Species Status Assessment (SSA) Report for Rio Grande Cooter (*Pseudemys gorzugi*)

Version 1.0

Photo: Drew R. Davis ©

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Version 1.0. This version of the Rio Grande cooter SSA and resulting report are Version 1.0. This report accompanies the 12-month finding for Rio Grande cooter, published in the Federal Register in January 2022.

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Contents

Executive Summary

This report summarizes the species status assessment conducted for Rio Grande cooter (*Pseudemys gorzugi*), in which we considered what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (together, the three Rs). This report is intended to provide the biological support for the decision on whether or not to propose to list the species as threatened or endangered under the Endangered Species Act of 1973, as amended (Act). The process and this SSA report do not represent a decision by the U.S. Fish and Wildlife Service (Service) regarding whether to list a species under the Act. Instead, this SSA report provides a review of the best available information strictly related to the biological status of the Rio Grande cooter.

The Rio Grande cooter is a medium to large freshwater turtle that occurs in a subset of lentic and lotic waterbodies in the Rio Grande/Rio Bravo watershed of New Mexico and Texas within the United States and the states of Coahuila, Nuevo León, and Tamaulipas in Mexico. The individual needs of the Rio Grande cooter vary somewhat by life stage (egg, hatchling, juvenile, adult); however, as a mostly aquatic species, water quality and quantity are central to the Rio Grande cooter's habitat needs.

The primary factors impacting the viability of Rio Grande cooter are related to habitat: the loss and decline of water quantity, and the degradation of water quality. Across the range of the species, modified hydrology has influenced the springs, streams, and rivers that Rio Grande cooter inhabit, as well as the groundwater systems to which these surface waters are linked. The influence of climate change plays out as an additive pressure on surface and groundwater availability. In addition, point and nonpoint source pollution has contaminated parts of the range. In New Mexico, conservation efforts aim to minimize negative impacts to surface water habitat, with an emphasis on maintaining flows. Other potential factors include direct mortality from predation, shooting, fish hook ingestion, bycatch, and collection.

We delineated 16 population analysis units based on watersheds, and used dams and associated reservoirs as boundaries for these units (Figure ES.1). While Rio Grande cooter may be able to negotiate around the dams and through the reservoirs, they are more likely to interbreed with individuals within the same population analysis unit, and therefore population analysis units may take on some of the attributes of a biological population. In addition, each population analysis unit tends to be managed similarly and face similar anthropogenic stressors, so this framework is useful for assessing resiliency in the face of such stressors.

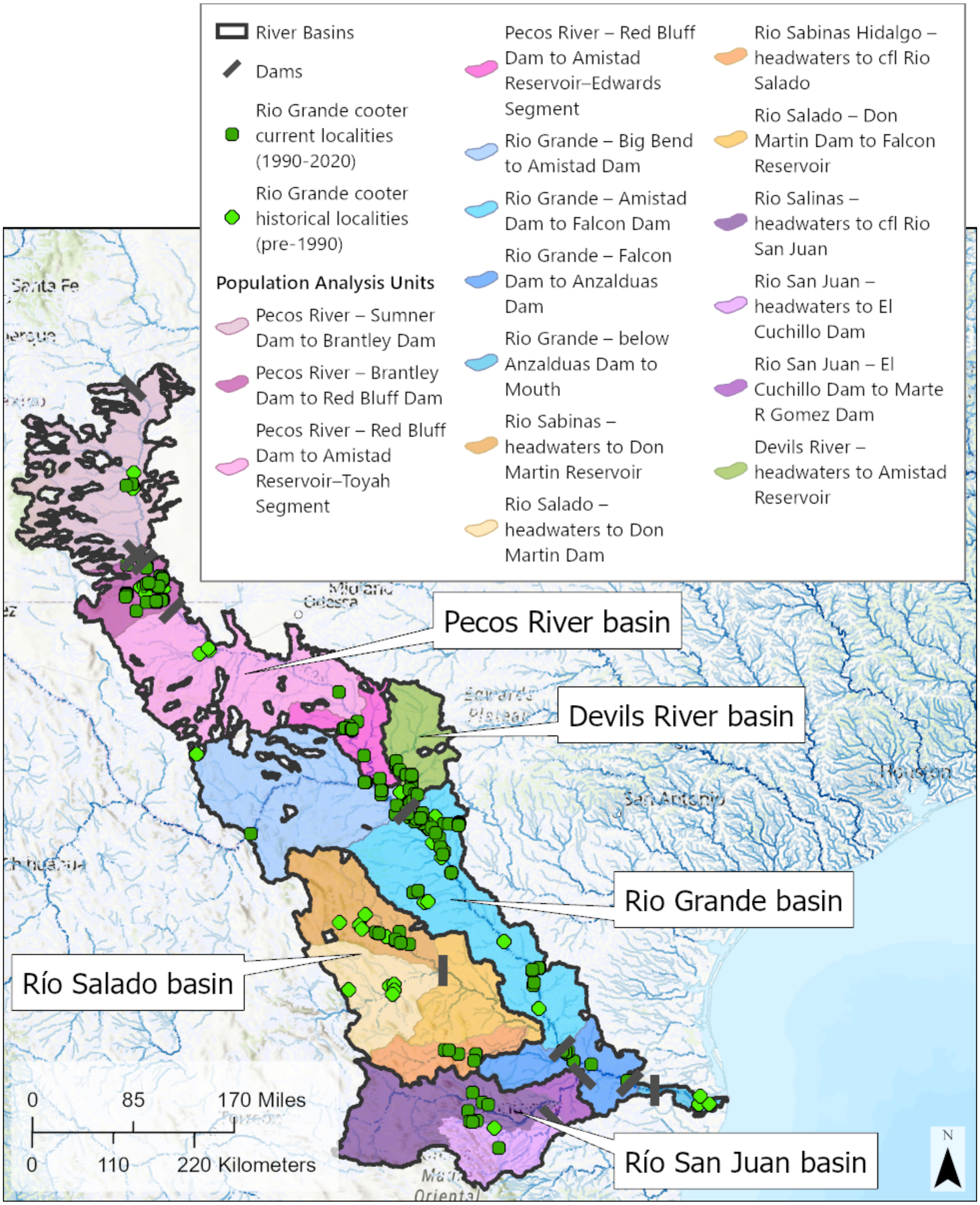


Figure ES.1. Population analysis units for Rio Grande cooter. River basins have thick black boundaries. Units within each river basin share a color family (pink, green, blue, orange, or purple). Dams are indicated with black bars. Light green diamonds represent historical observations (i.e., individuals detected during surveys prior to 1990). Dark green squares represent recent observations (i.e., detected during surveys from 1990 to 2020). The actual extent of areas occupied and used by Rio Grande cooter is limited to the water bodies and adjacent riparian areas within the shaded region. See legend for color matching individual population analysis units to the map.

Current Condition

To evaluate the current condition of the Rio Grande cooter, we selected two demographic factors (occurrence and subadult presence) and three habitat factors (occurrence complexity, water quantity, and water quality) for our resiliency analysis. Based on the available data and our understanding of Rio Grande cooter ecology, we developed a basis for assigning a risk category for each metric at the population analysis unit level. The risk category reflects a qualitative determination of the likelihood that Rio Grande cooter would be extirpated from a given population analysis unit within 30 years. For redundancy and representation, we assessed the number and distribution of population analysis units in different risk categories across the known historical distribution of the turtle. The species is well distributed across its range, despite the fact that Rio Grande cooter have not been observed in four population analysis units for many decades, presumably due to degraded water quantity and water quality. It occupies varying habitat types in terms of spring pools and streams of varying sizes and depths, and occurs across a wide range of temperature and precipitation regimes. Based on our analysis, the resiliency of Rio Grande cooter is characterized by having three population analysis units in the Low Risk category, seven in the Moderate Risk category, and six in the High Risk category. Given the current conditions of the population analysis units for Rio Grande cooter, the majority of populations have the ability to withstand stochastic events. The species currently has redundancy within major river basins and across the species range, and it currently has representation in that it maintains its distribution throughout its historical range across a variety of environmental conditions.

Future Condition

To construct plausible future scenarios, we considered the potential for changes in magnitude and severity of stressors in the future, and correspondingly, how those stressors may negatively impact the species' habitat and demographic needs. Where appropriate, we considered any existing efforts to conserve the species or its habitat and the likelihood that those efforts would continue in the future. As in the current conditions, we evaluated the species viability in terms of resilience at the population scale (i.e., analysis units), and representation and redundancy at the species scale (i.e., number, proximity, and condition of populations across the species range). We constructed two plausible future scenarios and projected the response of Rio Grande cooter to the environmental conditions at two future timesteps (2040 and 2060) in terms of the three Rs, and ultimately, species viability. Scenario 1 corresponds to the lower limit of plausible impacts and Scenario 2 corresponds to the upper limit of plausible impacts given the best available data (Table ES.1).

Table ES.1. Simple description of the conditions projected to occur for each influencing factor in the two future scenarios. We also identify the primary metric impacted by a given influencing factor.

Habitat Metric	Influencing Factor	Scenario 1	Scenario 2
Water Quantity	Climate change	Representative Concentration Pathway (RCP) 4.5 (moderate increase in greenhouse gas emissions)	RCP 8.5 (severe increase in greenhouse gas emissions)
	Water demand vs. availability	United States: Regional Water Plan projections accurately predict future water demand and availability. Mexico: Current trends continue.	United States: Regional Water Plan projections accurately predict future water demand and availability for most places, but underestimate water demand from mining in the Permian Basin and Eagle Ford play. Mexico: Current trends continue, with increased water stress in the Eagle Ford play.
	Conservation measures	Existing CCA/As on the lower Pecos River and permit conditions for the Bureau of Reclamation's management of the upper Pecos River succeed in maintaining instream flows and minimizing river and stream intermittency for population analysis units in New Mexico.	Existing CCA/As on the lower Pecos River and permit conditions for the Bureau of Reclamation's management of the upper Pecos River fail to maintain instream flows or minimize river and stream intermittency for population analysis units in New Mexico.
Water Quality	Specific conductance	Current trends continue; lower projected mean specific conductance.	Current trends continue; higher projected mean specific conductance.
	Hazardous materials spills or leaks; presence of contaminants	Current trends continue.	United States: Current trends continue, with increased risks from hazardous materials spills in the Permian Basin and Eagle Ford play. Mexico: Decreased water quality compared to current conditions with increased risks from hazardous materials spills in the Eagle Ford play.

Under Scenario 1, we do not project any changes to the *Overall Risk* to Rio Grande cooter in any of the population analysis units under Scenario 1 at either timestep 2040 or timestep 2060 (Table ES.2). Under this scenario, the overall resiliency of Rio Grande cooter is characterized at both timesteps by having six populations in the High Risk category, seven populations in the Moderate Risk category, and three populations in the Low Risk category. In total, 10 of 16 population analysis units (the majority) are categorized as Low Risk or Moderate Risk, and have the ability to withstand stochastic events (e.g., disturbance). This distribution is the same as the current conditions. We also project that the species will continue to have redundancy within the major river basins and across the species' range, and maintain current levels of representation at both future timesteps of the scenario.

In Scenario 2, we project changes to the *Overall Risk* to Rio Grande cooter in three population analysis units over the two timesteps (Table ES.2). At the 2040 timestep, the overall resiliency of Rio Grande cooter is characterized by having six populations in the High Risk category, eight populations in the Moderate Risk category, and two populations in the Low Risk category. The Overall Risk designation increases for one unit; the others remain the same as the current conditions. At the 2060 timestep, the overall resiliency of Rio Grande cooter is characterized by having seven populations in the High Risk category, eight populations in the Moderate Risk category, and one population in the Low Risk category. The Overall Risk designations increase for three units; the others remain the same as the current conditions. In total, the number of population analysis units categorized as Low Risk or Moderate Risk is 10 of 16 at timestep 2040, and 9 of 16 at timstep 2060; the majority thus have the ability to withstand stochastic events. As with Scenario 1, we project that the species will continue to have redundancy within the major river basins and across the species' range, and maintain current levels of representation at both future timesteps.

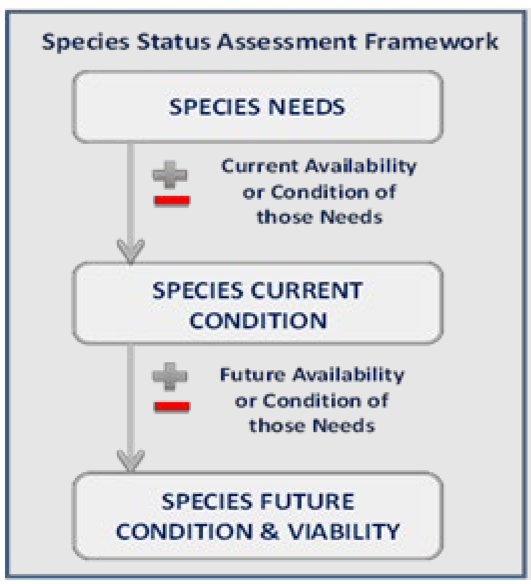
Table ES.2. Projected *Overall Risk* (Low, Moderate, or High) for Rio Grande cooter population analysis units. Increases in risk compared to the current conditions are denoted with an asterisk (*) next to the *Overall Risk* category term. Cell shading corresponds to category.

