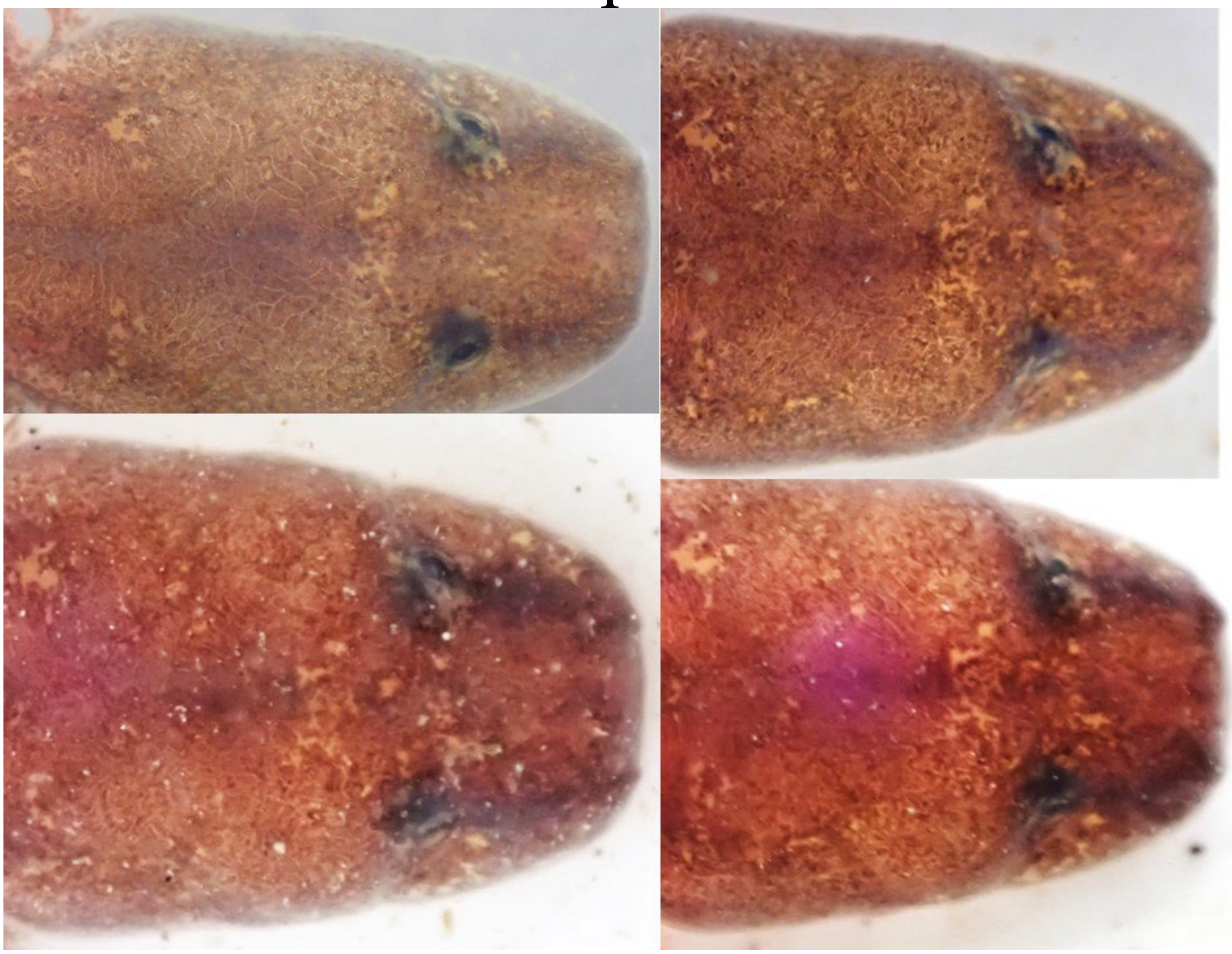
Salado Salamander Monitoring Final Report 2024



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Chaodytes ruthae from Robertson Springs.

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Executive Summary

Monitoring of the Salado salamander (*Eurycea chisholmensis*) concluded in December of 2024 finalizing the tenth year of monitoring at the Salado Downtown Spring Complex (DSC) and at Robertson Springs in Bell County (Figure 2). Eleven Salado salamander were detected during 2024 monitoring at Robertson Springs. No salamanders were observed or collected from the DSC. Flow at Side Spring in the DSC have been lower due to infrequent rainfall and consequent dropping of the aquifer. Salamanders were captured during active and passive searches. Rainfall in 2024 reached an average of 49 ft^3/s which is about the average of annual discharge since 2015 (45 ft^3/s; Gauge #08104300 accessed 1/29/2025).

Monitoring continued at Solana Ranch Spring #1 (SR1), providing a sixth year of quarterly data. A total of 78 detections composed of 43 individual salamanders (determined through photographic analysis) were documented over the 2024 seasonal monitoring period. A total of three juveniles were collected in May 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 2024 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 88 detections composed of 55 individual salamanders (determined through photographic analysis) were documented over 2024. No juveniles were collected in 2024 at Kings Garden.

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 consultants during surveys for development (Figure 1). At this time, the Salado salamander has been documented at 19 locations above Lake Georgetown.

There have been three peer-reviewed publications relating to the Salado salamander (Diaz et al. 2020; Nice et al. 2021; Diaz et al. 2023) since monitoring began. In addition, five 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. 2020; Alvear, Dominique et al. 2020a; Alvear, Dominique et al. 2020b; Perez et al. 2023). 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.

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 a long-term data set for the species within its known geographical range.

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 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 2024 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 – 2024. 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.

Water level and flow data was collected from the Cemetery Well (Monitor well #5804628) and from the USGS gauge on the Salado Creek (USGS #08104300) from 2014 to 2023. This data was plotted with the total collection of salamanders from each year of sampling since 2015. This analysis was conducted to determine if there is an indicator for the issuance of spring flow at Robertson, and to identify preliminary trends associated with the salamander collections.

Data collected over the years on the northern *Eurycea* spp. has been examined for this report is 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?

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 going back for over ten years now and have collected various types of data regarding the life history strategies, ranges, and surface estimates.

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.

