Salado Salamander Monitoring
Final Report 2025

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Salamander photographing trays courtesy of City of Austin Barton Springs salamander monitoring program

Acknowledgements

We appreciate the field assistance from David Thomasson, Lauren Granger, Bernadette Aguirre, Luke Kerner, Delaney Stourgeon, Marin Debolt, and Bridgette Zapalac for help with the collections. Thanks to Nate Bendik, Matthew Westbrook, Anderw MacLaren, and Zack Adcock, and Justin Camp for providing data and personal communications. All the help really was appreciated this year, thanks.

Executive Summary

Monitoring of the Salado salamander (*Eurycea chisholmensis*) concluded in December of 2025 finalizing the 11th year of monitoring at the Salado Downtown Spring Complex (DSC) and at Robertson Springs in Bell County (Figure 2). No Salado salamanders were detected during 2025 monitoring at Robertson Springs or from the DSC. Flow at Side Spring in the DSC has continued to decrease most likely due to infrequent rainfall and consequent dropping of the aquifer. In addition, no salamanders were captured during passive searches with drift nets at the Robertson or at the DSC sites. Discharge average for 2025 on Salado Creek was 21 ft^3/s which is about half the average of annual discharge measured since 2015 (~43 ft^3/s; Gauge #08104300 accessed 1/6/2026). In general flows decreased across the study area.

Monitoring continued at Solana Ranch Spring #1 (SR1), seventh year of quarterly data. A total of 39 detections composed of 22 individual salamanders (determined through photographic analysis) were documented over the 2025 seasonal monitoring period. One juvenile was collected in December at SR1.

Sampling at Kings Garden on the Tres Palacios Tract was added to the overall monitoring program for the Salado salamander in 2022. This site was visited four times during 2025 and during each visit salamanders were detected. Kings Garden much like SR1 is a stable site with detections present at each visit including juvenile salamanders documented in the spring. A total of 59 detections composed of 35 individual salamanders (determined through photographic analysis) were documented over 2025. Eight juveniles were detected in 2024 at Kings Garden.

Existing data from monitoring programs with over three years of data were used in two different ways for this report. First, in an examination of juvenile data to examine trends across the northern group of salamanders in relation to when the juveniles are present, what range of juveniles are observed at long term monitoring sites, and what is their relative abundance at these peak times was undertaken. Second, in terms of abundances or densities and how they relate to an estimate of karst thickness at the spring sites.

Introduction

The Salado salamander (*Eurycea chisholmensis*) was first described as a species in 2000 (Chippindale et al. 2000). Although the salamander had been discovered earlier and was in a collection kept at Baylor University by B.C. Brown, no formal description had been made. In addition, collecting individuals from this population proved to be difficult (Chippindale et al. 2000). Due to the limited knowledge about the species (population density, life history patterns), potential threats (dewatering and urbanization), and limited geographical range, this species was listed as threatened by the U.S. Fish and Wildlife Service (USFWS) on February 21, 2014. Critical habitat was designated in 2021 and more information can be found at *http://www.fws.gov/southwest/es/austintexas*.

The Salado salamander is the most northern population of fully aquatic *Eurycea* in Texas. The species is highly restricted geographically and is hypothesized to have a very low population within Central Texas (Norris et al. 2012). Nice et al. (2021) presented an analysis on the effective population size, showing that the northern populations (i.e. DSC, Robertson, Solana) have a lower effective population size compared to sampled populations in the southern group of Salado salamanders (Cowan Creek Spring and Twin Springs). Genetic diversity among all measured Salado salamander sites (Nice et al. 2021) was low, showing a Nei's G_{st} 0.0121, and between northern (Robertson and the DSC) and southern salamander sites, (Cowan and Twin springs) very low; $G_{st} = 0.0042$ (Nice et al. 2021).

Since the listing in 2014, the TXWFCO and TPWD have added two additional Salado salamander locations, one at Anderson Spring in the DSC and one at Keeta Spring further upstream along Salado Creek in the proximity of Kings Garden. Recently, on the Solana Ranch four other salamander locations were discovered by environmental consultants during surveys for development (Figure 1). At this time, the Salado salamander has been documented at 19 locations above Lake Georgetown.

Before the listing of the species, an active research or monitoring program had not been established for this species. In addition, the known community structure of aquifer-dwelling species in the northern segment of the aquifer was not well studied. Due to these gaps in scientific knowledge of the species and the aquifer, the TXFWCO has been collecting data on habitat associations, reproduction, seasonality, surface densities, and the aquifer community with the intent of creating this long-term data set for the species within its known geographical range.

There have been three peer-reviewed publications on the Salado salamander (Diaz et al. 2020; Nice et al. 2021; Diaz et al. 2023) since monitoring began. In addition, seven peer-reviewed publications describing the aquifer community in this northern section of the Edwards Aquifer have come from the Salado salamander work (Okan Külköylüoğlu et al. 2017; Gibson et al. 2021; Alvear, Dominique et al. 2020a; Alvear, Dominique et al. 2020b; Fend et al. 2023; Perez et al. 2023; Perez et al. 2025). A new aquifer species in the family Dytiscidae, is being submitted for publication and if formally accepted will be termed *Chaodytes ruthae*, in honor of the Robertson family for their dedication to conservation over the years. Our data on *C. ruthae* suggests strong genetic and morphological evidence for this new genus and species. The data collected on the northern segment of the Edwards Aquifer will hopefully be valuable by aiding in management decisions as the Village of Salado, Bell County and the northern portion of Williamson County continue to expand their conservation plans into the future.

Monitoring for neotenic *Eurycea* sp. along the Edwards Plateau, in almost all cases were initiated due to a petition to cover a species under the Endangered Species Act. There are four major neotenic *Eurycea* sp. monitoring programs across the Edwards Plateau. Two programs are below the Colorado River dealing with the Barton Springs, Austin Blind, and the San Marcos Springs salamanders. The City of Austin Watershed Protection Program is without doubt the most comprehensive, extensive, and longest effort established along the Plateau. They have been working with the Barton Springs salamander (*E. sosorum*) since 1993, it was federally listed in 1997. However, the Barton Springs salamander was petitioned in 1992 (61 FR 46608 46616). The COA has published 11 peer reviewed publications on the Barton Springs salamander. The COA also works occasionally with Travis County biologists to sample for Jollyville Plateau salamander (*E. tonkawae)*, The COA started monitoring the Jollyville Plateau salamander in 1996. The Jollyville salamander was petitioned in 2007 and is the only neotenic *Eurycea* sp. to have a relatively consistent program before a petition. The second effort to sample *Eurycea* salamanders below the Colorado River has been done by an environmental contractor on the San Marcos salamander (*E. nana*). The salamander was listed in 1980 and the monitoring program began in 1996. This program has been ongoing for about 20 years with the same consulting firm. There have been no peer reviewed publications on the San Marcos salamander from this monitoring effort.

The Northern group of salamanders, Jollyville, Georgetown (*E. naufragia*), and Salado (*E. chisholmensis*) salamanders have been monitored by another team of environmental consultants and university researchers. Our program focuses on the Salado salamander only. This group of environmental consultants and university researchers have been monitoring the Georgetown salamander since 2007 and the other two species, the Jollyville and some Salado populations since around 2012. This group has produced 18 peer reviewed publications on the three species. The Georgetown and Salado salamanders were both petitioned in 2004 (70 FR 24870 24934).

If these species are to remain in the environment and maintain their historical geographic ranges over time (~50 years) then people must collect ecologically meaningful data on them. If the species are to be delisted or downgraded, then there must be peer reviewed data to suggest resiliency or positive population patterns over time. Sporadic monitoring every couple of years might not be sufficient with the projected municipal growth in the area. The growth will trigger a cascade of demand for local resources (water, effluent discharge, and land coverage) and accelerating proven environmental consequences of the "urban stream syndrome" theory. Sporadic monitoring will not be able to draw correlations or strong conclusions (Walsh et al. 2005; Bendik et al. 2014; Diaz et al. 2020) to the activities surrounding the spring systems. These anthropogenic pressures have been shown to produce irregular water quality spikes (Cambrian Environmental 2018, pp. 13, 18, 42-43; Cambrian Environmental 2018, p. 22), changes in larval period (Rittenburg & Pierson 2024) and size due to warmer water (Rittenburg & Pierson 2025), changes in prey base (King et al. 2011), and a myriad of other hydrological issues (Walsh et al. 2005) in the catchment of the spring system.

Methods

Sampling was conducted quarterly this year at the DSC, Robertson Springs, Kings Garden, and SR1 (Figure 1). The DSC consists of Big Boiling, Side Spring, and Anderson Spring. Timed searches were used at the Robertson Spring complex (RSC), while Side and Anderson springs were searched entirely due to the small area of the springs. Solana Ranch Spring #1 was sampled from the spring orifice to a location where the spring run fans out and enters the main channel. Any areas where the water emerged from under the gravel and cobble were searched. Another smaller spring adjacent to the main spring was also entirely searched (from spring run to spring orifice) on each visit. Sampling at Kings Garden Spring was sampled quarterly and followed the same methods as Solana listed below. Sampling at Kings Garden was done from the spring orifice down to a pool approximately 20 feet from the opening. The pool creates a shift from a cobble and gravel run to silt substrates, which are present due to the slower flowing water in the pool.

All springs were actively searched by uniformly turning over rocks and sifting through vegetation and debris. During timed searches all mesohabitats were searched for salamanders. Salamanders were captured using small aquarium nets. Captured salamanders were placed into mesh bags and kept in the spring run for processing (see below).