Population Analysis Unit	Current	Scenario 1 – 2040	Scenario 1 – 2060	Scenario 2 – 2040	Scenario 2 – 2060
Pecos River – Sumner Dam to Brantley Dam	High	High	High	High	High
Pecos River – Brantley Dam to Red Bluff Dam	Moderate	Moderate	Moderate	Moderate	Moderate
Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment	High	High	High	High	High
Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment	Low	Low	Low	Low	Moderate ↑
Devils River – headwaters to Amistad Reservoir	Low	Low	Low	Low	Low
Rio Grande – Big Bend to Amistad Dam	Moderate	Moderate	Moderate	Moderate	Moderate
Rio Grande – Amistad Dam to Falcon Dam	Low	Low	Low	Moderate ↑	Moderate
Rio Grande – Falcon Dam to Anzalduas Dam	Moderate	Moderate	Moderate	Moderate	Moderate
Rio Grande – Anzalduas Dam to Mouth	High	High	High	High	High
Río Sabinas – headwaters to Don Martin Reservoir	Moderate	Moderate	Moderate	Moderate	Moderate
Río Salado – headwaters to Don Martín Dam	High	High	High	High	High
Río Sabinas Hidalgo – headwaters to cfl Río Salado	Moderate	Moderate	Moderate	Moderate	High ↑
Río Salado – Don Martin Dam to Falcon Reservoir	High	High	High	High	High
Río Salinas – headwaters to cfl Río San Juan	Moderate	Moderate	Moderate	Moderate	Moderate
Río San Juan – headwaters to El Cuchillo Dam	Moderate	Moderate	Moderate	Moderate	Moderate
Rio San Juan – El Cuchillo Dam to Marte R Gomez Dam	High	High	High	High	High

1 Introduction: Analytical Framework

The SSA report, the product of conducting an SSA, is intended to be a concise review of the species' biology and factors influencing the species, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA report to be easily updated as new information becomes available, and to support all functions of the Endangered Species Program. As such, if the Rio Grande cooter is listed under the Act, the SSA report will be a living document upon which other documents such as recovery plans and 5-year reviews will be based, supporting future decisions about the species' listing status and, eventually, a post-delisting monitoring plan.

The objective of this SSA is to thoroughly describe the viability of the Rio Grande cooter based on the best scientific and commercial information available (Smith et al. 2018, entire). Through our assessment, we determined what the species needs to support viable populations, its current condition in terms of those needs, and its forecasted future condition under plausible future scenarios. In conducting this analysis, we took into consideration the likely changes that are happening in the environment – past, current, and future – to help us understand what factors drive the viability of the species. For the purpose of this assessment, we define viability as the ability of the Rio Grande cooter to sustain populations in their natural habitat over time. Viability is not a specific state, but rather a continuous measure of the likelihood that the species will sustain populations over time (U.S. Fish and Wildlife Service 2016, p. 9). Using the SSA framework (Figure 1.1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf et al. 2015, entire; U.S. Fish and Wildlife Service 2016, entire).



- **Resiliency** is the ability of a species to withstand environmental stochasticity (normal, year-to-year variations in environmental conditions such as temperature, rainfall), periodic disturbances within the normal range of variation (fire, floods, storms), and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity) (Redford et al. 2011, p.

40). Simply stated, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions. We can best gauge resiliency by evaluating population level characteristics such as: demography (abundance and the components of population growth rate: survival, reproduction, and migration), genetic health (effective population size and heterozygosity), connectivity (gene flow and population rescue), and habitat quantity, quality, configuration, and heterogeneity.

- **Redundancy** is the ability of a species to withstand catastrophes. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population heath and for which adaptation is unlikely (Mangel and Tier 1993, p. 1083). We can best gauge redundancy by analyzing the number and distribution of populations relative to the scale of anticipated species-relevant catastrophic events. The analysis entails assessing the cumulative risk of catastrophes occurring over time. Redundancy can be analyzed at a population or regional scale, or for narrow-ranged species, at the species level.
- **Representation** is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability to adapt to new environments—referred to as adaptive capacity—is essential for viability, as species need to continually adapt to their continuously changing environments (Nicotra et al. 2015, p. 1269). We can best gauge representation by examining the breadth of genetic, phenotypic, and ecological diversity found within a species and its ability to disperse and colonize new areas. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of the species' morphology, habitat characteristics within the geographical range, or both.

The decision whether to list a species is based *not* on a prediction of the most likely future for the species, but rather on an assessment of the species' risk of extinction. Therefore, to inform this assessment of extinction risk, we describe the species' current biological status and assess how this status may change in the future under a range of scenarios to account for the uncertainty of the species' future. We evaluate the current biological status of the Rio Grande cooter by assessing the primary factors negatively and positively affecting the species to describe its current condition in terms of resiliency, redundancy, and representation (together, the 3Rs). We then evaluate the future biological status of the Rio Grande cooter by describing a range of plausible future scenarios representing a range of conditions for the primary factors affecting the species and forecasting the most likely future condition for each scenario in terms of the 3Rs. As a matter of practicality, the full range of potential future scenarios and potential future conditions for each potential scenario are too large to individually describe and analyze; therefore, our analysis is intentionally limited in scope. These scenarios do not include all possible futures, but rather include specific plausible scenarios that represent examples from the continuous spectrum of possible futures. Consequently, the results of this SSA do not describe the overall risk to the species. Recognizing these limitations, the results of this SSA nevertheless provide a framework for considering the overall risk to the species in listing decisions.

2 Species Ecology and Needs

In this chapter we provide basic biological information about Rio Grande cooter, including its taxonomic history, genetics, morphological description, and known life history traits. We then outline the resource needs of individuals and populations of Rio Grande cooter. We focus on those aspects of the life history of the species that are important to our analysis. For further information about Rio Grande cooter, refer to Ernst (1990, entire), Bailey (2005, entire), Ernst and Lovich (2009, pp. 377–80), Legler and Vogt (2013a, pp. 241–46), and Pierce et al. (2016, entire).

Species Description

The Rio Grande cooter is described as a medium-to-large freshwater turtle, with female adults ranging in size from 160–372 millimeters (mm) (6.3–14.6 inches [in]), and males ranging from 100–285 mm (3.9–11.2 in) (Degenhardt et al. 1996, pp. 102–3; Stout et al. 2005, p. 443; Bartlett and Bartlett 2013, pp. 63–64; Legler and Vogt 2013a, pp. 242–44; Hibbitts and Hibbitts 2016, pp. 135–36). As depicted in Figure 2.1, the carapace is an elongate oval with a serrated rear margin and an intricate pattern of black and yellow curvilinear lines on a green carapace (Degenhardt et al. 1996, pp. 102–3; Bartlett and Bartlett 2013, pp. 63–64; Hibbitts and Hibbitts 2016, pp. 135–36). The head, neck, legs, and tail are dark brown to black with yellow stripes (Degenhardt et al. 1996, pp. 102–3; Bartlett and Bartlett 2013, pp. 63–64; Hibbitts and Hibbitts 2016, pp. 135–36). Many individuals have red coloring on the margins of the carapace, and the yellow stripes may grade into red on the feet and tail (Degenhardt et al. 1996, pp. 102–3; Bartlett and Bartlett 2013, pp. 63–64; Hibbitts and Hibbitts 2016, pp. 135–36). The species is sexually dimorphic. The primary differences between the sexas are that females are larger than males, while males have thicker and longer tails than females, as well as long, straight foreclaws (Degenhardt et al. 1996, pp. 102–3; Bartlett and Bartlett 2013, pp. 63–64; Hibbitts and Hibbitts 2016, pp. 135–36). For a more detailed description of the morphological characteristics of Rio Grande cooter, see Ward (1984, pp. 29–33) and Ernst (1990, p. 461.1).

Figure 2.1. Adult male Rio Grande cooter. Image courtesy Dr. Drew Davis.

Taxonomy and Genetics

Turtles in the family Emydidae have a long history of taxonomic uncertainty and revision, which is now considered relatively stable, as discussed in a recent comprehensive review (Seidel and Ernst 2017, entire). Efforts to classify these turtles in a coherent taxonomy began in the 18th century; the family Emydidae, as is recognized today, was proposed in 1984 and subsequently confirmed using genetic data (Seidel and Ernst 2017, pp. 3–16). This family is divided into the aquatic subfamily Deirochelyinae and the semiterrestrial subfamily Emydinae (Seidel and Ernst 2017, pp. 91–92, 117–19). The generic assignments of the turtles in the aquatic subfamily have been unstable for much of the history of turtle taxonomy (Seidel and Ernst 2017, p. 49). Efforts have been made to categorize all of the genera using morphological, chemical, molecular, and genetic indicators (Seidel and Ernst 2017, pp. 49–53). Most of the available research supports the designation of *Pseudemys* as a monophyletic group (Seidel and Ernst 2017, p. 53). Questions remain about the boundaries of the species within *Pseudemys*, but are focused on *Pseudemys* species other than *Pseudemys gorzugi.* Strong evidence supports *P. gorzugi* as a monophyletic lineage within the genus (Seidel and Ernst 2017, pp. 68–77).

Pseudemys concinna gorzugi was recognized as a subspecies of river cooter (*P. concinna*) in 1984 with no common name (Ward 1984, pp. 29–43). The holotype locality is a specimen collected in 1952 from the Río San Diego near Jiménez, Coahuila (Ward 1984, p. 29). Rio Grande cooter was elevated to a full species (*P. gorzugi*) and assigned its common name in 1990 (Ernst 1990, pp. 461.1–461.2). Despite initial resistance to the elevation due to lack of evidence (Iverson 1992, p. 192), further analyses confirmed the now accepted species designation (Seidel 1994, p. 127; 1995, p. 335; Degenhardt et al. 1996, pp. 102–4; Turtle Taxonomy Working Group et al. 2007, pp. 176, 181; Spinks et al. 2013, p. 277; Crother 2017, p. 89).

Previous publications and identification of Rio Grande cooter refer to this species by other scientific names due to the past taxonomic uncertainty (Pierce et al. 2016, p. 100.1). For example, one early account of turtles from New Mexico, Texas, and Mexico, including from the Guadalupe Mountains, Pecos River in Texas, and Cadereyta, Nuevo León, considers turtles from those localities to be *P. texana* (Baur 1893, pp. 220–23). Turtles that are now believed to belong to *P. gorzugi* have been previously identified as *Chrysemys mobilensis* (A. E. Brown 1903, pp. 543–44), *C. texana* (Strecker 1909, p. 15; 1915, p. 12), *C. concinna* (Ernst and Barbour 1972, pp. 155–60; Conant 1977, pp. 471–72), *Pseudemys floridana* (Milstead et al. 1950, pp. 551, 607), *P. floridana texana* (Bundy 1951, p. 314; Legler 1958, pp. 230–31; Gehlbach 1964, p. 3), *P. concinna* (Powell et al. 1984, p. 79; NMDGF 1988, pp. 1–2), *P. concinna texana* (Gehlbach 1964, p. 3; Degenhardt and Christiansen 1974, pp. 36–37), and have occasionally been erroneously identified as *P. gaigeae* or *P. scripta gaigeae* (K. P. Schmidt and Smith 1944, p. 78; K. P. Schmidt and Owens 1944, p. 101; Legler 1960, p. 78). The history of specimens being identified as other species and subspecies of Emydid turtles is further discussed in Ward (1984, p. 33) and Ernst (1990, p. 461.1).

The Integrated Taxonomic Information System (ITIS 2019) currently accepted classification is:

Phylum: Chordata
Subphylum: Vertebrata
Class: Reptilia
Order: Testudines
Family: Emydidae
Subfamily: Deirochelyinae
Genus: *Pseudemys*
Species: *Pseudemys gorzugi*

Genetic studies of *Pseudemys* in general and *P. gorzugi* (Rio Grande cooter) in particular reveal low genetic diversity among both groups, while still resolving *P. gorzugi* as a monophyletic lineage (Seidel and Ernst 2017, pp. 68–77). One hypothesis for this observation is that the divergence of individual species may be relatively recent evolutionarily, or that there may be historical introgression and hybridization, making it more difficult to distinguish species using genetic data (Jackson et al. 2012, pp. 306–8). Bailey et al. (2008, pp. 407–10) was unable to distinguish geographic clusters, or populations, of Rio Grande cooter using genetic data. The lack of spatial structuring of Rio Grande cooter genetics may be due to low genetic diversity, a slow rate of evolution, or a truly panmictic population structure (Avise et al. 1992, pp. 466–69; Bailey et al. 2008, p. 410).

Life History

While there is wide variation among turtle life history traits, certain characteristics are commonly reported, including for Rio Grande cooter and closely related species. These include high mortality among eggs and hatchlings, slow growth, high adult survivorship, repeated reproduction, and long lives (Frazer et al. 1990, pp. 191–95; Reed and Gibbons 2003, p. 4; Vitt and Caldwell 2014, p. 523; Sirsi et al. 2018, pp. 10–11). Of the 58 extant species of turtles in the United States and Canada, basic demographic data are only available for fewer than 20 species; as of 2013, Rio Grande cooter was one of the least studied turtles (Reed and Gibbons 2003, p. 15; Lovich and Ennen 2013, p. 5; Seidel and Ernst 2017, p. 3). As a result, much of what is known about Rio Grande cooter life history comes from reports, field guides, and natural history notes (e.g., Sirsi et al. (2018, entire), Legler and Vogt (2013a, pp. 241–46), Curtis et al. (2017, p. 426)). Field research on Rio Grande cooter has emphasized surveying for species presence rather than estimating demographic parameters, and therefore we infer some life history traits from congeners or similarly sized freshwater turtles. In addition, the available information on Rio Grande cooter comes from a small subset of the extant populations and turtles; we do not know if these parameters vary across the range of the species, and more expansive research on the species could reduce uncertainty in the mean and range of these parameters. We present some of the known and inferred basic life history information in Figure 2.2 and summarize individual needs by life stage in Table 2.1.

