APPENDIX N
LITERATURE REVIEW - LIST OF ARTICLES AND REPORTS COMPLETED SINCE THE 2018 ANNUAL REPORT

List of Articles and Reports Completed Since the 2018 Annual Report

Title	Author(s)	Publication	Study Summary[1]
COVERED SPECIES LITERATURE			
Literature from 2019			
Turbidity affects association behavior in the endangered fountain darter (*Actinopterygii, Perciformes*).	Aspbury, Andrea S. DeColo, Sophia L. Goff, Cory B. Gabor, Caitlin R.	Hydrobiologia. Jul 2019. Volume 838, Issue 1, pp 45-54.	The study described in this article tested the hypothesis that fountain darter (*Etheostoma fonticola*) body size preferences are affected by reduced visibility. The research tested offspring of wild-caught fish in clear and reduced visibility treatments. The study found that increased levels of turbidity (leading to reduced visibility) affect the use of visual cues in *E. fonticola*. Reduced time spent in social interaction and effects on association preferences of the fountain darter were documented in the reduced visibility treatments as compared to results observed in clear treatments.
Species delimitation in endangered groundwater salamanders: Implications for aquifer management and biodiversity conservation.	Devitt, Thomas J. Wright, April M. Cannatella, David C. Hillis, David M.	Proceedings of the National Academy of Sciences of the United States of America. Feb 2019. Vol. 116 Issue 7, pp 2624-2633.	In this article, the authors examine "how geomorphological and hydrogeological processes have driven population divergence and speciation in a radiation of salamanders (*Eurycea*) endemic to the Edwards–Trinity system using phylogenetic and population genetic analysis of genome-wide DNA sequence data." Study results indicated that surface and subsurface hydrology create complex patterns of species isolation and reconnection that result in adaptive and nonadaptive population divergence and speciation. Employing regional climate models that predict increased air temperature, and hydrologic models that project decreased springflow, the study concluded that "Edwards – Trinity salamanders and other co-distributed groundwater-dependent organisms are highly vulnerable to extinction within the next century."
COVERED SPECIES LITERATURE			
Literature from 2019			
Creatures of the deep karst.	Devitt, Thomas J.	American Scientist. Sep/Oct 2019. Vol. 107 Issue 5, pp 260-262.	Fauna that occupy groundwater aquifers and the potential threats to such animal life that result from use of groundwater exceeding the amount of recharge into an aquifer (i.e., overdraft) are the focus of this article. The article discusses the *Eurycea* genus of groundwater salamanders, their distant relationship to the blind European salamander (*Proteus anguinus*), and the 15 species that have evolved in karst aquifers in west central Texas. Threats to endangered and threatened groundwater species related to water pollution and groundwater depletion are also described.

List of Articles and Reports Completed Since the 2018 Annual Report

Title	Author(s)	Publication	Study Summary[1]
Ecological contributions to body shape evolution in salamanders of the genus *Eurycea* (Plethodontidae).	Edington, Hilary A. Taylor, Douglas R.	PloS ONE. May 2019. Vol. 14 Issue 5, pp 1-14.	This article examines variation in body shape among salamanders in the genus *Eurycea* (Plethodontidae) and select outgroups that exhibit diversity in morphology, ecological niche, and life history. The study found "significant differences in body shape among cave-dwelling and non-cave-dwelling species and between aquatic and terrestrial species," as well as differences in shape variance among paedomorphic (i.e., retaining juvenile features as an adult) and biphasic (i.e., having two phases) species, suggesting that "functional limitations imposed by habitat and life history played a key role in the evolution of body shape in this group in the context of their phylogenetic history."
Rapid Assessment for Identifying Species of Greatest Conservation Need: Towards a Unified Approach	Faucheux, Nicky M. H.	American Fisheries Society. October 2019. Vol. 44 Issue 10, pp 488-497	This article discusses a new methodology for rapidly quantifying the threat assessment for species to be better able to justify what species require conservation and protection measures. This study focused on 50 different species of fish in three different ecoregions of Texas (including the Fountain Darter). In general, this methodology corresponded well with USFWS, International Union for Conservation of Nature (IUCN), and species of greatest conservation need (SGCN), although they also identified some additional species that might benefit from conservation measures. They determined that their rapid quantitative assessment was successful in providing quantitative information on the species and removing the subjectivity of expert opinions relied on by current conservation practices.