Results

Robertson and Downtown Spring Complex

No spring flow was detected at RSC since approximately June of 2022 till January 26th of 2024. The last collection of a salamander from RSC was in April of 2022 from Bathtub (Middle) Spring. After the rain events in the first and third weeks of January the springs on the Robertson property began to flow again. A net was set on Creek Spring within the Robertson Spring complex on January 30, 2024, and removed on February 9, 2024, after collecting eight salamanders over the collection period. No salamanders were captured at any DSC sites during 2024.

A total of 192 Salado salamanders have been captured since 2015 from the Robertson Spring complex and 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 amount 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 78 salamanders were captured at SR1 during 2024 monitoring. After removing recaptures of individual adult salamanders, the capture history shows that 43 adult salamanders were detected and photographed during 2024. This year, potentially 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. Three of the 43 salamanders were considered juveniles (<25 mm). Reviewing salamander capture data dating back to 2017, the majority of the surface captures were adults (92%). The size average, based on the 608 salamanders detected since 2017, is 53 mm. The largest Salado salamander (87 mm) captured to date was in October 2020. The most frequently encountered salamander (on cover) was captured in 2019 and has been recaptured 9 other times, as recently as August of 2024 and has grown from around 63 mm to 67 mm.

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). 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. Relationships with rainfall and the discharge of Salado Creek were examined for trends. Rainfall seemed to predict the density estimates the best when rainfall was calculated from the week before the sampling event (Figure 6).

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 2024 Kings Garden was sampled in April, July, October and December. Sampling in 2024 was conducted in the main branch along the first riffle below the orifice. A total of 88 detections were made during the quarterly sampling events including 15 juvenile salamanders. Following post processing with Wild ID to determine matches among events, a total of 55 individual salamanders were detected. The most salamanders were captured in October this year (n = 22). A total of 12 recaptures from previous years were documented in 2024 (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.

Our interest in Pipe and Pecan springs would involve restoration work at Pecan Spring. These springs were modified and now have no apparent orifice where water was discharging. Historically, each spring did have flow producing a slow spring run. The restoration should consider altering flow velocity. The low flow coming from either of these springs may allow the accumulation of silt within the interstitial spaces causing embedded cover objects. An elevational gradient from orifice to the end of a spring run could be used to combat the low flow issue. At Pecan Spring my recommendation would be to remove the blocks at the end of the pool and let time and a good rain clean the area. A conversation with Tim Brown in 2023 about the structure at Pecan Spring was interesting as he mentioned the blocks at the end of the pool were limestone, and there weren't quarries back in the time period that the Texas Historic Commission would be interested in; however the rest of the structure, probably so.

Stream Flow and Well Height Data

During this study, assessments of a potential connection between surface salamander population densities and rainfall, stream flow and/or well gauge height were examined. The Cemetery Well (#5804628) has shown the best connection between water level (gauge height) and surface population densities. Recently the available data from the Cemetery Well has been sporadic. From 2015 to 2019, the data was reported monthly. Gaps in the well data began to appear during 2020. For 2020, data is available from March to December is available. In 2021, only data from January and February are available. In 2022, the data reporting increased and includes data from February to December. Data for 2023, is mostly complete and in 2024 the data is complete however, there appear to have been some malfunction of the sensor in April, May and June.

We compared Cemetery Well (feet below surface (fbs)), Salado Creek flow (USGS, ft^3/s), and the number of captured salamanders per year (Figure 8). The goal is to be able to predict when Robertson Springs would have flows based off the Cemetery Well. We understand the Cemetery Well has an inverse relationship with salamander abundance at Robertson Springs (Figure 8). So, as the feet below surface decrease we observe more salamanders at Robertson Springs. Salamanders were captured at Robertson Spring when levels at the Cemetery Well water levels ranged from 12 to 75 feet below the surface. Although there have been varying levels of effort over the years, our data demonstrates that if the springs are dry no salamanders will be detected at the surface. Once the springs on the Robertson property go dry, a large percentage of salamanders are removed from the overall potential yearly. Only when flows return to Robertson Springs do the probabilities of capturing a salamander return.

Surface Estimates and Relative Abundance of Northern Eurycea

Northern *Eurycea* data collected for this exercise were from public reports and peer-reviewed publications. The criteria for data was 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. In Review: Animal Conservation). A total of 3,783 salamanders from the spring season were used for data analysis from the eight northern *Eurycea* spring sites to create the relative abundance curve for the northern populations, and 4,640 salamanders when data from Barton Springs was included. 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 the size classes from the available nine sites shows a slight 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 9). The data with Barton Springs included about mirrors the solely northern *Eurycea* relative abundance average except it shows more representation of other size classes.

A total of 32 population estimates have been undertaken for the northern *Eurycea* group. These estimates are made up of nine genetic estimates of effective population size, nine open models and 13 closed models. There are a total of 11 models for *E. tonkawae*, five 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. 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).

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.

Many of the concepts within this report have been expanded on 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 appears unique and could be facilitated 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 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 differently for each species and potentially at each site. In addition, the different timespans in which development has been present around an individual spring site has 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 10).

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. Kinbgs 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 2024.

Season	Robertson	Downtown Spring Complex	Solana Ranch Spring #1	Kings Garden
Spring	0	0	29	32
Summer	0	0	33	22
Fall	1	0	12	26
Winter	10	0	4	8

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
Recaps Previous Years	15	30	34	41	29
Recaps for Year	16	10	13	11	5
New Individuals	67	63	46	50	38
Naive Probability of recap	15	30	34	41	29

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
Recaps Previous Years	0	7	12
Recaps for Year	0	6	5
New Individuals	23	38	50
Naive Probability of recap	0	8	13

Table 5. Water quality collected during monitoring in 2024.