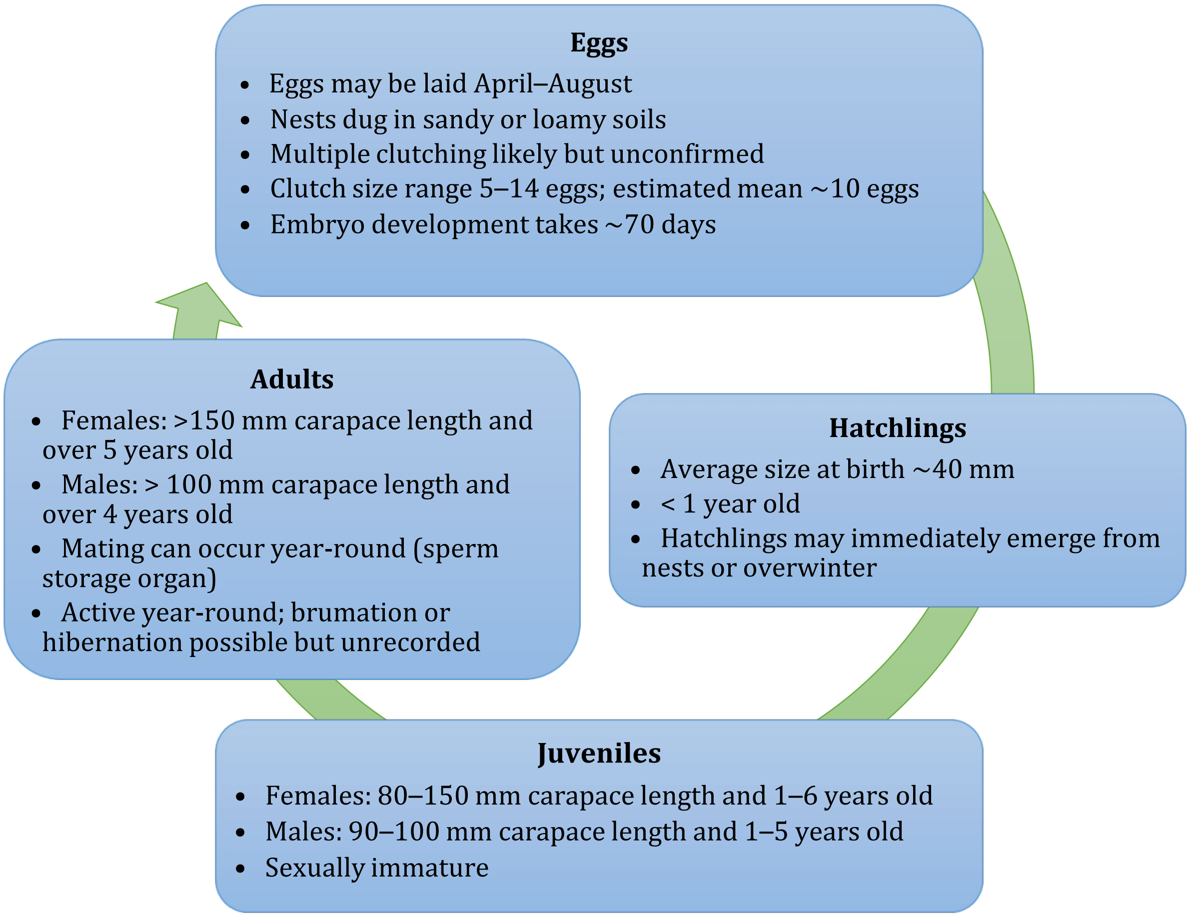


Figure 2.2. Life cycle diagram identifying elements of Rio Grande cooter eggs, hatchlings, juveniles, and adults life history (Congdon and Gibbons 1990, p. 50; Painter 1993, p. 3; Degenhardt et al. 1996, pp. 103–4; Bartlett and Bartlett 1999, p. 292; Iverson 2001, p. 365 [river cooter]; Legler and Vogt 2013a, pp. 244–45; Vitt and Caldwell 2014, p. 209; Lovich et al. 2016, p. 292; Letter et al. 2017, p. 836; Bohannon 2019a, pp. 8–10; Mali and Suriyamongkol 2019, pp. 4–7; Suriyamongkol and Mali 2019a, p. 3; 2019b, p. 191). Field research on Rio Grande cooter has emphasized surveying for species presence rather than estimating demographic parameters, and therefore we infer some life history traits from congeners or similarly sized freshwater turtles. Where information on Rio Grande cooter are available, we use those data.

Reproduction

The reproductive ecology of Rio Grande cooter is not well understood, but recent studies have increased the available information. A systematic study to determine size and age at sexual maturity across the range has not been undertaken for Rio Grande cooter. Legler (2013a, p. 244) suggested that sexual maturity in males occurs at about age four or five, and when the individual is around 100 mm carapace length (CL); in females, it occurs at about five or six years of age, and when the individual is around 160 mm CL (Legler and Vogt 2013a, p. 244). The smallest females with follicles in two recent studies were 150 mm CL and 185 mm CL (Bohannon et al. 2018, p. 7; Suriyamongkol and Mali 2019b, p. 191), indicating that Legler's estimates are reasonable but that an individual's size at sexual maturity may vary across the species' range.

Mating has been observed from January through October (Bohannon 2019a, p. 11; Davis et al. 2020, p. 43). Sperm storage and multiple paternity are common among turtles, and we presume that both apply to Rio Grande cooter as well (Pearse 2001, pp. 207–9; Vitt and Caldwell 2014, p. 209). Reproductive studies on Rio Grande cooter to date have found that many females captured during the breeding season were observed to have either shelled eggs or egg follicle development structures, although many females had neither (Bohannon 2019a, pp. 7–11; Mali and Suriyamongkol 2019, pp. 6–7). This may mean that female Rio Grande cooters, like a few other turtle species, do not necessarily nest every year (Congdon and Gibbons 1990, p. 50; Frazer et al. 1990, pp. 186–87). One recent study of Rio Grande cooter in Texas found large follicles in captured female turtles in every month of the year (Bohannon 2019a, p. 10). Gravid females have been captured from April through August (Degenhardt et al. 1996, p. 103; Lovich et al. 2016, pp. 292–93; Letter et al. 2017, p. 836; Bohannon 2019a, p. 9; Mali and Suriyamongkol 2019, p. 15; Suriyamongkol and Mali 2019b, p. 4; Mali et al. 2020a, p. 14) and multiple clutching is likely (Legler and Vogt 2013a, p. 245; Suriyamongkol and Mali 2019b, p. 5). Mean clutch frequency is unknown. Clutch size has been documented by several researchers. Across studies, the range is 5–17 eggs, and the mean is likely close to ten eggs (Painter 1993, p. 3; Degenhardt et al. 1996, p. 103; Lovich et al. 2016, p. 292; Letter et al. 2017, p. 836; Bohannon 2019a, pp. 8–9; Mali and Suriyamongkol 2019, pp. 6–7). Incubation time in captivity for a single clutch was about 70 days (Degenhardt et al. 1996, p. 103).

Nesting likely occurs from at least April to August, based on observations of shelled eggs in x-rayed females and evidence of recent emergence (Painter 1993, pp. 3–4; Legler and Vogt 2013a, p. 245; Lovich et al. 2016, p. 292; Letter et al. 2017, p. 836; Bohannon 2019a, p. 8; Mali and Suriyamongkol 2019, p. 15; Mali et al. 2020a, p. 14). Although these data are limited, they are in line with data from the closely related and better-studied river cooter (*Pseudemys concinna*) (Iverson 2001, p. 367). Painter (1993, pp. 3–4) found four hatched or predated nests presumed to belong to Rio Grande cooter during surveys in Eddy County, New Mexico and documented their location and setting. In this small sample, nest distance from the water ranged from 1.8–35.4 meters (m) (5.9–116.1 feet [ft]), nest cavity size was approximately 7–8 centimeters (cm) (2.8–3.1 in) by 7–8 cm (2.8–3.1 in), and ground cover near each nest ranged from dense grass, shrubs, and trees, to exposed soil with little to no shade (Painter 1993, p. 3). In 2020, nest surveys along the Black River found Rio Grande cooter nests 5–100 ft (1.5–30 m) from water in loose, sandy soil among open and grassy vegetation cover (Mali et al. 2020b, pp. 11–13). The evidence available to date suggests that Rio Grande cooter are like many other river turtles in that they lay their eggs in nest burrows that are dug by the female and resealed after the clutch is deposited (Moll and Moll 2004, p. 43).

Survival, Growth, and Longevity

Nest success is unknown, though estimates for other freshwater turtles range from 15–22% (Frazer et al. 1990, p. 189). Survivorship until hatching is also unknown for Rio Grande cooter. The probability of egg survivorship in studies of other freshwater turtles varies, potentially ranging from 0–70% for each individual (Frazer et al. 1990, p. 189). Ernst and Lovich (2009, p. 211) report survivorship rates to the hatchling stage for painted turtle (*Chrysemys picta*) as low as 8% or as high as 83% (the latter on an isolated island). Nest success and survivorship for Rio Grande cooter also probably vary over space and time.

Hatchlings with egg teeth present have been observed in April, August, and October; the April observation suggests that some hatchlings may overwinter in the nest (Degenhardt et al. 1996, pp. 103–4). The frequency of overwintering, and the timing of nest emergence for any overwintering hatchlings, is unknown. Overwintering, also referred to as delayed emergence, is common among turtle species for which hatchlings face a high degree of environmental variability and uncertainty (Gibbons 2013, p. 211). Given that variability and uncertainty characterize the natural environment across much of the Rio Grande cooter range (Follansbee and Jean 1915, entire; Combs 2012, p. 1; Runkle et al. 2017, entire),[1] it seems reasonable to conclude that Rio Grande cooter hatchlings that hatch later in the fall may subsequently overwinter in the nest. However, the only evidence for this is the discovery of very recently hatched turtles in the spring. Growth rates for hatchlings are not known.

Survivorship for juveniles is not known, although capture-mark-recapture studies underway on the Black River in New Mexico may yield estimates in the future (Mali and Suriyamongkol 2019, p. 13). Studies of juvenile pond sliders (*Trachemys scripta*) in South Carolina estimated increasing survivorship for each year of life up to age 4, with a cumulative survival rate of 18.4% from ages one to four (Frazer et al. 1990, pp. 195–97). Juvenile painted turtles also have moderate survivorship, on the order of 20–50% annually (Ernst and Lovich 2009, p. 211). Growth rates are not expected to vary between the sexes for juveniles since no sex-dependent behaviors exist (Gibbons 1990, p. 11). Juveniles in New Mexico have an estimated mean growth rate of 13.91 mm/year (0.55 in/year) (Mali, Letter, et al. 2018, p. 11).

Apparent survival for adult Rio Grande cooter at the Dolan Falls pool on the Devils River is available. For both sexes, apparent survival was estimated at 0.993 ± 0.004 (Sirsi et al. 2018, p. 10). For females only, apparent survival was estimated at 0.971 ± 0.01, while for males only, apparent survival was estimated at 0.999 ± 0.004 (Sirsi et al. 2018, p. 10). We did not find survivorship data for adult Rio Grande cooter elsewhere in the species' range. Continued mark-recapture studies may eventually yield more detailed estimates (Mali and Suriyamongkol 2019, p. 13). Studies of other freshwater turtle species in North America estimate adult survivorship ranging from 29–97% (Frazer et al. 1990, pp. 191–95; Ernst and Lovich 2009, p. 211). Frazer et al. (1990, pp. 191–95) suggested that annual survivorship is thought to exceed 90% for populations of turtles that are not exploited and occur in stable habitats.

Rio Grande cooter adult mean growth rates are about 3 mm/year (0.11 in/year), with high variability; some turtles do not show measurable growth over a one-year timestep (Mali, Letter, et al. 2018, p. 11). Longevity for Rio Grande cooter is unknown (Pierce et al. 2016, p. 100.7). Long-term studies of pond sliders reported an average survivorship of about 22 years, with a range of 6–36 years (Frazer et al. 1990, p. 197). Using pond sliders as a surrogate for Rio Grande cooter, we estimate the lifespan of most Rio Grande cooter is on the order of 20–25 years. Given that sexual maturity is reached at about six years, we estimate the average generation length to be about 15 years.

Individual Resource Needs: Habitat

The needs of individual Rio Grande cooters vary somewhat by life stage. A detailed description of individual needs by life stage is presented in Table 2.1. Our understanding of individual needs is

[1] When discussing the weather, Texans often repeat a quote attributed to National Weather Service meteorologist Isaac Cline: "Texas is a land of eternal drought interrupted occasionally by Biblical floods" (Strong 2017).

generally qualitative (e.g., adequate water quantity) rather than quantitative (e.g., river flows above 3 cubic feet per second). As a mostly aquatic species, water quality and quantity are central to Rio Grande cooter habitat needs. Hatchlings, juveniles, and adults all need water of adequate quality and quantity to meet their individual needs, including feeding, growth, survival, and breeding. Water must be of adequate depth to provide cover from predation. During hot weather, access to water of cooler temperatures is needed to allow for necessary thermoregulation. Contaminants or other potentially harmful constituents in water must be absent or below thresholds that cause acute or chronic toxicity directly to turtles or indirectly to resources upon which turtles rely (e.g., dietary components). Turtles in these life-stages also need adequate and reliable food supplies and access to safe basking habitat. Adequate water flows are necessary to support individual movements to locate breeding partners, access nesting areas, and retreat from unsuitable habitat. The upland habitat needs of the species are associated with nesting and egg development. Adult females require soil loose enough to dig a nest, in an area near water, where the eggs in that nest will then be adequately thermoregulated and safe from inundation, predation, or other disturbance during the incubation and/or overwintering stages.

Table 2.1. Summary of individual needs by life stage. The life stages are eggs, hatchling, juvenile, and adult. The Resource Function identifier in square brackets identifies whether the resource is needed for Breeding (B), Feeding (F), Sheltering (S), Dispersal or Migration (DM), or Thermoregulation (T).