If a salamander was captured during any survey the primary substrate and vegetation were documented. If a salamander was captured in the drift net placed over an orifice, a designation of cave conduit was applied for substrate. All captured salamanders had two sets of photographs taken. First, photographs alongside a ruler were taken to determine total length of the salamander (mm) using the program ImageJ (Schneider et al. 2012). Following that, a close-up photograph of the head was taken and analyzed with the program WildID (Bolger et al. 2012) to determine if any individuals were recaptures (Bendik et al. 2013).

Drift nets with 250 µm mesh were positioned over the spring opening and used for passive sampling at Robertson and Anderson springs and SR1 when spring flow was available. Nets were left in place for seven days to passively collect organisms as part of the monitoring regime. Aquatic invertebrates captured during this sampling were taken back to the lab, sorted, identified, and enumerated. Most taxa were photographed using a dissecting scope with certain taxa sent to experts for identification.

Due to low surface densities encountered at the sites over the years, the data have been collapsed and examined cumulatively. As in previous reports the overall dataset has been updated to include the 2025 collections. Data was grouped into seasonal blocks for a size distribution analysis. The relative abundance of salamanders was calculated for each season separated into size classes. Size classes are from 0-19, 20-29, 30-39, 40-49, 50-59, 60-69 mm; 1, 2, 3, etc. respectively. Associated substrate and vegetation percentages were updated to reflect the new collections.

Solana Ranch Spring #1 statistical analysis included the probability of capture from quarterly data collected from 2020 – 2025. The probability calculations marked each time a salamander was captured and identified as “1”, therefore the capture history of a salamander for 2019 may resemble 101001 (six number places for six events, 0 = not detected, 1 = detected). For this example, the probability is the sum of the captures divided by the number of events, therefore, 0.5. Examining the average probabilities of capture history provides some insight into the effort of sampling between years.

Using the Solana data from 2020 - 2025 open mark and recapture models were examined using the program Mark (White and Burnham 1999). Two different types of models were run. One type are Cormack Jolly Seber models and the other type was a POPAN approach. No covariates were added to these models. The relationship between count data or density and the selected covariates were examined using Pearsons Correlation Coefficient. The data will be examined as each individual sampling event or as an average for the year.

The northern clade of *Eurycea* in the sub genus Septentriomolge cover about 45 miles from the Colorado River north to Salado and at this time are made up of three closely related species. These species are known to have a defined breeding season with highest surface densities in the spring and into summer (Bendik 2017; Pierce et al. 2014; Diaz et al. 2023). These species have had monitoring programs for over ten years now at some sites and have collected various types of data regarding the life history strategies, ranges, and surface estimates.

Data from published reports and public monitoring efforts that span at least three years were used to examine juvenile data. Trends across the northern group of salamanders were looked for in relative abundance of size classes at these peak times and are larger proportions of a specific size class indicative of a more stable population or spring flow.

Data collected over the years on the northern *Eurycea* spp. has been examined for this report based on the question: What does a stable site look like in terms of a salamander surface population? Is the answer a number, a location, persistence overtime, presence of juveniles?

How to evaluate a site with salamanders present or even an individual salamander has been a question to many individuals working with this genus of lungless brook salamanders. There has been work done on tail width ratios for the species (Nissen and Bendik 2020; Pierce 2022), researchers have documented shrinking in salamanders following long times underground (Bendik and Gluesenkamp 2012), captive populations have documented toe loss (COA reports), and rarely at sites, deformities and loss of limbs have been documented (Diaz Activities 2021). These individual deformities are informative, however, they do not address the bigger question of population structure at the site and how that relates to site stability overtime. Trends across the northern group of salamanders were looked for in relation to what is their relative abundance at these peak times is and are larger proportions indicative of a more stable population.

Finally an examination of karst thickness around the spring sites for the Northern Group was undertaken by using a layer from the Texas Water Development Board Edwards Aquifer

Northern Segment GAM (https://www.twdb.texas.gov/groundwater/models/download.asp) to examine the abundance thinning hypothesis about the Northern Group (Jones 2003). Over the ~45 mile range of the Northern Group the thickness of the aquifer is estimated to thin by around 160 ft from Central Travis County to Southern Bell County (Jones 2003). Due to the thinning of the karst the aquifer in general as it moves northward, the thinner sites may have less available for habitat for inhabitants or spaces available for subterranean movement. Therefore, as the karst thins moving in a northern direction we would expect to see smaller surface populations of salamanders as we assume they are some reflection or percentage of the subsurface population.

Although these models were not intended for small scale interpretation, Jones (2026) states that the model may be applicable at the scale of a large water well field (Jones 2026). For these reasons, the area was selected to be 2 miles around the spring site, which is equivalent to ~1004 acres, or the size of large water well field in the area. The two mile radius circle was created using the site location as the center in ArcPro 3.5. This area was used to clip data from the GAM for the Northern Edwards Aquifer. Once the data was gathered it was transferred to an excel sheet and the Edwards thickness column was averaged to create a thickness score for each site. The root mean squared error for the calibration of all layers within the Jones (2026) Northern Aquifer GAM was reported at 56 ft (Jones 2026). The sites were then ordered from south to north and from east to west. The order of east to west was examined due to the estimated northeast to southwest oriented flow paths in the Northern Segment (Jones 2026). Finally, the thickness score was then placed in a scatter graph with known population estimates from sites in the south to north order to determine if any relationships were present.

Results

Robertson and Downtown Spring Complex

Spring flow at RSC was present on January 26th of 2024 and continued to flow with decreasing intensity from the headwaters down till around May of 2025. No flow was present from the headwaters or Beaver springs after June of 2025. Bathtub Spring continued to flow until around July of 2025. The last collection of a salamander from RSC was on December 12, 2024, from Bathtub Spring. Most of the year the beaver dam caused water to back up into the spring runs and might have contributed to the lower flows due to head pressure.

A net was set at Anderson Spring in the DSC in May of 2025 and was left on for two weeks, but no salamanders were detected. The last time a salamander was detected at Anderson was in April of 2023. The last detection from Big Boiling was in April of 2022. Side Spring adjacent to Big Boiling was productive in the past, however, there have been no collections from that site since May of 2021. The flow at Side Spring has been decreasing for several years now. No salamanders were captured at any DSC or at Robertson sites during 2025.

A total of 192 Salado salamanders have been captured since 2015 from the Robertson Spring complex and the DSC sampling locations. Only three of these salamanders do not have associated substrate or vegetation data, leaving 189 salamanders to examine with substrate and vegetation associations. A total of 75 (39%) salamanders were captured in drift nets, presumably leaving the aquifer. Of the remaining 114 salamanders caught on the surface, 76 (66%) were caught in gravel as the primary substrate, and 28 (24%) were caught in cobble as the primary substrate (Table 2). Other substrates included boulder, sand and silt. Data from past habitat sampling at Robertson Springs has shown around 50% of the substrate to be silt (Diaz et al. 2016). Salamanders are captured in different types of vegetation, however, in most cases it is caught within watercress (47 individuals; 39%; *Nasturtium* sp.), although in contrast, 54 (45%) were captured in areas with no vegetation.

From the 192 total individuals detected, 181 were used to examine the temporal shift in size for surface populations at the DSC and Robertson Springs. The updated temporal shift in surface population size classes displays a classic ecological progression from smaller to larger, over the course of the year (Figure 3). In spring, the majority of salamanders captured were in the smallest size class ranging from 10 to 19 mm. The spring trend line shows (dashed blue line) a minimal bimodal hump, with a smaller hump in the fifth size class. In summer (solid green line), the smallest size class is still prevalent by one salamander. However, the second hump in the third size class is comparable. During fall (dot and dash purple line), the community is dominated by the fourth size class. The winter trend line (dotted red) changed a bit due to the additions from the February collections this year. The initial hump of the line in the first size class has smoothed out to show about the same number of smaller salamanders on the surface with most salamanders in the 4th size class. Overall, more salamanders have been detected in spring, with the fewest detected in winter, with juveniles more prevalent in spring with adults more dominant in fall and winter.

Solana Ranch Spring #1

A total of 39 salamanders were captured at SR1 during 2025 monitoring. After removing recaptures of individual adult salamanders, the capture history shows that 21 adult salamanders were detected and photographed during 2024. One juvenile was detected in December of 2025 (<25 mm). This year, most likely due to lower flows, most metrics regarding recaptures and new salamanders encountered are lower than in previous years (Table 3). Probabilities for recapture are listed in Table 3 and have been adjusted from previous reports as the numbers were corrected to reflect the actual captures, recaptures and new individuals.

The temporal shifts in size class follow the same trends as the DSC and Robertson springs, but the overall population exhibits larger salamanders on the surface year-round (Figure 4). The analysis this year is made up of 783 salamander captures. During the fall there have been no documented occurrences of salamanders in the first or second size class. This type of graph when compared to individual graphs from the other springs in the monitoring area highlight the permanence of the small spring at Solana Ranch by exhibiting most of the salamander community at size classes 4 – 6 throughout the year (Figure 5).

Densities for each survey event were calculated by taking the salamander count and dividing by the area searched. The estimated area searched for salamanders at Solana Spring #1 was created by using a Trimble Geo7X with submeter accuracy and was determined to be 13.9 m^2. The average density of adults was calculated at 1.85 salamanders per m^3 and the average density of juveniles when present was 0.08 salamanders per m^2.

The results from the POPAN analysis were not reliable due to ranges including zeros, in confidence intervals and standard errors. The CJS model provided estimates of the probability of detection for the site at different times ranging from <0.01 from the first event in 2020 to 0.39 in 2021. The average probability of detection for the data set is at 0.16. The estimate of survival from the CJS model is at 0.83 (0.80-0.85).