List of Articles and Reports Completed Since the 2018 Annual Report

Title	Author(s)	Publication	Study Summary[1]
Ex situ phenology of *Zizania texana*, an endangered aquatic macrophyte, under different water velocities.	Hutchinson, Jeffrey T.	Aquatic Botany. Feb 2019. Vol. 153, pp 88-94.	This study examined the phenology of the federally endangered aquatic macrophyte *Zizania texana* (Texas wild-rice or TWR) under different water velocities ex situ over 24 months. Study results indicated that TWR has fast initial growth rates in flowing water; plants in slower flows produced greater numbers of flowers and tillers as well as greater numbers of seeds; the life cycle from seed to seed production is less than or equal to 31 weeks; the plant reproduces by both sexual and asexual propagules; self-fertilization is prevented by differential development of pistillate and staminate spikelets, which enhances genetic diversity; and greater root than shoot growth occurs at 24 months, possibly as an evolutionary function to increase survival rate in extreme flow conditions.
COVERED SPECIES LITERATURE			
Literature from 2019			
Life-History Aspects of *Stygobromus pecki*.	Kosnicki, Ely Julius, Eric	ResearchGate. Jan 2019. Technical Report.	In studies conducted for the EAA, the Peck's cave amphipod (*Stygobromus pecki*) was investigated with the goals of developing a better understanding of the life history of the species and contributing information towards the improvement of captive propagation of the species, consistent with the goals and objectives of the EAHCP. Specific study goals included improved understanding of sexual dimorphism, estimation of growth rates, estimation of the number of molts or length of time required for individuals to reach maturity, compilation of information related to fecundity, and development of a better understanding of mating behavior and of feeding preferences. Study results provided additional knowledge about the life history and environmental requirements of the species and resulted in specific recommendations regarding improved management practices for the captive refuge population.

List of Articles and Reports Completed Since the 2018 Annual Report

Title	Author(s)	Publication	Study Summary[1]
Life-history aspects of the Comal Springs dryopid beetle (*Stygoparnus comalensis*) and notes on life-history aspects of the Comal Springs riffle beetle (*Heterelmis comalensis*).	Kosnicki, Ely Julius, Eric	ResearchGate. Jan 2019. Technical Report.	This study was conducted for the EAA to develop a better understanding of the life history of the Comal Springs dryopid beetle (*Stygoparnus comalensis*) and to contribute information towards the improvement of captive propagation of this species, consistent with the goals and objectives of the EAHCP. Specific study goals included development of improved understanding of habitat requirements, sexual dimorphism, mating and oviposition requirements, egg incubation rates, larval habitat requirements, larval growth, and adult response to flow. While many questions remain unanswered regarding the life cycle and life history of this species, new insights were revealed as a result of the studies performed.
COVERED SPECIES LITERATURE			
Literature from 2019			
Determining Sexual Dimorphism of Living Aquatic Beetles, *Stygoparnus comalensis* (Coleoptera: Dryopidae) and *Heterelmis comalensis* (Coleoptera: Elmidae), Using Internal Abdominal Structures.	Kosnicki, Ely	Journal of Insect Science. 2019. 19(4): 9, pp 1-5	This study examined a number of potential methods for reliably distinguishing the sex of living Comal Springs dryopid beetle and Comal Springs riffle beetles to facilitate development of a captive self-propagating refuge. Methods evaluated included measurements to test for sexually dimorphic allometries and use of various lighting techniques to test for distinguishing gender-specific characteristics. Lateral lighting was found useful in discerning specific physiological differences between males and females in the riffle beetle. The report includes commentary regarding the use of cameras and photography for observing living subjects.