Life Stage	Resources and/or circumstances needed for individuals to complete each life stage [Resource Function]	References
eggs	1) Approximately 70 days without inundation or predation [S] 2) Nest cavity remains within temperature range and humidity conducive to embryo development [S]	1) (Degenhardt et al. 1996, p. 103; Ernst and Lovich 2009, p. 379; Pierce et al. 2016, p. 100.8) 2) (Painter 1993, pp. 3–4; Degenhardt et al. 1996, p. 103; Legler and Vogt 2013a, p. 245; Pierce et al. 2016, p. 100.7)
hatchling	1) Loose enough soil to escape from the nest [DM] 2) Distance from nest to water within limits of hatchling mobility and minimizes vulnerability to predation while in transit [DM] 3) If overwintering, nest cavity must persist for 4-8 months without inundation or predation, and remain within the temperature range conducive to overwintering success [S]	1) (NMDGF 1988, p. 2; Painter 1993, pp. 3–4) 2) (Gibbons 1990, p. 10; Gibbons et al. 1990, p. 202; Ernst and Lovich 2009, p. 379) 3) (Gibbons 1990, p. 10; 2013, pp. 204–9; Painter 1993, pp. 3–4; Degenhardt et al. 1996, p. 103; Ernst and Lovich 2009, p. 379; Legler and Vogt 2013a, p. 245; Pierce et al. 2016, pp. 100.7–100.8)
hatchling, juvenile, adult	1) Access to food resources. Plant *and* animal availability a plus. Transition from more omnivorous to more herbivorous throughout life. [F] 2) Water present at adequate depth for submergence, movement, and foraging. [S, T, DM, F] 3) Water quality is sufficient to meet life history needs, such as appropriate basic water chemistry (e.g., temperature) and contaminants are absent or below levels of concern [S, F, T] 4) Access to safe basking habitat [T] 5) Access to refugia during low flow, low water quality, or high temp events [S, T, DM] 6) Cover from predators in the water, such as crevices aquatic vegetation, and deep pools [S]	1) (Gibbons et al. 1990, p. 202; Painter 1993, p. 2; Degenhardt et al. 1996, p. 104; Forstner et al. 2004, pp. 26, 36; Pierce et al. 2016, pp. 100.4–100.6; Letter et al. 2019, p. 206; Mahan, Suriyamongkol, et al. 2020, p. 113) 2) (Degenhardt et al. 1996, p. 103; Pierce et al. 2016, pp. 100.5–100.6; Seidel and Ernst 2017, pp. 68–69) 3) (Ward 1984, p. 32; Pierce et al. 2016, pp. 100.7–100.8) 4) (Degenhardt et al. 1996, p. 103; Forstner et al. 2004, pp. 14–15, 28, 59; Ernst and Lovich 2009, p. 379; Pierce et al. 2016, p. 100.6; Mali, Letter, et al. 2018, p. 10; Suriyamongkol and Mali 2019a, pp. 1–3) 5) (Gibbons 1990, p. 10; Gibbons et al. 1990, pp. 202, 213; Cheek and Taylor 2016, pp. 345–48; Mali, Letter, et al. 2018, p. 10) 6) (Congdon and Gibbons 1990, p. 52; Gibbons 1990, p. 10; Gibbons et al. 1990, p. 202; Degenhardt et al. 1996, p. 103; Ernst and Lovich 2009, p. 379; Pierce et al. 2016, p. 100.8)
adult	1) Periodic access to opposite sex for mating [B, DM] 2) Females need access to nesting locations that meet sheltering needs of eggs and hatchlings [B, DM]	1) (Gibbons 1990, p. 10; Gibbons et al. 1990, p. 202; Pearse 2001, entire [sperm storage]; Vitt and Caldwell 2014, p. 123) 2) (NMDGF 1988, p. 2; Gibbons et al. 1990, pp. 202, 207; Ernst and Lovich 2009, p. 379)

Population and Species-level Needs

For Rio Grande cooter to maintain viability, its populations—or some portion thereof—must be able to withstand, or be resilient to, stochastic events and disturbance. Stochastic events potentially impacting Rio Grande cooter populations include drought, flooding, and contamination events, which modify or destroy the habitat upon which they depend. To have the highest resiliency to stochastic events, populations need an abundance of individuals within habitat patches of adequate area and quality to maintain survival and reproduction despite natural disturbances. The abundance within a population is influenced by fecundity (and other reproduction-related demographic factors), survival, and dispersal (i.e., immigration and emigration). Such movement between populations, or lack thereof, also promotes or hinders gene flow, which can influence whether or to what extent there is geographic variation among populations and across the species as a whole, which can be important to ensure population survival after stochastic events.

As with other turtle species, survival rates among adults and juvenile Rio Grande cooter must be high in order to offset relatively low rates of nest success (Frazer et al. 1990, pp. 188–95; Vitt and Caldwell 2014, p. 145). Population growth rates must be stable or increasing over the long term. We assume that a larger occupied area means a larger total population size, and that the availability of suitable habitat among spring pools, streams, and rivers implies the availability of refugia if a catastrophic stochastic event occurs. Therefore, individuals within a population will have the highest resiliency if they can and do occupy multiple sites in multiple waterways (spatial extent and occurrence complexity). Additionally, the habitat resources needed by individuals—those that support the breeding, feeding, and sheltering functions necessary for basic survival and reproduction—must exist in sufficient quantity and quality to support entire populations. Without all of these factors, a population has an increased likelihood for localized extirpation.

Redundancy describes the ability of a species to withstand catastrophic events. It reduces the risk of losing representation from the effect of stochastic events that depress or eliminate populations or subpopulations, and minimizes the effect of localized extirpation on the rangewide persistence of a species (Shaffer and Stein 2000, p. 308; Tear et al. 2005, p. 841; Redford et al. 2011, p. 42). Redundancy for Rio Grande cooter is characterized by having locally self-sustaining (in terms of abundance and recruitment) subpopulations in multiple stream and river reaches distributed across the river basins historically occupied by the species. In addition, some level of connectivity is needed to allow for immigration and emigration, and to increase the likelihood of recolonization should a population become extirpated.

For a species to persist and thrive over time, it must exhibit attributes across its range that relate to either representation or redundancy. Representation describes the ability of a species to adapt to changing environmental conditions over time and encompasses the “ecological and evolutionary patterns and processes that not only maintain but also generate species” (Shaffer and Stein 2000, p. 308). It is characterized by the breadth of genetic, behavioral, or environmental diversity within and among populations. The more representation, or diversity, that a species has, the more it is capable of adapting to changes (natural or human-caused) in its environment. For Rio Grande cooter to exhibit adequate representation, resilient populations should occur in the range of river systems and watersheds where it is native. These populations should occur at the widest extent possible across the historic range of the species and they should occupy multiple sites in multiple waterways in drainages where they are native. Connectivity among populations maintains representation by facilitating genetic exchange and maintaining potential for adaptive capacity.

Rio Grande cooter species-level needs are summarized in Table 2.2. Ultimately, Rio Grande cooter viability depends on there being a sufficient number and distribution of healthy populations to ensure that the species can withstand annual variation in its environment (i.e., resiliency), catastrophes (i.e., redundancy), and novel biological and physical changes in its environment (i.e., representation).

Table 2.2. Rio Grande cooter species level needs, based on the 3 Rs of resiliency, redundancy, and representation.

3 Rs	**Requisites of long-term viability**
Resiliency	• Healthy populations (stable to increasing abundance) occupying habitats that support key resource functions (e.g., breeding, feeding, sheltering) • Potential for periodic dispersal or migration events across population units
Redundancy	• Sufficient distribution of individuals and populations to recover from catastrophic events • Maintain healthy populations in multiple river basins and across the full range of habitats currently supporting the species
Representation	• Maintain healthy populations across the full range of climatic characteristics currently supporting the species • Maintain population abundance and intrapopulation connectivity at sufficient levels to ensure healthy genetics and maintain potential adaptive capacity in the extant population

3 Species Range, Distribution, and Population Analysis Units

Historical Range and Distribution

Most accounts of Rio Grande cooter focus on the current range of the species, and the field guides that are a basic source of information typically only document part of its total range (Ernst and Barbour 1972, pp. 155–60; Degenhardt et al. 1996, pp. 102–4; Conant and Collins 1998, p. 179; Bartlett and Bartlett 1999, pp. 291–92; 2013, pp. 63–64; Ernst and Lovich 2009, p. 378; Dixon 2013, p. 151; Legler and Vogt 2013a, p. 243; Hibbitts and Hibbitts 2016, p. 134). A distribution map including the United States and Mexico was published in 2017 by the Turtle Taxonomy Working Group et al. (2017, p. 60), and a virtually identical map was also presented in Pierce et al. (2016, p. 100.5) as the historical distribution of the species. That map covers a greater geographical extent than those in the publications identifying Rio Grande cooter as a new subspecies of *Pseudemys concinna* (Ward 1984, pp. 29–33) or elevating it to the species level (Ernst 1990, p. 461.1).

Because there is not a single authoritative range map for Rio Grande cooter that identifies the date and location of its source observations, we developed one to use in this assessment. We compiled over 650 occurrence records using the scientific literature, reports, books, and locality databases (including state heritage datasets, aggregators of museum collection data, and iNaturalist). Due to the past taxonomic uncertainty discussed in Chapter 2, some older records and accounts misidentify the species at some localities (Ernst 1990, p. 461.1; Degenhardt et al. 1996; Pierce et al. 2016, p. 100.1). These localities have been corrected by authors who physically re-examined museum specimens and/or used inferences made from contemporary species distribution information (Ernst 1990, p. 461.1; Degenhardt et al. 1996; Pierce et al. 2016, p. 100.1). We occasionally employed the latter tactic on publicly available datasets such as GBIF (GBIF.org 2020). In addition, some of the older records have been identified as questionable or unconfirmed (Strecker 1915, p. 12; Conant 1977, p. 461; Degenhardt et al. 1996, p. 104; Pierce et al. 2016, p. 100.5). We note this as appropriate in the section on population analysis units below. Some of the available datasets did not include geographic coordinates for all records. We resolved missing coordinates for as many records as possible by reviewing other data fields with locality information and consulting additional literature. For iNaturalist localities obscured due to Rio Grande cooter's International Union for Conservation of Nature (IUCN) status, we contacted individual users and requested true coordinates or verified the approximate location or waterways where Rio Grande cooter was observed.

We explored the historical distribution using only occurrence records from before 1990. However, most of the available records are from the current time period (defined as 1990 to the present), so the historical data points (1850s–1989) are sporadic throughout the range (Figure 3.1). Although the historical localities are sporadic, we do not believe that Rio Grande cooter's historical presence was extremely disjunct. Given that the watershed was historically fully connected, we presume that Rio Grande cooter could access most of the waters within the connected portion, even if resource use and turtle densities varied considerably within the aquatic range. Consequently, we assume that the historical localities are representative of the range of springs, streams, and rivers historically occupied by Rio Grande cooter, and that the range was continuous between those springs, streams, and rivers. We generally assume that recent observations are an indicator of historical presence. Possible exceptions include Rio Grande cooter observations in Berrendo Creek (Chaves County, NM) and Big Bend National Park, which may represent recent colonization.

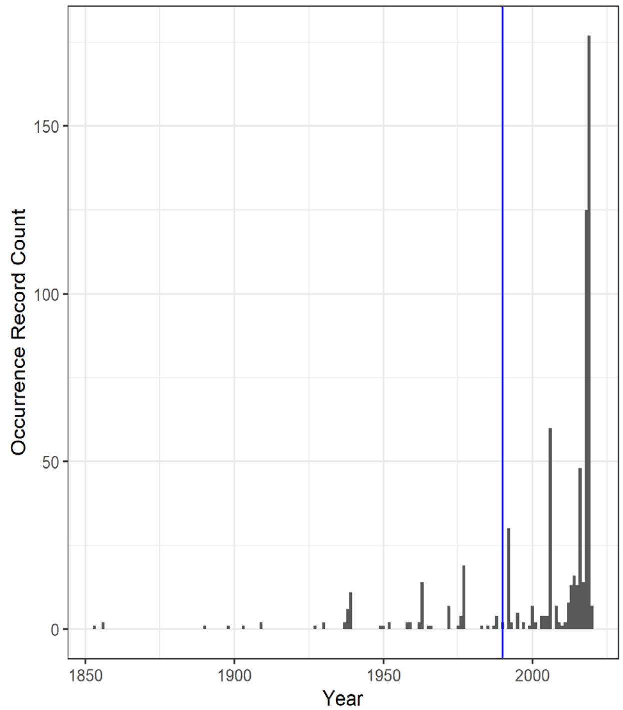


Figure 3.1. Histogram of Rio Grande cooter occurrence records over time. A vertical blue line is placed at 1990, the dividing point between "historical" and "recent" observations.

The historical distribution map shown in Figure 3.2 was developed using GIS in order to standardize the inclusion of geographies across the Rio Grande cooter range. We used level 12 watersheds[2] as the basic unit for constructing the historical range following the Turtle Taxonomy Working Group et al. (2017, pp. 16–18). We began with a simple and standardized starting point for the analysis: include all level-12 watersheds nested within a level-8 watershed that contain an observation of Rio Grande cooter. We next refined the distribution map using biological and ecological information from the literature and an evaluation of each stream within each watershed. This information includes the ranges of other aquatic turtles in the region, geologic history, recent Rio Grande cooter occurrence records, and hydrological datasets.

We used hydrological data in conjunction with historical localities to excise stream segments (and associated level 12 watersheds) determined to be too small to have supported Rio Grande cooter, even prior to European settlement. On the Pecos River, this historical upstream distribution limit is unclear due to a lack of surveys or occurrence data about this species. We use the Sumner Dam as the upstream limit for practical purposes, recognizing that all potential historical localities, as well as current localities, are well downstream of the dam, but that aquatic connectivity persists between known localities and the dam. On the Rio Grande, we consider the natural range of Rio Grande cooter to fade out around the

[2] In the United States, we used Hydrologic Unit Code-12 polygons from the U.S. Geological Survey's hierarchical set of drainage, or hydrological areas. In Mexico, we used level-12 HydroBASINS polygons from Lehner and Grill (2013) from a global set of sub-basins, which are also a type of hydrological area. These polygons are frequently referred to colloquially as "watersheds," even though they do not always meet the technical hydrological definition of watershed because they are a "truncated portion of a larger watershed" that does not "include all of the source area contributing water to a single defined outlet point." This is frequently true at the level-12 unit that we used.

confluence of Tornillo Creek with the Rio Grande in Big Bend National Park. The ranges of Rio Grande cooter and Big Bend slider (*Trachemys gaigeae*) appear to intergrade in the portion of the Rio Grande cooter range from Big Bend to Amistad Reservoir (Legler and Vogt 2013b, pp. 549–50, 642–43; Turtle Taxonomy Working Group et al. 2017, pp. 60, 65). The fact that Rio Grande cooter do not inhabit the Rio Grande further upriver may be related to the geological evolution of the Rio Grande, which eroded upstream through the Big Bend region to connect two previously separate rivers: the upper Rio Grande in New Mexico and the lower Rio Grande in Texas (Legler and Vogt 2013b, p. 644). It could also be related to competition between these two turtle species. This would further support a historical range where Rio Grande cooter are found in the Pecos River and the Rio Grande below Big Bend, but not in the Rio Grande above Big Bend or extending into New Mexico, or in the Río Conchos (areas that are part of the Big Bend slider range). We excluded the Cuatro Ciénegas basin from the historical range. Rio Grande cooter and Cuatro Ciénegas slider (*Trachemys scripta taylori*) appear to be allopatric; the latter occurring only within the Cuatro Ciénegas basin in Coahuila (Legler and Vogt 2013b, p. 580). The Cuatro Ciénegas basin was separated hydrologically from the rest of the Río Salado basin for millions of years by the Puerto Sacramento, a natural feature separating the basin from downstream watersheds, and the historical Rio Grande cooter range (McCoy 1984, p. 49; Legler and Vogt 2013b, p. 632).

