percent.

4 STATUS SURVEY

4.1 METHODS

We sampled 20 sites on the mainstem Brazos River from just below Possum Kingdom reservoir to near Bryan, Texas (Table 3 and Figure 12), using gears and methods appropriate for targeting *Notropis buccula* and *N. oxyrhynchus*. This study area was chosen in consultation with USFWS (Arlington Office) and Texas Parks and Wildlife (River Studies Division) since this reach lacks recent records of these two species and exhaustive sampling could help better assess their current status. Life history studies of these two species above Possum Kingdom Reservoir (Marks 1999) and throughout the Brazos River (Moss and Mayes 1993) indicate that both species are likely to have spawned shortly before our survey and we thus anticipated they might occur at the time of our sampling (September 17, 18, 19, 20 and October 15, 16, 2012) primarily as small individuals. We sampled each site for approximately 1-2 hours using seines of various sizes (9.14m(width) X 1.8m(height) X 0.64cm(mesh); 3.05m X 1.8m X 0.47cm; 3.66m X 2.44m X 0.47cm; and

4.57m X 1.8m X 0.32cm) to ensure capture of the entire cyprinid diversity including small (young-of-year) cyprinids, which we found present at all sites and abundant at most. Measures of survey effort were recorded in the field, including seine type, length and number of seine hauls, number of people sampling and total time spent sampling (Table 4).

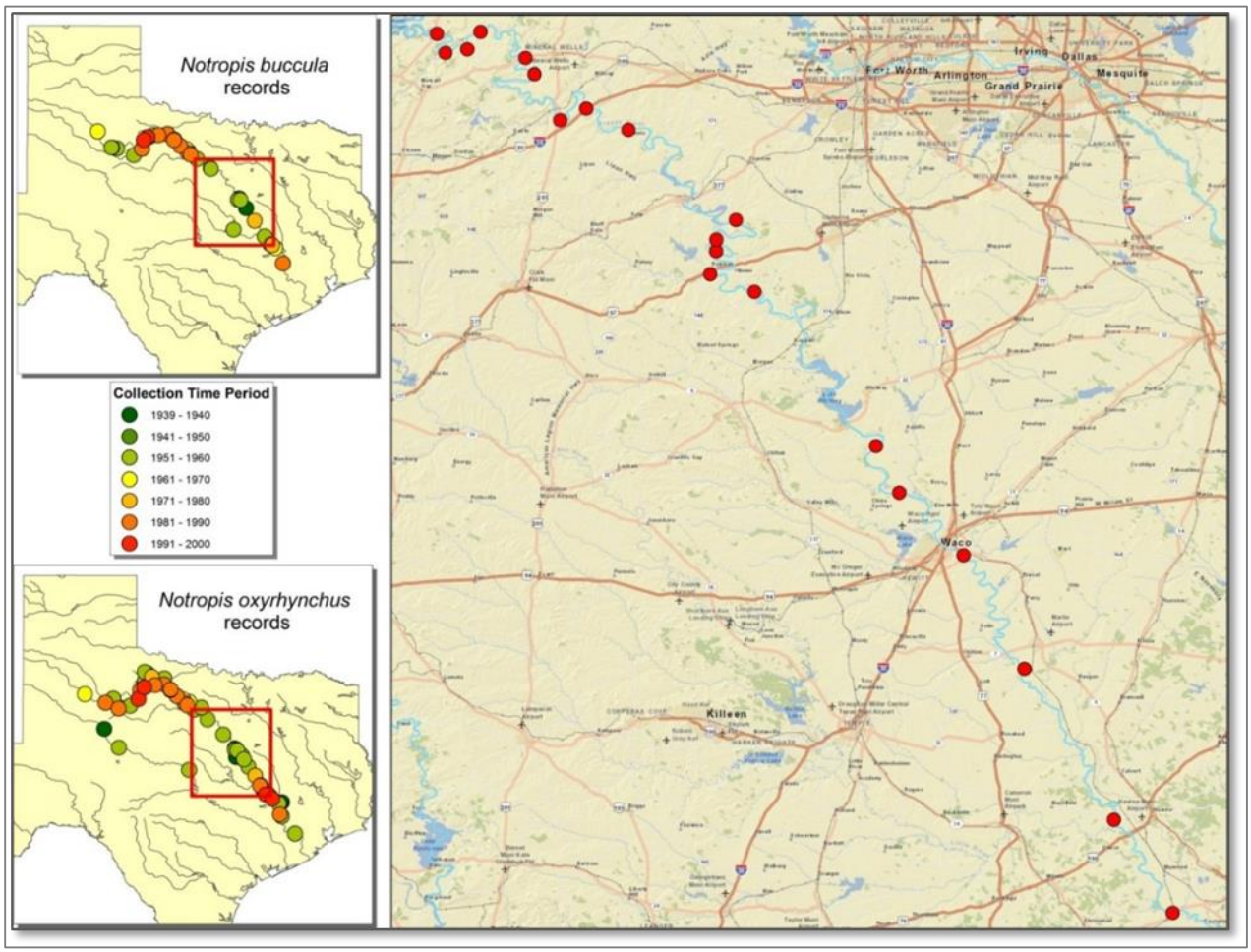

Figure 12. Map of Brazos survey site distribution. The insets indicate historic distributions of N. buccula and N. oxyrhynchus with more recent collections shown in red. The box in both insets indicate the extent of the survey.

Collection of large numbers of small specimens (at some sites filling 5-gallon buckets) and known difficulties of field identifications, especially for small cyprinids, prompted us to preserve vouchers in the field and perform nearly all identifications of these difficult-to-identify specimens in the lab with microscopes and consistent lighting. Only very easily identified species, representing an estimated <1% of individuals collected, were enumerated and released in the field. All other specimens were preserved in buffered 10% formalin and accessioned into the Texas Natural History Collections (Accession #'s 2012-35 through 2012-38 and 2012-42 and 2012-43). For select species of interest, including two introduced species, *Cyprinodon variegatus* and *Fundulus grandis*, we collected and archived tissues in our own institutional collection, Texas Natural History Collection (TNHC – http://www.utexas.edu/tmm/tnhc) for future study. Complete results of our collections and identifications are provided as Appendix 3.

4.2 NOTEWORTHY FINDINGS FROM THE SURVEY

65,840 individuals of 46 species, including 11 species of cyprinids, were collected but no specimens of the target species, *N. buccula* & *N. oxyrhynchus*, were found (Figure 13). Collections downstream of Possum Kingdom Lake to Lake Whitney (14 sites) include 5 native cyprinids, *Cyprinella venusta, Cyprinella lutrensis, Pimephales vigilax, Campostoma anomalum* (only 18 specimens), and *Notropis volucellus* (only 1 specimen). Additional cyprinid species seen below Lake Whitney include *Macrhybopsis hyostoma* (n = 23), *Notropis buchanani* (27), *Opsopoeodus emiliae* (12), *Hybognathus nuchalis* (2), *and Notemigonus crysoleucas* (5).

Non-native species captured represented 2.5% of total fish captured, and included *Cyprinus carpio (4 individuals), Lepomis auritus (90), Cyprinodon variegatus (1,339), Fundulus grandis (203),* and *Oreochromis aureus (1).*

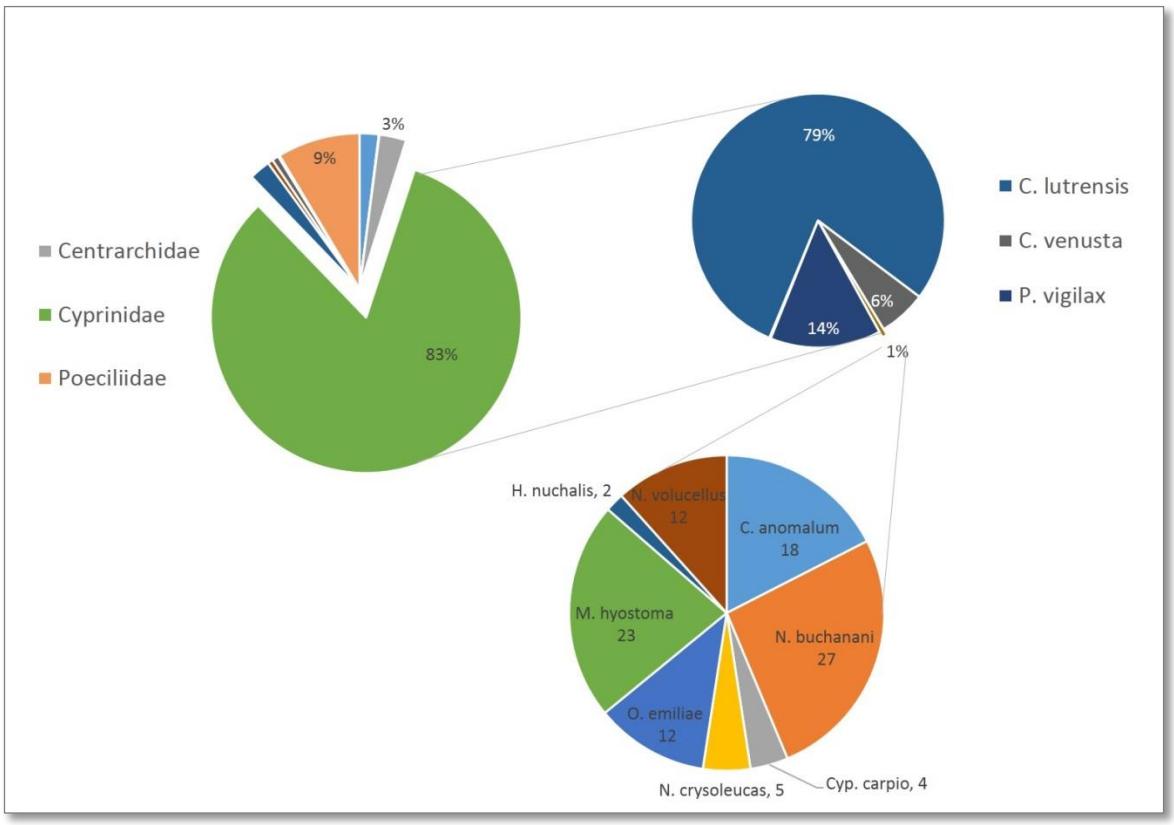

Figure 13. Proportions of various species collected. The three individual charts include families, species within Cyprinidae, and numbers of cyprinids captured other than C. lutrensis, C. venusta, and P. vigilax.

The introduced species, *Cyprinodon variegatus*, was found at most sites above Lake Whitney in large numbers (Figure 14), but were clearly under-represented in our collections due to their ability to retreat into cobble substrates and evade capture by seine.

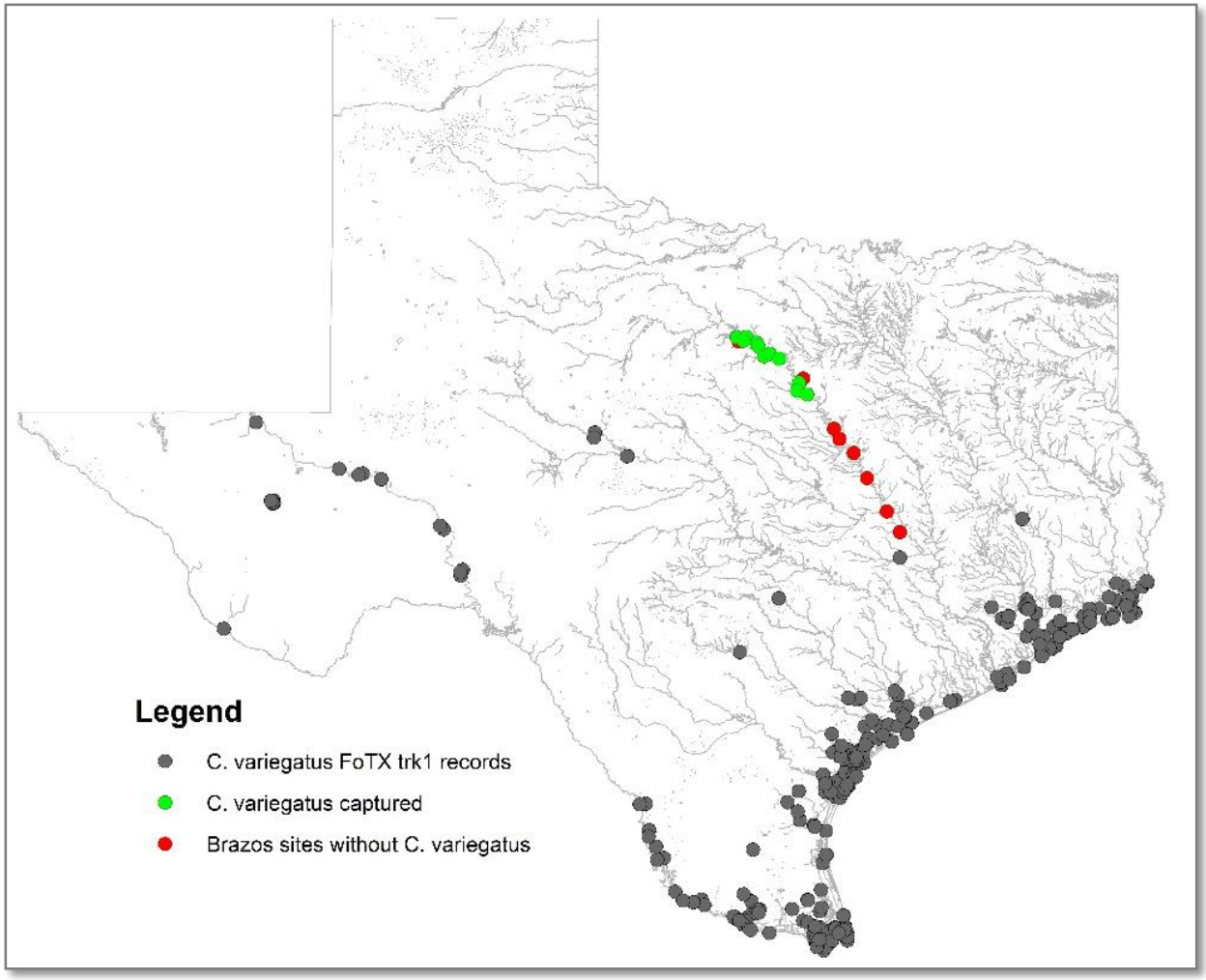

Figure 14. Distribution of Cyprinodon variegatus captured during survey shown alongside records from the Fishes of Texas Project's initial dataset of specimen-based records (track1) which documents the distribution prior to discovery of this species in the upper and middle Brazos.

The introduced species, *Fundulus grandis*, was found at most sites above Waco (Figure 15) and often inhabiting riffles (not available in their native marine/estuarine habitat).

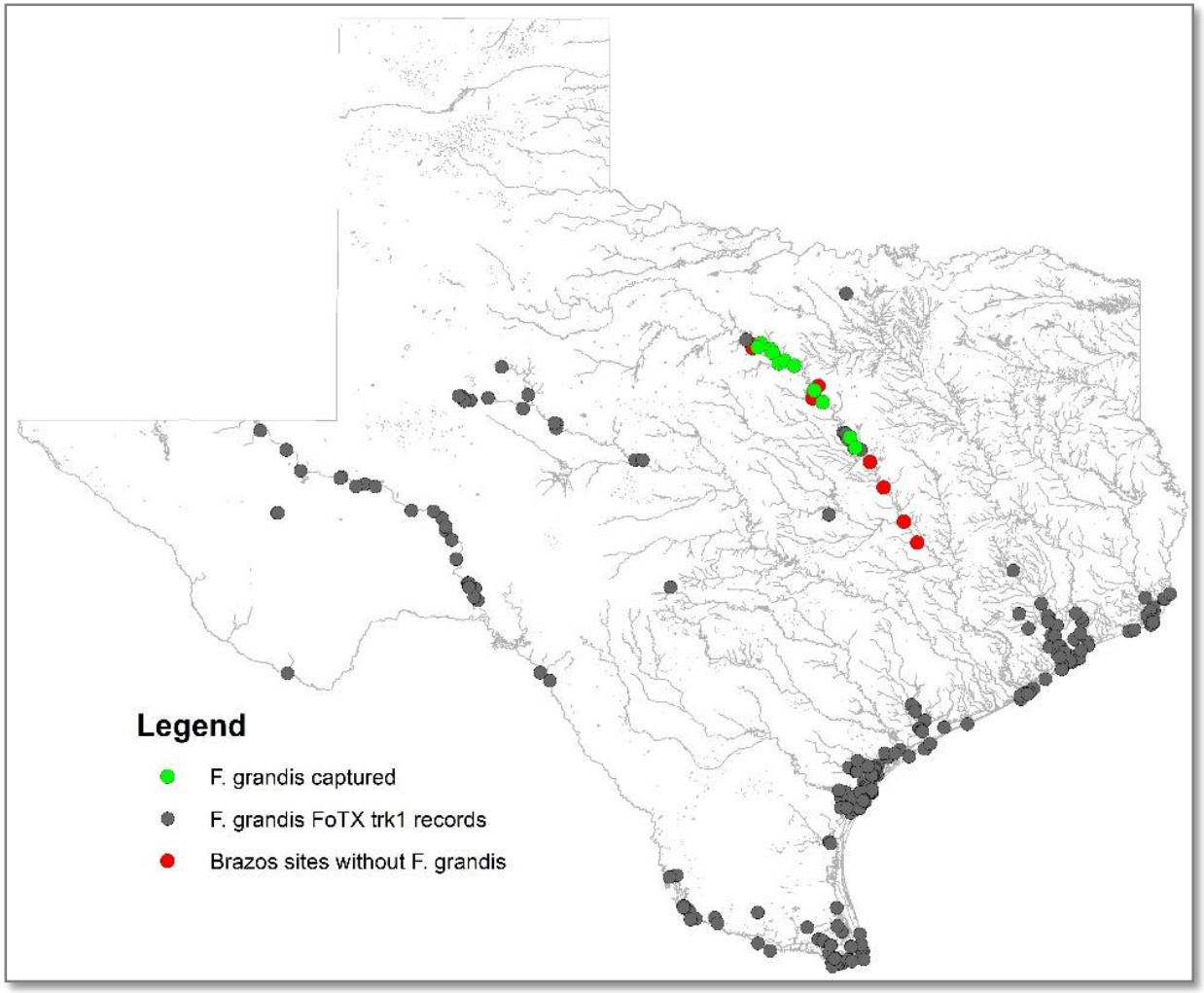

Figure 15. Distribution of Fundulus grandis captured during survey shown alongside records from the Fishes of Texas Project's initial dataset of specimen-based records (track1) which documents the distribution prior to our survey.

The known range of *Poecilia latipinna* was extended by this survey to include the lower Brazos River mainstem upstream to Bryan (Figure 16). Prior to this survey the species had been taken from the mainstem near Rosharon (specimen voucher TNHC 42679) in the lowest reaches of the river, but had also been recorded from other locations in the Brazos drainage including the San Gabriel River, which is thermally buffered by plentiful springs, and in a small isolated roadside pond near College Station.