		Date	Temperature °C	Dissolved Oxygen mg/L	pH	Conductivity µs/cm
Big Boiling	Bell	1/26/2024	20.64	8.16	7.06	579
Robertson	Middle	1/26/2024	20.8	8.26	7.45	552
Robertson	Beaver Spring	1/26/2024	20.3	8.26	7.47	551
Side	Bell	1/26/2024	20.8	8.28	7.37	552
Stagecoach	Bell	1/26/2024	20.37	NA	7.29	594.7
Robertson	Middle	2/9/2024	20.57	7.02	7.29	449
Robertson	Middle	2/13/2024	20.34	7.21	7.34	459
Kings Garden	Williamson	4/23/2024	20.97	7.38	7.04	481.6
Solana	Bell	5/14/2024	20.55	7.9	7.4	454
Solana	Bell	5/14/2024	20.57	7.49	7.42	454.6
Big Boiling	Bell	5/23/2024	20.98	7.68	7.15	588
Robertson	Middle	5/23/2024	21.08	7.26	7.54	562.7
Robertson	Beaver Spring	5/23/2024	20.94	7.8	7.14	569
Side	Bell	5/23/2024	21.14	7.02	7.51	578

Kings Garden	Williamson	7/26/2024	21.28	6.61	7.57	534
Solana	Bell	8/7/2024	21.44	6.9	7.93	408.2
Anderson	Bell	8/8/2024	21.72	6.67	8.15	514
Robertson	Middle	8/8/2024	22.13	6.7	8.24	503
Stagecoach	Bell	8/8/2024	24.43	6.3	8.21	495.6
Anderson	Bell	10/24/2024	21.28	7.88	7.17	589
Robertson	Middle	10/24/2024	20.99	7.93	7.21	584
Robertson	Beaver Spring	10/24/2024	21.38	5.52	7.23	588
Side	Bell	10/24/2024	21.00	8.1	7.21	587
Stagecoach	Bell	10/24/2024	20.99	8.12	7.11	587
Kings Garden	Williamson	10/28/2024	21.72	6.8	8.21	513.6
Kings Garden	Williamson	12/18/2024	21.3	7.27	6.84	539.2
Anderson	Bell	12/20/2024	20.7	6.94	6.76	522.6
Robertson	Middle	12/20/2024	20.34	6.58	6.89	503.5
Side	Bell	12/20/2024	20.2	0.687	6.89	494.2
Solana	Bell	1/8/2025	19.18	8.00	7.00	429.6

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.

		USGS Impervious Cover			Size Class Relative Abundance								
	n	2006	2011	2021	1	2	3	4	5	6	7	Adults	Juveniles
Solana	323		0.07	0.17	0.10	0.03	0.02	0.11	0.40	0.31	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
Eliza	857	13.24	16.80	27.36	0.17	0.19	0.22	0.24	0.27	0.29	0.324	552	305
$\bar{x}$					0.12	0.11	0.10	0.15	0.35	0.20	0.05		
$\bar{x}$ No Barton Springs					0.11	0.09	0.09	0.14	0.36	0.19	0.01		

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)	$N_{something}$
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. 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	286	11
Open	328	5
Closed	251	6
Georgetown	162	5
Open	374	1
Closed	109	4
Salado	91	6
Open	110	3
Closed	74	4

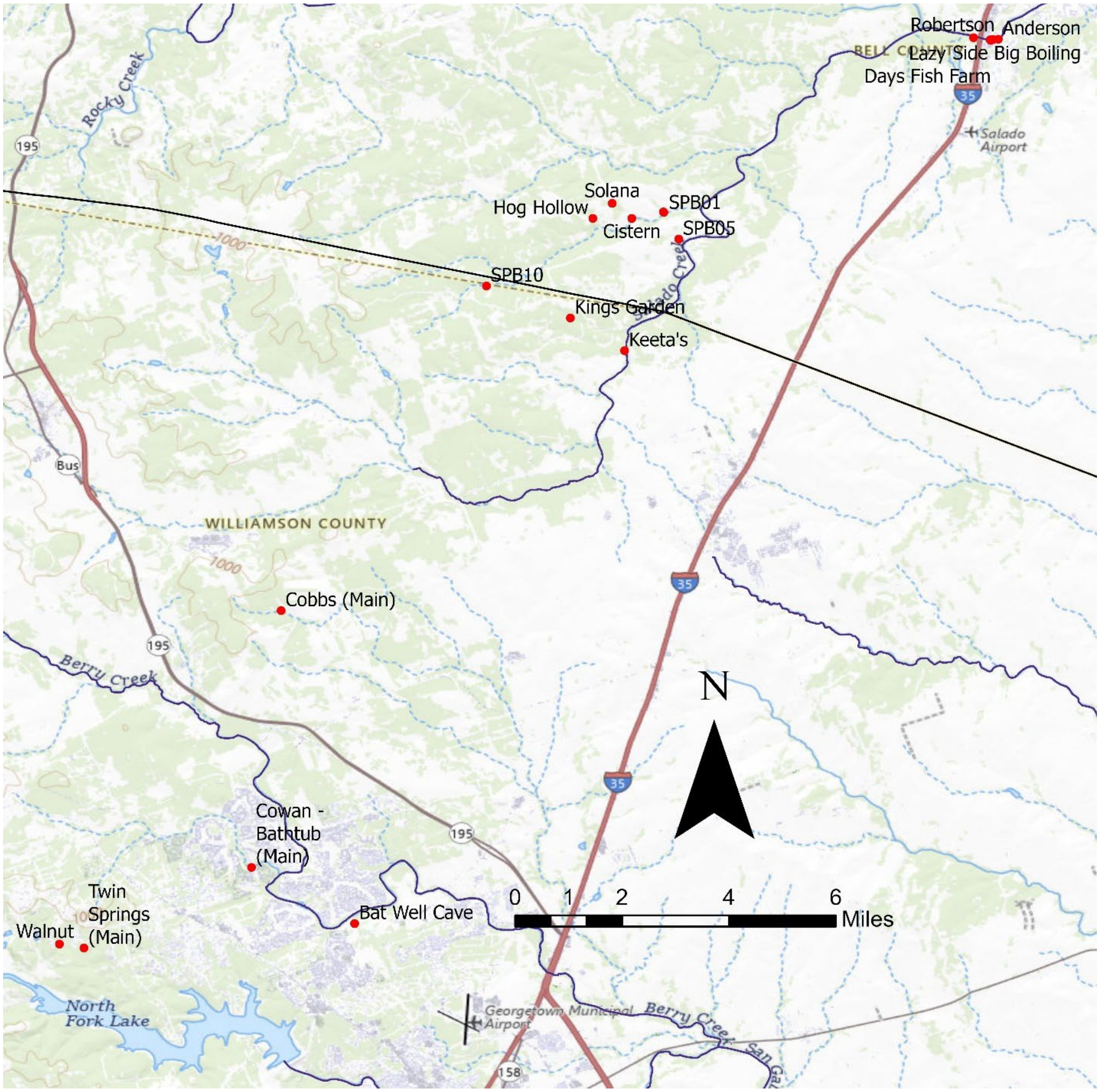

Figure 1. Study area for Salado salamander monitoring or searches conducted from 2015 to 2024.