We consider the historical distribution a conservative (inclusive) one, which could be further narrowed if additional scientific data on the historical conditions of outlying streams becomes available. That is, the full shaded area in the historical distribution map (Figure 3.2) covers a larger spatial extent than the true historical distribution of habitat used and occupied. Our distribution map includes the areas where Rio Grande cooter spend most of their time (aquatic habitat), areas for nesting (terrestrial riparian habitat), and the areas that directly influence aquatic habitat (uplands within watersheds). This map does not depict intensity of use of any area, or relative densities or abundance within any given watercourse.

Our confidence in the accuracy of the historical distribution is highest for currently and recently perennial streams and rivers. We summarize the Rio Grande cooter's historical range as comprised of the following water bodies and their tributaries, with occasional occupancy or use of nearby lentic bodies such as springs and ponds (Pierce et al. 2016, pp. 100.4–100.5):

- The Rio Grande mainstem from the Lower Canyons of the Rio Grande to the mouth in the Rio Grande Valley (including its many tributaries such as the Río San Diego and Río San Rodrigo in Coahuila, and Las Moras Creek and San Felipe Creek in Texas)
- The Pecos River drainage in New Mexico and Texas (including tributaries such as Berrendo Creek, the Black River, and the Delaware River in New Mexico, and Independence Creek in Texas) from Chaves County, NM to the mainstem Rio Grande
- The Calamity Creek drainage in Texas
- The Devils River in Texas for its entire length to its confluence with the mainstem Rio Grande (including tributaries such as Evans Creek)
- The Río Salado in Coahuila, Nuevo León, and Tamaulipas to its confluence with the mainstem Rio Grande (including tributaries and branches such as the Río Sabinas in Coahuila, the Río Salado de los Nadadores, and the Río Sabinas Hidalgo in Nuevo León)
- The Río San Juan (including tributaries such as the Río Salinas) in Nuevo León and Tamaulipas to its confluence with the mainstem Rio Grande

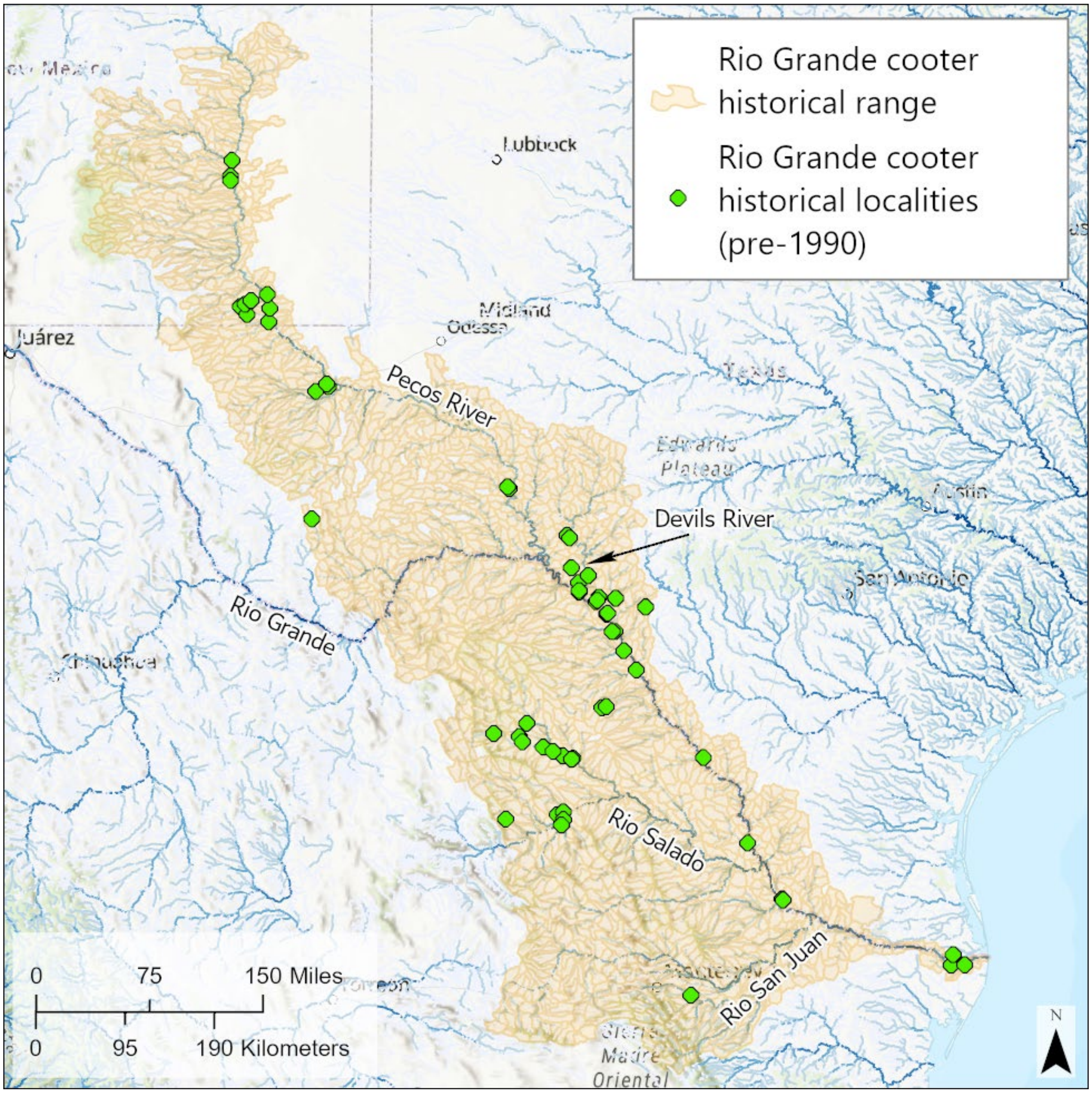


Figure 3.2. Potential historical distribution of Rio Grande cooter, delineated in light orange. Green diamonds represent historical localities. The actual extent occupied and used by Rio Grande cooter is limited to the water bodies and adjacent riparian areas within the shaded region.

Current Range and Distribution

Efforts to survey for Rio Grande cooter have increased significantly in the past several years, and as a result we understand the broad scope of its distribution, particularly within the United States (e.g., Painter 1993, pp. 5–6; 2013, pp. 6, 32–34; Christman and Kamees 2007, entire; Bailey et al. 2008, pp. 408–10; Bonner and Littrell 2016, entire; Sirsi et al. 2018, p. entire; Mali and Suriyamongkol 2019, entire; Davis et al. 2020, pp. 16–75). In Mexico, there are fewer recent data and observations come almost exclusively from research-grade observations shared on the iNaturalist citizen science database (GBIF.org 2020), so our understanding of the current extent of Rio Grande cooter in Mexico is less robust. In general, we presume that Rio Grande cooter are found in perennial rivers and streams and any associated spring pools, and occasionally found in intermittent streams that contain pools of adequate depth and size. We generally assume they occupy or use (that is, are able to survive in, and are not extirpated from) the rivers and streams between two localities when no barriers to movement are present. We believe their distribution within any given reach of river or stream is likely uneven, with greater abundances near springs and spring-fed tributaries (Degenhardt et al. 1996, p. 103; Legler and Vogt 2013a, p. 244; Hibbitts and Hibbitts 2016, p. 137; Bogolin 2020, pp. 121–32). Further details on this and any exceptions are detailed in the population analysis units section of this chapter. As with our historical range map, we recognize that our conservative inclusion of tributary streams and headwater systems in our current range map (Figure 3.3) includes some streams unlikely to currently support Rio Grande cooter. Additional information about the actual on-the-ground characteristics of these streams or the development of a species distribution model would allow the current distribution map to be revised.

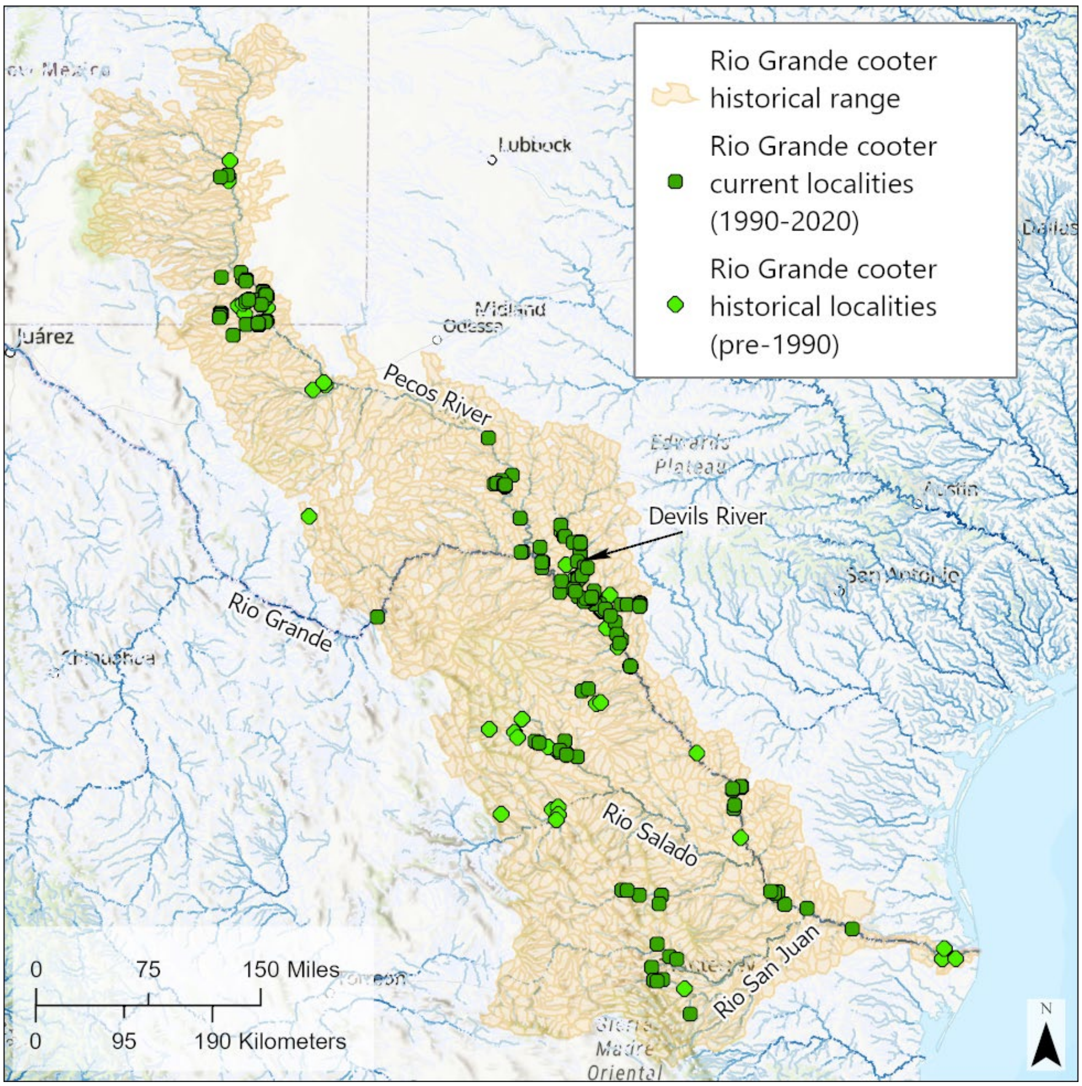


Figure 3.3. Historical and current range of Rio Grande cooter within the Rio Grande watershed. Light orange areas delineate the full extent of the potential historical distribution. Light green diamonds represent historical localities. Dark green squares represent recent localities. The actual extent occupied and used by Rio Grande cooter is limited to the water bodies and adjacent riparian areas within the shaded region.

In New Mexico, the presence of Rio Grande cooter is well established in Eddy County springs, streams, and rivers, and the Black River population is the focus of intensive research (Painter 1993, entire; 2013, pp. 32–34; Christman and Kamees 2007, entire; Legler and Vogt 2013a, pp. 242–45; Bonner and Littrell 2016, entire; Mali and Forstner 2017, entire; Mali, Letter, et al. 2018, entire; Mali and Suriyamongkol 2019, pp. 11–16; Suriyamongkol and Mali 2019a, entire; 2019b, entire; Cirrincione 2020, personal communication). Our confidence in the continued occupancy of the Pecos River watershed below Brantley Dam and above Red Bluff Dam is high. Rio Grande cooter were trapped in Berrendo Creek, a tributary to the Rio Hondo, itself a tributary to the Pecos River, in 2018 and 2019, but their presence elsewhere in the Pecos River watershed above Brantley Dam has not been established (Mali and Suriyamongkol 2019, pp. 11, 16).