List of Articles and Reports Completed Since the 2018 Annual Report

Title	Author(s)	Publication	Study Summary[1]
COVERED SPECIES LITERATURE			
Literature from 2019			
A *Vavraia*-like microsporidium as the cause of deadly infection in threatened and endangered *Eurycea* salamanders in the United States.	Yu, Xue Hoyle, Rachel L. Guo, Fengguang Ratliff, Cameron M. Cantu, Valentin Crow, Justin Xiang, Lixin Heatley, J. Jill Zhu, Guan	*Parasites & Vectors*. 2019. Volume 12, Article number: 108.	Unexpected and increased mortality rates of *Eurycea* salamanders over the past few years at the captive breeding program in a USFWS facility in San Marcos, Texas indicate the possibility of an infectious disease. The goal of this study was to "identify the cause of the infection, determine the taxonomic position of the pathogen, and investigate the potential reservoirs of the pathogen in the environment." A microsporidian infection in the sick and dead *Eurycea* salamanders was confirmed as a result of the study. The study also determined the ribosomal gene from the microsporidian pathogen and its phylogenetic position, which allowed the researchers to design primers for detection of the pathogen. The study concluded that a *Vavraia*-like microsporidian was one of the major pathogens, that it may have been solely responsible for the sickness and mortality in the salamanders, and that environmental invertebrates likely served as a source and reservoir of the microsporidian pathogen. The study provided "new knowledge and a foundation for future conservation efforts for *Eurycea* salamanders including molecular surveys, monitoring of the pathogen, and discovery of effective treatments."

List of Articles and Reports Completed Since the 2018 Annual Report

Title	Author(s)	Publication	Study Summary[1]
HABITAT LITERATURE			
Literature from 2018			
Instream Habitat Use and Management of Invasive Armored Catfishes in the Upper San Marcos River.	Warner, Kristopher John Philip	Thesis. Dec 2018. The University of Houston-Clear Lake, Clear Lake, Texas, USA.	This research was conducted to determine utilization of the San Marcos River by species of invasive armored catfish and the effectiveness of removal efforts in reducing the population of these species in the river. The results indicated that armored catfish occur most frequently in deeper pools created by dams and supporting dense stands of submerged vegetation in the lower reaches of the river (downstream of Spring Lake Dam). Based on observations of the armored catfish burrowing habits, issues related to altered water quality due to sediment displacement, uprooting of aquatic macrophytes, and alteration of nutrient cycling were identified. According to this research, ongoing suppression efforts appear to be effectively reducing the biomass of armored catfish populations in the San Marcos River.
Literature from 2019			
Ecophysiology and Food Web Dynamics of Spring Ecotone Communities in the Edwards Aquifer, USA.	Nair, Parvathi	Dissertation. Aug 2019. Texas State University, San Marcos, Texas, USA.	This dissertation examined the ecology and evolution of spring ecotone communities, including testing the hypothesis that organisms living in physicochemically stable spring ecotones should exhibit small tolerance ranges. The effects of elevated temperature and decreased dissolved oxygen were investigated on several riffle beetle species (Coleoptera: Elmidae), including two ecotone specialists, and findings indicated that ecotone-associated species were able to tolerate only a small range of temperature (i.e., exhibit stenothermal tolerance profiles) when compared to surface species. Resource use in invertebrate communities at two spring ecotones were also examined, with results indicating that “spring ecotones contain trophically complex communities with substantial niche partitioning among species.” The author also examined whether reduced metabolic rates are exhibited by subterranean organisms that inhabit systems with ample energy resources. Findings indicated that *Stygobromus pecki* exhibited lower metabolic rates (compared to relatives living in surface ecosystems) despite occupying spring opening ecotones with relatively abundant resources.