Kings Garden and Pecan Springs

Kings Garden is located just south of the Bell County line and north of Cobbs Spring, for *E. chisolmensis* this will be a new genetic sample based on historical sampling (Figure 1). Other reports have shown a small genetic shift highlighting species variability from Robertson springs and associated sites to the north of Solana Ranch (Nice 2021). The goal now is to monitor Kings

Garden Spring quarterly with active searches while sampling aquifer taxa using the passive sampling techniques previously described following the surveys.

Kings Garden Spring run consists of two branches (main and secondary). The branch termed “secondary” was searched for salamanders in April of 2022, however, none were detected. Cobble and gravel substrates were present in the run although most were embedded or covered in silt. The “main” branch has a noticeable orifice where water emerges and flows over cobble and gravel substrates. The flow continued down over a small riffle covered in watercress, and aquatic moss with cobble and gravel substrate. The salamanders were detected in this riffle that was supported by laminar flow. Downstream of the riffle section was a larger silt dominated shallow pond. The silted pond flowed into another riffle that feeds into a more stream like habitat (narrow with flow). This second riffle below the silted pond also has salamanders, however they are not always detected in this riffle.

In 2025 Kings Garden was sampled in April, July, September, and December. Sampling in 2025 was conducted in the main branch along the first riffle below the orifice. A total of 59 detections were made during the quarterly sampling events including eight juvenile salamanders. Following post processing with Wild ID to determine matches among events, a total of 35 individual salamanders were detected. The most salamanders were captured in July this year (n = 26). A total of 13 recaptures from previous years were documented in 2025 (Table 4). Shifts in community relative abundance are similar to what is seen at Solana Ranch Spring #1 (Figure 7) in that the largest representation of juveniles is seen in spring. The curve for spring has size class six as the dominant class which is a bit different than at Solana with size class five being dominant. This may be an artifact of less time sampling, changes in the weather cycles, and/or the change of the curve over time as we populate the data with observations. At this time the curve in the spring appears to show a healthy population at this site.

Juvenile Salamander Analysis

Juvenile salamanders were observed at all of the northern sites during the course of the monitoring period examined. Twin Springs had the lowest reported relative abundance of juveniles in the data set. Robertson/DSC, Kings Garden and Avery Deer had the highest relative abundance of juveniles in the data set. No relationships between impervious cover and juveniles relative abundance were observed. The average for size class one (10 – 19 mm) was 14% from the data set with the average for the second size class at 9% relative abundance. In summation, a site with three years of data in the northern segment during the spring season could have about 25% of measured salamanders between 10 and 29.99 mm, or in size class one and two.

Surface Estimates, Relative Abundance, and Karst Thickness of Northern Eurycea

Northern *Eurycea* data collected for this exercise were from public reports and peer-reviewed publications. The criteria for data were that the sites had three or more years of available data. Due to the breeding season of the salamanders, only data from spring seasons were used because the juveniles should be present and larger surface densities are available, representing a potentially larger proportion of the overall population. Data was broken into size classes by ten-millimeter groups. Impervious cover scores were collected for each catchment (HUC-14) and estimates of surface populations for open, closed, or genetic estimates were collected.

Eight northern *Eurycea* sites fit the requirements for data. An additional ninth site, Barton Springs, was added to the data collection to provide a larger permanent spring for comparison. Barton Spring has documented the presence of juveniles all year as in San Marcos Springs (Tupa and Davis 1976) to the south. However, even the Barton Springs data from shows a peak in juvenile abundance in the spring months (March, April, May; Bendik et al.2025). A total of 3,864 salamanders from the spring season were used for data analysis from nine northern *Eurycea* spring sites to create the relative abundance curve for the northern populations, and 4,721 salamanders when data from Barton Springs was included (Table 6). Impervious cover data was collected from USGS national land cover datasets from all years available (Table 6).

No ecologically meaningful correlations were seen between the impervious cover scores (2021) and any of the size classes. The curve created using the average of size classes from the available nine sites shows a slightly bimodal curve. There is a small peak in the 1st size class then another large peak in the 5th size class when looking at the northern data only (Figure 8). The data with Barton Springs included mirrors the solely northern *Eurycea* relative abundance average except it shows more representation of other size classes, potentially due to the consistency of Barton Springs as it never has gone dry.

Abundance estimates from open and closed models have been undertaken for the northern *Eurycea* group. There are a total of 19 models for *E. tonkawae*, nine for E. *naufragia*, and 15 for *E. chisholmensis* (Table 8). These data were separated into open and closed models for each species. One caveat is that *E. naufragia* only has one open model estimate at this time, all other estimates are averages of each type of model. Averages were taken for sites with more than one estimate of a closed or open model. The general trend is for the surface abundance estimates to decrease from the southern species *E. tonkawae* to the most northern species, *E. chisholmensis* (Figure 9).

Thickness of karst scores with a 2 mile radius buffer around the spring openings ranged from 54 ft to 275 ft thick. (Table 9; Figure 9). A total of 4,399 data points were clipped from the TWDB layer and used to calculate karst scores for the 18 sites. Of those data points 362 or about 8% were set at -9999. This score was interpreted to mean the pixel was unidentifiable by the model. These scores of -9999 were removed from the data set before the average of the karst scores. Data points for each individual karst calculation ranged from 91 data points (rows) at Wheless to 183 data points at Cobbs. The thickest section from these calculations is the northern Jollyville group southwest of the Georgetown area. The thinnest sites identified were Wheless, Hog Hollow, and Solana, at all around 50+ ft thickness. Abundance estimates for these sites appear to track the thickness scores moving south to north (Figure 10), and with closed estimates correlated to the karst thickness score at 0.49 (Table 10).

Discussion

Following 11 years of monitoring *E. chisholmensis*, many of the life history patterns (cryptic, depositing eggs in aquifer, breeding season), habitat associations (proximity to spring orifice, watercress, rocks), diets (opportunistic generalist) and associated aquifer communities are similar if not the same as other more well know species south of the Colorado River. Although the Hill Country ends with the southwestern distribution of *E. tonkawae*, these patterns persist, as in hypothesized western species, to the northern end of the neotenic *Eurycea* in Salado Texas.

One concept not discussed over the course of this monitoring program is the movement of these northern salamanders in either surface or subsurface environment. Movement of these northern salamanders has been documented in at least two publications (Pierce et al. 2014, Bendik et al. 2016). Pierce et al. (2014) sampled Swinbank and Twin springs in Williamson County, TX and found that 25% of 60 recaptured salamanders and 45% of 29 recaptured salamanders, respectively, had moved out of their 5 m section over the duration of a two year study. Therefore, around 30% and 50%, respectively, of the salamanders were not recaptured in the Pierce study. Some most certainly moved or died, while others were present, just not detected during the two year survey period. Bendik et al. 2016 found that 1 individual moved over 500 m in a two year period at Lanier Spring. In summation, Bendik et al. (2016) found that the largest density of juveniles was in the most downstream section of the survey, movement was favored towards larger bodied individuals, and that in this study *Eurycea tonkawae* had more movement than in other non-neotenic *Eurycea* spp. studies (Lowe 2003, Cecala et al. 2009). Bendik et al. (2016) results may highlight the lack of swimming ability and/or habitat partitioning in juveniles, and the fitness in larger bodied salamanders, presumably not juveniles, to move against the flow.

Movement for these salamanders may be influenced by the type of spring (seep, orifice, alluvium), present either in a losing or gaining section, or conduit size supplying the spring. Most likely movement on the surface is different than in the subsurface habitats, due to light, temperature (Hutchison 1958), prey pressure on the salamanders from fish (Davis and Gabor), cannibalism (Diaz et al. 2019), food availability, and flow (pool, stream or hydraulically controlled). Dye tracing in the San Antonio segment of the Edwards Aquifer has documented conduit travel velocities ranging from approximately 80 ft/d to 13,000 ft/d, with 13 of 14 tracer tests exceeding 1,000 ft/d (Smith et al. 2005). In the Barton Springs segment, calculated conduit flow velocities under high aquifer conditions can reach up to 30,000 ft/d (Smith et al. 2005). In the Trinity Aquifer and related Edwards-Trinity units, Watson et al. (2018) documented groundwater movement exceeding 7,000 ft/d along a flow path in the Driftwood, Texas area near RR12 and FM150. Devitt et al. (2019) discusses how mitochondrial DNA, or salamanders, may move from San Marcos Springs to Barton Springs assumingly over a series of generations under “rare conditions” due to groundwater dynamics, implying that these salamanders may in fact be moving with the flow subsurface. This shifting and movement with flows is most likely occurring more frequently than documented in other locations across the Edwards Plateau.

The other concepts related to the Salado salamander within this report have been expanded year by year. The patterns examined for the Cemetery Well and the potential relationship with the spring complex at Robertson are still elusive although the data for this year on well depths is more complete. While a relationship was shown it is not predictive enough with the salamander data to be useful at this time. The effects of time spent underground for surface species have been documented and correlate to loss of tail width during long periods without surface interaction (Bendik and Gluesenkamp 2013). The temporal shifts in salamander size are classic responses that highlight the breeding season of this species (Diaz et al. 2023). This breeding season in the northern *Eurycea* group is uniquely significant and could be intensified by the shallowing of the aquifer as the limestone generally decreases in depth as the aquifer moves north. This shallowing of the limestone in this northern segment (Jones 2003; Collins 2002) could cause the influx of recharge water into inhabited areas more quickly than in deeper portions of the aquifer to the south.