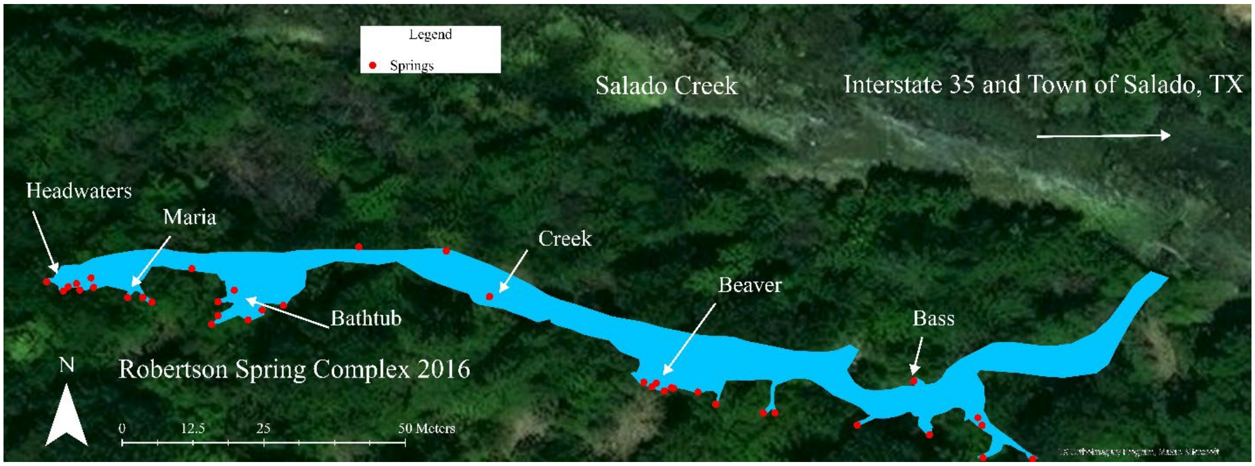

Figure 2. Map of Robertson Springs showing spring zones mapped in 2016 during optimal flow conditions at the site. Red dots are orifices, and the blue is the spring run terminating into Salado Creek. From July of 2022 to January 2024, the system was dry to the creek.

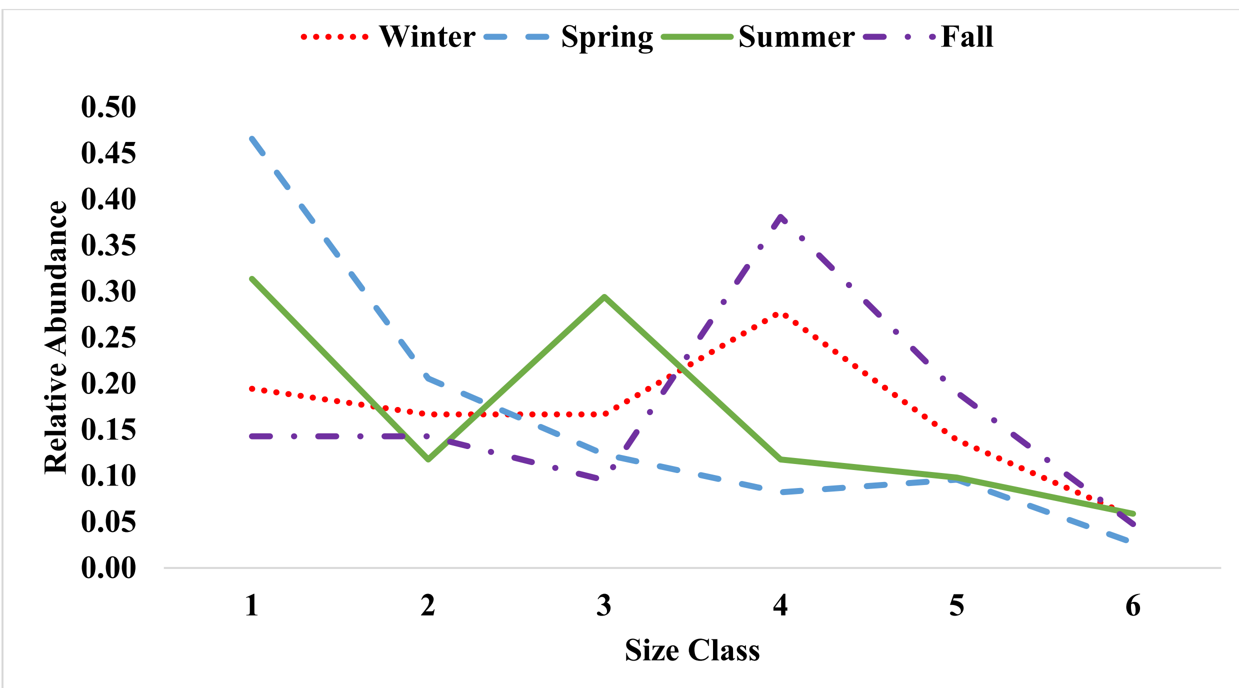

Figure 3. Relative abundance of Salado salamanders reflecting the dominant size class captured from the Downtown Spring Complex (DSC) and Robertson Springs by season from 2015 to 2024 for 181 salamanders. Size classes range from 10 - 19.99 mm = 1; 20 - 29.99 mm = 2; etc.