In Texas, systematic surveys of the full range of Rio Grande cooter in State waters has been frequently precluded by a lack of public access (Bogolin 2020, pp. 13–14; Davis et al. 2020, p. 16). However, the long-term presence of Rio Grande cooter is well established at Independence Creek, its associated springs, and the area around its confluence with the Pecos River (Davis et al. 2020, pp. 20, 35, 37; GBIF.org 2020). Rio Grande cooter can be found in the Pecos River downriver of Independence Creek to the confluence with Amistad Reservoir and the Rio Grande (Prestridge 2019; Davis et al. 2020, pp. 8, 35, 37; GBIF.org 2020). Observations of Rio Grande cooter in the Rio Grande above its confluence with the Pecos River are limited to an artificial impoundment in Big Bend National Park and the vicinity of Langtry, TX, (Bailey et al. 2005, pp. 465–66; Forstner et al. 2014, p. 344; Davis et al. 2020, pp. 8, 35, 37, 67, 61; Forstner 2020, personal communication; GBIF.org 2020). Rio Grande cooter occurrences have been recorded throughout the perennial extent of the Devils River to its confluence with Amistad Reservoir (Bailey et al. 2008, p. 409; Sirsi et al. 2018, entire; Bohannon 2019a, pp. 7–8; Prestridge 2019; Davis et al. 2020, pp. 8, 15, 37, 71; Howard 2020a; GBIF.org 2020). They have been found in Amistad and Falcon Reservoirs, usually but not exclusively near stream inflows; they are not believed to prefer the open lentic waters of either reservoir (Legler and Vogt 2013a, pp. 244–46; Zhuang 2019; Bogolin 2020, pp. 121–32; Davis et al. 2020, p. 8; Howard 2020a; GBIF.org 2020). We additionally have high confidence that Rio Grande cooter are present in the Rio Grande and many of its tributaries from the Amistad Dam to Falcon Reservoir (Conant 1977, p. 472; Bailey and Forstner 2004, p. 407; Lemos-Espinal and Smith 2007, p. 536; Legler and Vogt 2013a, p. 244; Orrell 2016; Hernandez et al. 2018, p. 502; Bogolin, Davis, Ruppert, et al. 2019, p. 745; R. Brown 2019; Cannatella and LaDuc 2019; Gottfried 2019; Grant and Resetar 2019; Laurencio 2019; Prestridge 2019; Rickart and Derieg 2019; Spencer 2019; Zhuang 2019; Davis et al. 2020, pp. 8, 35–38, 71–72; Gluesenkamp 2020, personal communication; GBIF.org 2020). Support for continued Rio Grande cooter occurrence below Falcon Dam was poor prior to 2014, but since then they have been repeatedly observed in the Rio Grande from Falcon Dam to at least Rio Grande City, TX (Legler and Vogt 2013a, p. 244; Brush et al. 2017, p. 124; Davis et al. 2020, pp. 8, 21, 34–38; Franklin and Ricardez 2020; GBIF.org 2020; Farr 2021, personal communication).

In Mexico, we have lower confidence in the estimated range of Rio Grande cooter, especially where observations are lacking, because we know less about the specifics of the habitat conditions, and there are fewer observations to draw on. In addition, it is difficult to predict the prevalence or existence of Rio Grande cooter in regions of Mexico further from cities because the potential presence of drug cartels in remote areas restricts travel, and because iNaturalist observations are skewed toward more populated areas (González 2020, personal communication; Strenth 2020, personal communication; Berg 2020, personal communication). Some minor tributaries to the Rio Grande in Mexico have recent observations, while others may still be occupied but lack conclusive evidence (Hernandez et al. 2018, p. 502; Gluesenkamp 2020, personal communication; GBIF.org 2020). Rio Grande cooter appear to be extant in both of the major drainage basins to the Rio Grande in northeastern Mexico: the Río Salado and the Río San Juan (GBIF.org 2020). The distribution of observations in these rivers is highly uneven, and Rio Grande cooter may be absent from broad swaths of both watersheds. In the Río Salado watershed, Rio Grande cooter are still extant in the upper Río Sabinas, above the Don Martin Dam, as well as the Río Sabinas de Hidalgo upriver from the town of Sabinas Hidalgo (GBIF.org 2020). In the Río San Juan watershed, there are recent observations of Rio Grande cooter in springs and tributaries of the Río San Juan, including in the Río Salinas and tributaries on the outskirts of Monterrey (GBIF.org 2020).

Comparison of Historical and Current Range

Areas of potential range contraction

Any Calamity Creek area populations in Texas to the north of Big Bend National Park were probably extirpated decades ago, possibly during the drought of 1949–1957, which extirpated other uncommon aquatic species, or possibly due to ongoing water development in the region that resulted in the drying of springs and reduction of streamflow (Strecker 1909, p. 15; Scudday 1977, pp. 515–20). Similarly, development of water in the Pecos River basin coupled with impacts from energy development (e.g., oil spills) has resulted in "essentially a dead stream from the New Mexico state line to about Sheffield" (Scudday 1977, p. 518), from which there are no documented Rio Grande Cooter occurrences. Accounts of Rio Grande cooter consistently identify a distributional gap from Red Bluff Dam to the confluence of Independence Creek and the Pecos River, and associate it with consistently poor water quality and low flows in this affected reach (Ward 1984, p. 461.1; Ernst 1990, p. 461.1; Ernst et al. 1994, pp. 331–32; Conant and Collins 1998, pp. 179–80; Bartlett and Bartlett 1999, p. 291; Ernst and Lovich 2009, pp. 377–78; Hibbitts and Hibbitts 2016, p. 137). Although there are no barriers to Rio Grande cooter movement into this reach from downstream, there is no indication that the reach has been repopulated by a self-sustaining, consistently present population of Rio Grande cooter. An additional area of potential contraction is the lower Rio Grande Valley. Recent surveys for Rio Grande cooter extending as far downriver as Brownsville, TX yielded visual observations only as far as Rio Grande City, TX (Davis et al. 2020, p. 21).

In Mexico, it is more difficult to say definitively that Rio Grande cooter are absent from a given area because all current localities are from incidental observations rather than intentional surveys. However, there are a few areas where extirpation or extremely low abundance is likely based on a lack of observations and loss of habitat. For example, we were unable to identify any records from the Río Salado below the Don Martin Dam to its confluence with the Rio Grande, or from the Río San Juan between the El Cuchillo and Marte R. Gomez Dams. In these river segments, water flow is thought to be compromised to nonexistent, and water quality is poor (Contreras-Balderas and Lozano-Vilano 1994, pp. 381–83; Sanchez 1997, p. 429; Návar Cháidez 2011, pp. 131–33; Trujillo 2020, personal communication; Hendrickson 2020, personal communication; Strenth 2020, personal communication; Berg 2020, personal communication). In contrast, descriptions of the Río Salado (de los Nadadores) above the Don Martin dam are similar to other relatively healthy river reaches in Mexico where Rio Grande cooter are present (Trujillo 2020, personal communication; Strenth 2020, personal communication; Berg 2020, personal communication). However, records from this reach probably date from the 1980s, if not earlier (Lemos-Espinal and Smith 2007, p. 536; Lemos-Espinal 2020, personal communication) and there is no evidence of current Rio Grande cooter presence.

Areas of potential range expansion

In the United States, Rio Grande cooter have recently been found in an impoundment next to Rio Grande Village campground in Big Bend National Park in Texas, and near a recreational site along Berrendo Creek outside of Roswell, NM (Bailey et al. 2005, pp. 465–66; Suriyamongkol et al. 2020, pp. 536–37). It is not clear whether these occurrences represent a chance short-term colonization event, a range expansion event, or simply a belated previously undocumented discovery of some members of a self-sustaining population. The presence of Rio Grande cooter in Big Bend National Park was considered a surprise when five were trapped during the summer of 2005, as the researchers conducting the trapping had been working in the area for many years without seeing this species (Dixon 2013, p. 151). One potential explanation is that the turtles were able to move upriver from the Lower Canyons of the Rio Grande due to the very low flows in the Rio Grande at that time, as the next closest contemporary observation of the species is in Rio Grande above Langtry (Forstner et al. 2014, p. 344; Forstner 2020, personal communication). It is unknown if these turtles are successfully reproducing.

Similarly, Rio Grande cooter presence in Berrendo Creek in Chaves County, NM, was unknown to researchers prior to 2018, when a member of the public sent a photo of an incidental turtle catch to Dr. Ivana Mali at Eastern New Mexico University (Mali and Suriyamongkol 2019, p. 16). Subsequent trapping efforts in this area confirmed that at least 7 adult Rio Grande cooter inhabit the area (Mali and Suriyamongkol 2019, p. 12; Suriyamongkol et al. 2020, pp. 536–37). It is unknown whether reproduction is occurring in this group. Trapping efforts on the nearby Bitter Lake National Wildlife Refuge inspired by the discovery of a dead Rio Grande cooter on the refuge failed to yield any additional captures (Mali and Suriyamongkol 2019, pp. 11–16; Suriyamongkol et al. 2020, pp. 536–37). It is possible but not established that Rio Grande cooter in Berrendo Creek are indicative of broader occupancy by this species in the area. No sampling has been done that could confirm its absence. However, other ESA-listed species in this portion of the Pecos River have been well documented and we would expect that if there were significant numbers of Rio Grande cooter present in that they would have been discovered. Consequently, it remains unclear whether the Berrendo Creek turtles represent a new population comprised of turtles that moved upriver from below Brantley Dam, or if they are the last remaining turtles from a population that once occupied a larger proportion of the Pecos watershed between Sumner and Brantley Dams.

Population Analysis Units

In the context of our status assessment, species viability is the ability of Rio Grande cooter to sustain populations in the wild, over time, and under plausible future scenarios. Therefore, it is important to identify and describe the historical and current populations of Rio Grande cooter. Prior to European settlement and associated water development efforts, barriers to Rio Grande cooter movement that would serve as clear population delineation boundaries were not present (Bailey et al. 2008, pp. 409–10; Pierce et al. 2016, pp. 100.4–100.8). In addition, Rio Grande cooter are capable of traveling very long distances, and no spatially separate populations were identified via genetic analysis (Bailey et al. 2008, pp. 409–10; MacLaren, Sirsi, et al. 2017, p. 180; Sirsi et al. 2018, pp. 9–15). Therefore, it is possible that Rio Grande cooter functioned as a single population historically. Since European settlement in the species' range began, anthropogenic barriers, primarily dams and their associated reservoirs, have been installed (González Escorcia 2016, pp. 63–64; Pierce et al. 2016, p. 100.8). These dams may not present a complete barrier to travel, but it is assumed that Rio Grande cooter movement is inhibited. There are also gaps in the distribution that may be true absences (Ward 1984, pp. 29–33; Bailey et al. 2008, p. 409;

Pierce et al. 2016, p. 100.5). In combination, this implies that anthropogenic and hydrogeologic landscape alterations to the Rio Grande watershed have separated once contiguous populations. Given the lack of genetic data and detailed demographic study across the range, we could not define true biological populations. Thus, we frame our analysis on a set of population analysis units based on watersheds, and used dams and associated reservoirs as boundaries for these units (Figure 3.4). While Rio Grande cooter may be able to negotiate around the dams and through the reservoirs, they are more likely to interbreed with other Rio Grande cooters within the same population analysis unit, and therefore may take on some of the attributes of a biological population. In addition, each population analysis unit tends to be managed similarly and face similar anthropogenic stressors, so this framework is useful for assessing resiliency in the face of such stressors.

Regarding the geospatial development of these units, we used the ESRI Living Atlas National Inventory of Dams layer to identify dam locations (U.S. Army Corps of Engineers 2021) and level 12 watersheds, as discussed above. In some cases, the level 12 watershed do not line up exactly with the dam location. When this occurs, we select the level 12 watershed boundary closest to the dam that still includes the reservoir created by that dam. An example of this is the *Pecos River – Sumner Dam to Brantley Dam* population analysis unit, which includes a small amount of area below the Brantley Dam. We reviewed all point data as needed to ensure information was assigned to the most appropriate population analysis unit.

The remainder of this chapter includes a brief description of each of the 16 population analysis units. For each, we provide the upstream and downstream boundary location on the primary river (namesake for the unit), important dams, known information about the historical and current flow regimes, notes on geology where relevant, a very brief description of general water quality, the treaties or compacts governing surface water where applicable, and an overview of historical and current observations. Details on Rio Grande cooter surveys, occurrences and localities, and water quantity and water quality are discussed in the relevant sections in Chapters 4 and 5. We also frame some of our analysis in the context of five major river basins throughout the Rio Grande cooter range: the Pecos River, Rio Grande, Devils River, Río Salado, and Río San Juan basins. In Chapter 4, the geographic scope of factors influencing the viability of Rio Grande cooter is discussed in the context of each basin. In Chapters 5 and 6, the basins are used in our redundancy analyses to assess the distribution of conditions in population analysis units across the range.

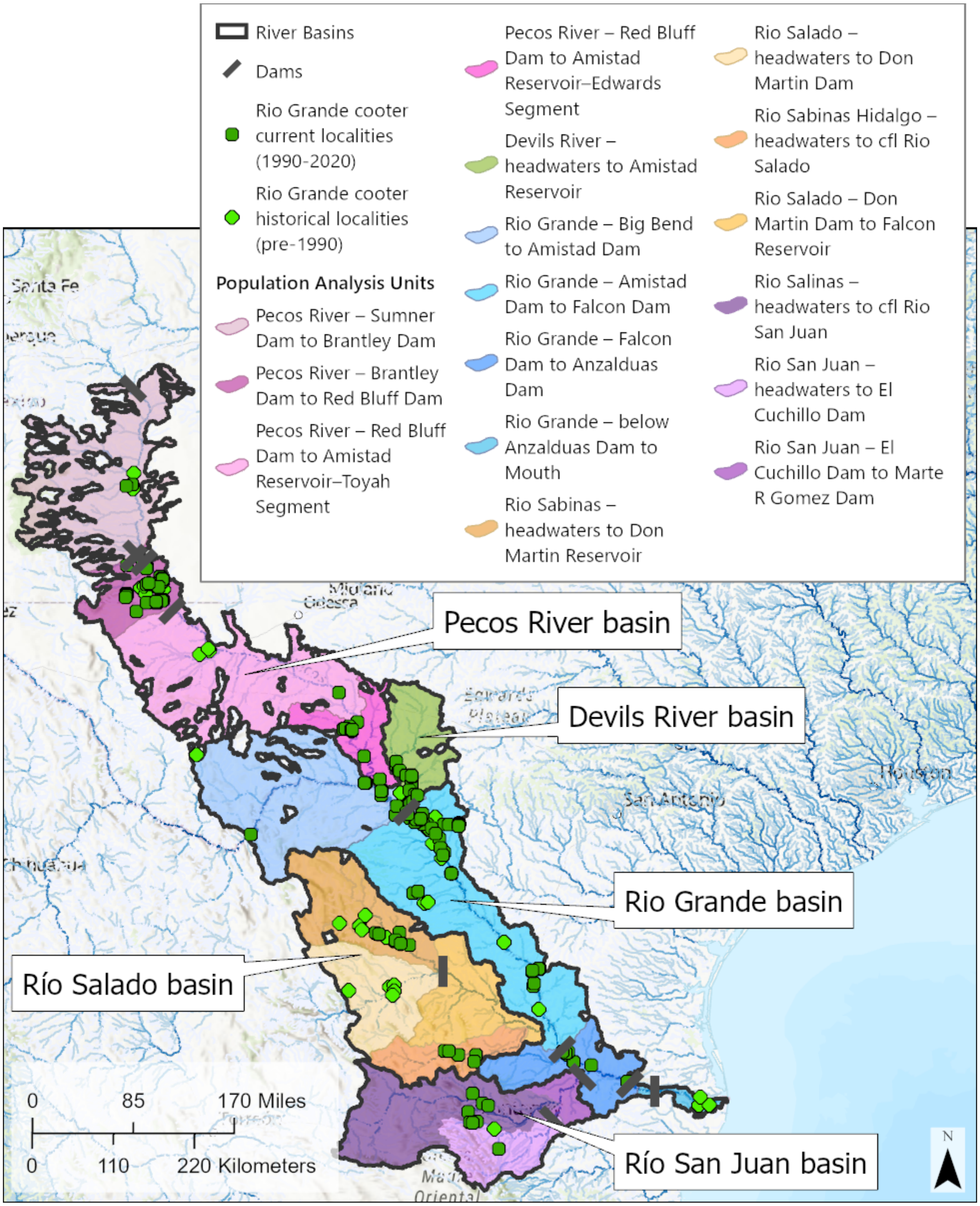


Figure 3.4. Population analysis units for Rio Grande cooter. River basins have thick black boundaries. Units within each river basin share a color family (pink, green, blue, orange, or purple). Dams are indicated with black bars. Light green diamonds represent historical observations (i.e., individuals detected during surveys prior to 1990). Dark green squares represent recent observations (i.e., detected during surveys from 1990 to 2020). The actual extent of areas occupied and used by Rio Grande cooter is limited to the water bodies and adjacent riparian areas within the shaded region. See legend for color matching individual population analysis units to the map.