This year we were interested in the northern species grouped as a whole and how their surface densities or surface estimates that might explain or provide insights into why the surface populations of Salado salamanders are smaller in general than the species to the south. Right now, there are 19 known locations for the Salado salamander, and of those sites only four or five are large enough to conduct mark and recapture estimates. The trend seen in smaller surface abundance estimates in the species as you move north, from *E. tonkawae* to *E. chisholmensis,* is interesting and corresponds with a general narrowing of karst availability following the same northern trend (Collins 2002; Jones 2003). In general, the karst thickness goes from a combined ~420 ft of combined thickness in Travis County to ~260 ft in southern Bell County. The reduced available karst in the range of the Salado salamander would imply less space available for salamanders to occupy than thicker karst spaces to the south, and in turn smaller overall abundances. This trend is alluded to in genetic estimates of effective population size between the northern and southern populations of Salado salamanders (Table 7; Nice et al. 2021).

Although these three species (*E. tonkawae*, *E. naufragia*, and *E. chisholmensis*) share a number of biological traits and strategies, trying to compare their habitats or springs is difficult as they encompass different types of apparent landscapes. The landscape not only changes from south to north organically but shifts from heavily populated areas north of the Colorado River to less densely populated areas into southern Bell County. Underlying geological differences in flow paths, conduit size, karst thickness, porosity, all known and unknown, are also most likely to occur in varying magnitudes for each site creating a unique mix of local and older recharge. In addition, the different timespans in which development has been present around an individual spring site have proven to be a factor showing negative correlations in densities of salamanders within older developments (Bendik et al. 2014) and larger body burdens of contaminants in salamanders at these older sites (Diaz et al. 2020). Taking what we know about the southwestern *E. tonkawae* populations in the most northeast stretches of the Hill Country, in gaining streams, is problematic to compare to *E. tonkawae* sites in the Brush Creek area with flatter surface topography, losing streams, higher population density and comparatively newly developed areas (Figure 11).

Other insights into why the surface densities or surface populations of *E. chisholmensis* are historically small (Norris et al. 2012), are addressed extensively in previous reports. Briefly, the hydroperiod of the springs (i.e. the duration of discharge over time), proximity to larger order streams, (i.e. ecological disturbance), individuals are slow to emerge from the subsurface (~1 salamander every 30 days; Diaz and Bronson-Warren 2018), and finally this species is on the northern fringe of neotenic *Eurycea* distribution in Texas. In comparison, the surface populations present at SR1 and Kings Garden, to the south of Salado, have always been detectable and relatively consistent. Kings Garden and SR1 have consistent hydroperiods, are not near a larger order stream or river, and are south of the known northern locations for these salamanders and presumably on a thicker layer of available kart formations.

The views expressed in this paper are those of the authors and do not necessarily reflect the view of the U.S. Fish and Wildlife Service or Texas Parks and Wildlife Department.

Table 1. Number of Salado salamanders collected during quarterly monitoring using active and passive sampling techniques in 2025.

Season	Robertson	Downtown Spring Complex	Solana Ranch Spring #1	Kings Garden
Spring	0	0	15	20
Summer	0	0	8	26
Fall	1	0	9	4
Winter	0	0	7	7

Table 2. Habitat associations of the Salado salamander, determined by 189 salamanders collected from 2015 to 2024 at the Downtown Springs Complex (DSC) and Robertson Springs.

	#	%
Cave Conduit	75	39.68
Substrate		
Silt	3	2.63
Sand	3	2.63
Gravel	7	66.67
Cobble	28	24.56
Boulder	4	3.51
Vegetation		
***Sagittaria* sp.**	1	0.83
***Nasturtium* sp.**	47	39.17
Filamentous Algae	5	4.17
***Ludwigia* sp.**	3	2.50
***Amblystegium* sp.**	5	4.17
***Hydrocotyle* sp.**	2	1.67
none	54	45.00
Organic Debris	2	1.67
Grass	1	0.83

Table 3. History of quarterly monitoring data from Solana Spring Ranch #1 (SR1). "Recaps Previous Years" are individuals that were captured more than once between sampling years.

	2020	2021	2022	2023	2024	2025
Recaps Previous Years	15	30	34	41	29	18
Recaps within Year	16	10	13	11	5	2
New Individuals	67	63	46	50	38	19
Naive Probability of recap	6.2	10	11.7	13	8.5	5

Table 4. History of quarterly monitoring data from Kings Garden Spring. "Recaps Previous Years" are individuals that were captured more than once between sampling years.

	2022	2023	2024	2025
Recaps Previous Years	0	7	12	13
Recaps for Year	0	6	5	0
New Individuals	23	38	50	35
Naive Probability of recap	0	8	13	3.25

Table 5. Water quality collected during monitoring in 2025.

		Date	Temperature °C	Dissolved Oxygen mg/L	pH	Conductivity µs/cm
Solana	Bell	1/8/2025	19.18	8	7	429.6
Robertson	Bell	3/31/2025	23.17	6.91	8.55	638.1
Solana	Bell	4/22/2025	20.4	7.89	7.5	491.3
Anderson	Bell	7/11/2025	21.25	7.27	6.95	592.9
Big Boiling	Bell	7/11/2025	21.1	7.63	7.2	591
Side	Bell	7/11/2025	21.6	na	7.38	510
Robertson	Middle	7/11/2025	21.13	7.6	7.9	583
Kings Garden	Williamson	7/14/2025	21.83	na	na	584.4
Solana	Bell	7/16/2025	21.01	7.94	7.35	452.5
Anderson	Bell	9/24/2025	21.26	na	7.06	518
Big Boiling	Bell	9/24/2025	21.19	na	7.01	516
Hidden Spring	Bell	9/24/2025	23.75		7.8	632
Kings Garden	Williamson	9/25/2025	21.4	7.24	6.97	583
Solana	Bell	9/26/2025	21.02	7.49	7.13	490.1
Kings Garden	Williamson	12/8/2025	21.3	7.9	7.07	595
Solana	Bell	12/9/2025	20.63	na	6.98	434.4
Anderson	Bell	12/12/2025	20.22	na	7.06	591.8
Big Boiling	Bell	12/12/2025	20.58	7.84	7.25	512.1

Table 6. Data used to create an average relative abundance of northern Eurycea in the spring and impervious cover scores for each catchment (HUC-14) the spring is in. DSC = Downtown Spring Complex in Salado Texas. $\bar{x}$ = Average. Values for Avery sites and Hill Marsh are the same due to occupying the same catchment (HUC-14).

		USGS Impervious Cover			**Size Class Relative Abundance**								
	n	2006	2011	2021	1	2	3	4	5	6	7	Adults	Juveniles
Solana	338		0.07	0.17	0.09	0.03	0.02	0.11	0.39	0.32	0.03	623	51
Twin Springs	364	1.49	1.75	4.65	0.01	0.01	0.04	0.09	0.54	0.28	0	1058	18
DSC/Robertson	73	5.06	6.25	10.86	0.47	0.21	0.12	0.08	0.10	0.03	0	93	79
Swinbank	985	5.38	6.26	11.78	0.01	0.02	0.09	0.23	0.43	0.18	0.006	3615	57
Cowen	212	1.34	7.57	19.24	0.10	0.11	0.07	0.16	0.35	0.18	0.004	641	50
Avery Deer Spring	343	13.22	22.36	40.10	0.09	0.11	0.07	0.16	0.33	0.18	0.035	606	39
Avery Deer SH	534	13.22	22.36	40.10	0.07	0.15	0.15	0.10	0.29	0.19	0.015	1222	93
Hill Marsh	949	13.22	22.36	40.10	0.03	0.07	0.09	0.19	0.45	0.14	0	1006	32
Kings Garden	81		0.05		0.33	0.09	0	0.03	0.13	0.29	0.09	51	32
Eliza	857	13.24	16.80	27.36	0.17	0.19	0.22	0.24	0.27	0.29	0.324	552	305
$\bar{x}$	4721				0.14	0.10	0.09	0.14	0.33	0.21	0.05		
$\bar{x}$ No Barton Springs	3864				0.14	0.09	0.08	0.13	0.34	0.20	0.02		

Table 7. List of all available surface estimates for the northern *Eurycea* group. Date signifies when the study began and years is how long it went on after that. Cam = Cambrian Environmental.COA = City of Austin. TXST = Texas State University. SWU = Southwestern University.

Species	Location (Spring)	Date	Years	Who	Type	Closure	Capture Probability (*p*)	$N_{\text{something}}$
E. tonkawae	Avery Deer	2013	11	TXST/Cam	POPAN 5	Open	0.09	114
E. tonkawae	Avery Springhouse	2013	11	TXST/Cam	POPAN 5	Open	0.059	445
E. tonkawae	Brushy Creek	2015	8	TXST/Cam	POPAN 5	Open	0.298	3
E. tonkawae	Hill Marsh	2013	11	TXST/Cam	POPAN 5	Open	0.046	928
E. tonkawae	PC (1&2)	2013	10	TXST/Cam	POPAN 5	Open	0.105	150
E. tonkawae	PC1	2023	1	Cam	Robust CMR	Closed	0.431	162.0
E. tonkawae	PC2	2023	1	Cam	Robust CMR	Closed	0.228	386.4
E. tonkawae	Lanier	2007	3	COA	CMR	Closed	0.26	225
E. tonkawae	Wheeles	2007	3	COA	CMR	Closed	0.19	581
E. tonkawae	Ribelin	2007	3	COA	CMR	Closed	0.26	144
E. tonkawae	Spicewood	2022	1	Cambrian	Robust CMR	Closed	0.522	5.8
E. naufragia	Swinbank	2012	10	SWU/Cambrian	POPAN 5	Open	0.093	374
E. naufragia	Swinbank	2012	1	SWU	Robust CMR	Closed	0.350	137
E. naufragia	Capitol Aggregates (Avant)	2020	1	Cambrian	Robust CMR	Closed	0.143	88.7
E. naufragia	Cedar Breaks Hiking Trail	2020	1	Cambrian	Robust CMR	Closed	0.190	206.0
E. naufragia	Buford Hollow	2020	1	Cambrian	Robust CMR	Closed	0.190	6.0
E. naufragia	Hog Hollow	2025	1	Cambrian	CMR	Closed	0.530	45
E. naufragia	Shadow Canyon	2025	1	Cambrian	CMR	Closed	0.300	30
E. chisholmensis	Cobbs	2016	5	Cambrian	POPAN 5	Open	0.1	161
E. chisholmensis	Cowan	2016	8	Cambrian	POPAN 5	Open	0.141	56