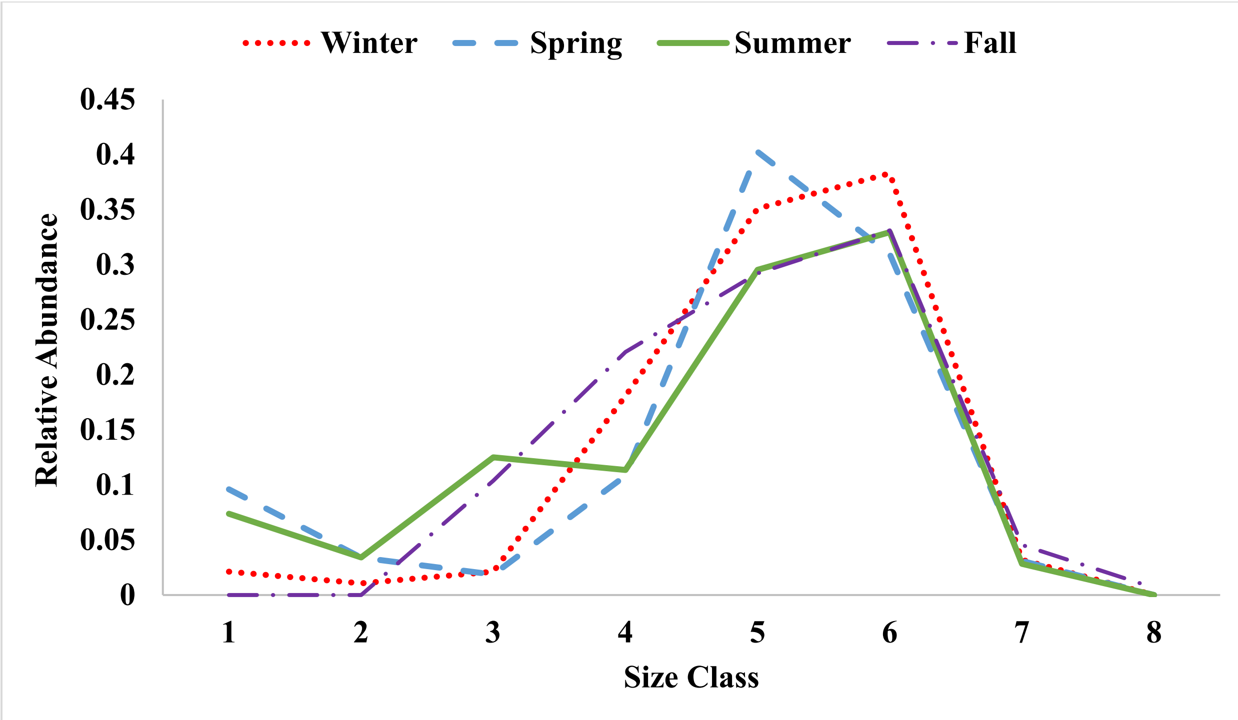

Figure 4. Relative abundance of Salado salamanders reflecting the dominant size class captured from the Solana Ranch Spring #1 by season from 2018 to 2024 for 747 salamander observations. Size classes range from 10 - 19.99 mm = 1; 20 - 29.99 mm = 2; etc.

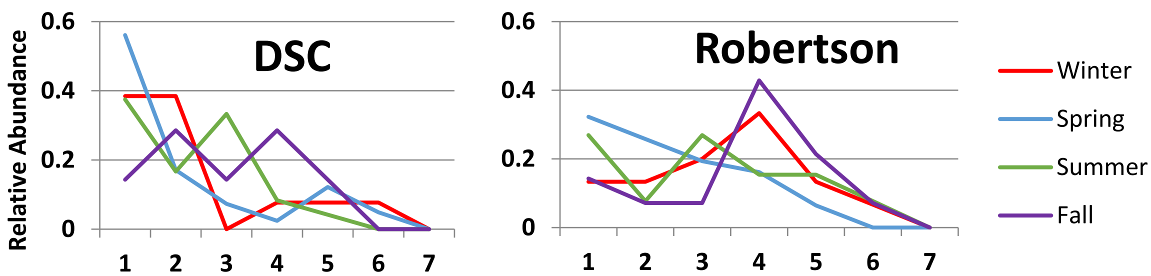

Figure 5. Relative abundance of Salado salamanders reflecting the dominant size class captured from the Downtown Spring Complex (DSC) and Robertson Springs by season from 2015 to 2024. Salamander observations; 86 from Robertson Springs and 85 from the DSC. Size classes (x-axis) range from 10 - 19.99 mm = 1; 20 - 29.99 mm = 2; etc.

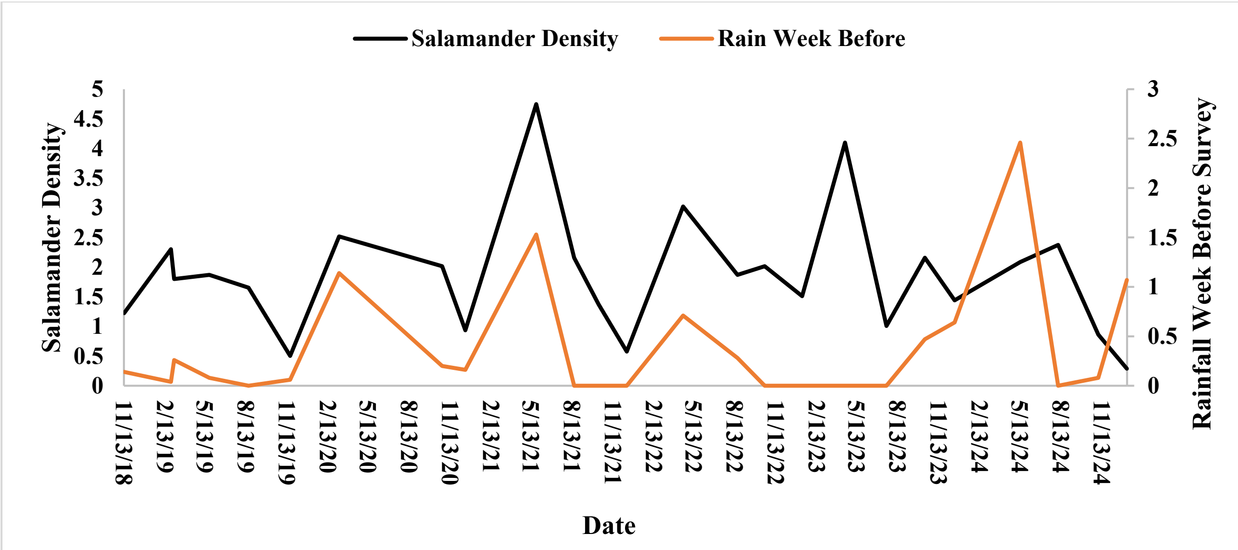

Figure 6. Salamander density at Solana Ranch Spring #1 over time and the rain fall in inches the week before the survey taken from WeatherUnderground.