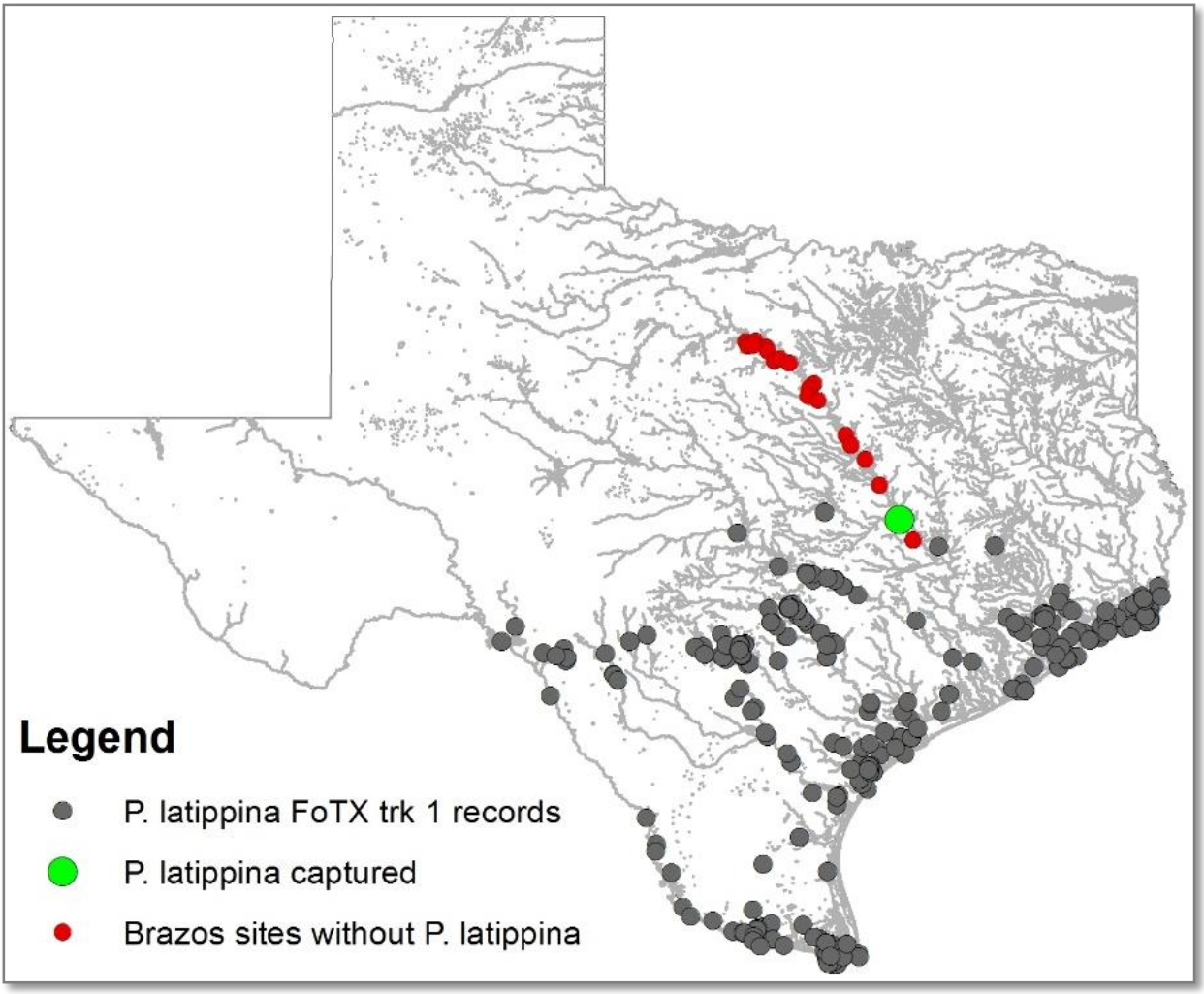

Figure 16. Distribution of Poecilia latipinna captured during survey shown alongside records from the Fishes of Texas Project's initial dataset of specimen-based records (Track1) which documents the distribution prior to discovery of this species in the middle Brazos.

4.3 Summary of findings

Relevant to this project's primary objectives, the most significant finding was our inability to collect these two species from the Brazos mainstem despite considerable effort. Our 22.2 hours of seine dragging sampled a total of 6.84 linear km (including 3.99 km with a 0.32cm mesh seine for collecting small individuals) and strained approximately 34,006,974 liters of mainstem water. The same reach was surveyed for these species in the late 1980's and early 1990's (Moss and Mayes 1993) with the same result, though that survey did collect them both further downstream and above Possum Kingdom reservoir. The Fishes of Texas database (www.fishesoftexas) of historical specimen-based occurrences contains 653 fish occurrence records including 73 species, from our study reach. The last record of *N. buccula* collected from our study reach was in 1976 (TCWC 38.07) and the last record of *N. oxyrhynchus* was in 1988 (TCWC 10862.01). These two surveys, over a decade apart, each failing to sample these species, in conjunction with data provided by the Fishes of Texas database, strongly suggest that both *N. buccula* and *N. oxyrhynchus* are now absent, or at least very rare, in the reach sampled in this project.

It is worth noting that Texas Parks and Wildlife Department released approximately 700 reproductive individuals of *N. buccula* and *N. oxyrhynchus* to the Brazos River at the crossing of FM 485 near Hearne, TX on May 29, 2012 (Hodge 2012; Tresaugue 2012). We sampled at this location and sites short distances above and below on October 16, 2012, approximately 5 months after the release, and did not recover any adults or young.

Our survey results indicate that the Brazos River above Waco and below Possum Kingdom Reservoir (the upper section of our survey reach) harbors much lower fish diversity than it did historically. The Fishes of Texas Project database (http://www.fishesoftexas.org) has records of 52 fish species from this river segment, while our recent survey documented 38 species (including 6 non-natives) – a reduction of 39%. Though our survey's methods were clearly not optimal for detection of all fishes, and the temporal extent of our sampling limited, the gears used and effort expended should have confidently detected all species of cyprinids. Twenty cyprinid species are documented from this reach by the Fishes of Texas database and we found only 5 in this survey - a reduction of 75%.

The survey data indicate that this reach is less diverse relative to the segment immediately below (Figure 17). Despite the much lower sampling intensity in the segment below Waco (4 sites) compared to above Waco (16 sites) we recorded 10 cyprinid species below Waco, or double the number found above there. This also supports our contention that our methods were appropriate for cyprinids.

This reduced diversity (especially among cyprinids) along with our collections of 6 non-natives above Waco, including the now ubiquitous and relatively recently introduced *Cyprinodon variegatus* and *Fundulus grandis*, suggests a deviation from historic condition, specific to this reach (or at least lesser so further downstream), that we think likely related to habitat fragmentation and hydrologic alteration of flows via controlled releases from Lake Whitney, Lake Granbury, and Possum Kingdom Reservoir. Our supposition that these reservoirs are impacting fish diversity is well supported by other sources (Moss and Mayes 1993; Durham and Wilde 2009; Perkin and Gido 2011).

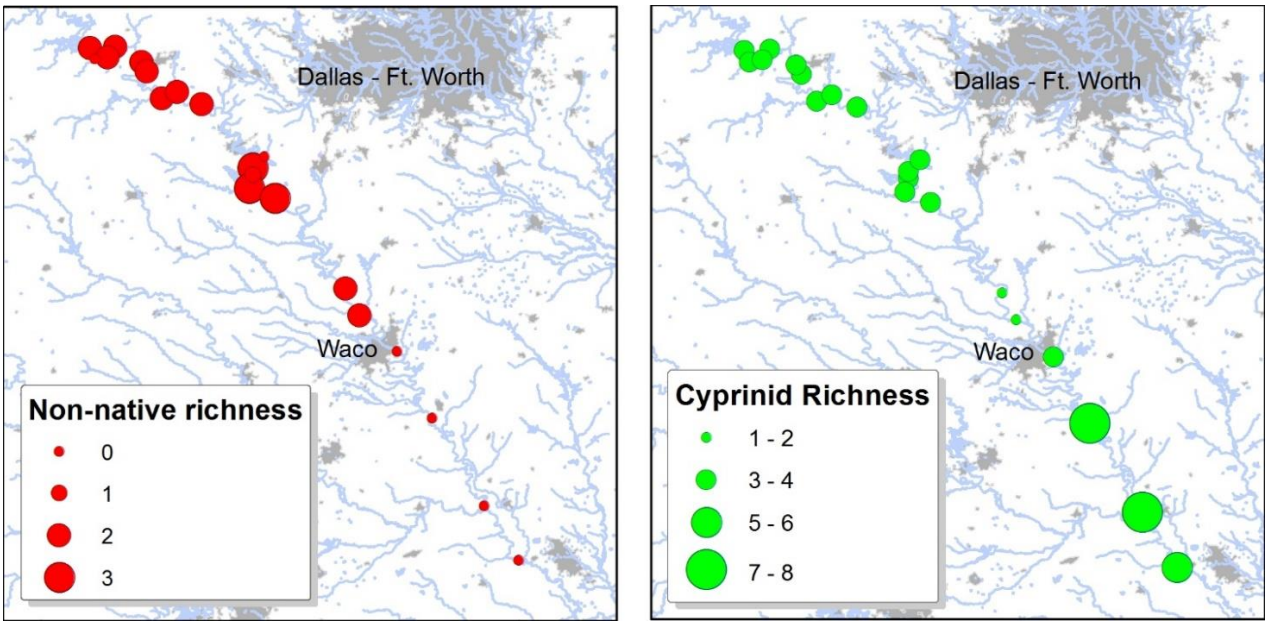

Figure 17. Patterns of non-native and cyprinid richness across survey sites in the Brazos River. Cyprinid richness values exclude records of the non-native common carp.

4.4 SURVEY ADDENDUM

Somewhat outside the specific scope of this project, near the end of this project we sampled an additional six sites on five tributaries of the Brazos in the vicinity of Waco (in McLennan and Hill counties; on Anguilla Creek (2 sites), Blue Hole Branch, North Branch Rock Creek, White Rock Creek and Tehuacana Creek). We believe the target species have a low probability of occurring in these tributaries since they are known to prefer mainstem habitat (Marks 1999; Moss and Mayes 1993) and all collections of this species documented in the Fishes of Texas database are from mainstem sites. However, given the degradation of this preferred habitat in this reach of the Brazos we thought it prudent to sample in some tributaries since it is possible that either species may have shifted habitat. This additional sampling was performed on July 11-12, 2013 and September 9, 2013 using seines (3.66m X 2.44m X 0.47cm) for approximately 40 minutes at each site. All specimens were brought back to the lab for careful identification and were being processed (sorted, identified, counted and cataloged) into the Texas Natural History Collections, Ichthyology Collection at the time this report was produced. We have sorted and identified specimens from four of the six sites, and those four collections average of 10.8 species per site and the target species were not collected at any of these sites. The other two sites remain completely unprocessed at the time of this writing; however our field observations indicate that neither target species was collected at these sites. The complete specimen holdings from these six sites, as well as specimens from another six upper Brazos sites collected August 5-6, 2013, will be available via the Global Biodiversity Information Facility (http://www.gbif.org/) and the Fishes of Texas Project (http://www.fishesoftexas.org/).

Table 3. Brazos survey site details and sampling dates.

Field Number	Sample Date	Site No.	Locality	Latitude	Longitude	Richness
AEC20120917-1	17-09-2012	1	Brazos River at SH 16	32.85882	-98.41138	14
AEC20120917-2	17-09-2012	2	Brazos River at Fortune Bend	32.81015	-98.3897	20
AEC20120917-3	17-09-2012	3	Brazos River at SH4	32.86373	-98.30083	16
AEC20120918-1	18-09-2012	4	Brazos River at US 180	32.79769	-98.18677	16
AEC20120918-2	18-09-2012	5	Brazos River at Worth Ranch (at Chick Bend)	32.81932	-98.3345	18
AEC20120918-3	18-09-2012	6	Brazos River at Pleasant Valley Rd.	32.75629	-98.16403	16
AEC20120918-4	18-09-2012	7	Brazos River at US 281	32.63981	-98.09856	25
AEC20120918-5	18-09-2012	8	Brazos River at IH20	32.6687	-98.0326	13
AEC20120919-1	19-09-2012	9	Brazos River at SH 1189/1543	32.61544	-97.92551	19
AEC20120919-2	19-09-2012	10	Brazos River at Pecan Plantation Ranch	32.38667	-97.65238	12
AEC20120919-3	19-09-2012	11	Brazos River at Camp Arrowhead (Cox Bend)	32.30728	-97.70258	15
AEC20120920-1	20-09-2012	12	Brazos River, btw Mitchell and Abby Bends	32.33677	-97.70193	16
AEC20120920-2	20-09-2012	13	Brazos River at confluence with Paluxy River	32.24883	-97.71767	18
AEC20120920-3	20-09-2012	14	Brazos River at CR 1118 (near Brazos Point)	32.20422	-97.60564	17
AEC20121015-1	15-10-2012	15	Brazos River at SH 2114	31.81266	-97.29712	9
AEC20121015-2	15-10-2012	16	Brazos River at Brazos River R.V. Park	31.69503	-97.23769	12
AEC20121015-3	15-10-2012	17	Brazos River at SH6/SH340, E of Waco	31.53622	-97.07484	14
AEC20121016-1	16-10-2012	18	Brazos River at falls, downstream of SH 712	31.24776	-96.92029	20
AEC20121016-2	16-10-2012	19	Brazos River at SH 485, W of Hearne	30.86528	-96.69343	17
AEC20121016-3	16-10-2012	20	Brazos River at SH 21, W of Bryan	30.62884	-96.54406	15

Table 4. Brazos survey effort summary. Total length (meters) of all seine hauls at each sample site by seine dimensions (width X height X mesh).

Site	9.14m X 1.8m X 0.64cm	3.66m X 2.44m X 0.47cm	3.05m X 1.8m X 0.47cm	4.57m X 1.8m X 0.32cm	Total length	Sampling time (hr:min)
Brazos River at SH 16	265.18	0.00	0.00	124.97	390.14	1:15
Brazos River at Fortune Bend	143.26	0.00	0.00	188.98	332.23	2:00
Brazos River at SH4	45.72	0.00	42.67	100.58	188.98	1:10
Brazos River at US 180	124.97	0.00	30.48	198.12	353.57	1:00
Brazos River at Worth Ranch (at Chick Bend)	160.02	0.00	0.00	149.35	309.37	0:50
Brazos River at Pleasant Valley Rd.	100.58	0.00	0.00	199.64	300.23	0:50
Brazos River at US 281	100.58	0.00	0.00	294.13	394.72	1:10
Brazos River at IH20	85.34	0.00	0.00	265.18	350.52	0:30
Brazos River at SH 1189/1543	97.54	0.00	41.15	350.52	489.20	0:45
Brazos River at Pecan Plantation Ranch	0.00	0.00	48.77	169.16	217.93	0:40
Brazos River at Camp Arrowhead (Cox Bend)	39.62	0.00	48.77	249.94	338.33	1:15
Brazos River, btw Mitchell and Abby Bend	128.02	0.00	76.20	214.88	419.10	1:20
Brazos River at confluence with Paluxy River	243.84	0.00	0.00	65.53	309.37	0:50
Brazos River at CR 1118 (near Brazos Point)	94.49	0.00	243.84	45.72	384.05	0:25
Brazos River at SH 2114	0.00	190.50	0.00	219.46	409.96	1:40
Brazos River at Brazos River R.V. Park	0.00	27.43	0.00	225.55	252.98	1:30
Brazos River at SH6/SH340, E of Waco	0.00	344.42	0.00	335.28	679.70	1:25
Brazos River at falls, downstream of SH 712	0.00	0.00	124.97	118.87	243.84	2:00
Brazos River at SH 485, W of Hearne	0.00	0.00	0.00	222.50	222.50	1:15
Brazos River at SH 21, W of Bryan	0.00	0.00	0.00	249.94	249.94	0:30

5 ACKNOWLEDGEMENTS

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Ed Lowe (Friends of the Brazos River): Brazos River access and lodging.

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Hayley Gillespie (Texas Natural History Collections volunteer): Fieldwork assistance.

Floyd Douglas Martin (Texas Natural History Collections volunteer): Specimen identification.

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7 SUGGESTED CITATION

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APPENDIX 1. QUERY METADATA FOR INITIAL DATA GATHERING OF TARGET SPECIES OCCURRENCE DATA

Direct Data Source	url	N Records Received	Date Accessed	Query Specifications	Database Description
FishNet2	http://www.fishnet2.net/	4471	Nov 9, 2010	Unbounded by geography and limited only by target species names (including historical synonyms)	Includes global data on fish occurrences from numerous data sources.
FishBase	http://www.fishbase.org/search.php	201	Nov 2010	Unbounded by geography and limited only by target species names (including historical synonyms)	Includes global data on fish occurrences from numerous data sources.
Global Biodiversity Information Facility (GBIF)	http://www.gbif.org/	8686	Nov 3-8, 2010	Unbounded by geography and limited only by target species names (including historical synonyms)	Includes global data on organism occurrences from numerous data sources.
Great Plains Landscape Conservation Cooperative (GPLCC) project database (Hendrickson et al. 2012)		41098	Aug, 31, 2010 (CSU); Sept 16, 2010 (MSB); June 28, 2010 (OMNH)	all fish data within the GPLCC area	Dataset includes occurrence data for various animal taxa within the GPLCC area; for fish it includes data from Colorado State Univ., Museum of Southwestern Bio., and Oklahoma Museum of Natural History
Fishes of Texas Project	www.fishesoftexas.org	46504	Feb 14, 2012	Query includes all out of TX records, but target species and Rio Grande records within TX	Includes fish specimen data from 44 institutions
Global Biodiversity Information Facility (GBIF)	http://www.gbif.org/	33469	July 2011	Request for fish data within DLCC area (donors often provided from larger geographic area)	Includes global data on organism occurrences from numerous data sources.