E. chisholmensis	Twin	2012	9	SWU/Cambrian	POPAN 5	Open	0.065	112
E. chisholmensis	Twin	2021	3	Cambrian	Robust CMR	Closed	0.195	55.4
E. chisholmensis	Twin	2012	1	SWU	Robust CMR	Closed	0.046	119.0
E. chisholmensis	Solana	2019	1	TPWD/USFWS	CMR	Closed	0.55	41
E. chisholmensis	Solana	2020	1	TPWD/USFWS	LincolnPetersen	Closed	0.11	80
E. chisholmensis	Anderson	2018	1	USFWS/TXST	Genetic			1328
E. chisholmensis	Big Boiling	2018	1	USFWS/TXST	Genetic			719
E. chisholmensis	Side	2018	1	USFWS/TXST	Genetic			25
E. chisholmensis	Robertson	2018	1	USFWS/TXST	Genetic			2600
E. chisholmensis	Solana	2018	1	USFWS/TXST	Genetic			2209
E. chisholmensis	Cowan	2018	1	USFWS/TXST	Genetic			2441
E. chisholmensis	Twin	2018	1	USFWS/TXST	Genetic			1877
E. chisholmensis	Northen Group	2018	1	USFWS/TXST	Genetic			1785
E. chisholmensis	Southern Group	2018	1	USFWS/TXST	Genetic			1931

Table 8. The three northern Eurycea species (*E. tonkawae*, *E. naufragia*, and *E. chisholmensis)* and their average of open and closed models along with the averages for just open and closed models. N = the number of estimates used to create the averages.

Species	Average	N
Jollyville	260	13
Open	268	7
Closed	251	6
Georgetown	127	7
Open	374	1
Closed	85	6
Salado	99	8
Open	115	5
Closed	72	3

Table 9. Table showing calculated karst scores for the Northern Group of Eurycea and their associated abundance estimates. Abundance estimates are not from the same year in most cases.

Site	Karst Score	Open	Closed
Ribelin	89	na	144
Lanier	92	na	225
Wheeless	54	581	na
PC I	275	150	172
PC II	275	na	593
Avery Spring House	204	446	136.1
Hill Marsh	209	928	na
Avery Deer I	225	114	101.7
Shadow Canyon	188	na	na
Avants Capitol Agg II	153	na	86.6
Buford Hollow	169	na	8
Cedar Breaks Hiking Trail	104	na	201
Hog Hollow	56	na	44
Twin	63	112	na
Cowan	93	61	na
Cobbs	120	161	na
Kings	97	57	na
Solana	55	96	41
Correlation		0.23	0.49

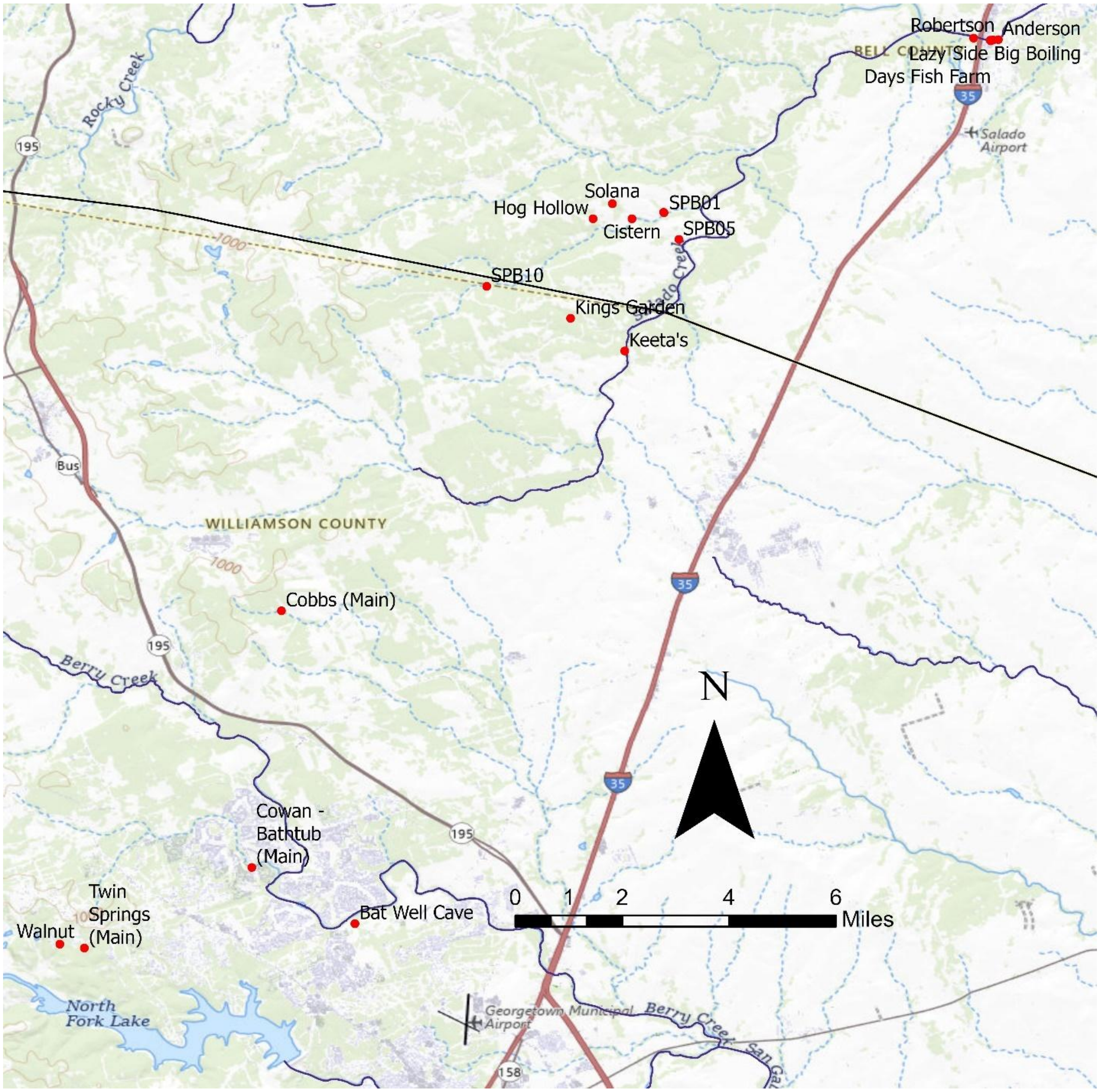


Figure 1. Study area for Salado salamander monitoring or searches conducted from 2015 to 2025.

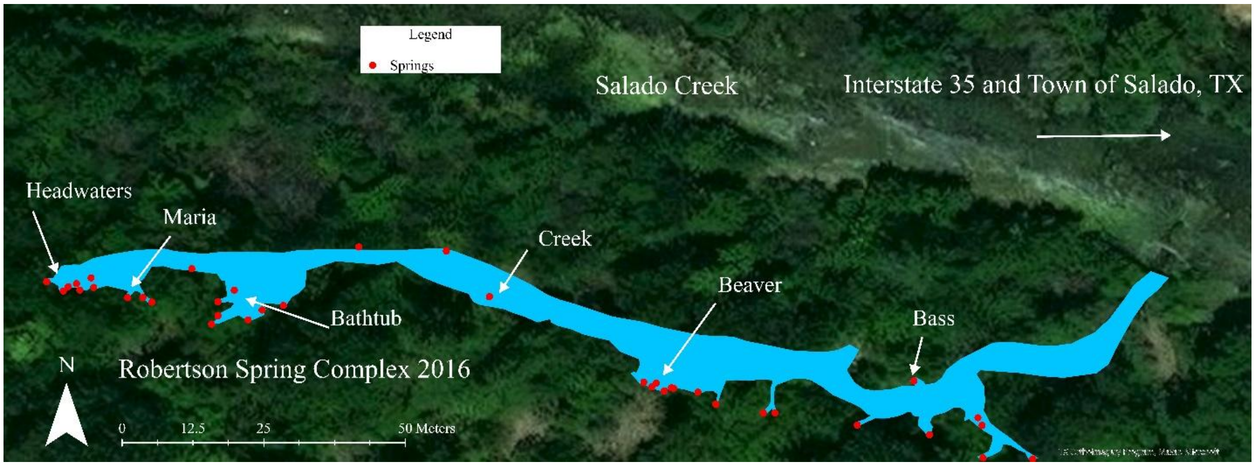


Figure 2. Map of Robertson Springs showing spring zones mapped in 2016 during optimal flow conditions at the site. Red dots are orifices, and the blue is the spring run terminating into Salado Creek.