List of Articles and Reports Completed Since the 2018 Annual Report

Title	Author(s)	Publication	Study Summary[1]
HABITAT LITERATURE			
Literature from 2019			
Storage dynamics of the upper Nueces River alluvial aquifer: Implications for recharge to the Edwards Aquifer, Texas	Hackett, Caroline Croft	Thesis. September 2019. The University of Texas at Austin, Austin, TX.	This thesis sought to answer the question of how interconnected the groundwater found in the upper Nueces River alluvial aquifer is to streamflow in the Nueces River and what impacts this has to the recharge in the Edwards Aquifer. It was anticipated that findings from this study might have implications on groundwater pumping in the shallow aquifer and potentially the management of recharge to the Edwards Aquifer in this area. This study confirmed that the Nueces River and Candelaria Creek (a spring-fed tributary) are hydraulically connected at least during the wet season, though it can be lost during dry conditions. They also confirmed that the Nueces River alluvial aquifer supplies discharge to the river that increases with increasing drought. As a result, recharge to the Edwards Aquifer is increasingly more from the aquifer rather than the Nueces River during droughts.
The Edwards Aquifer: The Past, Present, and Future of a Vital Water Resource	Edited by: Sharp, John M. Green, Ronald T. Schindel, Geary M.	The Geological Society of America. 2019. Memoir 215.	This is a recently published book of articles on the Edwards Aquifer. These articles cover a broad range of topics on the Edwards Aquifer including the aquifer segments, groundwater modeling, water quality, emerging contaminants, geology, groundwater law, the EAHCP, use of the water, urbanization over the aquifer, climate change, aquifer storage and recovery, geophysics, dye tracing, biology in the aquifer, and the history of the aquifer and expectations for the future of this resource. The purpose of this memoir was to gather together some of the best scientific data and studies conducted on a broad range of topics covering the Edwards Aquifer in order to concisely present the current body of knowledge, discuss the upcoming challenges and stressors on the aquifer, and a discussion of new technologies that will help study the aquifer and address future challenges.

List of Articles and Reports Completed Since the 2018 Annual Report

Title	Author(s)	Publication	Study Summary[1]
Effects of Parasite Infection and Host Body Size on Habitat Associations of Invasive Aquatic Snails: Implications for Environmental Monitoring.	Tolley-Jordan, Lori R. Chadwick, Michael A.	Journal of Aquatic Animal Health. Mar 2019. Vol. I pp 121-128.	This article is a re-evaluation of snail collection data from the Comal River, a spring-fed system in central Texas, which was invaded in the 1960s by two Asian aquatic snails (Thiaridae: red-rimmed melania, *Melanoides tuberculata* and quilted melania, *Tarebia granifera*) and subsequently by three of their trematode parasites. Previous evaluation of the snail collections (2001-2002) established that habitat conditions significantly affect the distribution of both the Asian snail species but did not address the effects of snail size (known to influence infection prevalence) or habitat conditions (known to influence snail size) on trematode infection patterns. In this re-evaluation, logistic regression analyses with individual snails showed that for both Asian snail populations, large snails were more likely to be infected than small snails, and habitat conditions were significantly related to infection in *T. granifera*, while only snail size was significant in explaining the probability of infection in *M. tuberculata*. The conclusions related to size and habitat conditions suggested that "targeted sampling of large individuals of *M. tuberculata* in habitats with high detritus and vegetation and of large individuals of *T. granifera* in any habitat can be used to efficiently ascertain parasite "hot spots" and to evaluate changes in parasite prevalence or detect the invasion of new parasites in these thiarid snails."
Is Standardized Precipitation Index (SPI) a Useful Indicator to Forecast Groundwater Droughts? – Insights from a Karst Aquifer.	Uddameri, V. Singaraju, S. Hernandez, E. A.	Journal of the American Water Resources Association. Feb 2019. Vol. 55 Issue 1, pp 70-88.	The study used Standardized Precipitation Index (SPI)-styled Standardized Groundwater Index (SGI) to quantify groundwater droughts in an effort to understand the relationships between meteorological and groundwater droughts on water levels and spring discharges in the Edwards Aquifer, Texas. The utility of SPI for groundwater drought forecasting was found to be minimal in this aquifer, and long-term, high-resolution monitoring was recommended to properly characterize groundwater droughts, with particular emphasis on monitoring and inventory of spring flows. Conclusions indicated that SPI, while useful for initiating groundwater drought contingency measures, should not be used to remove drought restrictions.