FishNet2	http://www.fishnet2.net/	63508	July 2011	Request for fish data within DLCC area (donors often provided from larger geographic area)	Includes global data on fish occurrences from numerous data sources.
SONO DB	NA	1948	July 2011	Request for fish data within DLCC area (donors often provided from larger geographic area)	Compiled by by Peter Unmack includes unvouchered and specimen-vouchered records from northern Mexico via 18 institutions
University of Michigan Ichthyology Collection	http://www.lsa.umich.edu/ummz/fishes/	3826	July 2011	Request for fish data within DLCC area (donors often provided from larger geographic area)	
New Mexico Biodiversity Collections Consortium	http://nmbiodiversity.org/index.php	2690	Jan 19, 2012	all fish data	Database restricted to New Mexico records only
University of Alabama Ichthyology Collection	http://www.as.ua.edu/uaic/	212	Feb 14, 2012	Request for fish data within DLCC area (donors often provided from larger geographic area)	

Universidad Nacional Autónoma de México, Ichthyology Collection	http://www.ibiologia.unam.mx/zoologia/html_09/coleccion.php?nick=cnpe&titulo=Colecci%C3%B3n%20Nacional%20de%20Peces	793	Oct 12, 2012	Request for fish data within DLCC area (donors often provided from larger geographic area)	
Cuatro Ciénegas database	NA	2476	Feb 10, 2012	All data	Compiled by Dean Hendrickson and Adam Cohen; contains unvouchered and specimen-vouchered data from Cuatro Cienegas Basin and Rio Salado de los Nadadores in Coahuila Mexico
Global Biodiversity Information Facility (GBIF)	http://www.gbif.org/	184454	Jan 31, 2012	fish from Texas' neighbor states	Includes global data on organism occurrences from numerous data sources.
FishNet2	http://www.fishnet2.net/	118435	Jan 30, 2012	fish from Texas' neighbor states	Includes global data on fish occurrences from numerous data sources.

APPENDIX 2. ALL ENTITIES CONTRIBUTING DATA TO THE INITIAL DATASET AND ACCEPTED CODONS.

Institution code	Institution/Collection Name
OZCAM	Online Zoological Collections of Australian Museums
AMNH	American Museum of Natural History, New York; see also F:AM (paleo)
ANSP	Academy of Natural Sciences, Philadelphia, Pennsylvania; current for fishes, herps and vertebrate paleontology as three separately cataloged collections
ARC	Atlantic Reference Centre, St. Andrews, New Brunswick
ASU	Arizona State University
AZGF	Arizona Game and Fish Department
BMNH	Natural History Museum [formerly British Museum (Natural History)], London; also as NHM
BPBM	Bernice P. Bishop Museum, Department of Zoology, Honolulu, Hawaii
BYU	Brigham Young University, Monte L. Bean Life Science Museum, Provo, Utah

CAS	California Academy of Sciences, San Francisco, California; also as CAS-GVF, CAS-IU, CAS-SU
CIAD	Centro de Investigación en Alimentación y Desarrollo, A.C., Hermosillo, Sonora; current for fishes; also as CES (herps).
CICIMAR	Centro Interdisciplinario de Ciencias Marinas, Instituto Politécnico Nacional, La Paz, Baja California Sur; also as CI (Colección Ictiológica del CICIMAR), CICIMAR-CI (for non-ictioplancton vs. CICIMAR for ictioplancton)
CMNFI	Canadian Museum of Nature Fish Collection, Ottawa; also as NMC, National Museums of Canada; Includes VMMB collection
FMNH	Field Museum of Natural History, Zoology Department, Chicago, Illinois [obsolete as CNHM, Chicago Natural History Museum]; includes fishes from IU.
CSIRO	Commonwealth Scientific & Industrial Research Organisation, Division of Marine & Atmospheric Research, Hobart, Tasmania; formerly Division of Fisheries & Oceanography at Cronulla, NSW; includes specimens from Marine Lab, Sydney
CU	Cornell University Museum of Vertebrates, Ithaca, New York; also as CUMV
DEDSZC	Comisión Nacional para el Conocimiento y Uso de la Biodiversidad
DGR	Arctos - DGR Fishes Specimens
ENCB-IPN	Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional, Mexico City; current for fishes; also as IPN, IPN-ENCB (both obsolete for fishes).
ENMU	Eastern New Mexico University, Portales, New Mexico

CPUM	Universidad Michoacana de San Nicolás de Hidalgo, Facultad de Biologia, Laboratory de Biologia Acuática, Morelia, Michoacán; current for fishes; also as UMSNH (herps)
UANL	Universidad Autónoma de Nuevo León, Facultad de Ciencias Biológicas, Departamento de Zoología de Vertebrados, San Nicolás de los Garza [also as Monterrey], Nuevo León; also as FCB (obsolete)
GCRL	Gulf Coast Research Laboratory, The University of Southern Mississippi, Ocean Springs, Mississippi; also as GCRLM; Some specimens moved to USM
GNM	Göteborgs Naturhistoriska Museum, Göteborg; replaces NHMG (sensu Leviton et al. 1985), also as GNHM, NMG
HU	unknown "HU"
CNP-IBUNAM	Colección Nacional de Peces, Instituto de Biología, Universidad Nacional Autónoma de México (UNAM), Mexico City; also as IBUNAM, UNAM, UNAM-CNPE (all obsolete for fishes)
IIPB	Instituto de Ciencias del Mar [formerly Instituto de Investigaciones Pesqueras], Departament de Biologia Marina i Oceanografia, Barcelona; also as ICM
ITESM	Inventario y monitoreo del Canal de Infiernillo para el comanejo de los recursos marinos en el territorio Seri, Golfo de California
IGFA	unknown "IGFA"
ITESM-OTO	Consolidacion y sistematizacion de las colecciones de referencia de peces y mamiferos marinos del ITESM Campus Guaymas
ITLM	Genetica y taxonomia de los robalos (Centropomus spp) del golfo de California, Mexico

JFBM	[James Ford] Bell Museum of Natural History, University of Minnesota, Minneapolis, Minnesota
KU	University of Kansas Natural History Museum, Lawrence, Kansas; current for Recent fishes and herps; see KUVP for paleo collection
LACM	Natural History Museum of Los Angeles County, Los Angeles, California
LBM	National Museum of Nature and Science, Japan, Freshwater Fish Specimens of Lake Biwa Museum
LEMA	Inventario de la biota marina (invertebrados, peces y macroalgas bentonicos) del parque nacional Isla Isabel
LSUMZ	Louisiana Museum of Natural History [formerly Louisiana State University, Museum of Zoology (-1999)], Baton Rouge, Louisiana
MDUG	Museo Alfredo Dugès, Universidad de Guanajuato, Guanajuato; contains many herp types of Dugès; also as MADUG
MCNB	Museu de Ciencies Naturals de Barcelona: MCNB-Cord
MCZ	Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts; also as MCZH
MNHP	Národní muzeum [National Museum], Prague; also as MHP, NMP6V (both herps)
MMNS	Mississippi Museum of Natural Science [formerly Fannye A. Cook Memorial Museum], Jackson, Mississippi; some Cook fish specimens at FMNH, USNM, AMNH

MNCN	Museo Nacional de Ciencias Naturales, Madrid
MHNM	Museo Nacional de Historia Natural y Antropología (MUNHINA) [formerly Museo de Historia Natural de Montevideo], Montevideo; suggested replacement for MNHN
MNHN A	Museo Nacional de Historia Natural y Antropología (MUNHINA) [formerly Museo de Historia Natural de Montevideo], Montevideo; suggested replacement for MNHN
MNHN BE	Museo Nacional de Historia Natural y Antropología (MUNHINA) [formerly Museo de Historia Natural de Montevideo], Montevideo; suggested replacement for MNHN
MSB	Museum of Southwestern Biology, Department of Biology, University of New Mexico, Albuquerque; also as UNM
MSU	Mississippi State University, Mississippi
MSUM	Michigan State University Museum, East Lansing, Michigan; also as MSU (obsolete)
MTKD	Museum für Tierkunde, Senckenberg Naturhistorische Sammlungen [Staatliche Naturhistorische Sammlungen], Dresden; also as MTD
MVZ	Museum of Vertebrate Zoology, University of California at Berkeley, California; also as BNHM (obsolete); most of fish collection now at CAS
MZUS	Musée Zoologique de la ville de Strasbourg, Université de Strasbourg [includes formerly independent Université Louis-Pasteur], Strasbourg; also as MZS
NCSM	North Carolina Museum of Natural Sciences [formerly North Carolina State Museum], Raleigh, North Carolina

ND	Especies de peces introducidas en aguas continentales de Mexico. Catilogo y manuscrito
No proporcionado	Diversidad dinamica y patrones reproductivos en la comunidad de peces demersales del Golfo de Tehuantepec
not recorded	not recorded
NRM	Naturhistoriska Riksmuseet, Department of Vertebrate Zoology, Stockholm; Replaces NHRM (sensu Leviton et al. 1985); also seen as SMNH, NRMS
NTSRV	NatureServ
NTUM	National Taiwan University, Institute of Zoology, Taipei
OMNH	University of Oklahoma, Sam Noble Oklahoma Museum of Natural History [formerly Stovall Museum], Norman, Oklahoma; currently used for cataloging fishes & herps (also as OMNH-N); previously proposed abbreviation UOMZ (Leviton et al. 1985) not adopted; alternative abbreviation OKMNH proposed by Leviton & Gibbs (1988) cited in publications for fishes
OSM	Ohio State University, Museum of Biological Diversity, Museum of Zoology, Columbus, Ohio; also as OSUM (obsolete)
OSUS	Oklahoma State University, Department of Zoology, Stillwater, Oklahoma; also as OAM, OSUMZ (both obsolete)
PBDB	Marine Science Institute, UCSB, Paleobiology Database
RMNH	Naturalis–Nationaal Natuurhistorisch Museum [formerly Rijksmuseum van Natuurlijke Historie], Leiden; dry fish collection preceded by "D"; museum officially includes collections of ZMA which ultimately will be transferred from Amsterdam to Leiden.

ROM	Royal Ontario Museum, Department of Natural History, Toronto, Ontario
ROM-CID	Royal Ontario Museum, Department of Natural History, Toronto, Ontario
RUSI	Rhodes University and the Council for Scientific and Industrial Research, J.L.B. Smith Institute of Ichthyology, Grahamstown; renamed SAIAB.
S	unknown "S"
SAIAB	South African Institute for Aquatic Biodiversity, [formerly Rhodes University, J.L.B. Smith Institute of Ichthyology (RUSI)], Grahamstown
SAMA	South Australian Museum, Adelaide, South Australia
SBMNH	Santa Barbara Museum of Natural History, Santa Barbara, California
SIO	Scripps Institution of Oceanography, Marine Vertebrate Collection, La Jolla, California
SMK	Sarawak Museum, Kuching; also as SM.
SM-AM	Registro de datos de peces del pacifico mexicano de la Coleccion Biologica de la Secretaria de Marina
SMF	Senckenberg Forschungsinstitut und Naturmuseum [alternatively Senckenberg Research Institute and Natural History Museum], Frankfurt

SMNS	Staatliches Museum für Naturkunde, Stuttgart; also as MNS
SU	Stanford University, Palo Alto, California; also as LSJUM; Fishes transferred to CAS (CAS-SU) with 100,000 added to each SU catalog numbers for computerization
TCWC	Texas Cooperative Wildlife Collection, Texas A&M University, College Station, Texas
TNHC	Texas Natural History Collections, Texas Natural Science Center, Texas Memorial Museum, University of Texas at Austin, Austin, Texas
TU	Tulane University Museum of Natural History [formerly F. Edward Hebert Riverside Research Laboratories (fishes)], Belle Chasse, Louisiana
UAMZ	University of Alberta, Museum of Zoology, Edmonton, Alberta; see also UALVP for paleo collections
UABC	Universidad Autónoma de Baja California, Ensenada, Baja California; also as CI-UABC (for fishes)
UAChi	Peces de la region de Norogachi, Alta Sierra Tarahumara, Chihuahua
ARK	University of Arkansas, Museum, Fayetteville
UAM	University of Alaska Museum of the North, Fairbanks, Alaska
UAZ	University of Arizona, Department of Ecology and Evolutionary Biology, Tucson, Arizona; also as UA

UBC	University of British Columbia, Cowan Vertebrate Museum [part of Beaty Biodiversity Museum], Vancouver, British Columbia
UCD	University of California, College of Biological Sciences, Davis, California
UCLA	University of California at Los Angeles, Department of Ecology and Evolutionary Biology [formerly Biology], Los Angeles, California; much of fish collection now at LACM
UCM	University of Colorado Museum of Natural History, Boulder, Colorado
UMZC	University Museum of Zoology, University of Cambridge, Cambridge, England; also as ZMC
UMMZ	University of Michigan Museum of Zoology, Ann Arbor, Michigan
UNSM	University of Nebraska State Museum, Lincoln; replaces UN (sensu Leviton et al. 1985)
USGS-NAS	United States Geological Survey, Nonindigenous Aquatic Species Database
USNM	National Museum of Natural History, Smithsonian Institution [formerly United States National Museum], Department of Vertebrate Zoology, Washington D.C.
USON	Coleccion de los peces nativos de Sonora
UW	University of Washington, College of Ocean and Fishery Sciences [formerly College of Fisheries], Seattle, Washington; also as MNHW, UWF

WNMU	Western New Mexico University
YPM	Yale University, Peabody Museum of Natural History, New Haven, Connecticut; also as BOC
ZMA	Zoölogisch Museum, Universiteit van Amsterdam [alternatively Zoological Museum Amsterdam], Amsterdam; collections now officially part of Naturalis Museum (RMNH) and ultimately to be transferred to Leiden
ZMH	Zoological Museum Hamburg [Biozentrum Grindel und Zoologisches Museum; formerly Zoologisches Institut und Museum], Universität Hamburg, Hamburg; also as NMH, ZIM
ZMO	unknown "ZMO"
ZMUC	Københavns Universitet, Zoologisk Museum [Zoological Museum, University of Copenhagen], Vertebrater, Fiskesamlingen, Copenhagen; also seen as UZMK
ZSM	Zoologische Staatssammlung München [alternatively as Bavarian State Collection of Zoology; previously as Zoologisches Sammlung des Bayerischen Staates], München
DMNH	Dallas Museum of Natural History, Dallas, Texas
NLU	University of Louisiana at Monroe [formerly Northeast Louisiana University], Museum of Natural History [formerly Zoology], Monroe, Louisiana; also as NLM
SIUC	Southern Illinois University, Department of Zoology, Carbondale, Illinois
SMBU	Strecker Museum [moved to Mayborn Museum Complex], Baylor University, Waco, Texas; replacement for BU (Baylor University)

SRSU	Sul Ross State University, Alpine, Texas
UF	University of Florida, Florida Museum of Natural History [formerly Florida State Museum (FSM)], Gainesville, Florida; also as FLMNH (obsolete for fishes & herps)
UT	University of Tennessee, Department of Zoology, Knoxville, Tennessee
AUM	Auburn University Natural History Museum, Auburn, Alabama (fishes and herps); also as AU and API (both obsolete)
INHS	Illinois Natural History Survey [descended in part from Illinois State Laboratory of Natural History], University of Illinois, Champaign, Illinois
UAIC	University of Alabama Ichthyological Collection, Tuscaloosa, Alabama; replacement for ALA (sensu Leviton et al. 1985)
UA	Arkansas State University Museum of Zoology – Fish Collection
USM	University of Southern Mississippi, Museum of Ichthyology, Department of Biological Sciences, Hatiesburg, Mississippi; also as USMS
UAFS	University of Arkansas at Fort Smith (formerly University of West Arkansas)
VPN	Vertebrate Paleontology Laboratory, University of Texas
SHVM	Sam Houston State University

APPENDIX 3. SPECIMENS CATALOGUED INTO THE TEXAS NATURAL HISTORY COLLECTION, ICHTHYOLOGY COLLECTION, FROM THE BRAZOS RIVER SURVEY DONE AS PART OF THIS PROJECT

Catalog Number	Locality [Formatted]	Site No.	Genus	Species	Number of specimens preserved by preservation type			
					Fluid	Tissue	Skeleton	Total
52400	Brazos River at SH 16	1	Campostoma	anomalum	2			2
52401	Brazos River at SH 16	1	Gambusia	affinis	16			16
52402	Brazos River at SH 16	1	Labidesthes	sicculus	22			22
52403	Brazos River at SH 16	1	Pimephales	vigilax	123			123
52404	Brazos River at SH 16	1	Micropterus	dolomieu	5			5
52405	Brazos River at SH 16	1	Micropterus	punctulatus	5			5
52406	Brazos River at SH 16	1	Cyprinodon	variegatus	5	3		8
52407	Brazos River at SH 16	1	Menidia	beryllina	508			508
52408	Brazos River at SH 16	1	Lepomis	macrochirus	8			8
52409	Brazos River at SH 16	1	Lepomis	megalotis	22			22
52410	Brazos River at SH 16	1	Micropterus	salmoides	7			7
52411	Brazos River at SH 16	1	Cyprinella	lutrensis	1065			1065
52412	Brazos River at SH 16	1	Cyprinella	venusta	667			667
51918	Brazos River at Fortune Bend	2	Cyprinella	lutrensis	1422			1422
51919	Brazos River at Fortune Bend	2	Morone	chrysops	1			1
51920	Brazos River at Fortune Bend	2	Pimephales	vigilax	676			676
51921	Brazos River at Fortune Bend	2	Cyprinella	venusta x lutrensis	352			352
51922	Brazos River at Fortune Bend	2	Lepomis	megalotis	44			44
51923	Brazos River at Fortune Bend	2	Etheostoma	spectabile	1			1
51924	Brazos River at Fortune Bend	2	Percina	sciera	1			1
51925	Brazos River at Fortune Bend	2	Percina	carbonaria	4			4
51926	Brazos River at Fortune Bend	2	Menidia	beryllina	94			94
51927	Brazos River at Fortune Bend	2	Labidesthes	sicculus	89			89
51928	Brazos River at Fortune Bend	2	Moxostoma	congestum	2			2

51929	Brazos River at Fortune Bend	2	Lepomis	sp.	38		38
51930	Brazos River at Fortune Bend	2	Micropterus	punctulatus	5		5
51931	Brazos River at Fortune Bend	2	Dorosoma	petenense	10		10
51932	Brazos River at Fortune Bend	2	Lepomis	macrochirus	52		52
51933	Brazos River at Fortune Bend	2	Campostoma	anomalum	5		5
51934	Brazos River at Fortune Bend	2	Gambusia	affinis	8		8
51935	Brazos River at Fortune Bend	2	Lepomis	humilis	1		1
51936	Brazos River at Fortune Bend	2	Dorosoma	cepedianum	7		7
51937	Brazos River at Fortune Bend	2	Micropterus	dolomieu	1		1
51248	Brazos River at SH4	3	Cyprinella	lutrensis	336		336
51249	Brazos River at SH4	3	Lepomis	megalotis	10		10
51250	Brazos River at SH4	3	Cyprinella	venusta	118		118
51251	Brazos River at SH4	3	Gambusia	affinis	83		83
51252	Brazos River at SH4	3	Fundulus	grandis	1	1	2
51253	Brazos River at SH4	3	Cyprinodon	variegatus	1	1	2
51254	Brazos River at SH4	3	Pimephales	vigilax	70		70
51255	Brazos River at SH4	3	Lepomis	macrochirus	9		9
51256	Brazos River at SH4	3	Campostoma	anomalum	1		1
51257	Brazos River at SH4	3	Menidia	beryllina	17		17
51258	Brazos River at SH4	3	Lepomis	gulosus	4		4
51259	Brazos River at SH4	3	Lepomis	humilis	2		2
51260	Brazos River at SH4	3	Labidesthes	sicculus	8		8
51261	Brazos River at SH4	3	Lepomis	sp.	33		33
51262	Brazos River at SH4	3	Etheostoma	spectabile	10		10
51567	Brazos River at SH4	3	Micropterus	punctulatus	16		16
52089	Brazos River at US 180	4	Micropterus	punctulatus	4		4
52090	Brazos River at US 180	4	Etheostoma	spectabile	1		1
52091	Brazos River at US 180	4	Gambusia	affinis	130		130
52092	Brazos River at US 180	4	Lepomis	macrochirus	16		16
52093	Brazos River at US 180	4	Pimephales	vigilax	195		195
52094	Brazos River at US 180	4	Ictalurus	punctatus	1		1
52095	Brazos River at US 180	4	Menidia	beryllina	11		11
52096	Brazos River at US 180	4	Fundulus	grandis	2	1	3
52097	Brazos River at US 180	4	Labidesthes	sicculus	19		19
52098	Brazos River at US 180	4	Lepomis	megalotis	36		36
52099	Brazos River at US 180	4	Cyprinodon	variegatus	10	2	12