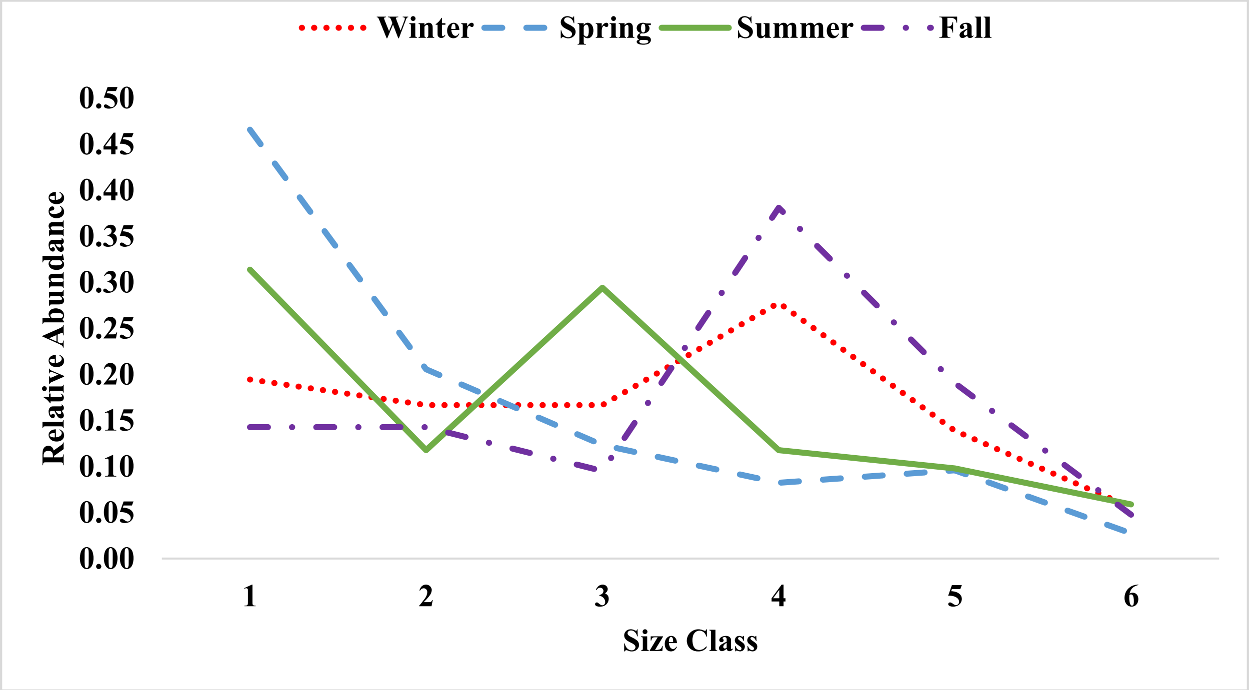


Figure 3. Relative abundance of Salado salamanders reflecting the dominant size class captured from the Downtown Spring Complex (DSC) and Robertson Springs by season from 2015 to 2025 for 181 salamanders. Size classes range from 10 - 19.99 mm = 1; 20 - 29.99 mm = 2; etc.

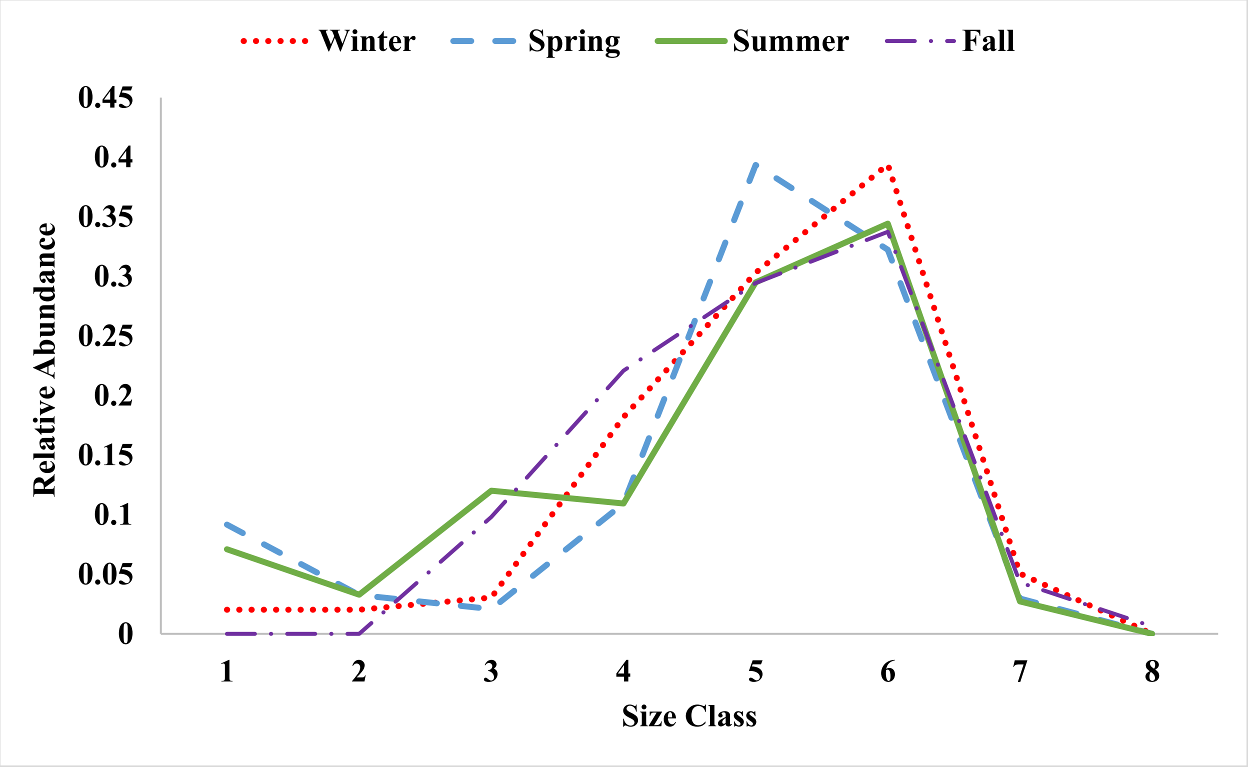


Figure 4. Relative abundance of Salado salamanders reflecting the dominant size class captured from the Solana Ranch Spring #1 by season from 2018 to 2025 for 783 salamander observations. Size classes range from 10 - 19.99 mm = 1; 20 - 29.99 mm = 2; etc.

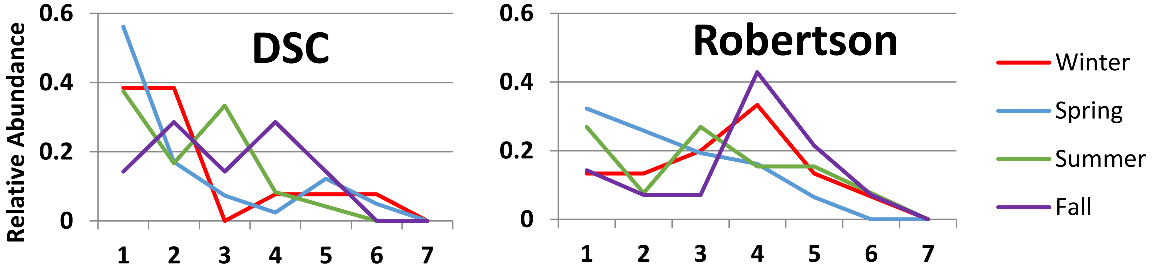


Figure 5. Relative abundance of Salado salamanders reflecting the dominant size class captured from the Downtown Spring Complex (DSC) and Robertson Springs by season from 2015 to 2025. Salamander observations; 86 from Robertson Springs and 85 from the DSC. Size classes (x-axis) range from 10 - 19.99 mm = 1; 20 - 29.99 mm = 2; etc.

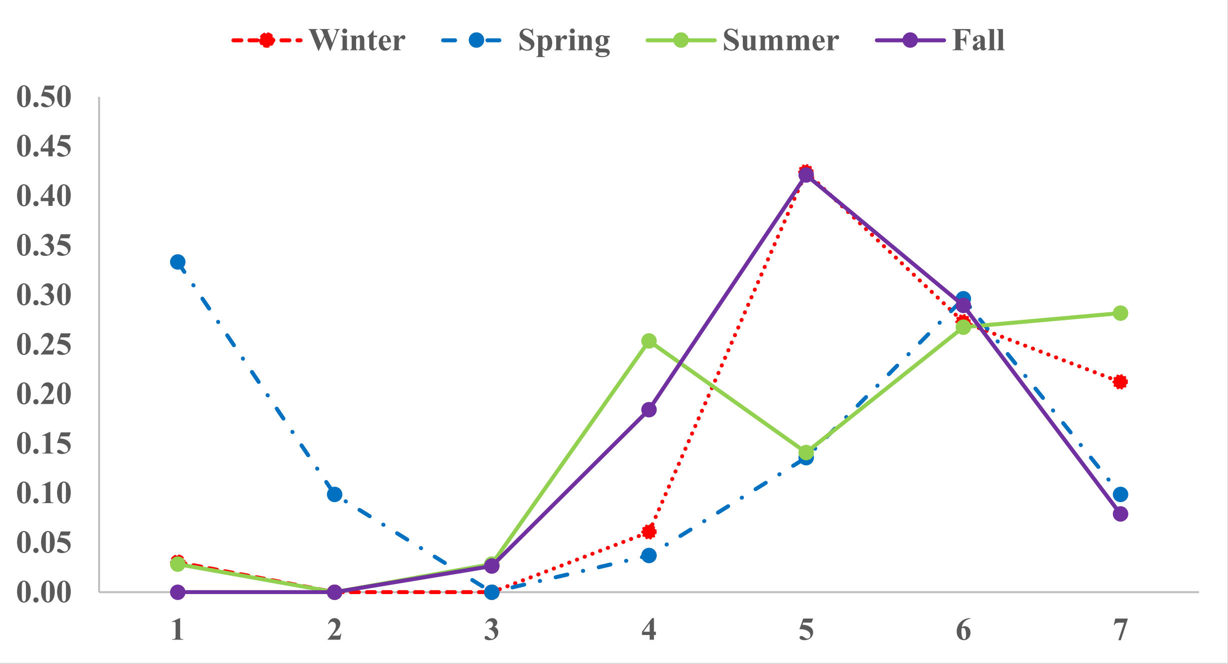


Figure 7. Relative abundance of Salado salamanders reflecting the dominant size class captured from King Garden Spring by season from 2022 to 2025 for 241 salamander observations. Size classes range from 10 - 19.99 mm = 1; 20 - 29.99 mm = 2; etc.