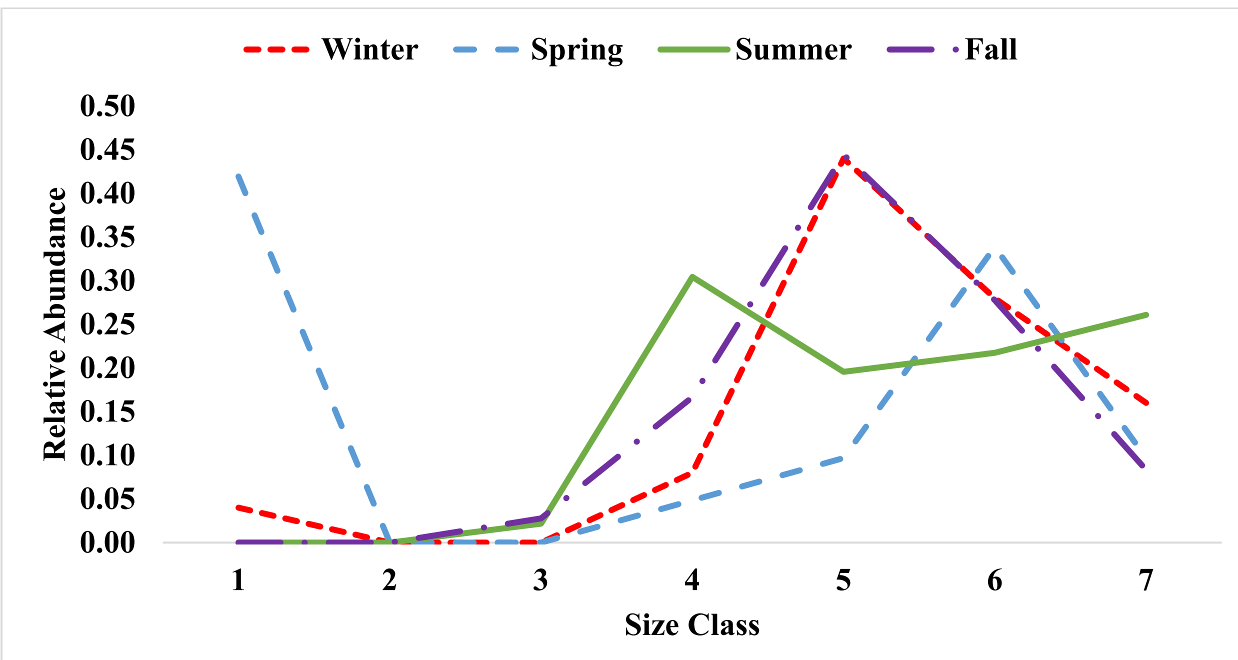

Figure 7. Relative abundance of Salado salamanders reflecting the dominant size class captured from King Garden Spring by season from 2022 to 2024 for 169 salamander observations. Size classes range from 10 - 19.99 mm = 1; 20 - 29.99 mm = 2; etc.

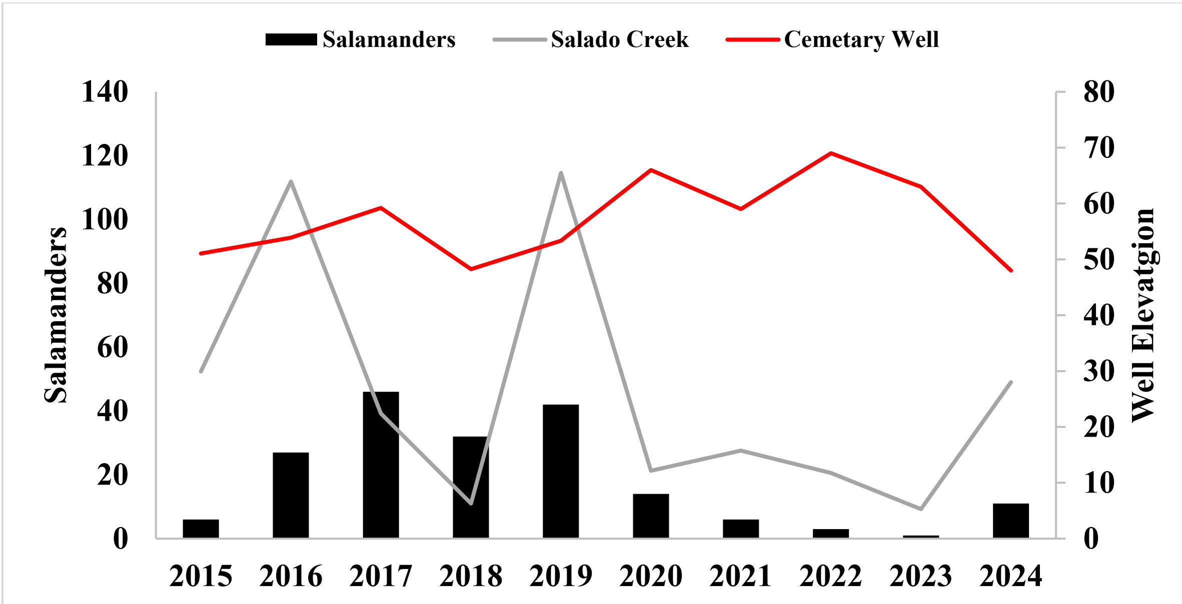

Figure 8. Data collected from the Cemetery Well (Monitor well #5804628; feet below surface) and from the USGS gauge on the Salado Creek (USGS #08104300; ft^3/sec) plotted with the total collection of salamanders (n) from each year sampled at the Downtown Spring Complex (DSC) and Robertson Springs.