52100	Brazos River at US 180	4	Cyprinella	venusta	190		190
52101	Brazos River at US 180	4	Carpiodes	carpio	1	1	2
52102	Brazos River at US 180	4	Micropterus	salmoides	5		5
52103	Brazos River at US 180	4	Cyprinella	lutrensis	1477		1477
52104	Brazos River at US 180	4	Moxostoma	congestum	1	1	2
51568	Brazos River at Worth Ranch (at Chick Bend)	5	Micropterus	dolomieu	3		3
51569	Brazos River at Worth Ranch (at Chick Bend)	5	Lepomis	megalotis	43		43
51570	Brazos River at Worth Ranch (at Chick Bend)	5	Moxostoma	congestum	2		2
51571	Brazos River at Worth Ranch (at Chick Bend)	5	Micropterus	punctulatus	9		9
51572	Brazos River at Worth Ranch (at Chick Bend)	5	Cyprinella	venusta	192		192
51573	Brazos River at Worth Ranch (at Chick Bend)	5	Cyprinella	lutrensis	497		497
51574	Brazos River at Worth Ranch (at Chick Bend)	5	Lepomis	gulosus	2		2
51575	Brazos River at Worth Ranch (at Chick Bend)	5	Menidia	beryllina	86		86
51576	Brazos River at Worth Ranch (at Chick Bend)	5	Pylodictis	olivaris	1		1
51577	Brazos River at Worth Ranch (at Chick Bend)	5	Lepomis	macrochirus	2		2
51578	Brazos River at Worth Ranch (at Chick Bend)	5	Fundulus	grandis	4		4
51579	Brazos River at Worth Ranch (at Chick Bend)	5	Labidesthes	sicculus	12		12
51580	Brazos River at Worth Ranch (at Chick Bend)	5	Campostoma	anomalum	1		1
51581	Brazos River at Worth Ranch (at Chick Bend)	5	Cyprinodon	variegatus	14		14
51582	Brazos River at Worth Ranch (at Chick Bend)	5	Gambusia	affinis	70		70
51583	Brazos River at Worth Ranch (at Chick Bend)	5	Pimephales	vigilax	120		120
51584	Brazos River at Worth Ranch (at Chick Bend)	5	Dorosoma	cepedianum	1		1

51585	Brazos River at Worth Ranch (at Chick Bend)	5	Etheostoma	spectabile	4		4
51859	Brazos River at Pleasant Valley Rd.	6	Cyprinodon	variegatus	87		87
51860	Brazos River at Pleasant Valley Rd.	6	Ictalurus	punctatus	10		10
51861	Brazos River at Pleasant Valley Rd.	6	Gambusia	affinis	157		157
51862	Brazos River at Pleasant Valley Rd.	6	Labidesthes	sicculus	1		1
51863	Brazos River at Pleasant Valley Rd.	6	Notropis	volucellus	1		1
51864	Brazos River at Pleasant Valley Rd.	6	Lepomis	megalotis	11		11
51865	Brazos River at Pleasant Valley Rd.	6	Campostoma	anomalum	3		3
51866	Brazos River at Pleasant Valley Rd.	6	Pylodictis	olivaris	1		1
51867	Brazos River at Pleasant Valley Rd.	6	Menidia	beryllina	56		56
51868	Brazos River at Pleasant Valley Rd.	6	Cyprinella	venusta	116		116
51869	Brazos River at Pleasant Valley Rd.	6	Micropterus	salmoides	3		3
51870	Brazos River at Pleasant Valley Rd.	6	Lepomis	macrochirus	2		2
51871	Brazos River at Pleasant Valley Rd.	6	Carpiodes	carpio	1	1	2
51872	Brazos River at Pleasant Valley Rd.	6	Pimephales	vigilax	224		224
51873	Brazos River at Pleasant Valley Rd.	6	Cyprinella	lutrensis	1624		1624
51874	Brazos River at Pleasant Valley Rd.	6	Fundulus	grandis	65		65
52125	Brazos River at US 281	7	Morone	chrysops	2		2
52126	Brazos River at US 281	7	Carpiodes	carpio	2	1	3
52127	Brazos River at US 281	7	Lepomis	macrochirus	8		8
52128	Brazos River at US 281	7	Ameiurus	natalis	4		4
52129	Brazos River at US 281	7	Pimephales	vigilax	191		191
52130	Brazos River at US 281	7	Dorosoma	cepedianum	1		1
52131	Brazos River at US 281	7	Dorosoma	petenense	2		2
52132	Brazos River at US 281	7	Cyprinodon	variegatus	33		33
52133	Brazos River at US 281	7	Fundulus	grandis	13		13
52134	Brazos River at US 281	7	Campostoma	anomalum	1		1
52135	Brazos River at US 281	7	Lepomis	humilis	17		17
52136	Brazos River at US 281	7	Lepomis	gulosus	3		3
52137	Brazos River at US 281	7	Etheostoma	spectabile	1		1
52138	Brazos River at US 281	7	Lepomis	microlophus	1		1
52139	Brazos River at US 281	7	Fundulus	notatus	2		2
52140	Brazos River at US 281	7	Menidia	beryllina	19		19
52141	Brazos River at US 281	7	Labidesthes	sicculus	14		14
52142	Brazos River at US 281	7	Pomoxis	annularis	1		1

52143	Brazos River at US 281	7	Percina	carbonaria	5		5
52144	Brazos River at US 281	7	Lepomis	megalotis	24		24
52145	Brazos River at US 281	7	Cyprinella	venusta	165		165
52146	Brazos River at US 281	7	Cyprinella	lutrensis	1419		1419
52147	Brazos River at US 281	7	Gambusia	affinis	610		610
52148	Brazos River at US 281	7	Ictalurus	punctatus	4		4
52149	Brazos River at US 281	7	Micropterus	sp.	33		33
51458	Brazos River at IH20	8	Carpiodes	carpio	3	3	6
51459	Brazos River at IH20	8	Pimephales	vigilax	163		163
51460	Brazos River at IH20	8	Cyprinella	lutrensis	2328		2328
51461	Brazos River at IH20	8	Percina	sciera	1		1
51462	Brazos River at IH20	8	Cyprinella	venusta	77		77
51463	Brazos River at IH20	8	Cyprinodon	variegatus	118		118
51464	Brazos River at IH20	8	Gambusia	affinis	255		255
51465	Brazos River at IH20	8	Lepomis	macrochirus	3		3
51466	Brazos River at IH20	8	Labidesthes	sicculus	4		4
51467	Brazos River at IH20	8	Micropterus	dolomieu	4		4
51468	Brazos River at IH20	8	Fundulus	grandis	13		13
51469	Brazos River at IH20	8	Menidia	beryllina	12		12
51470	Brazos River at IH20	8	Lepomis	megalotis	10		10
51824	Brazos River at SH 1189/1543	9	Micropterus	salmoides	11		11
51825	Brazos River at SH 1189/1543	9	Lepomis	macrochirus	141		141
51826	Brazos River at SH 1189/1543	9	Morone	chrysops	10	2	12
51827	Brazos River at SH 1189/1543	9	Fundulus	grandis	14		14
51828	Brazos River at SH 1189/1543	9	Menidia	beryllina	34		34
51829	Brazos River at SH 1189/1543	9	Gambusia	affinis	26		26
51830	Brazos River at SH 1189/1543	9	Lepomis	sp.	83		83
51831	Brazos River at SH 1189/1543	9	Pimephales	vigilax	175		175
51832	Brazos River at SH 1189/1543	9	Lepomis	humilis	29		29
51833	Brazos River at SH 1189/1543	9	Pomoxis	annularis	7		7
51834	Brazos River at SH 1189/1543	9	Cyprinella	venusta	40		40
51835	Brazos River at SH 1189/1543	9	Cyprinodon	variegatus	57		57
51836	Brazos River at SH 1189/1543	9	Labidesthes	sicculus	1		1
51837	Brazos River at SH 1189/1543	9	Lepomis	megalotis	13		13
51838	Brazos River at SH 1189/1543	9	Dorosoma	cepedianum	5		5
51839	Brazos River at SH 1189/1543	9	Dorosoma	petenense	4		4

51840	Brazos River at SH 1189/1543	9	Notropis	volucellus		1			1
51841	Brazos River at SH 1189/1543	9	Cyprinella	lutrensis		470			470
51842	Brazos River at SH 1189/1543	9	Carpiodes	carpio		5	2		7
51586	Brazos River at Pecan Plantation Ranch	10	Lepisosteus	osseus				1	1
51587	Brazos River at Pecan Plantation Ranch	10	Lepomis	macrochirus		21			21
51588	Brazos River at Pecan Plantation Ranch	10	Lepomis	megalotis		45			45
51589	Brazos River at Pecan Plantation Ranch	10	Micropterus	salmoides punctulatus	x	30			30
51590	Brazos River at Pecan Plantation Ranch	10	Pomoxis	annularis		5			5
51591	Brazos River at Pecan Plantation Ranch	10	Gambusia	affinis		119			119
51592	Brazos River at Pecan Plantation Ranch	10	Etheostoma	spectabile		14			14
51593	Brazos River at Pecan Plantation Ranch	10	Lepomis	sp.		142			142
51594	Brazos River at Pecan Plantation Ranch	10	Cyprinella	lutrensis		3			3
51595	Brazos River at Pecan Plantation Ranch	10	Cyprinella	venusta		7			7
51596	Brazos River at Pecan Plantation Ranch	10	Percina	carbonaria		2			2
51597	Brazos River at Pecan Plantation Ranch	10	Pimephales	vigilax		5			5
51234	Brazos River at Camp Arrowhead (Cox Bend)	11	Menidia	beryllina		21			21
51235	Brazos River at Camp Arrowhead (Cox Bend)	11	Lepomis	macrochirus		3			3
51236	Brazos River at Camp Arrowhead (Cox Bend)	11	Etheostoma	spectabile		2			2
51237	Brazos River at Camp Arrowhead (Cox Bend)	11	Gambusia	affinis		140			140
51238	Brazos River at Camp Arrowhead (Cox Bend)	11	Lepomis	sp.		25			25
51239	Brazos River at Camp Arrowhead (Cox Bend)	11	Pimephales	vigilax		54			54
51240	Brazos River at Camp Arrowhead (Cox Bend)	11	Cyprinodon	variegatus		768	2		770
51241	Brazos River at Camp Arrowhead (Cox Bend)	11	Cyprinella	venusta		75			75
51242	Brazos River at Camp Arrowhead (Cox Bend)	11	Campostoma	anomalum		1			1
51243	Brazos River at Camp Arrowhead (Cox Bend)	11	Morone	chrysops		1			1
51244	Brazos River at Camp Arrowhead (Cox Bend)	11	Lepomis	megalotis		17			17

51245	Brazos River at Camp Arrowhead (Cox Bend)	11	Dorosoma	cepedianum	7		7
51246	Brazos River at Camp Arrowhead (Cox Bend)	11	Cyprinella	lutrensis	1008		1008
51247	Brazos River at Camp Arrowhead (Cox Bend)	11	Ictalurus	punctatus	9		9
51517	Brazos River at Camp Arrowhead (Cox Bend)	11	Lepisosteus	oculatus	1		1
52109	Brazos River, btw Mitchell and Abby Bends	12	Etheostoma	spectabile	13		13
52110	Brazos River, btw Mitchell and Abby Bends	12	Pimephales	vigilax	60		60
52111	Brazos River, btw Mitchell and Abby Bends	12	Cyprinodon	variegatus	125	1	126
52112	Brazos River, btw Mitchell and Abby Bends	12	Campostoma	anomalum	4		4
52113	Brazos River, btw Mitchell and Abby Bends	12	Morone	chrysops	2		2
52114	Brazos River, btw Mitchell and Abby Bends	12	Menidia	beryllina	20		20
52115	Brazos River, btw Mitchell and Abby Bends	12	Gambusia	affinis	149		149
52116	Brazos River, btw Mitchell and Abby Bends	12	Lepomis	cyanellus	1		1
52117	Brazos River, btw Mitchell and Abby Bends	12	Cyprinella	lutrensis	1032		1032
52118	Brazos River, btw Mitchell and Abby Bends	12	Micropterus	salmoides	10		10
52119	Brazos River, btw Mitchell and Abby Bends	12	Fundulus	grandis	38	1	39
52120	Brazos River, btw Mitchell and Abby Bends	12	Lepomis	macrochirus	13		13
52121	Brazos River, btw Mitchell and Abby Bends	12	Cyprinella	venusta	73		73
52122	Brazos River, btw Mitchell and Abby Bends	12	Lepomis	megalotis	29		29
52123	Brazos River, btw Mitchell and Abby Bends	12	Lepisosteus	osseus	2	1	3
52124	Brazos River, btw Mitchell and Abby Bends	12	Cyprinus	carpio	1		1

51513	Brazos River at confluence with Paluxy River	13	Lepisosteus	osseus	1	1	2
51938	Brazos River at confluence with Paluxy River	13	Cyprinodon	variegatus	106		106
51939	Brazos River at confluence with Paluxy River	13	Pimephales	vigilax	48		48
51940	Brazos River at confluence with Paluxy River	13	Gambusia	affinis	430		430
51941	Brazos River at confluence with Paluxy River	13	Oreochromis	aureus	1		1
51942	Brazos River at confluence with Paluxy River	13	Morone	chrysops	1		1
51943	Brazos River at confluence with Paluxy River	13	Lepomis	macrochirus	13		13
51944	Brazos River at confluence with Paluxy River	13	Menidia	beryllina	90		90
51945	Brazos River at confluence with Paluxy River	13	Cyprinella	lutrensis	192		192
51946	Brazos River at confluence with Paluxy River	13	Cyprinella	venusta	47		47
51947	Brazos River at confluence with Paluxy River	13	Lepomis	sp.	20		20
51948	Brazos River at confluence with Paluxy River	13	Micropterus	salmoides	4		4
51949	Brazos River at confluence with Paluxy River	13	Lepomis	auritus	20		20
51950	Brazos River at confluence with Paluxy River	13	Micropterus	punctulatus	15		15
51951	Brazos River at confluence with Paluxy River	13	Dorosoma	cepedianum	12		12
51952	Brazos River at confluence with Paluxy River	13	Lepomis	megalotis	28		28
51953	Brazos River at confluence with Paluxy River	13	Ictalurus	punctatus	2		2
51954	Brazos River at confluence with Paluxy River	13	Carpiodes	carpio	4		4
51598	Brazos River at CR 1118 (near Brazos Point)	14	Dorosoma	cepedianum	4		4
51599	Brazos River at CR 1118 (near Brazos Point)	14	Menidia	beryllina	6		6

51600	Brazos River at CR 1118 (near Brazos Point)	14	Lepomis	megalotis		3	3
51601	Brazos River at CR 1118 (near Brazos Point)	14	Cyprinodon	variegatus		6	6
51602	Brazos River at CR 1118 (near Brazos Point)	14	Dorosoma	petenense		2	2
51603	Brazos River at CR 1118 (near Brazos Point)	14	Pimephales	vigilax		105	105
51604	Brazos River at CR 1118 (near Brazos Point)	14	Lepomis	sp.		18	18
51605	Brazos River at CR 1118 (near Brazos Point)	14	Lepomis	macrochirus		6	6
51606	Brazos River at CR 1118 (near Brazos Point)	14	Fundulus	grandis		21	21
51607	Brazos River at CR 1118 (near Brazos Point)	14	Pomoxis	annularis		4	4
51608	Brazos River at CR 1118 (near Brazos Point)	14	Morone	chrysops		1	1
51609	Brazos River at CR 1118 (near Brazos Point)	14	Gambusia	affinis		3	3
51610	Brazos River at CR 1118 (near Brazos Point)	14	Ictalurus	punctatus		1	1
51611	Brazos River at CR 1118 (near Brazos Point)	14	Cyprinus	carpio		3	3
51612	Brazos River at CR 1118 (near Brazos Point)	14	Micropterus	salmoides punctulatus	x	4	4
51613	Brazos River at CR 1118 (near Brazos Point)	14	Cyprinella	lutrensis		786	786
51614	Brazos River at CR 1118 (near Brazos Point)	14	Cyprinella	venusta		130	130
51955	Brazos River at SH 2114	15	Menidia	beryllina		22	22
51956	Brazos River at SH 2114	15	Micropterus	salmoides		2	2
51957	Brazos River at SH 2114	15	Noturus	gyrinus		2	2
51958	Brazos River at SH 2114	15	Cyprinella	venusta		103	103
51959	Brazos River at SH 2114	15	Fundulus	grandis		23	23
51960	Brazos River at SH 2114	15	Lepomis	cyanellus		1	1
51961	Brazos River at SH 2114	15	Etheostoma	spectabile		1	1
51962	Brazos River at SH 2114	15	Gambusia	affinis		67	67
51963	Brazos River at SH 2114	15	Lepomis	auritus		25	25