List of Articles and Reports Completed Since the 2018 Annual Report

Title	Author(s)	Publication	Study Summary[1]
HABITAT LITERATURE			
Literature from 2019			
New County Records in Texas (U.S.A) for the Invasive Aquatic Plant *Hygrophila polysperma* (Acanthaceae).	Williams, Casey R.	Journal of the Botanical Research Institute of Texas. 2019. Vol. 13 Issue 1, pp 349-353.	Three new county records in Texas for the non-native aquatic plant *Hygrophila polysperma*, and a brief background history of the species occurrence in Texas are documented in this report.
OTHER LITERATURE			
Literature from 2018			
Program Study and Analysis Services for the Edwards Aquifer Protection Program.	Reilly, Francis J., Jr. Carter, Kaitlyn A.	ResearchGate. Oct 2018. Technical Report.	This report, which was prepared for the City of San Antonio's Parks and Recreation Department, describes a program study and analysis for the Edwards Aquifer Protection Program (EAPP). The EAPP uses real estate approaches to protect sufficient land to meet the program goals of protecting water quality in the aquifer as well as aquifer recharge volume. The recharge rate from the real estate included in the EAPP for protection of aquifer recharge was estimated and compared with known and projected benchmarks for San Antonio's water requirements. The potential for water quality issues was examined and the success of the EAPP in meeting the future needs of the City of San Antonio was estimated. Although contaminants of concern identified in well water samples were not considered pervasive or sources of surface water impairment in the contributing zone or Edwards Aquifer recharge area, the study recommended that the City of San Antonio consider changes to land-use practices in contributing and recharge areas of the aquifer to reduce the risk of water contamination and reduce the potential for water shortages. The study analyzed policy options for the EAPP (i.e., continuation of current funding, reduced funding starting in 2020, and discontinuation of funding after 2020) and compared the conservation efforts under each option with the goals for protection of projected withdrawals during the planning horizon.

List of Articles and Reports Completed Since the 2018 Annual Report

Title	Author(s)	Publication	Study Summary[1]
OTHER LITERATURE			
Literature from 2018			
Climate, Water, Water Markets, and Texas Agriculture: Three Essays	Thayer, Anastasia	Dissertation. Dec 2018. Texas A&M University, College Station, Texas, USA.	This dissertation explores agricultural output in two agriculturally productive regions in Texas under scenarios in which irrigation water decreases as a result of economic market forces (i.e., due to transfers of water out of irrigation in the Edwards Aquifer region) or aquifer depletion (i.e., due to irrigation pumping rates exceeding recharge in the Ogallala aquifer region). The work also considers future climate impacts and the effect of a warmer and drier climate on agricultural output, crop mix, farmer income and aquifer characteristics. A mathematical program was used to forecast expected agricultural and aquifer conditions in the Texas High Plains under existing conditions and expected conditions with climate change. Results show that future adjustments to agricultural practices in response to climate change will have a negative effect on the regional economy.
OTHER LITERATURE			
Literature from 2019			
Infrastructure Planning and Operational Scheduling for Power Generating Systems: An Energy-Water Nexus Approach.	Allen, R. Cory Nie, Yaling Avraamidou, Styliani Pistikopoulos, Efstratios N.	Computer Aided Chemical Engineering. 2019. Vol. 47 pp 233-238.	This article focuses on the increasing future demands for energy and water and the need for decision-making strategies for power generating systems that make full use of the Energy-Water Nexus (EW-N). In this article, the EW-N problem is presented as a two-stage program that minimizes the capital expenditures, operational cost, and water usage of the system. The model (which uses the Edwards Aquifer region of Texas as a case study) includes planning decisions related to optimal power plant expansions, operations, and technology conversions, as well as scheduling decisions related to energy production, allocation, and storage.
The Future of Water in San Antonio: An Evaluation of Ways to Meet Demand by 2070.	Hudock, Mathias	TC 660H – Plan II Honors Program. Apr 2019. The University of Texas at Austin, Texas, USA.	Three options for meeting San Antonio's projected 2070 water demand were evaluated according to their cost-efficiency, additional benefits and drawbacks, and likeliness of gaining public acceptance. The results suggested that city-wide rainwater harvesting was the most viable option and could provide additional benefits to the community. While a new reservoir was determined to be the most cost-efficient option, it was considered to be less viable due to concerns regarding public acceptance.