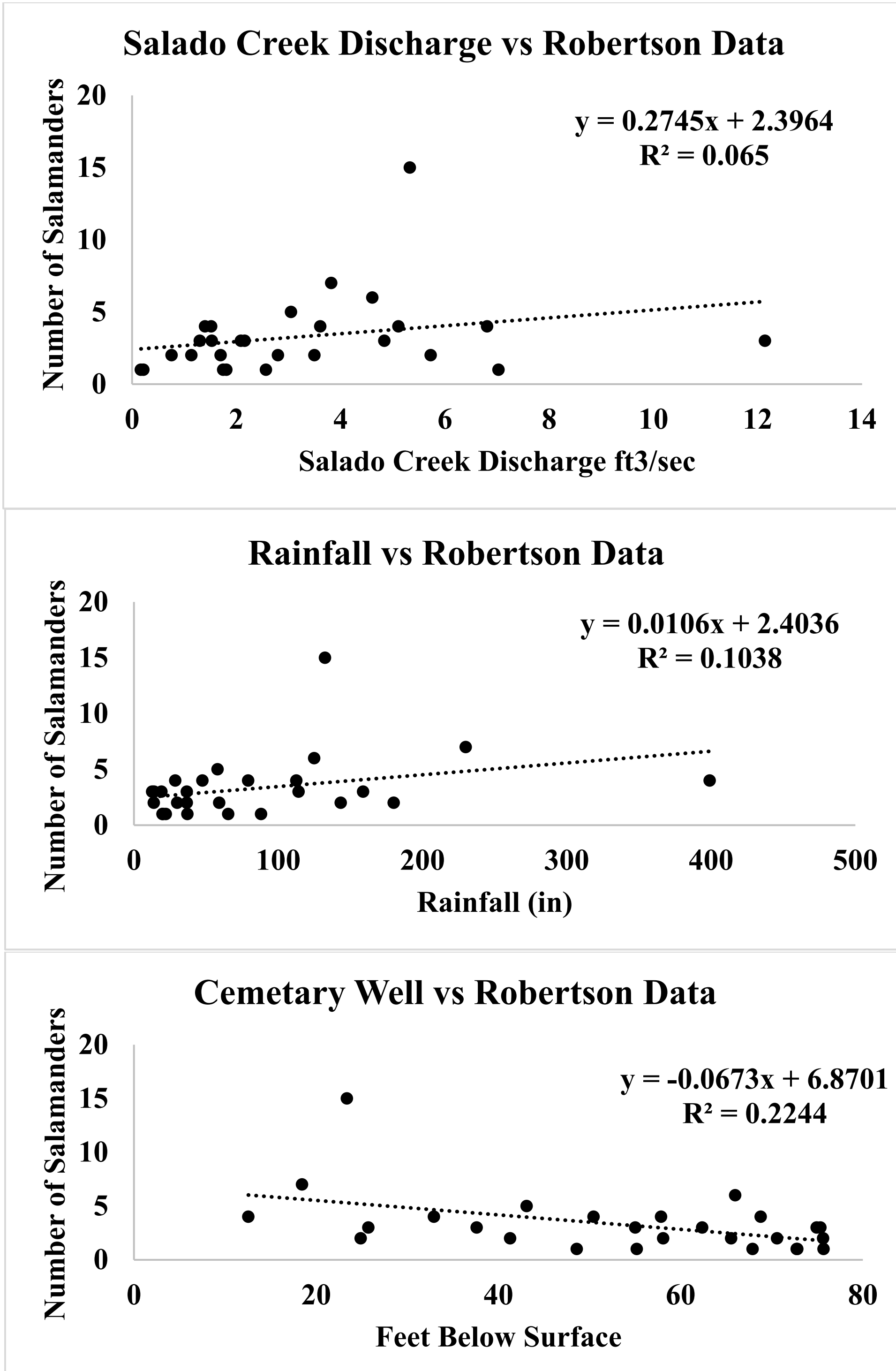

Figure 7. Relationships between Salado salamander capture data from Robertson Springs (2015 to January 2023) and predictors of abundance data.

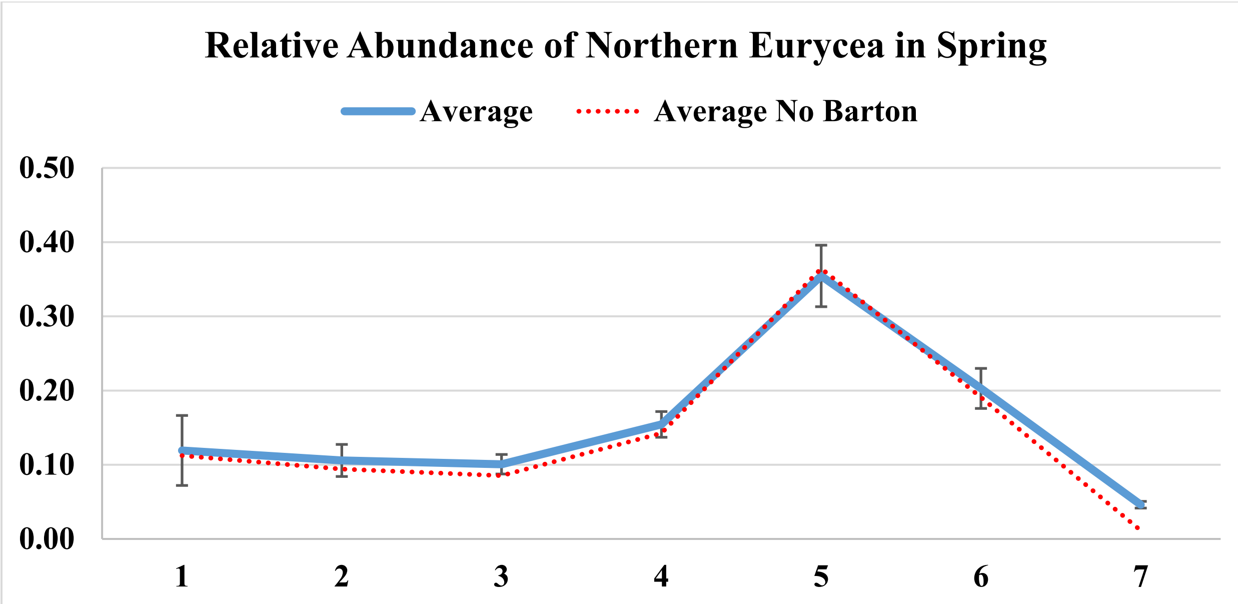

Figure 8. Average relative abundance of northern *Eurycea* in the spring season collected from 8 sites with large enough surface densities to execute mark and recapture work representing 3,783 salamanders. Error bars represent standard error for each size class.