51969	Brazos River at Brazos River R.V. Park	16	Pimephales	vigilax	2		2
51970	Brazos River at Brazos River R.V. Park	16	Fundulus	notatus	21		21
51971	Brazos River at Brazos River R.V. Park	16	Percina	sciera	4		4
51972	Brazos River at Brazos River R.V. Park	16	Micropterus	salmoides	3		3
51973	Brazos River at Brazos River R.V. Park	16	Fundulus	grandis	6		6
51974	Brazos River at Brazos River R.V. Park	16	Ictalurus	punctatus	2		2
51975	Brazos River at Brazos River R.V. Park	16	Menidia	beryllina	24		24
51976	Brazos River at Brazos River R.V. Park	16	Gambusia	affinis	21		21
51977	Brazos River at Brazos River R.V. Park	16	Etheostoma	spectabile	11		11
51978	Brazos River at Brazos River R.V. Park	16	Lepomis	megalotis	40		40
51979	Brazos River at Brazos River R.V. Park	16	Cyprinella	venusta	398		398
51980	Brazos River at Brazos River R.V. Park	16	Lepomis	auritus	45		45
52900	Brazos River at SH6/SH340, E of Waco	17	Pimephales	vigilax	1324		1324
52901	Brazos River at SH6/SH340, E of Waco	17	Cyprinella	lutrensis	10220		10220
52902	Brazos River at SH6/SH340, E of Waco	17	Dorosoma	cepedianum	1		1
52903	Brazos River at SH6/SH340, E of Waco	17	Menidia	beryllina	79		79
52904	Brazos River at SH6/SH340, E of Waco	17	Micropterus	punctulatus	9		9
52905	Brazos River at SH6/SH340, E of Waco	17	Lepomis	megalotis	49		49
52906	Brazos River at SH6/SH340, E of Waco	17	Notropis	volucellus	8		8
52907	Brazos River at SH6/SH340, E of Waco	17	Micropterus	salmoides	1		1
52908	Brazos River at SH6/SH340, E of Waco	17	Lepomis	macrochirus	2		2
52909	Brazos River at SH6/SH340, E of Waco	17	Ictalurus	punctatus	1		1
52910	Brazos River at SH6/SH340, E of Waco	17	Labidesthes	sicculus	11		11
52911	Brazos River at SH6/SH340, E of Waco	17	Cyprinella	venusta	145		145
52912	Brazos River at SH6/SH340, E of Waco	17	Gambusia	affinis	311		311
52913	Brazos River at SH6/SH340, E of Waco	17	Etheostoma	chlorosomum	1		1
52631	Brazos River at falls, downstream of SH 712	18	Mugil	cephalus	1	1	2
52963	Brazos River at falls, downstream of SH 712	18	Gambusia	affinis	278		278
52964	Brazos River at falls, downstream of SH 712	18	Dorosoma	cepedianum	2		2
52965	Brazos River at falls, downstream of SH 712	18	Labidesthes	sicculus	2		2
52966	Brazos River at falls, downstream of SH 712	18	Percina	carbonaria	2		2

52967	Brazos River at falls, downstream of SH 712	18	Notropis	volucellus	2	2
52968	Brazos River at falls, downstream of SH 712	18	Pylodictis	olivaris	1	1
52969	Brazos River at falls, downstream of SH 712	18	Menidia	beryllina	27	27
52970	Brazos River at falls, downstream of SH 712	18	Macrhybopsis	hyostoma	5	5
52971	Brazos River at falls, downstream of SH 712	18	Notropis	buchanani	1	1
52972	Brazos River at falls, downstream of SH 712	18	Opsopoeodus	emiliae	1	1
52973	Brazos River at falls, downstream of SH 712	18	Lepomis	humilis	3	3
52974	Brazos River at falls, downstream of SH 712	18	Etheostoma	spectabile	1	1
52975	Brazos River at falls, downstream of SH 712	18	Lepomis	gulosus	1	1
52976	Brazos River at falls, downstream of SH 712	18	Micropterus	punctulatus	8	8
52977	Brazos River at falls, downstream of SH 712	18	Cyprinella	venusta	561	561
52978	Brazos River at falls, downstream of SH 712	18	Lepomis	megalotis	41	41
52979	Brazos River at falls, downstream of SH 712	18	Pimephales	vigilax	1263	1263
52980	Brazos River at falls, downstream of SH 712	18	Ictalurus	punctatus	223	223
52981	Brazos River at falls, downstream of SH 712	18	Cyprinella	lutrensis	12040	12040
52587	Brazos River at SH 485, W of Hearne	19	Ictalurus	punctatus	2	2
52588	Brazos River at SH 485, W of Hearne	19	Opsopoeodus	emiliae	8	8
52589	Brazos River at SH 485, W of Hearne	19	Percina	sciera	4	4
52590	Brazos River at SH 485, W of Hearne	19	Notemigonus	crysoleucas	5	5
52591	Brazos River at SH 485, W of Hearne	19	Cyprinella	venusta	1	1
52592	Brazos River at SH 485, W of Hearne	19	Hybognathus	nuchalis	2	2
52593	Brazos River at SH 485, W of Hearne	19	Macrhybopsis	hyostoma	12	12
52594	Brazos River at SH 485, W of Hearne	19	Poecilia	latipinna	42	42
52595	Brazos River at SH 485, W of Hearne	19	Notropis	buchanani	5	5

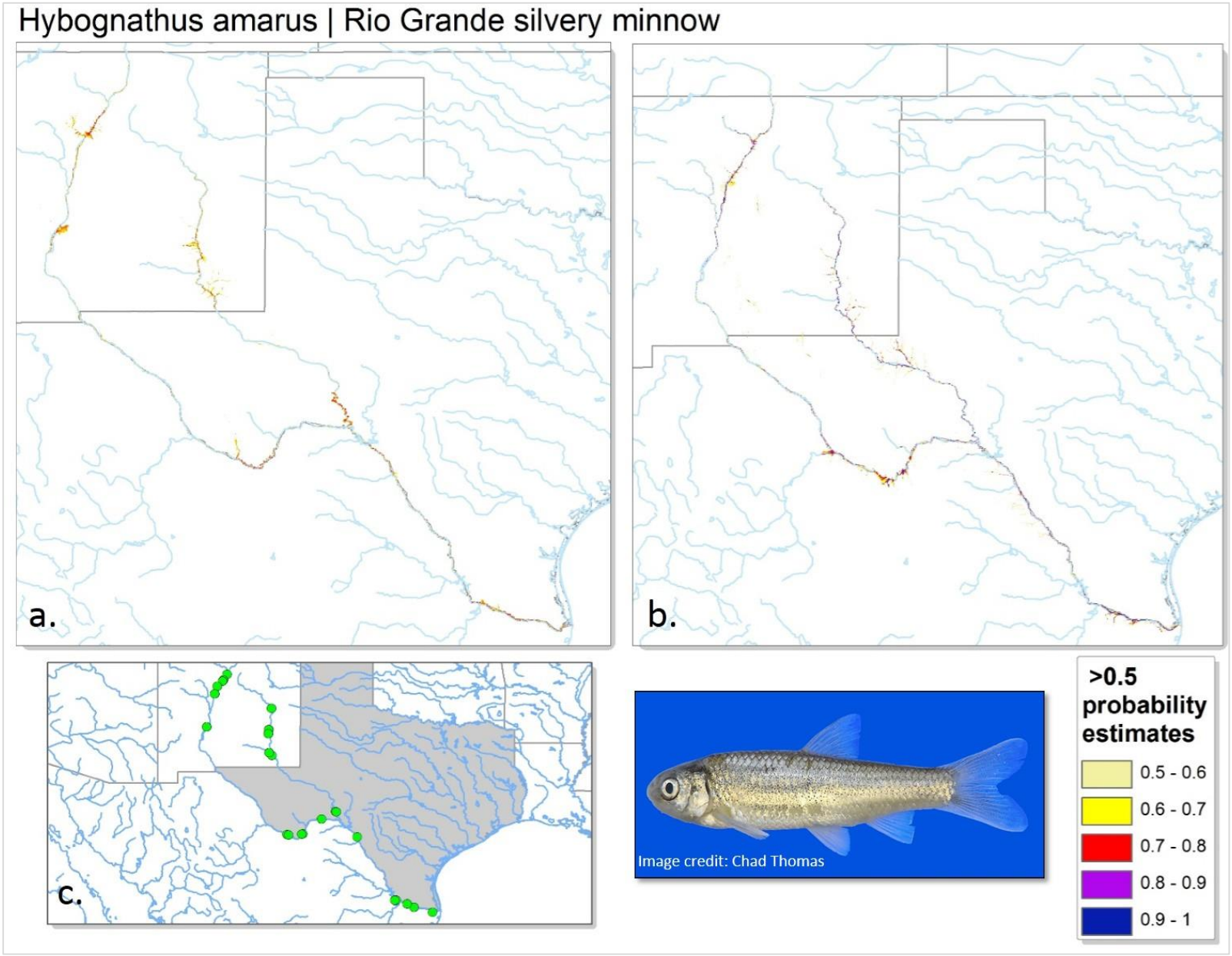
52596	Brazos River at SH 485, W of Hearne	19	Lepomis	humilis	1	1
52597	Brazos River at SH 485, W of Hearne	19	Dorosoma	cepedianum	36	36
52598	Brazos River at SH 485, W of Hearne	19	Pimephales	vigilax	1277	1277
52599	Brazos River at SH 485, W of Hearne	19	Lepomis	megalotis	85	85
52600	Brazos River at SH 485, W of Hearne	19	Carpiodes	carpio	7	7
52601	Brazos River at SH 485, W of Hearne	19	Gambusia	affinis	1886	1886
52602	Brazos River at SH 485, W of Hearne	19	Cyprinella	lutrensis	4550	4550
52630	Brazos River at SH 485, W of Hearne	19	Lepisosteus	osseus	2	2
52074	Brazos River at SH 21, W of Bryan	20	Opsopoeodus	emiliae	3	3
52075	Brazos River at SH 21, W of Bryan	20	Lepomis	sp.	34	34
52076	Brazos River at SH 21, W of Bryan	20	Lepomis	megalotis	24	24
52077	Brazos River at SH 21, W of Bryan	20	Percina	sciera	1	1
52078	Brazos River at SH 21, W of Bryan	20	Carpiodes	carpio	2	2
52079	Brazos River at SH 21, W of Bryan	20	Pomoxis	annularis	1	1
52080	Brazos River at SH 21, W of Bryan	20	Macrhybopsis	hyostoma	6	6
52081	Brazos River at SH 21, W of Bryan	20	Lepomis	macrochirus	4	4
52082	Brazos River at SH 21, W of Bryan	20	Notropis	buchanani	21	21
52083	Brazos River at SH 21, W of Bryan	20	Dorosoma	cepedianum	13	13
52084	Brazos River at SH 21, W of Bryan	20	Gambusia	affinis	648	648
52085	Brazos River at SH 21, W of Bryan	20	Lepomis	humilis	1	1
52086	Brazos River at SH 21, W of Bryan	20	Cyprinella	lutrensis	2400	2400
52087	Brazos River at SH 21, W of Bryan	20	Pimephales	vigilax	1560	1560
52088	Brazos River at SH 21, W of Bryan	20	Micropterus	punctulatus	2	2

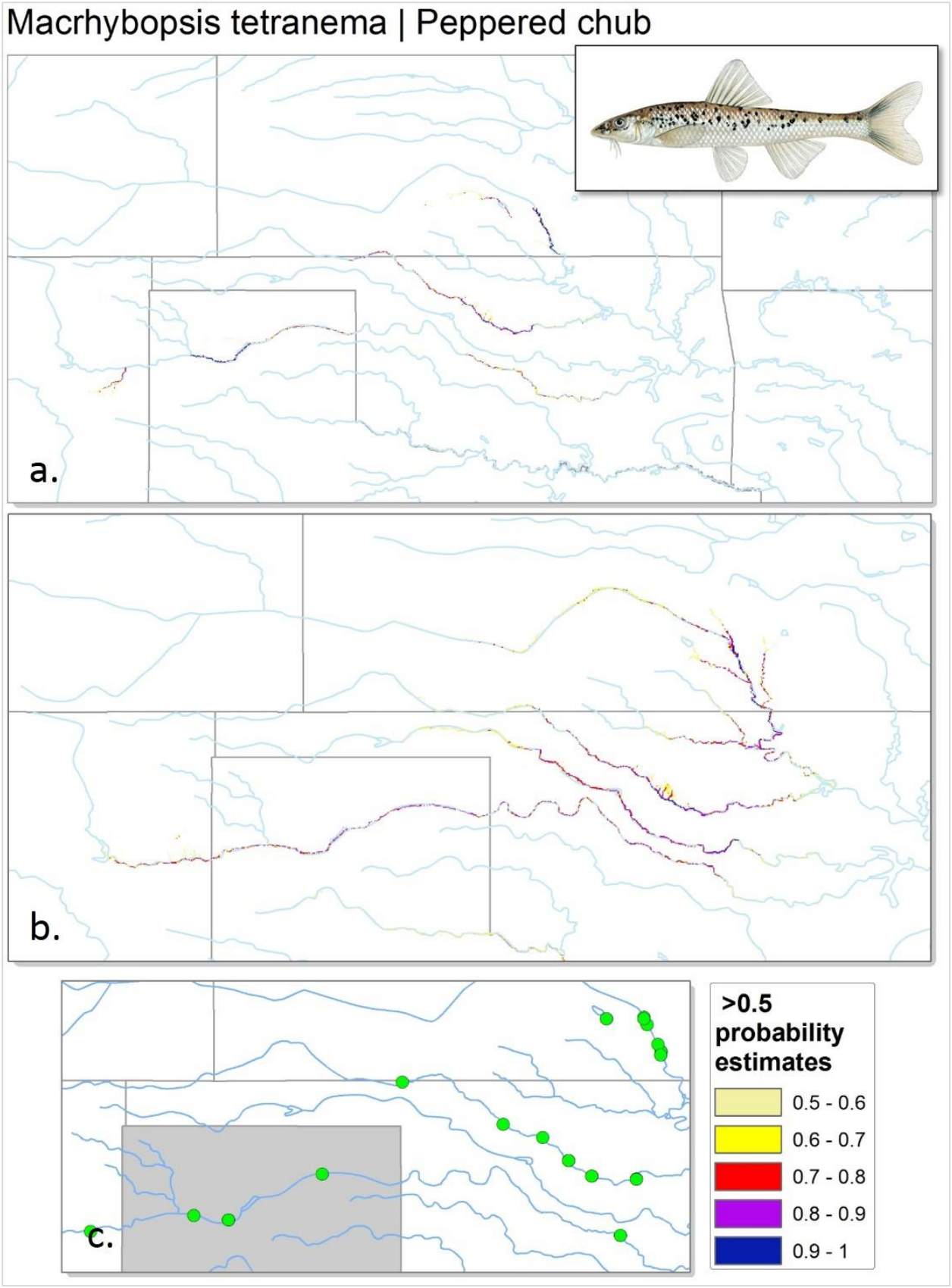
APPENDIX 4. SPECIES DISTRIBUTION MODEL MAPS

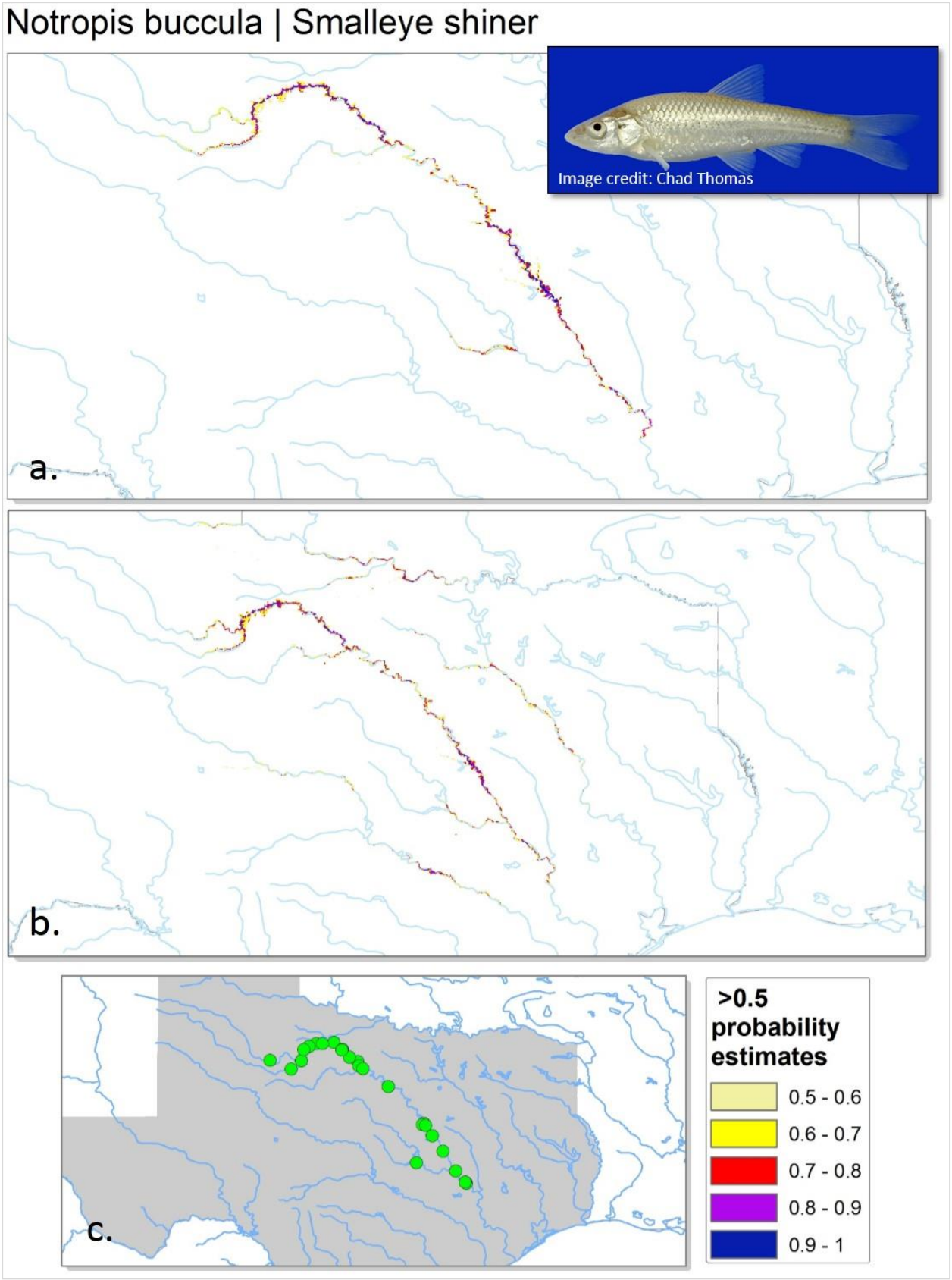
The models are displayed as symbolized rasters layered over a shapefile of major streams. Only modeled probabilities > 0.5 are shown to aid in interpretation and to illustrate what we suggest be interpreted as prime suitable habitat based on high quality occupancy data. Complete raw models are available as asciis provided but separate from this report. Additionally we provide, in supporting documents, html files of the Maxent model summary for individual replicates as well as the average run. This summary includes plots of individual variable importance.