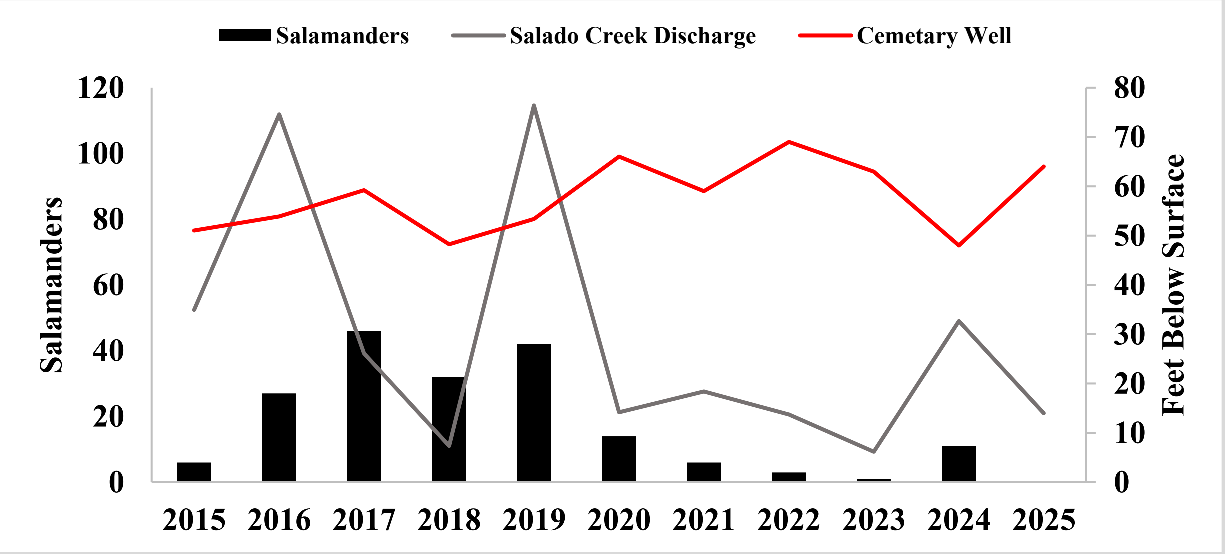


Figure 8. Data collected from the Cemetery Well (Monitor well #5804628; feet below surface) and from the USGS gauge on the Salado Creek (USGS #08104300; ft^3/sec) plotted with the total collection of salamanders (n) from each year sampled at the Downtown Spring Complex (DSC) and Robertson Springs.

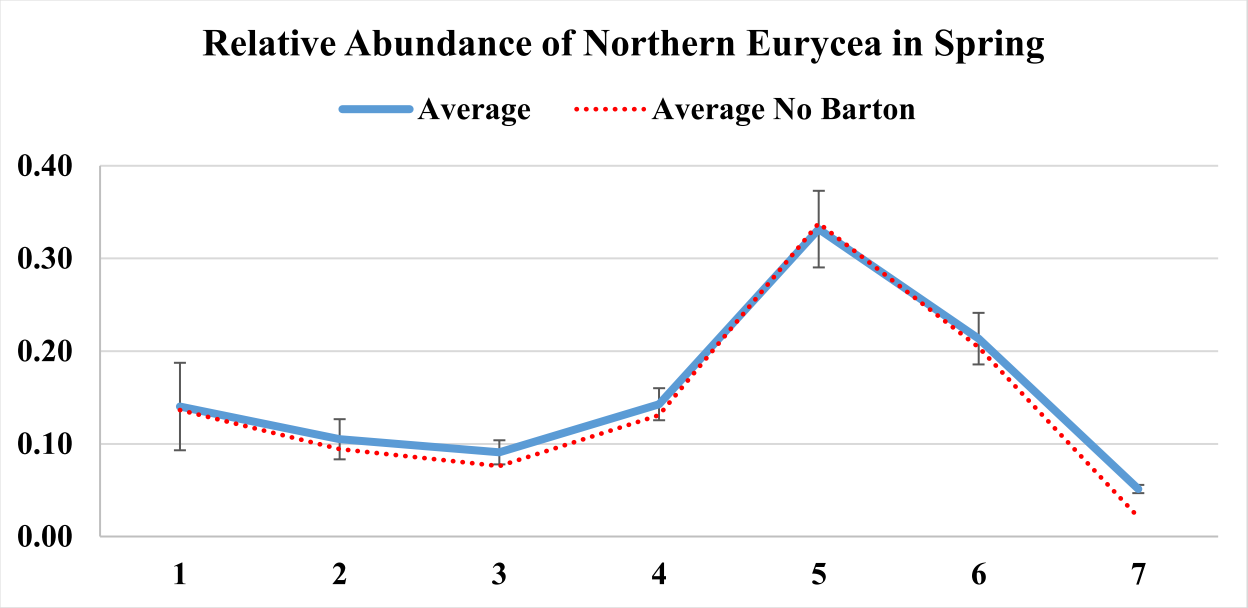


Figure 8. Average relative abundance of northern *Eurycea* in the spring season collected from 9 sites with large enough surface densities to execute mark and recapture work representing 3,864 salamanders. Error bars represent standard error for each size class.

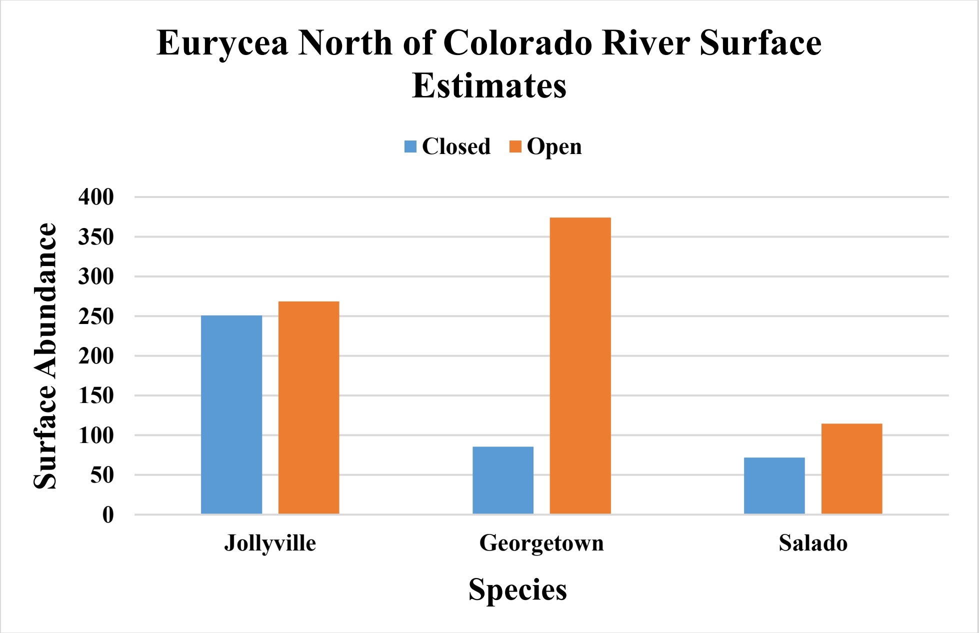


Figure 9. Bar chart showing average of estimates from different abundance models for each northern species of *Eurycea* species (*E. tonkawae*, *E. naufragia*, and *E. chisholmensis)*. It should be noted that the Georgetown open model is comprised of only one individual estimate, not an average as the others, as it was the only open model available for *E. naufragia* at the time of this report. All closed model averages show a decreasing trend in surface abundances as species ranges move north.