List of Articles and Reports Completed Since the 2018 Annual Report

Title	Author(s)	Publication	Study Summary[1]
OTHER LITERATURE			
Literature from 2019			
Timescales of water-quality change in a karst aquifer, south-central Texas.	Musgrove, M. Solder, J. E. Opsahl, S. P. Wilson, J. T.	Journal of Hydrology X. 2019. 4, 100041.	The goal of the research addressed in this paper was to better understand the timescales on which changes in groundwater quality occur, as well as the drivers of those changes, especially considering the importance of groundwater quality in the management, use, and protection of the resource. Three wells were instrumented and sampled in the Edwards aquifer in south-central Texas by the USGS 's National Water-Quality Assessment Enhanced Trends Network program to better understand these timescales over short (daily to monthly) and long (seasonal to decadal) periods. Water quality data collected from the wells (over a four-year period) and from additional sites were evaluated relative to historical records of climatic and hydrologic conditions. The evaluation revealed differences in hydrologic conditions, geochemistry, and groundwater age in the updip/unconfined part of the aquifer compared to downdip/confined sites. The results provide "insight into timescales at which the aquifer's public supply is vulnerable to changes in the water quality of recharge."
Hydrogeophysical characterization of the Haby Crossing fault, San Antonio, Texas, USA.	Saribudak, Mustafa	Journal of Applied Geophysics. Mar 2019. Vol. 162, pp 164-173.	Regionally, the Haby Crossing fault has been characterized as a lateral barrier to groundwater flow between the Edwards aquifer recharge zone and the confined portion of the Edwards aquifer. In this hydrogeophysical investigation, mapping of hydrogeologic and structural features demonstrated that karstification along the fault plane created conduits for lateral flow between the Edwards and Trinity aquifers, with the contact between the aquifers occurring on the upthrown side of the Haby Crossing fault. The study results could aid in determining where additional studies should be undertaken to better understand the lateral flow between aquifers, which has previously not been considered in groundwater flowpath models.

List of Articles and Reports Completed Since the 2018 Annual Report

Title	Author(s)	Publication	Study Summary[1]
OTHER LITERATURE			
Literature from 2019			
Testing Water Quality from Space: A Comparison between Remote Sensing and *in situ* Measurements.	Sturm, Hannah	Directed Research Thesis. May 2019. Texas State University, San Marcos, Texas, USA.	This research paper described the potential utility of remote sensing data to estimate water quality conditions. The research explored the question of: "How effective are Sentinel-2 satellite data for estimating turbidity and total suspended solids in the Guadalupe and Comal Rivers, near New Braunfels, TX, compared to in situ measurements collected by the Guadalupe Blanco River Authority?" and hypothesizes that "reflectance values from the satellite imagery can be used to estimate quantities that GBRA collected at their testing sites." Through the comparison of reflectance values and linear regression, the researcher produced a water quality assessment of five testing locations and concluded that reflectance values from satellite imagery can be useful in estimating certain water quality parameters remotely.
A PHREEQC Model of the Geochemical Variation Across a Freshwater and Saline Water Interface, Edwards Balcones Fault-Zone Aquifer, South-Central Texas.	Webster, Philip	Thesis. May 2019. The University of Texas at San Antonio, San Antonio, TX.	The purpose of this Thesis was to test the hypothesis that an area of brackish-water developed by mixing in a zone of convergent flow of freshwater from the Edwards Balcones Fault-Zone aquifer and saline water from further downdip in the Edwards Group. The hypothesis was tested by analyzing results of a geochemical model that was developed using PHREEQC and comparing those results to analyses of total dissolved solids data from monitoring wells. Noted benefits of modeling geochemical variation across the freshwater/saline water interface included the opportunity to explore mixing effects and the ability to highlight areas in the conceptual model that need further research.

[1] Study summaries are based on published abstracts, with direct quotes from abstracts designated by use of quotation marks.