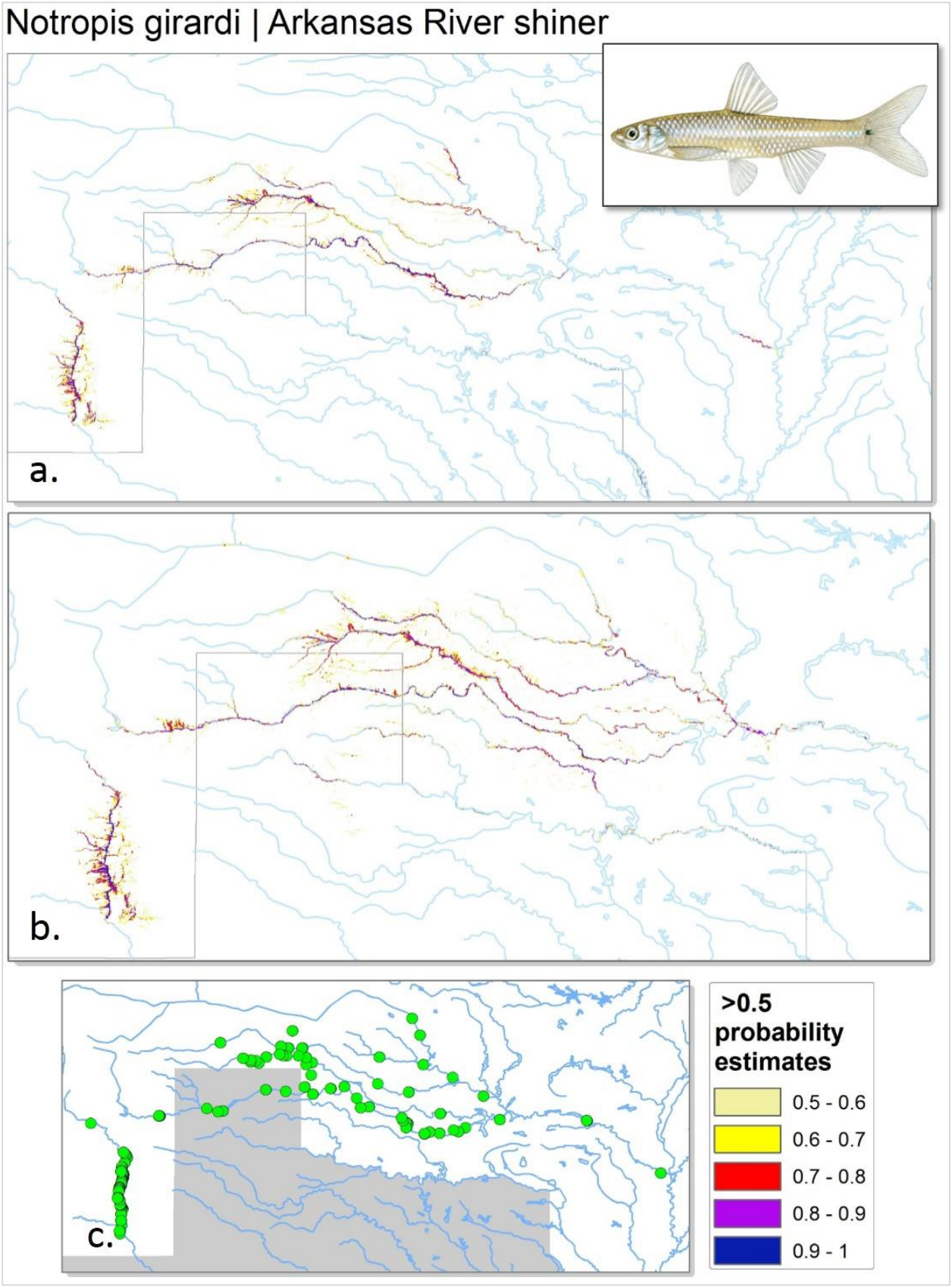
Note that models do not directly account for anthropogenic influences such as dams or land use, and should thus be considered to estimate a species' potential, not necessarily actual, distribution and general habitat suitability.

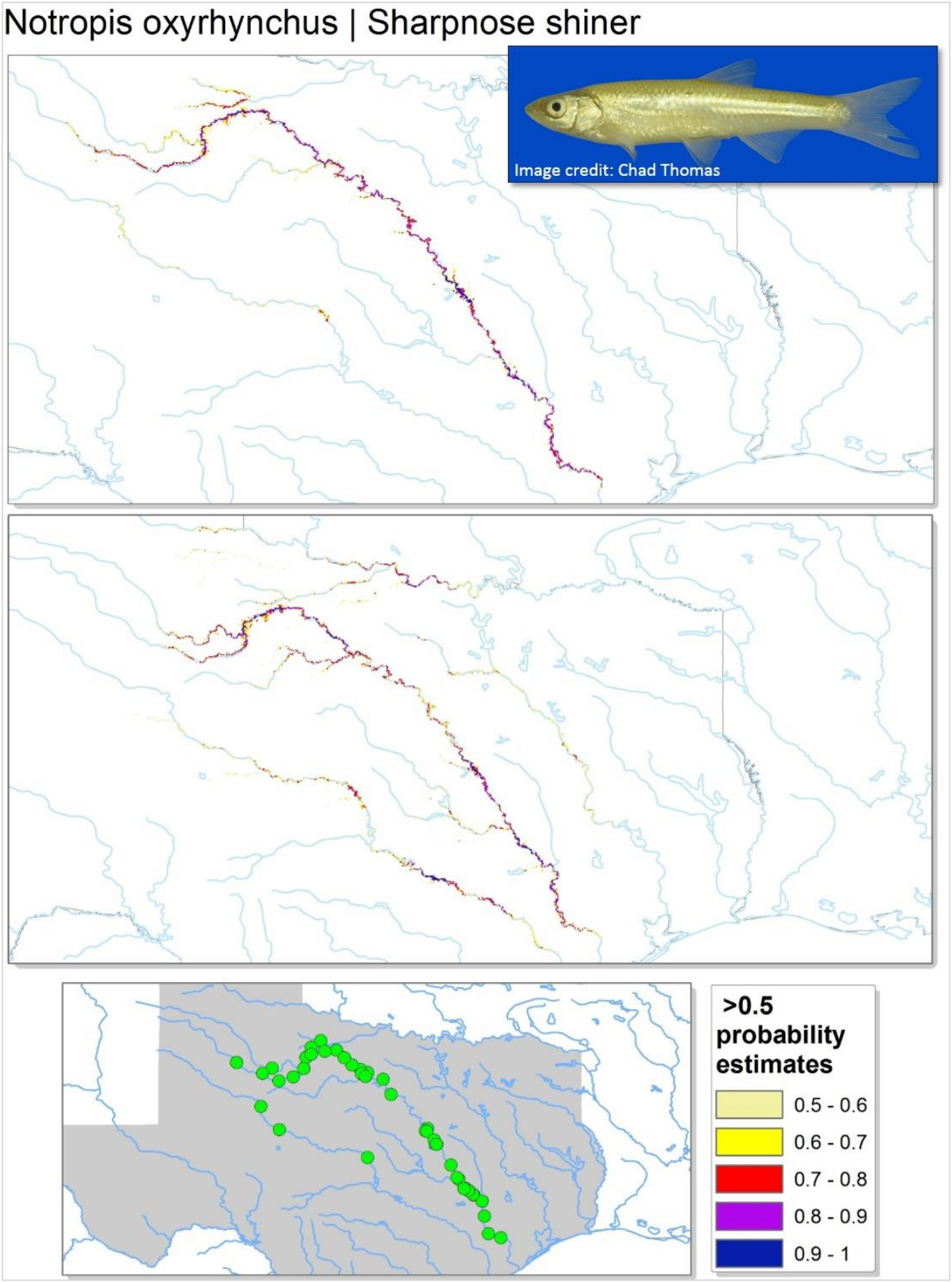
For each figure, subfigure "a" represents the model derived using the full variable set, "b" represents the model derived after omitting the two categorical geographic variables (major river basins & 8-digit HUC), and "c" shows the spatial distribution of occurrence records used in models. Subfigure b was provided to allow comparison to a less "restricted" model and to illustrate all potential (including unoccupied) suitable habitat. This could help in understanding not just current distribution relative to historic, but also where repatriation or new survey efforts might be productive.

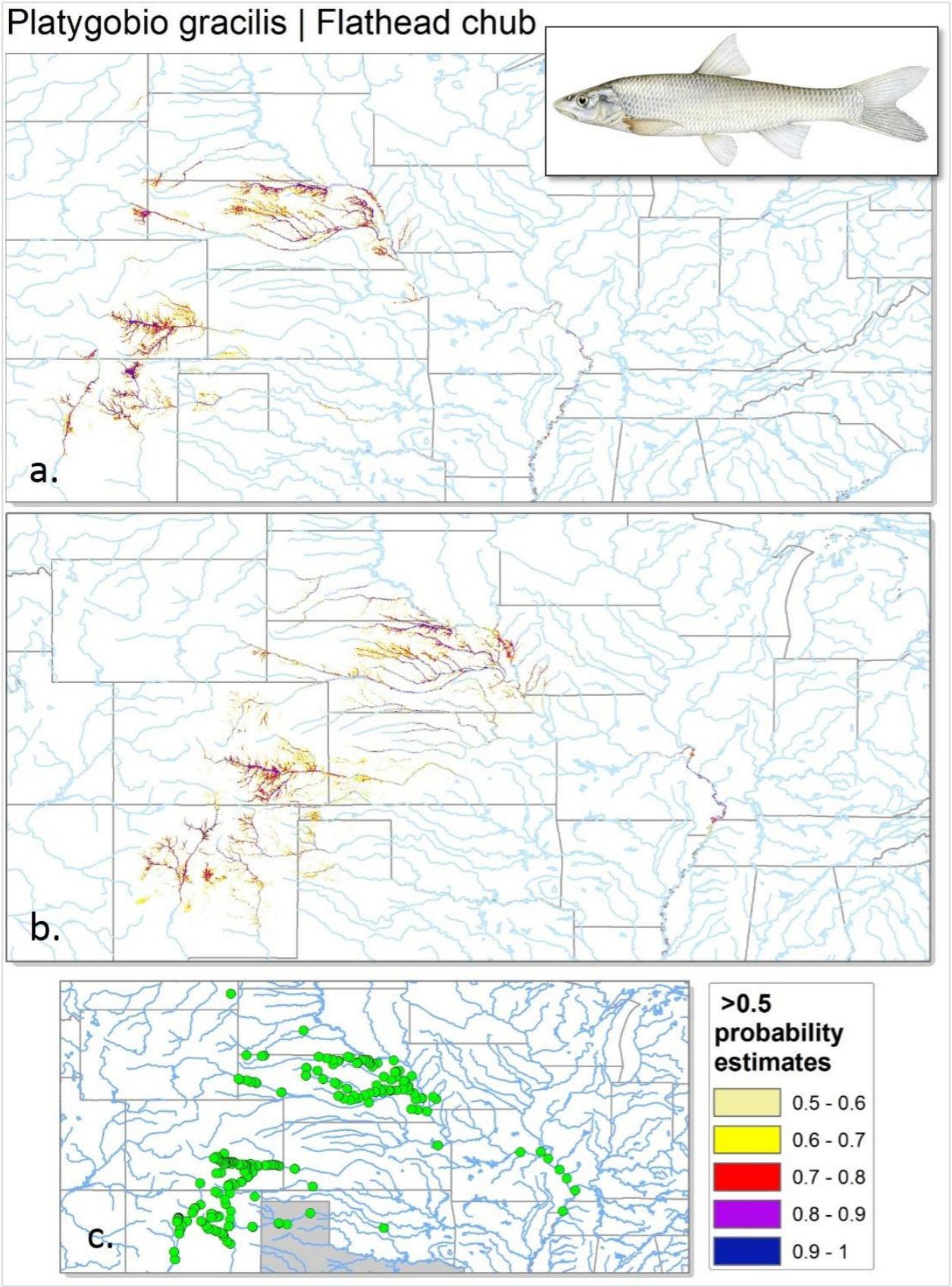

Hybognathus amarus | Rio Grande silvery minnow
a.
b.
c.
Image credit: Chad Thomas
>0.5 probability estimates
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1

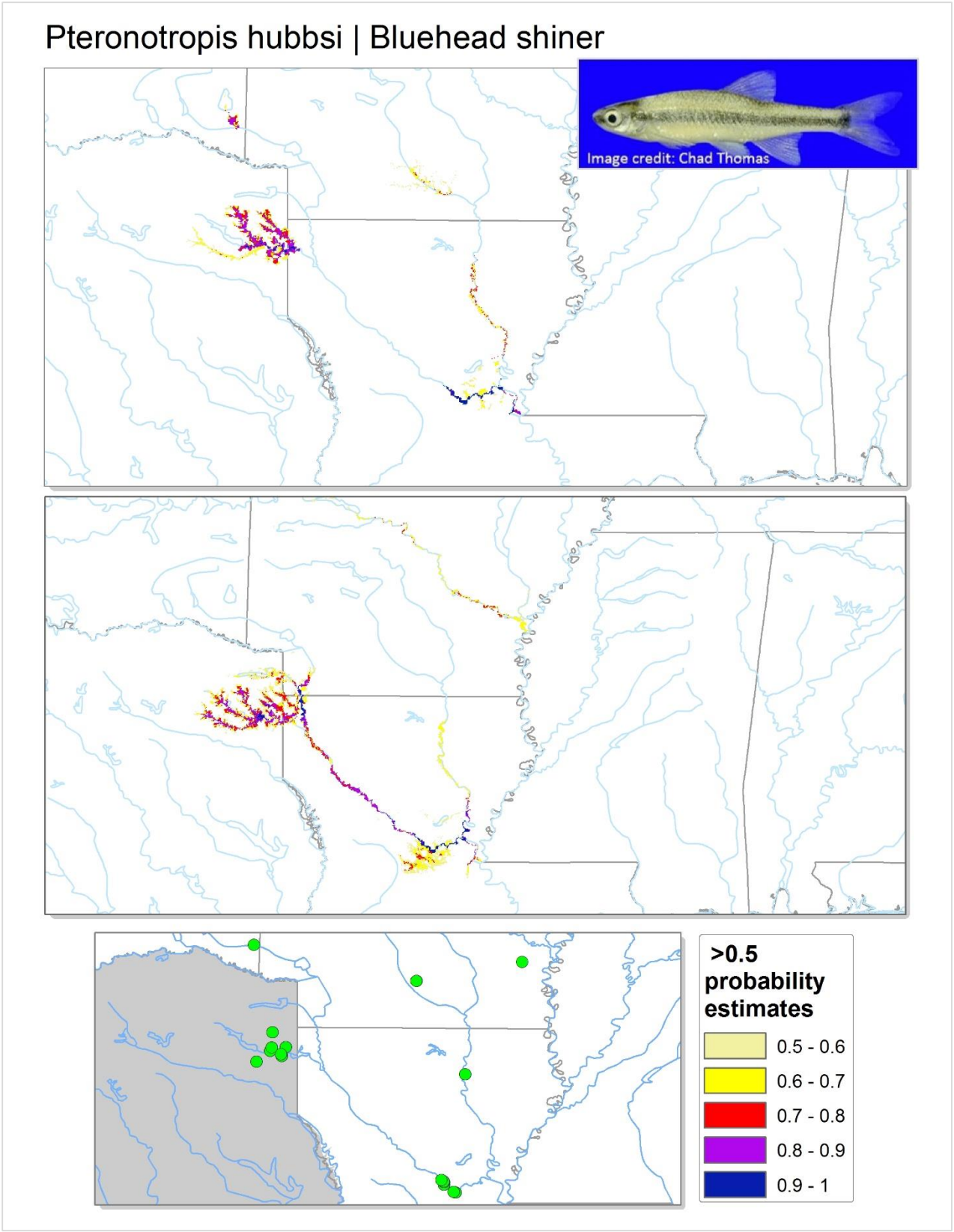

Macrhybopsis tetranema | Peppered chub
a.
b.
c.
>0.5 probability estimates
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1

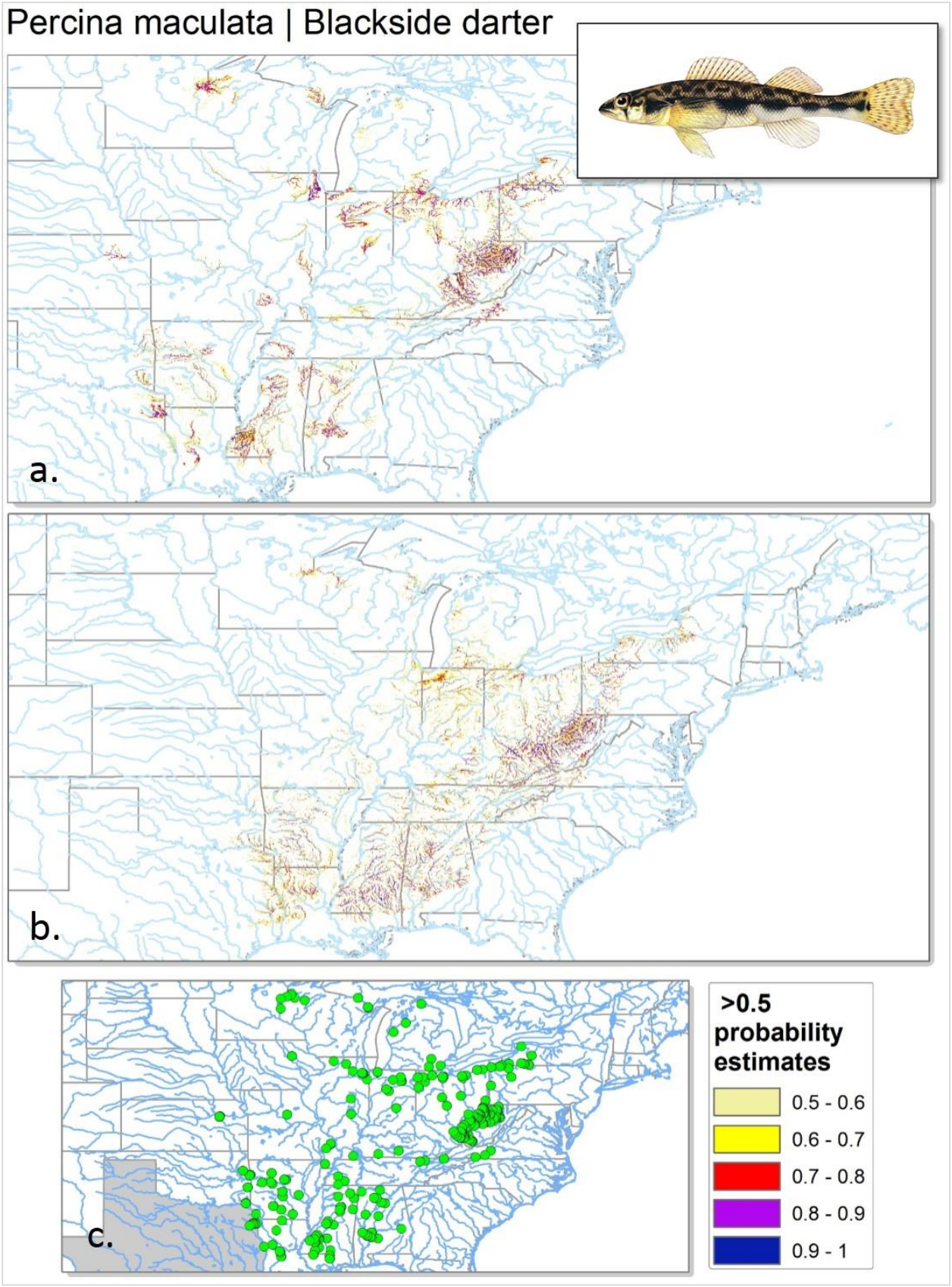

Notropis buccula | Smalleye shiner
Image credit: Chad Thomas
a.
b.
c.
>0.5 probability estimates
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1