Pecos River – Sumner Dam to Brantley Dam

This unit is comprised of the Pecos River, and its tributaries, from the Sumner Dam to the Brantley Dam, inclusive of the Brantley and McMillan Reservoirs (Figure 3.5). It is located entirely within New Mexico. There are no other dams in this section (Hoagstrom et al. 2008, p. 6). Historically, this segment of the Pecos River had much higher flows and erosive banks with a potentially shifting channel, and it received sediment inputs from tributaries during flash flood events associated with the summer monsoon (Follansbee and Jean 1915, pp. 475–88; U.S. Fish and Wildlife Service 2010, p. 5). It was a low gradient, fairly shallow river with meandering flows (Hatch et al. 1985, p. 556). The Pecos River today is more homogenous than it was before dams and diversions in terms of water depth, substrate, flow, and channel morphology (U.S. Fish and Wildlife Service 2010, pp. 11–12). Springflow and streamflow into the Pecos River has declined or ceased due to water extraction from the artesian and shallow aquifers in the basin (Havenor 1968, p. 3). A few chemical exceedances were recorded in this unit in 2003, but basic water quality parameters are in line with those in other parts of the range where Rio Grande cooter are present (New Mexico Environment Department 2006, pp. 14–15; Davenport 2019, pp. 41–43; Davis et al. 2020, pp. 80–84). The surface water in this unit is governed by the Pecos River Compact, an interstate compact between New Mexico and Texas which establishes a commission to apportion the waters of the Pecos River body (Upper Rio Grande Basin and Bay Expert Science Team (BBEST) 2012, pp. 2–37; Arm et al. 2014, p. 42). There are a few historical observations in the area near Roswell and the Bitter Lake National Wildlife Refuge (Bundy 1951, p. 314; Thomas 1963, pp. G-1–G-2; Conant 1977, p. 472). Degenhardt and Christiansen (1974, p. 36) were unable to confirm the Bundy record, but they state “it is certainly possible that these turtles are present that far north along the Pecos River.” In the current period (1990–2020), observations include one dead specimen found at Bitter Lake National Wildlife Refuge and seven unique turtles trapped on Berrendo Creek (Mali and Suriyamongkol 2019, pp. 11–16).

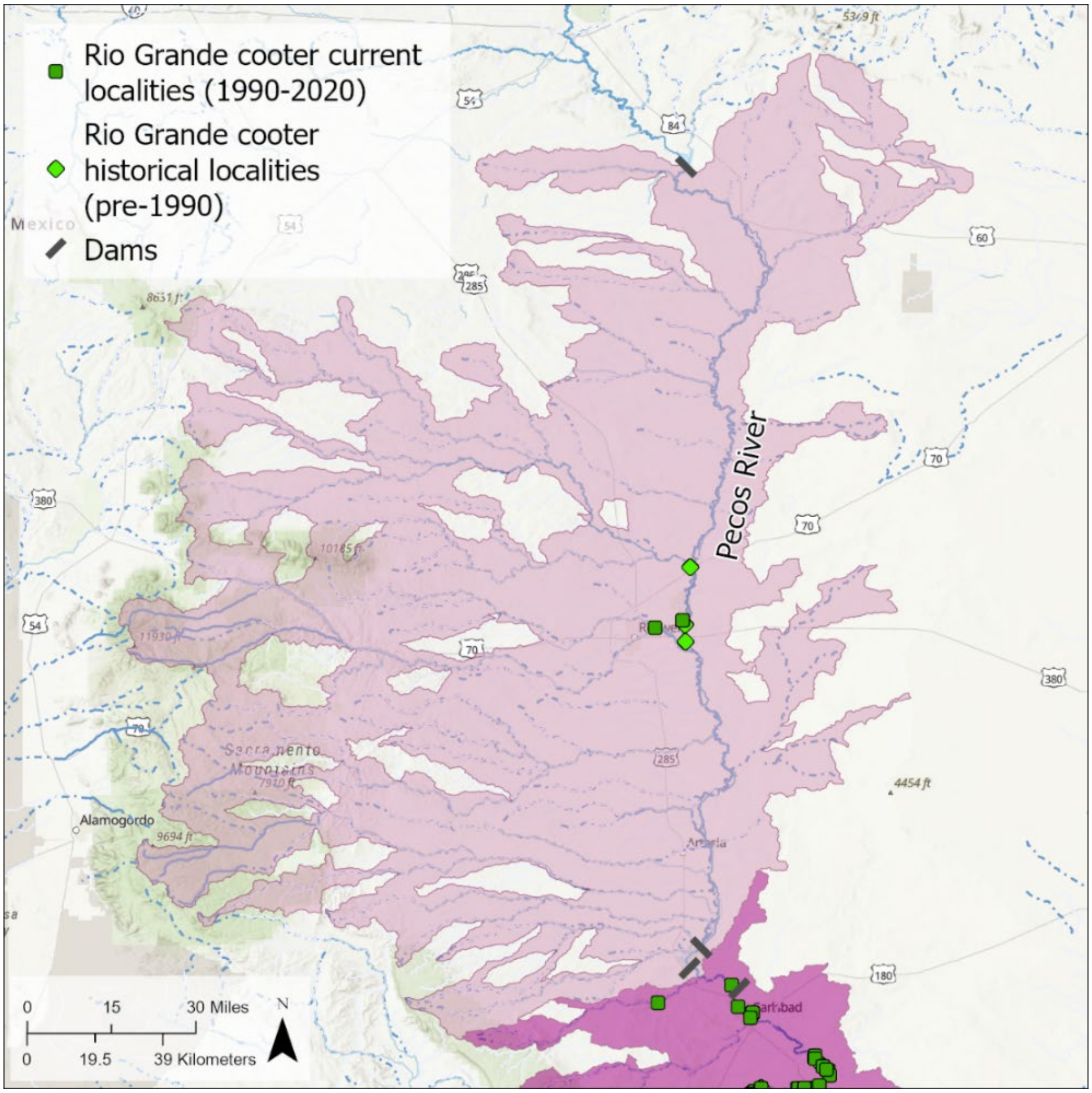


Figure 3.5. Pecos River – Sumner Dam to Brantley Dam population analysis unit.

Pecos River – Brantley Dam to Red Bluff Dam

This unit is comprised of the middle Pecos River basin between Brantley Dam and Red Bluff Dam, including tributaries such as Rocky Arroyo, the Black River, and the Delaware River (Figure 3.6). This unit is located in New Mexico and Texas. Historically, this section of the Pecos was influenced by springflow, had a riffle-and-pool morphology, and could be deep and fast-moving (Hatch et al. 1985, p. 556; Hoagstrom 2003, pp. 93–94). Dams and diversions have changed the character of the river so that it is more homogeneous and has lower, more regular flow than its historical condition (Follansbee and Jean 1915, pp. 507–10; Hoagstrom 2003, p. 94; Inoue et al. 2014, p. 1880). Freshwater springflow is a conduit between the shallow artesian aquifers and surface water, and is important for water quality (Bjorklund and Motts 1959, pp. 38–40; Havenor 1968, p. 3; Arm et al. 2014, pp. 19–28). Water quality in this unit is under pressure due to salinity, accidental spills of hazardous materials, and illegal dumping (Houston, Thomas, Jonathan V., Ging, et al. 2019, pp. 25–27; Hedden 2020c; 2020b; 2020a; Gregston 2021, personal communication). The surface water in this unit is governed by the Pecos River Compact (Upper Rio Grande BBEST 2012, pp. 2–37; Arm et al. 2014, p. 42).

Rio Grande cooter have been observed historically and in the present along the Pecos, Black, and Delaware Rivers, smaller creeks like Rocky Arroyo, and associated springs such as Rattlesnake Springs. They are most abundant in the Black River (Legler 1958, pp. 230–31; Conant 1977, pp. 471–72; Painter 1993, entire; Christman and Kamees 2007, entire; Zymonas 2009, p. 216; Legler and Vogt 2013a, p. 244; Pierce et al. 2016, p. 100.5; Bonner and Littrell 2016, entire; Letter and Mali 2017, entire; Mali, Letter, et al. 2018, pp. 8–17). A capture-mark-recapture effort on the Black River during the 2016 field season yielded estimated abundance at two sites. At Site 1, described as a 0.9 mi (1.5 km) long reach around 66 ft (20 m) wide, Mali et al. (2018, pp. 3, 7) estimated abundance as 67 adult turtles (95% credible interval [CI] = 49–110 turtles) and 18 juvenile turtles (95% CI = 15–25 turtles). At Site 2, described as a 0.9 mi (1.5 km) long reach varying from 6.6–164 ft (2–50 m) wide, Mali et al. (2018, pp. 3, 7) estimated abundance as 128 adult turtles (95% credible interval [CI] = 96–211 turtles) and 37 juvenile turtles (95% CI = 32–51 turtles).

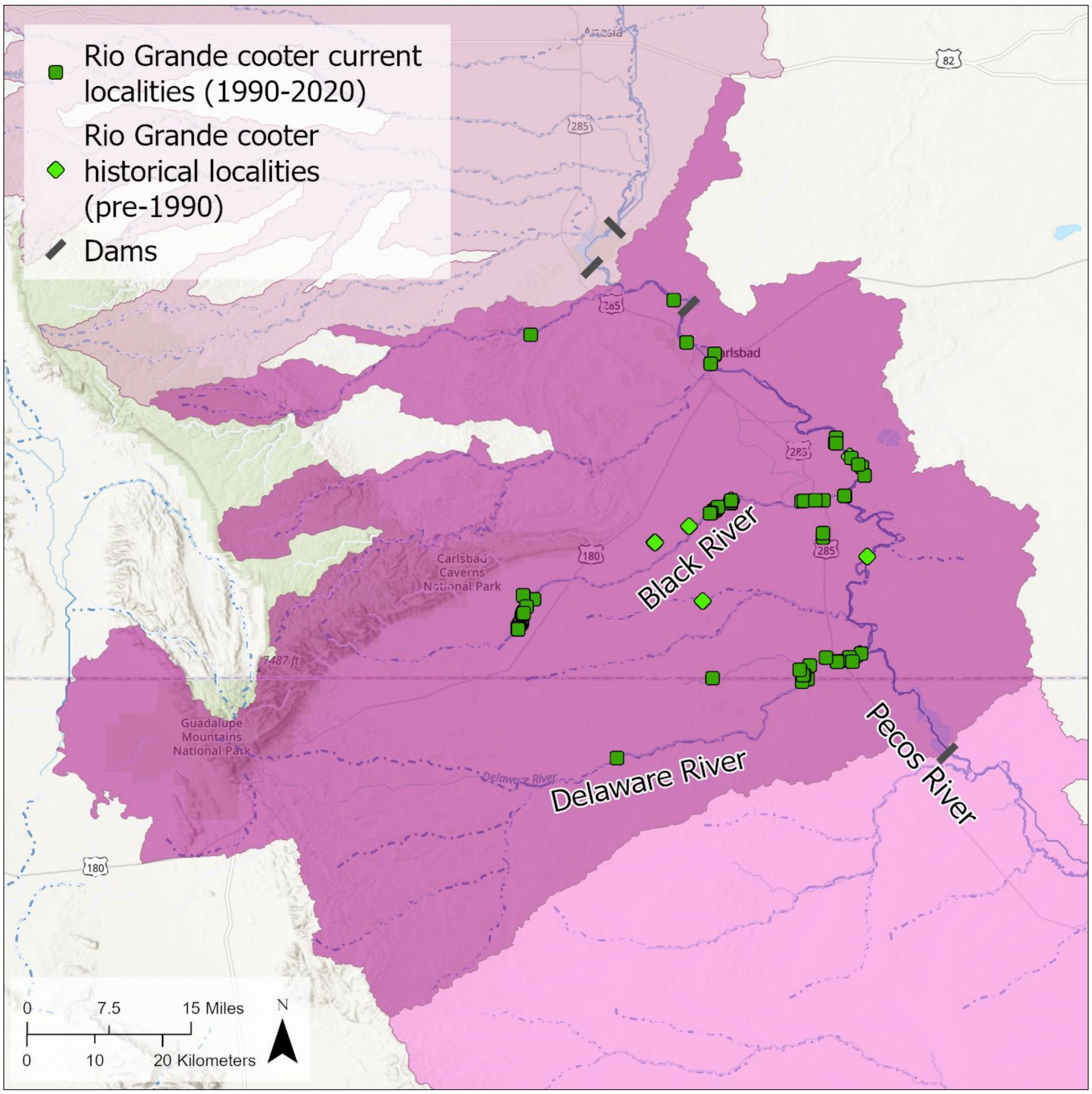


Figure 3.6. Pecos River – Brantley Dam to Red Bluff Dam population analysis unit.