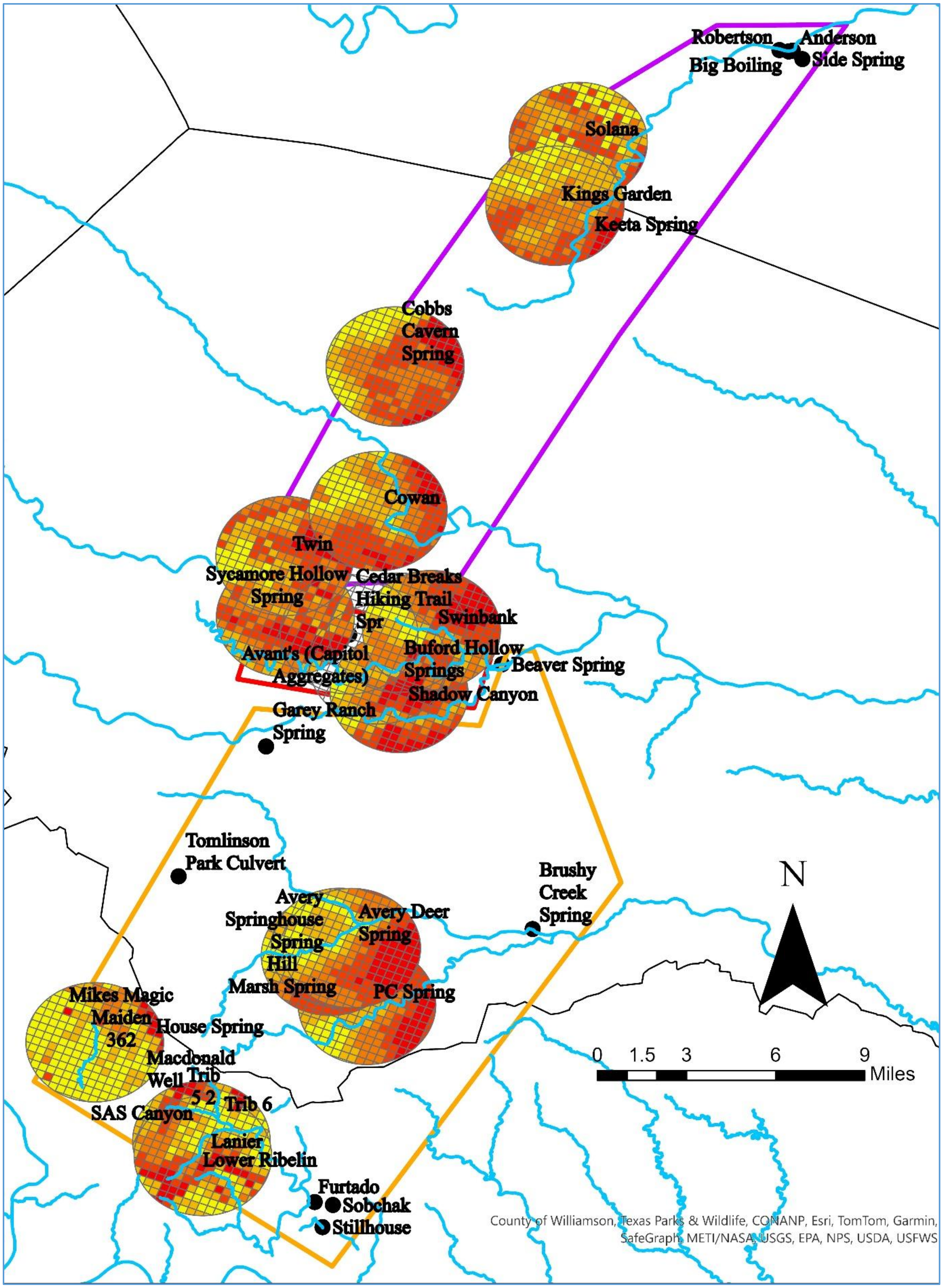


Figure 10. Visual representation of the area used to create the karst scores along the Northern Edwards segment.

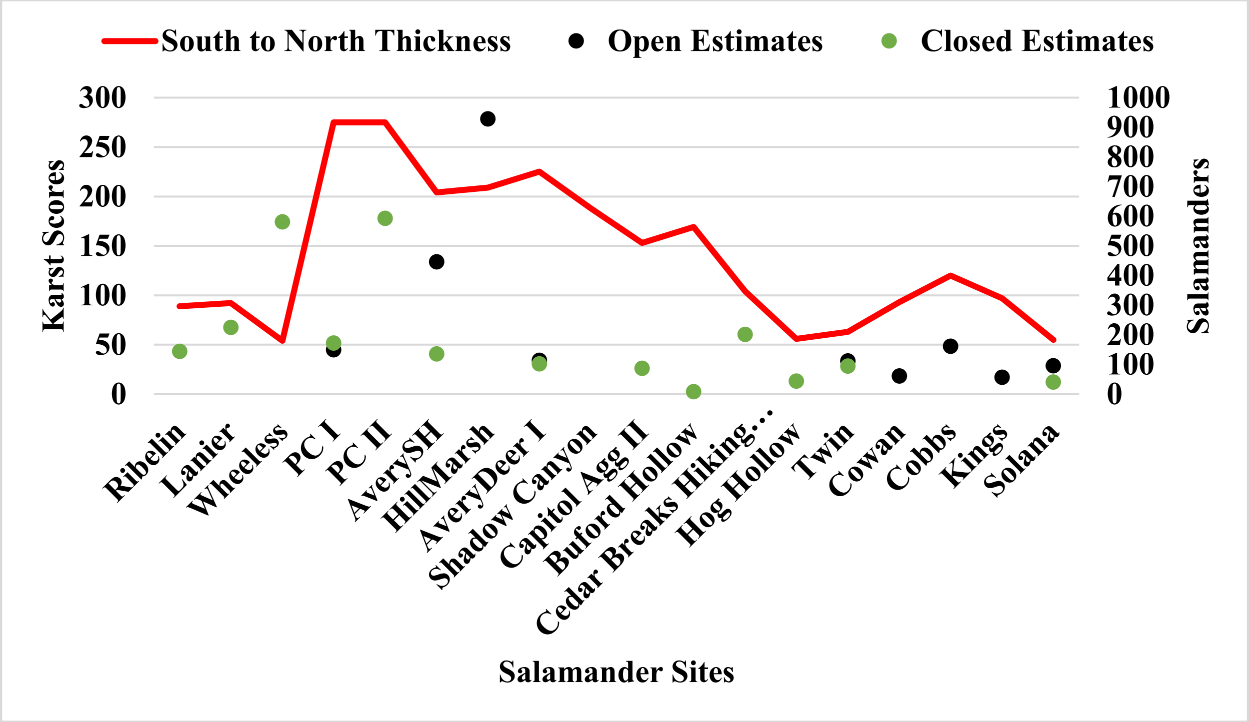
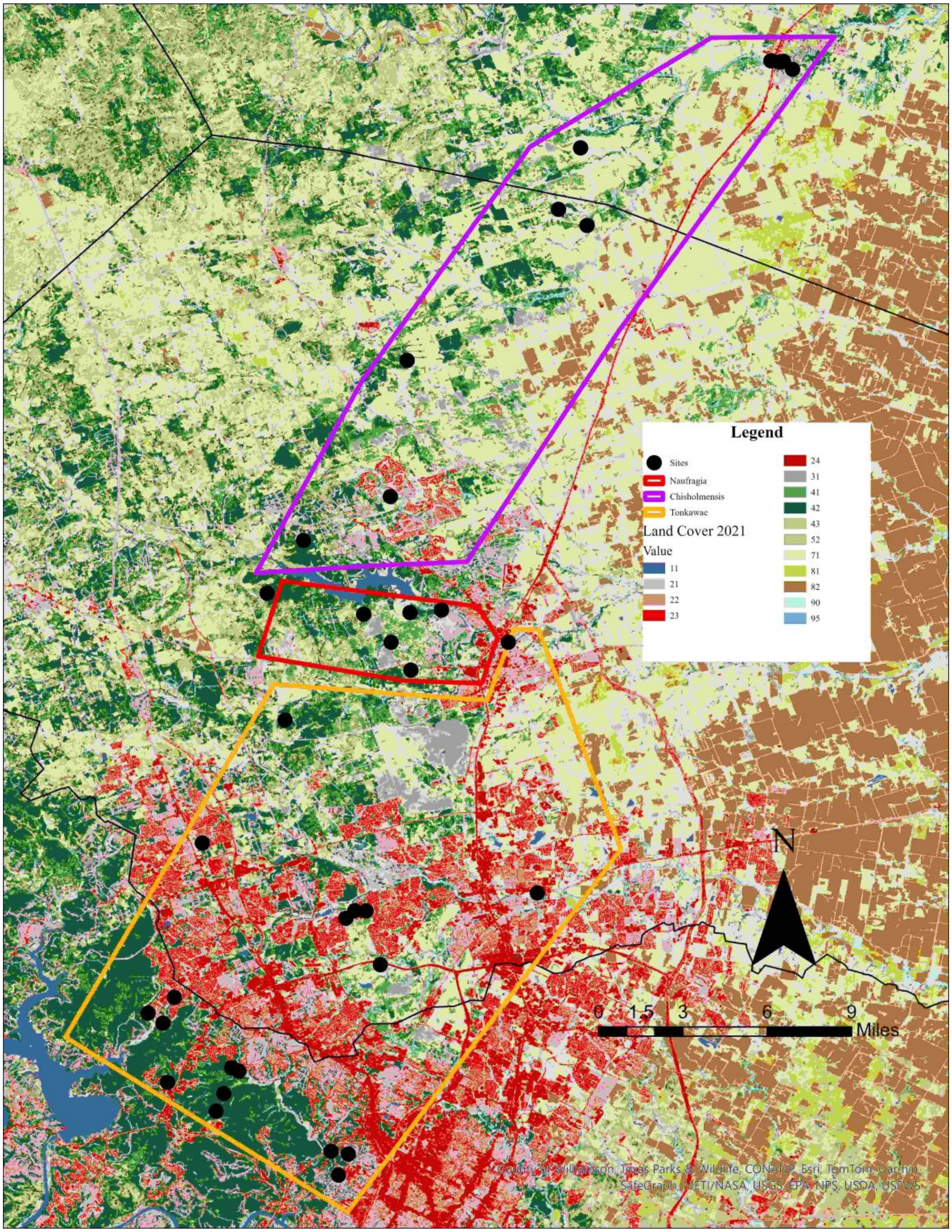


Figure 10. Scatterplot of karst scores depicted as the thickness line (red) for each salamander site arranged from south to north and their associated abundance estimate for open and closed models that are available. Not all abundance estimates are from the same year.



County of Williamson, Texas Parks & Wildlife, CONANP, Esri, TomTom, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA, USFWS

Figure 11. Three northern Eurycea species ranges and land cover present across their respective ranges. Colors signify different types of land cover. Reddish colors = Development.

The views presented herein are those of the authors and do not necessarily represent those of the U.S. Fish and Wildlife Service or Texas Parks and Wildlife Department.

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