Notropis girardi | Arkansas River shiner
a.
b.
c.
>0.5 probability estimates
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1


Notropis oxyrhynchus | Sharpnose shiner
Image credit: Chad Thomas
>0.5 probability estimates
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1

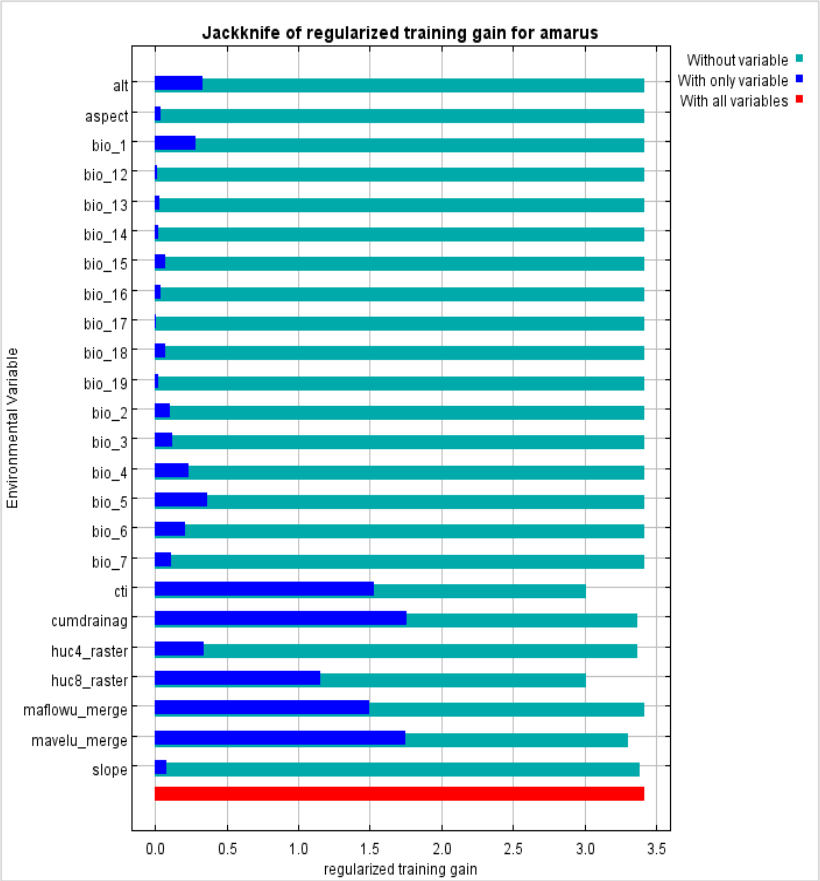

Platygobio gracilis | Flathead chub
a.
b.
c.
>0.5 probability estimates
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1


Pteronotropis hubbsi | Bluehead shiner
Image credit: Chad Thomas
>0.5 probability estimates
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1

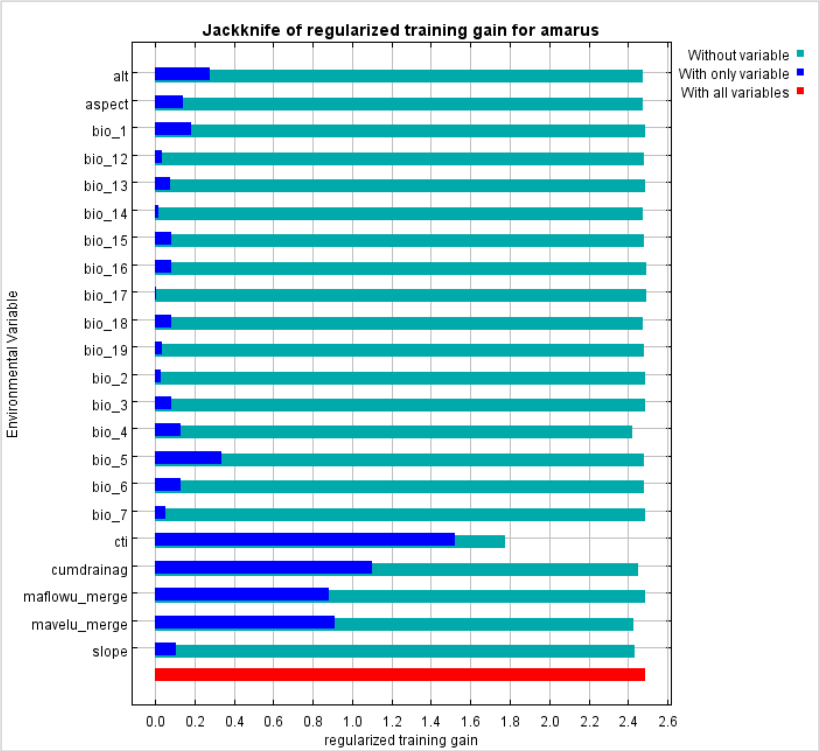

Percina maculata | Blackside darter
a.
b.
c.
>0.5 probability estimates
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1

APPENDIX 5. MAXENT'S JACKKNIFE TEST OF VARIABLE IMPORTANCE FOR EACH SPECIES.

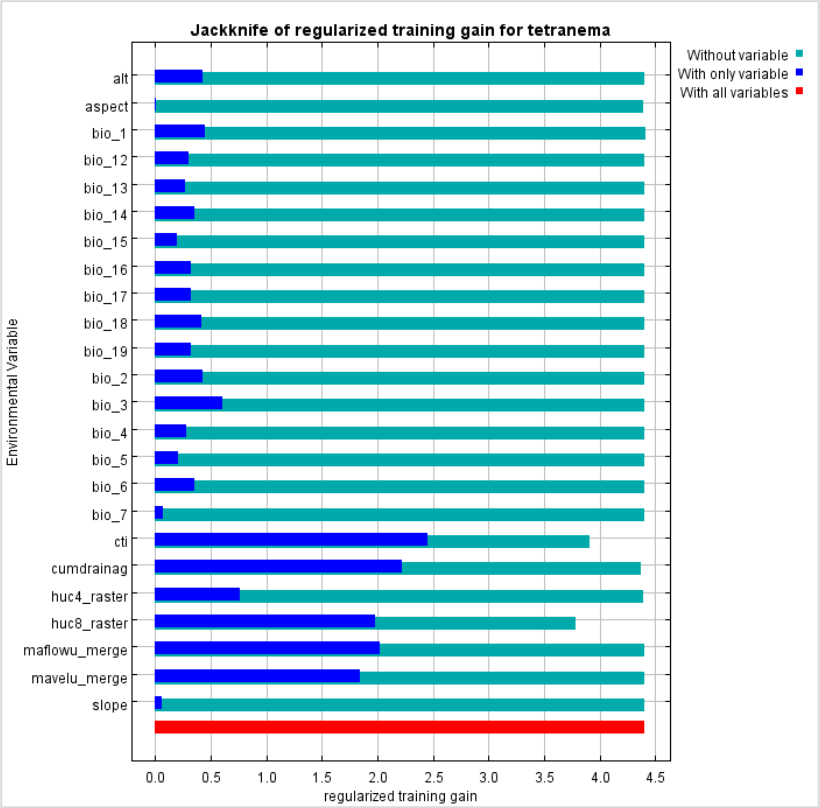
The environmental variable with highest gain (importance) when used in isolation has the longest dark blue line, which represents the variable that has the most useful information by itself as determined by how well it contributes to prediction of occurrences. The environmental variable that decreases the gain the most when it is omitted shows the shortest light blue line, which represents the variable that has the most information that isn't present in the other variables. Values shown are averages over 10 replicate runs.



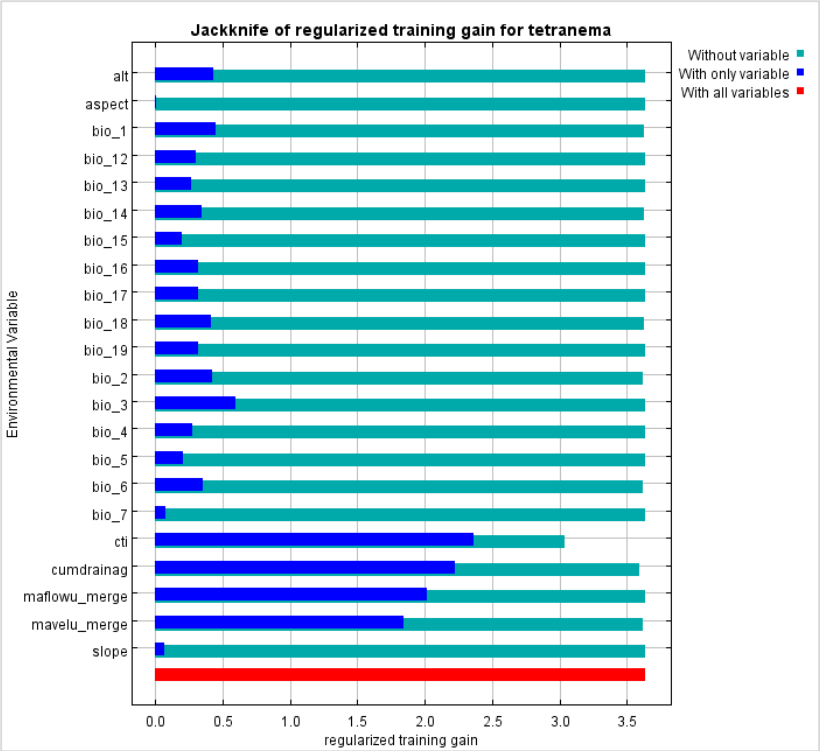
a. Jackknife of variable importance for *Hybognathus amarus* when including categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



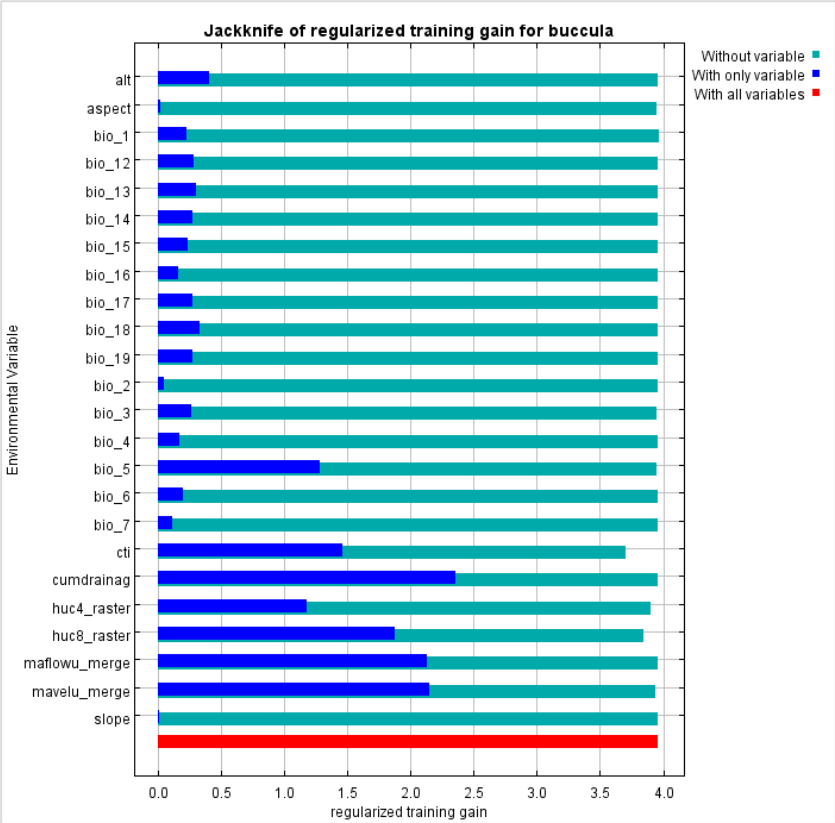
b. Jackknife of variable importance for *Hybognathus amarus* when excluding categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



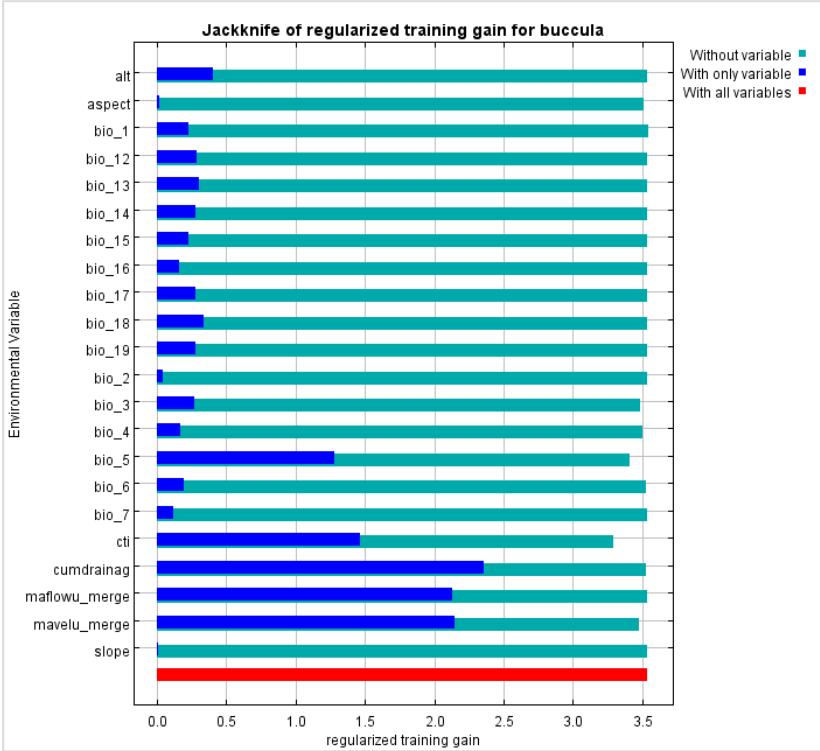
a. Jackknife of variable importance for *Machrybopsis tetranema* when including categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



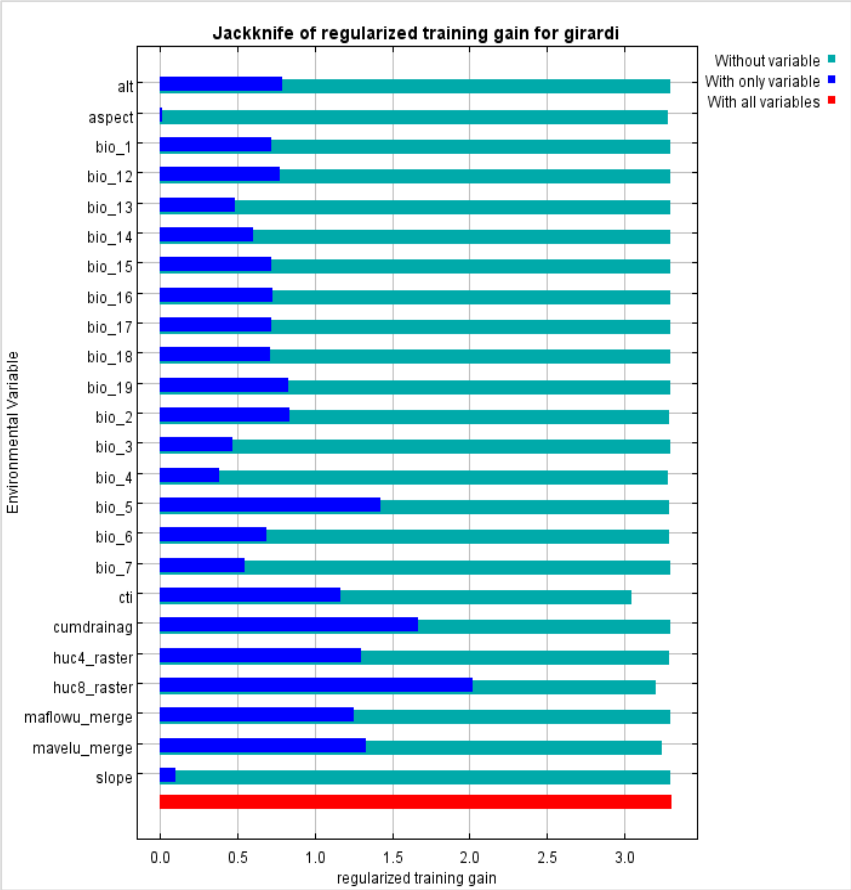
b. Jackknife of variable importance for *Machrybopsis tetranema* when excluding categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



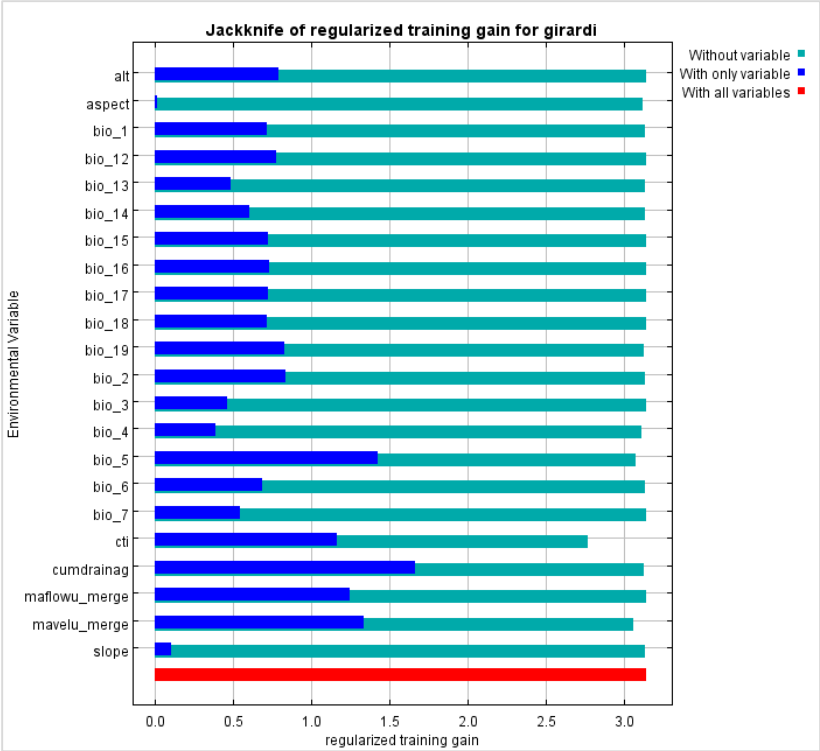
a. Jackknife of variable importance for *Notropis buccula* when including categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