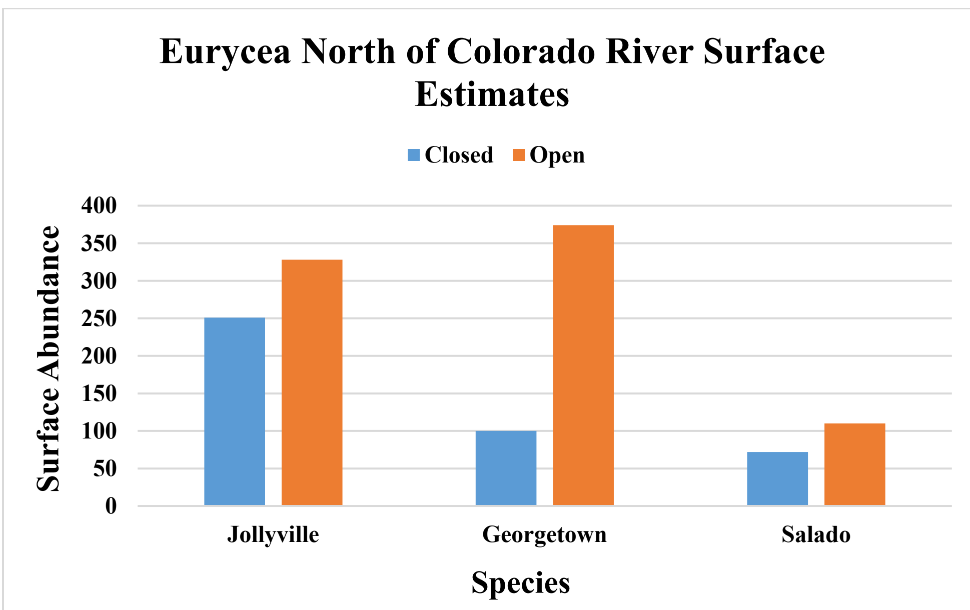

Figure 9. Bar chart showing average of estimates from different abundance models for each northern species of *Eurycea* species (*E. tonkawae*, *E. naufragia*, and *E. chisholmensis)*. It should be noted that the Georgetown open model is comprised of only one individual estimate, not an average as the 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.

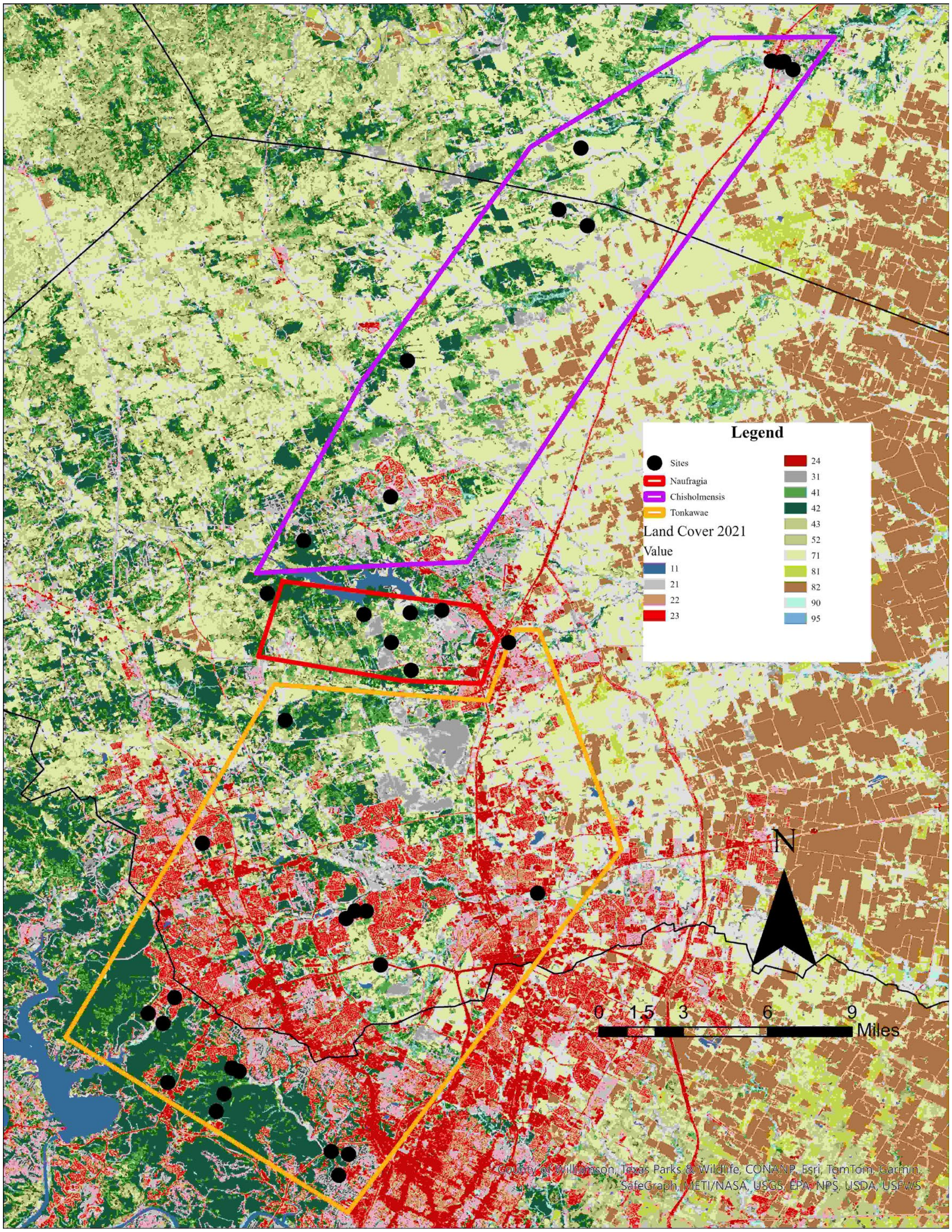

Figure 10. Three northern Eurycea species ranges and land cover present across their respective ranges. Colors signify different types of land cover. Reddish colors = Development.

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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