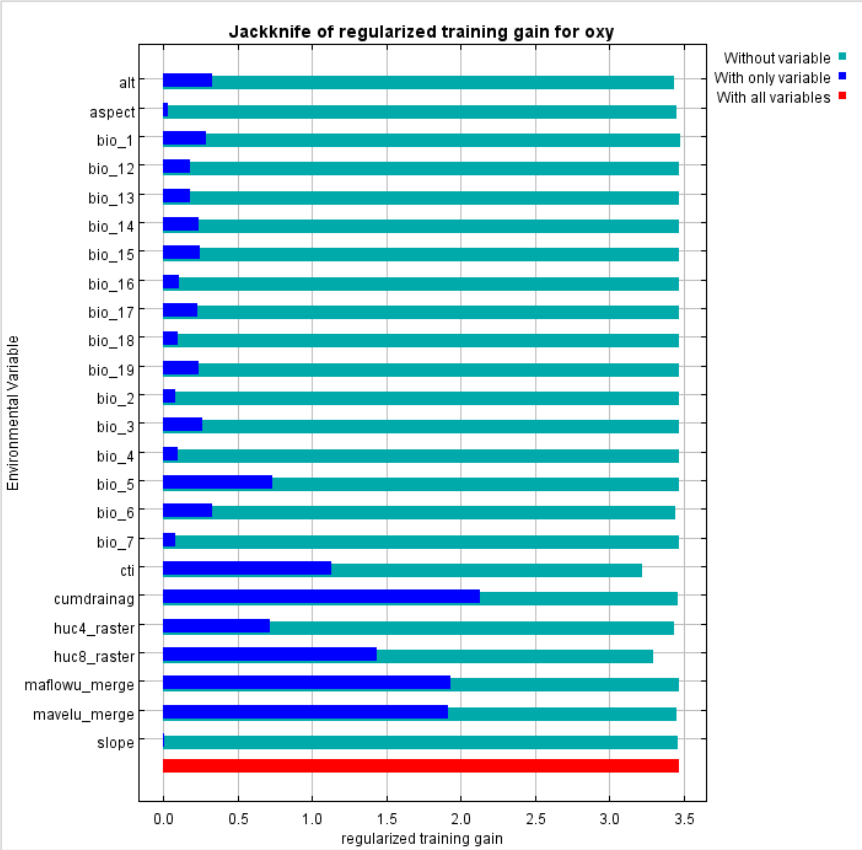
b. Jackknife of variable importance for *Notropis buccula* when excluding categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



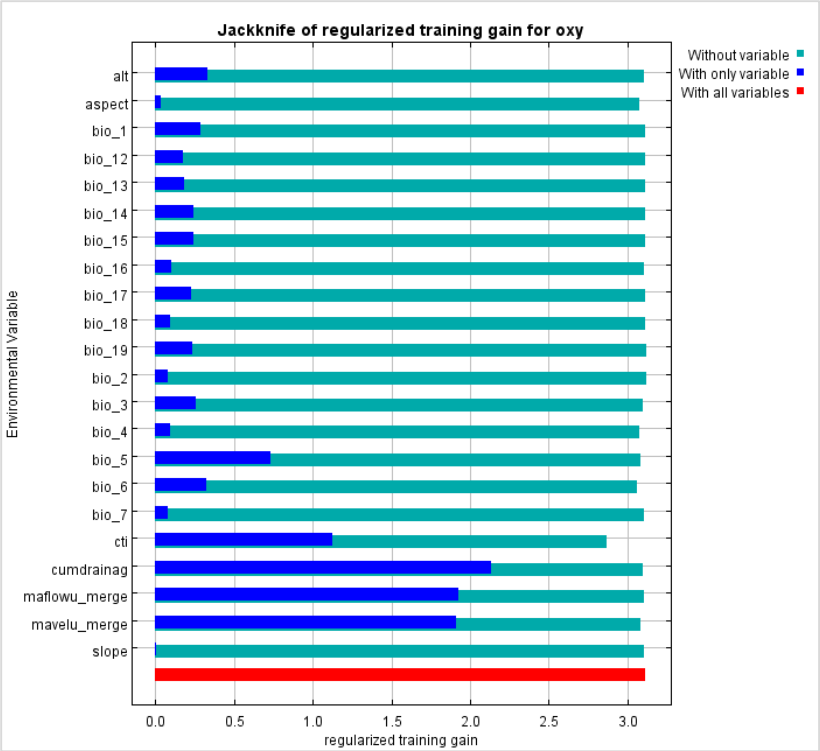
a. Jackknife of variable importance for *Notropis girardi* when including categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



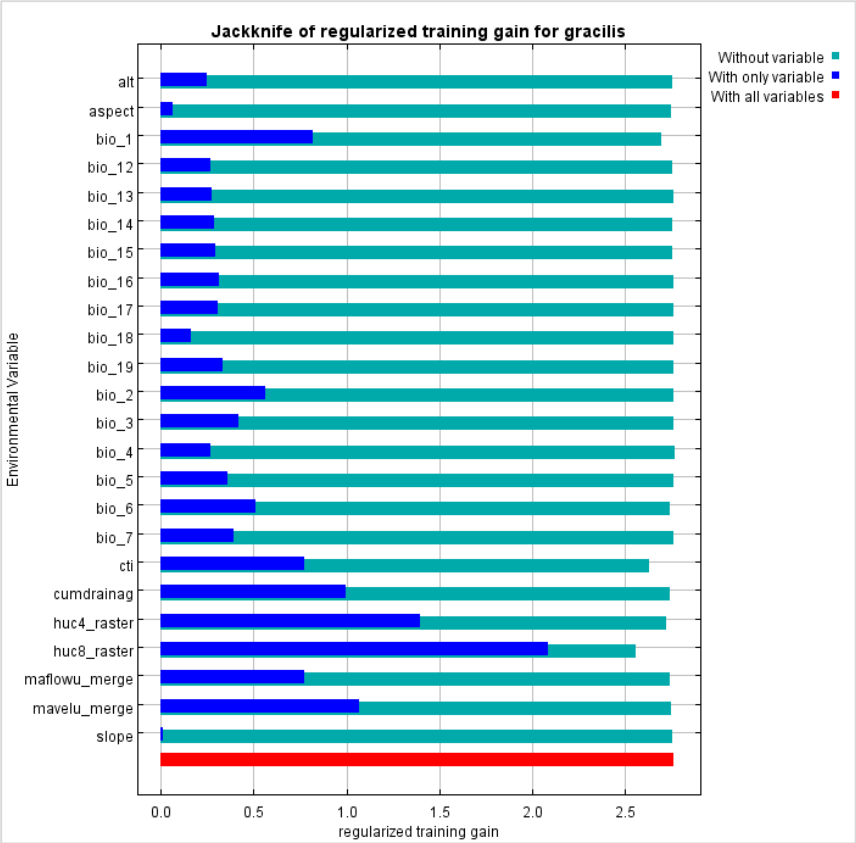
c. Jackknife of variable importance for *Notropis girardi* when excluding categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



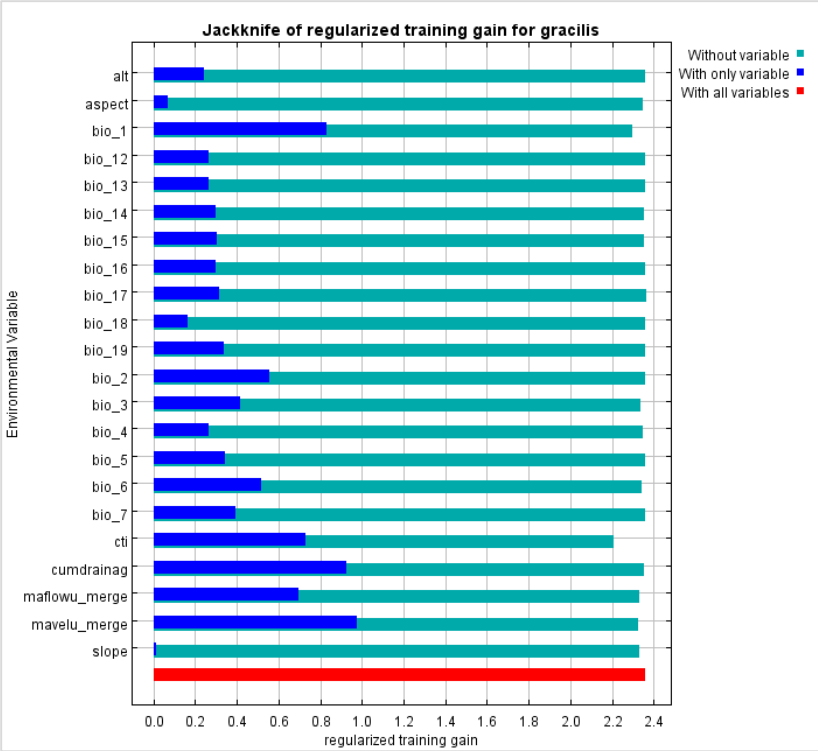
a. Jackknife of variable importance for *Notropis oxyrhynchus* when including categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



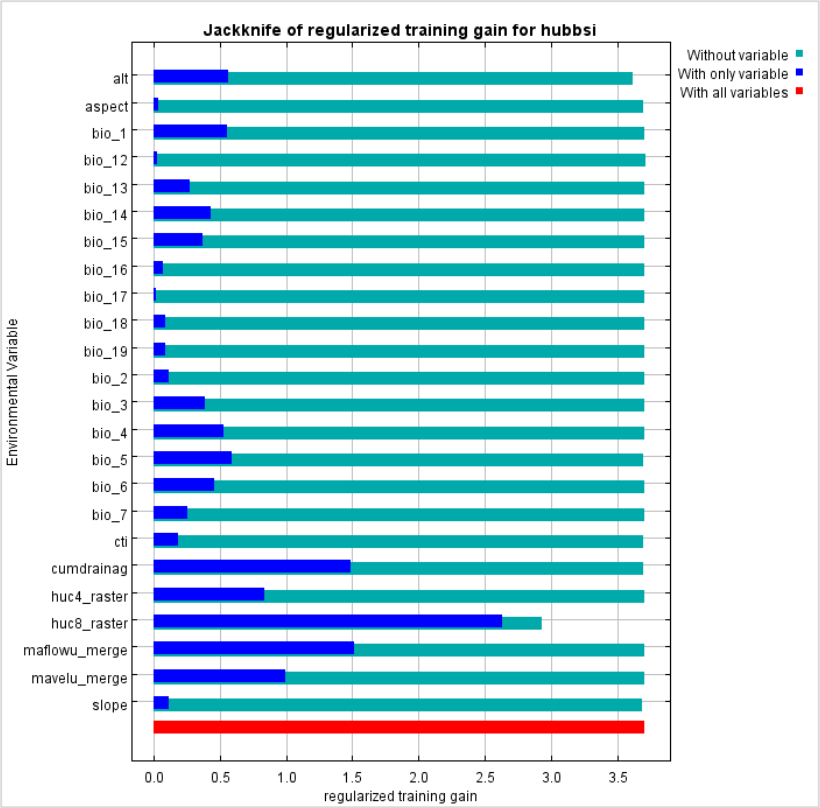
a. Jackknife of variable importance for *Notropis oxyrhynchus* when excluding categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



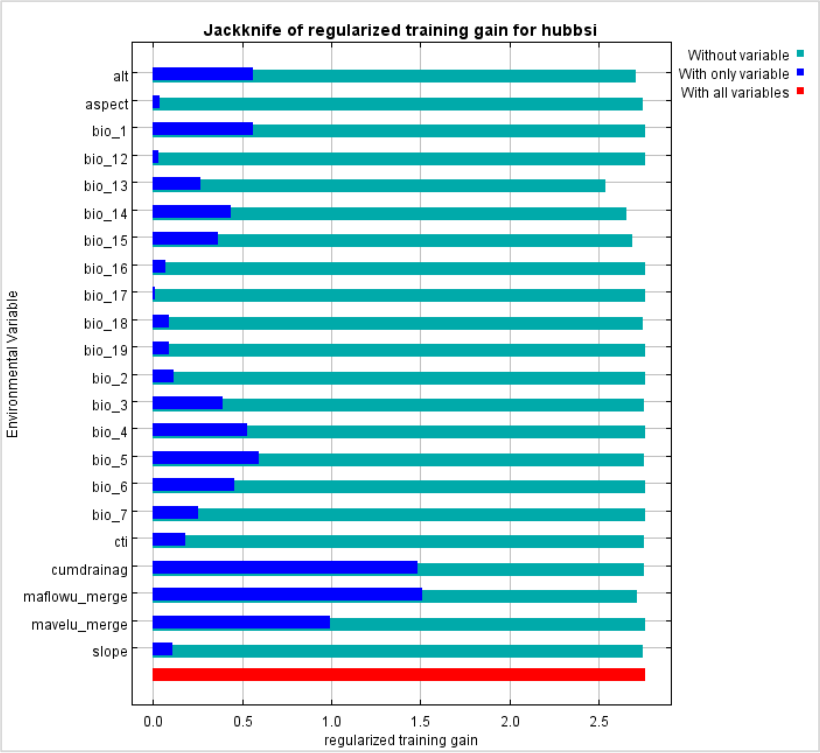
a. Jackknife of variable importance for *Platygobio gracilis* when including categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



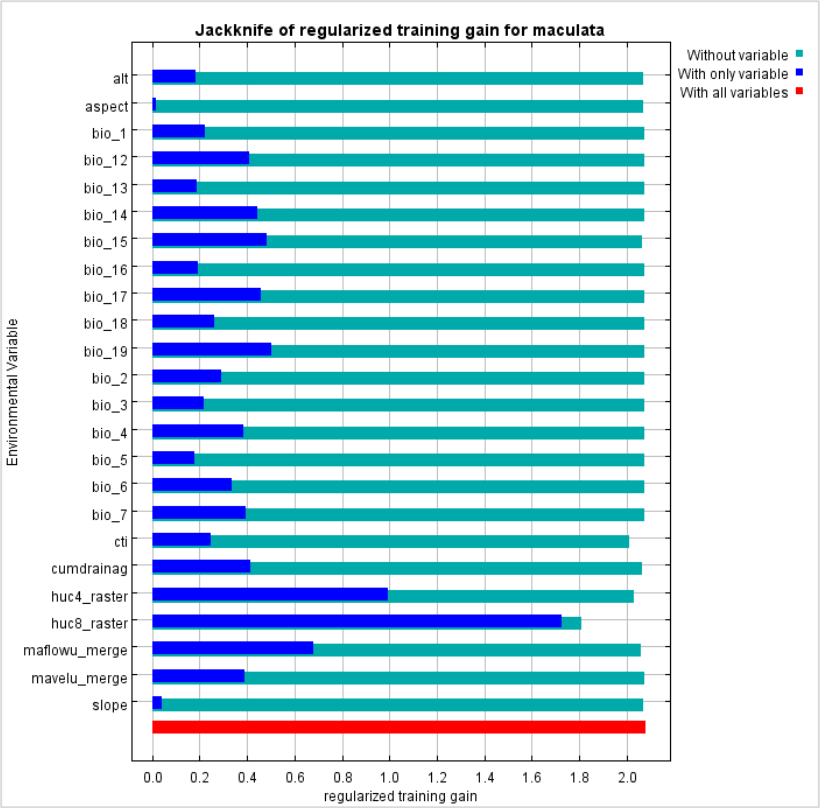
b. Jackknife of variable importance for *Platygobio gracilis* when excluding categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



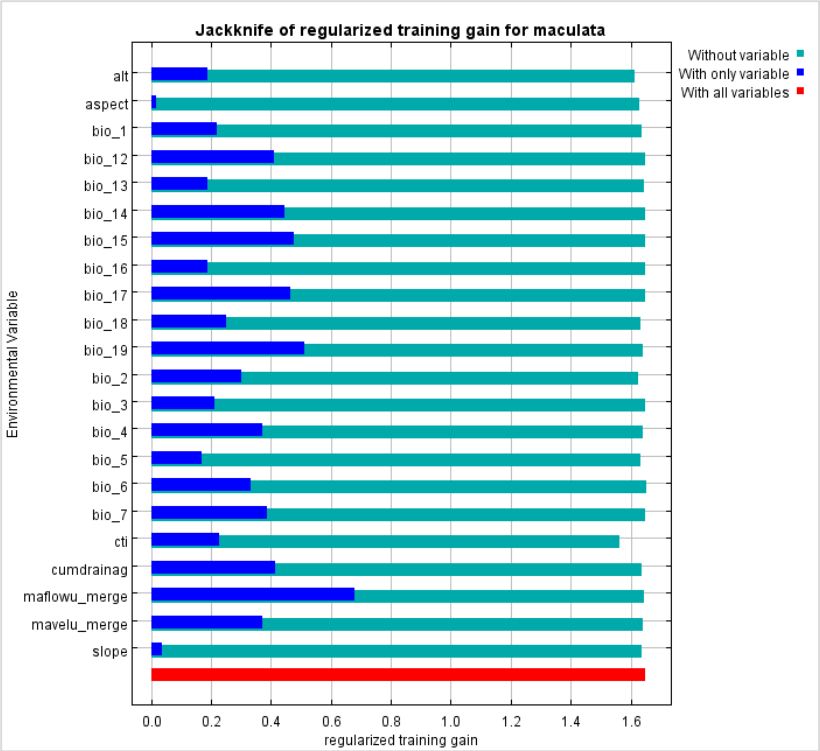
a. Jackknife of variable importance for *Pteranotropis hubbsi* when including categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



b. Jackknife of variable importance for *Pteranotropis hubbsi* when excluding categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



a. Jackknife of variable importance for *Percina maculata* when including categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).



b. Jackknife of variable importance for *Percina maculata* when excluding categorical hydrologic variables HUC4 (major basin) and HUC8 (subbasin).

8 SUPPLEMENTAL DATA

This report and the following supplemental data files will be permanently archived in the Digital Repository of the University of Texas Austin (http://repositories.lib.utexas.edu/). The archive contains this complete report and supplemental data files (total 1.05 GB in 24,922 files in 47 folders. The complete file structure is described as follows:

\consnet_analyses – Contains model output in ASCII format ready for use in a GIS for the four conservation planning products: 20% fixed-target multicriteria, 30% fixed-target multicriteria, variable target (based on conservation status), and the zonation product which contains solutions for representation at 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, & 90%. This directory also contains JEPG images identical to what are provided in the report section 3.

\data – Contains CSV (comma separated values) files: Data, Notes to data fields, Institution Codes, and Production and processing.

\species_distribution_models – Contains i.) images of both model runs for each species as well as a map of occurrence records used in modeling. These maps are useful for visual inspection and interpretation, ii.) complete raw models for each model run for each species in ASCII format, iii.) the Maxent results log, containing model parameterization and result details, and iv.) the html files of each model's Maxent summary for the individual 10 replicates as well as the average run. The summary includes plots of individual variable importance.