Pecos River – Red Bluff Dam to Amistad Reservoir

Although there are no physical barriers between Red Bluff Dam and Amistad Reservoir along the Pecos River to prevent Rio Grande cooter from traveling between them, anthropogenic alterations have resulted in differences in flow, geomorphology, and water chemistry in the portion occurring from Red Bluff Dam to near the confluence with Independence Creek, compared to the portion occuring downriver from that confluence (Hoagstrom 2003, p. 94). Consequently, we divide what would otherwise be a single unit into two: the *Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment*, and the *Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment*. The surface water entering these units is governed by the Pecos River Compact (Upper Rio Grande BBEST 2012, pp. 2–37; Arm et al. 2014, p. 42). Both are located in Texas.

Historically, the character of the two reaches would have been more similar. Prior to water development, flows were strong and deep, springs were found along the Pecos River and its tributaries, and large floods were common, both in the springtime from snowmelt and in the summer from the monsoonal thunderstorms (Follansbee and Jean 1915, pp. 452, 516–29; Campbell 1958, pp. 3–4; Brune 1975, pp. 23, 57–62; 1981, pp. 139–42, 356, 423–24; Hoagstrom 2009, p. 30). Dams and diversions have reduced flows and made floods rare in these units (Hoagstrom 2009, pp. 31–32). Water quality is under pressure in these units because of high salinity and ongoing hazardous materials spills and leaks (Boyer 1986, pp. 302–11; Ashworth 1990, pp. 30–32; Houston, Thomas, Jonathan V., Ging, et al. 2019, pp. 28–29; Railroad Commission of Texas 2020).

Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment

This unit is comprised of the Pecos River and its tributaries from the Red Bluff Dam to a short distance above confluence of Independence Creek and the Pecos River (Hoagstrom 2003, p. 92; Crump 2020, p. 1) (Figure 3.7). The Toyah Segment is significantly altered today compared to before water development because its low flows are further exacerbated by the drying of tributary streams and springs, and by the diversion of water for agriculture (Grozier et al. 1966, pp. 1–8; Gregory and Hatler 2008, pp. 7–10). Impacts from river flow management, irrigated agriculture, and activities associated with oil and gas development, both use water and degrade water quality (Hoagstrom 2003, pp. 102–3; 2009, pp. 30–36; Upper Rio Grande BBEST 2012, pp. 1-8–1-11; Cheek and Taylor 2016, pp. 348–49). There is some evidence that Rio Grande cooter were present in this unit in the first half of the 20th century (A. E. Brown 1903, pp. 543–44; Conant 1977, p. 472). However, more recent species accounts suggest that Rio Grande cooter are rarely seen and unlikely to be regularly present in this unit, due to reduced streamflow and poor water quality (Ward 1984, p. 29; Hibbitts and Hibbitts 2016, pp. 134–37).

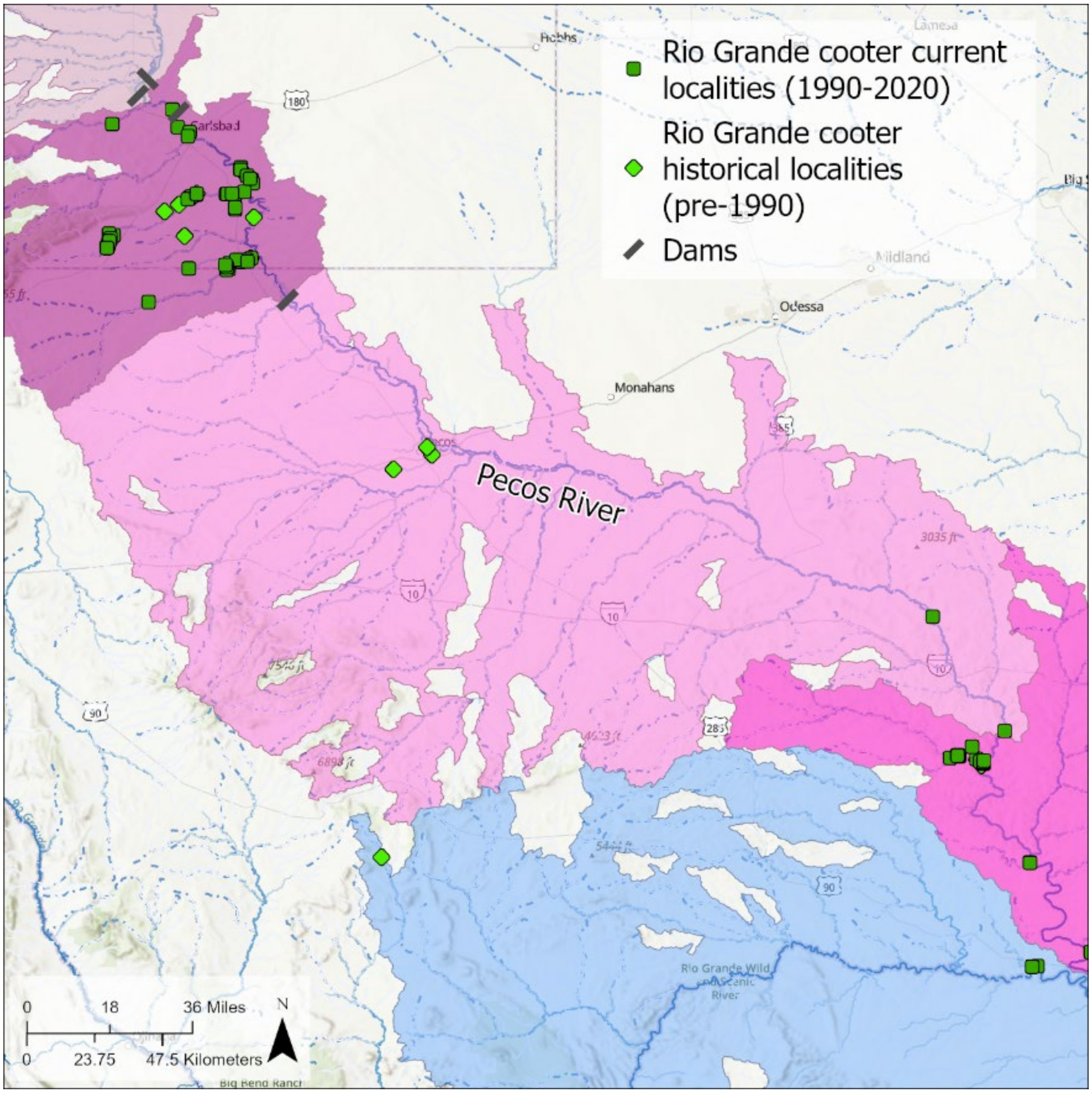


Figure 3.7. Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment population analysis unit,.

Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment

This unit is comprised of the Pecos River and its tributaries from to a short distance above the confluence of Independence Creek and the Pecos River to the confluence of the Pecos River and the Amistad Reservoir at Deadmans Canyon (Hoagstrom 2003, p. 92; Howard 2020b) (Figure 3.8). Compared to the *Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment*, this unit is less impacted by oil and gas development, irrigated agriculture, or urban development, and its flow is augmented significantly by a large number of springs emanating from the Edwards-Trinity Plateau aquifer (Brune 1981, pp. 422–25; Hoagstrom 2003, p. 103; 2009, p. 30). These springs increase both the streamflow and quality of Pecos River water in the unit (Hoagstrom 2003, pp. 102–3; 2009, pp. 33–36; Upper Rio Grande BBEST 2012, pp. 1-8–1-11; Cheek and Taylor 2016, pp. 348–49). In the Edwards Segment, Rio Grande cooter were historically, and continue to be, reliably encountered in and around Independence Creek and its confluence with the Pecos River (Milstead et al. 1950, pp. 551, 607; Conant 1977, p. 472; Bogolin, Davis, Ruppert, et al. 2019; Cannatella and LaDuc 2019; Prestridge 2019; Davis et al. 2020, pp. 8, 20, 35, 37, 71; GBIF.org 2020). They have also been observed in the Pecos River downstream of Independence Creek to the confluence with Amistad Reservoir (Prestridge 2019; Davis et al. 2020, pp. 8, 20, 35, 37, 71; GBIF.org 2020).

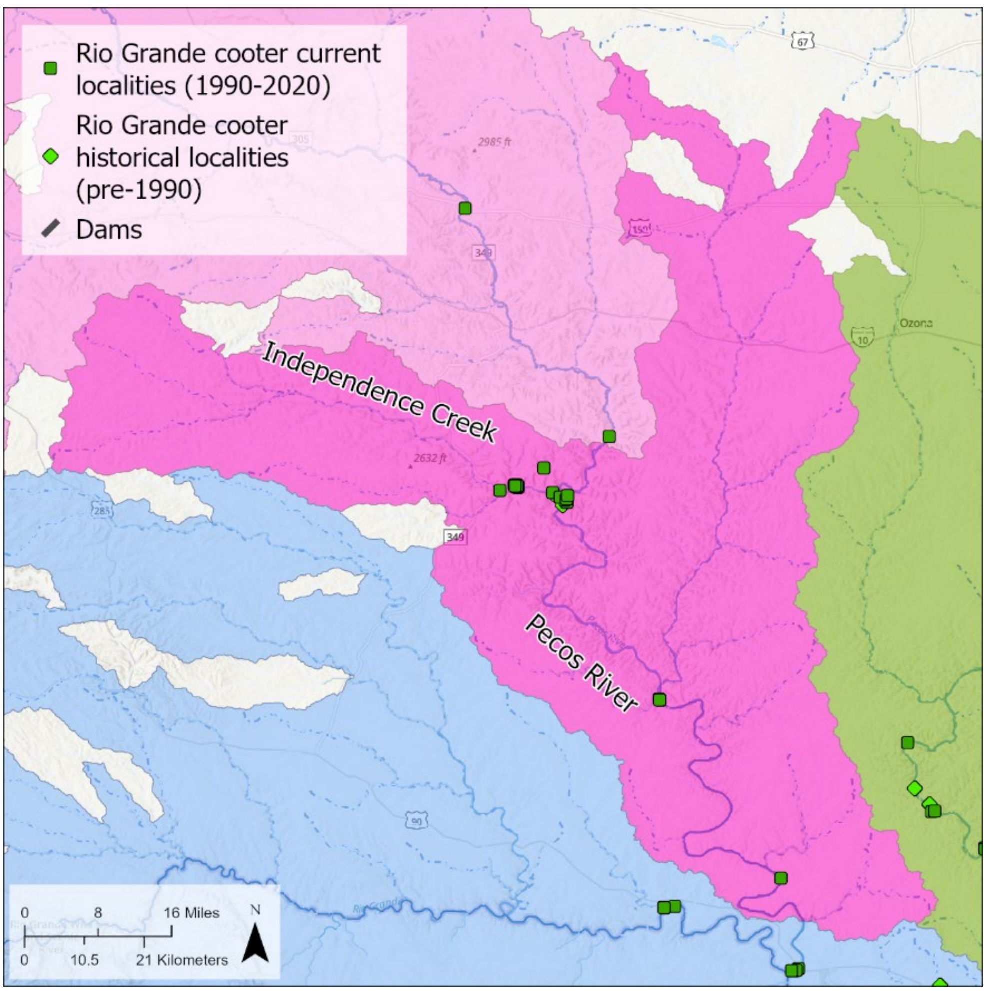


Figure 3.8. The Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment population analysis unit.

Devils River – headwaters to Amistad Reservoir

This unit is comprised of the free-flowing Devils River and its tributaries, from its headwaters to Indian Spring, where the river merges with Amistad Reservoir (Figure 3.9). It is located in Texas. The Devils River is known for being undammed and for having some of the best water quality in Texas (Upper Rio Grande BBEST 2012, pp. 1–11). It cuts through rocky canyons and has few tributaries, but contains many seeps and springs due to its location within the Edwards-Trinity Aquifer (Upper Rio Grande BBEST 2012, pp. 2-28–2-30). Much of the land along the Devils River is protected from development by easement or is managed by the state of Texas for conservation (Upper Rio Grande BBEST 2012, p. 2-29).

The headwater springs of the Devils River may have shifted downstream over time. Brune (1981, p. 450) describes Beaver Springs as supporting a "beautiful stream" in 1916, six km (3.7 mi) above Juno, Val Verde County, TX. Springflow declined to a trickle by 1939 and disappeared by 1971 (Brune 1981, p. 450). Juno Springs, near Juno, TX, followed the same pattern as Beaver Springs, though was found flowing in 1976, so the Devils River may have been intermittent or ephemeral here rather than dry (Brune 1981, p. 450). Pecan Springs, the current headwaters of the Devils River, are located 12 km (7.5 mi) downstream from Juno, representing a potential loss of about 18 km (11.2 km) of perennial river habitat (Brune 1981, pp. 450–51; Upper Rio Grande BBEST 2012, pp. 2–28). However, Weinberg et al. (Weinberg et al. 2018a, pp. 45–81) counters the primarily anecdotal evidence presented by Brune with anecdotal evidence that suggest that the Devils River between Pecan Springs and Juno was historically intermittent. If they are correct, then the perennial headwaters of the Devils River have been stable at Pecan Springs for over 100 years (Weinberg et al. 2018a, p. 45). At this time, the questions of whether and to what extent the Devils River between Beaver Springs and Pecan Springs shifted from perennial to intermittent, and if this was due to natural variability in precipitation and aquifer recharge, groundwater pumping, other factors, or some combination of these, are not resolved (Green 2018, entire).

Compared to the present, changes to the Devils River include the downstream shift of its headwaters, decreased springflows, and the inundation of its lower reach by Amistad Reservoir (Brune 1981, pp. 450–52; Upper Rio Grande BBEST 2012, pp. 1–11; González Escorcia 2016, pp. 80–81). Rio Grande cooter are abundant in the vicinity of Dolan Falls and Finnegan Springs, but can be found throughout the length of the river (Sirsi et al. 2018, pp. 9–15; Davis et al. 2020, pp. 18, 35, 48, 71). There are several historical observations, and many recent observations (Laurencio 2019; Prestridge 2019; Spencer 2019; Davis et al. 2020, p. 8; GBIF.org 2020). A capture-mark-recapture effort at Dolan Falls from May 2011 to September 2017 yielded a superpopulation estimate for the pool below the falls of 738 ± 59 turtles (Sirsi et al. 2018, pp. 9–10).

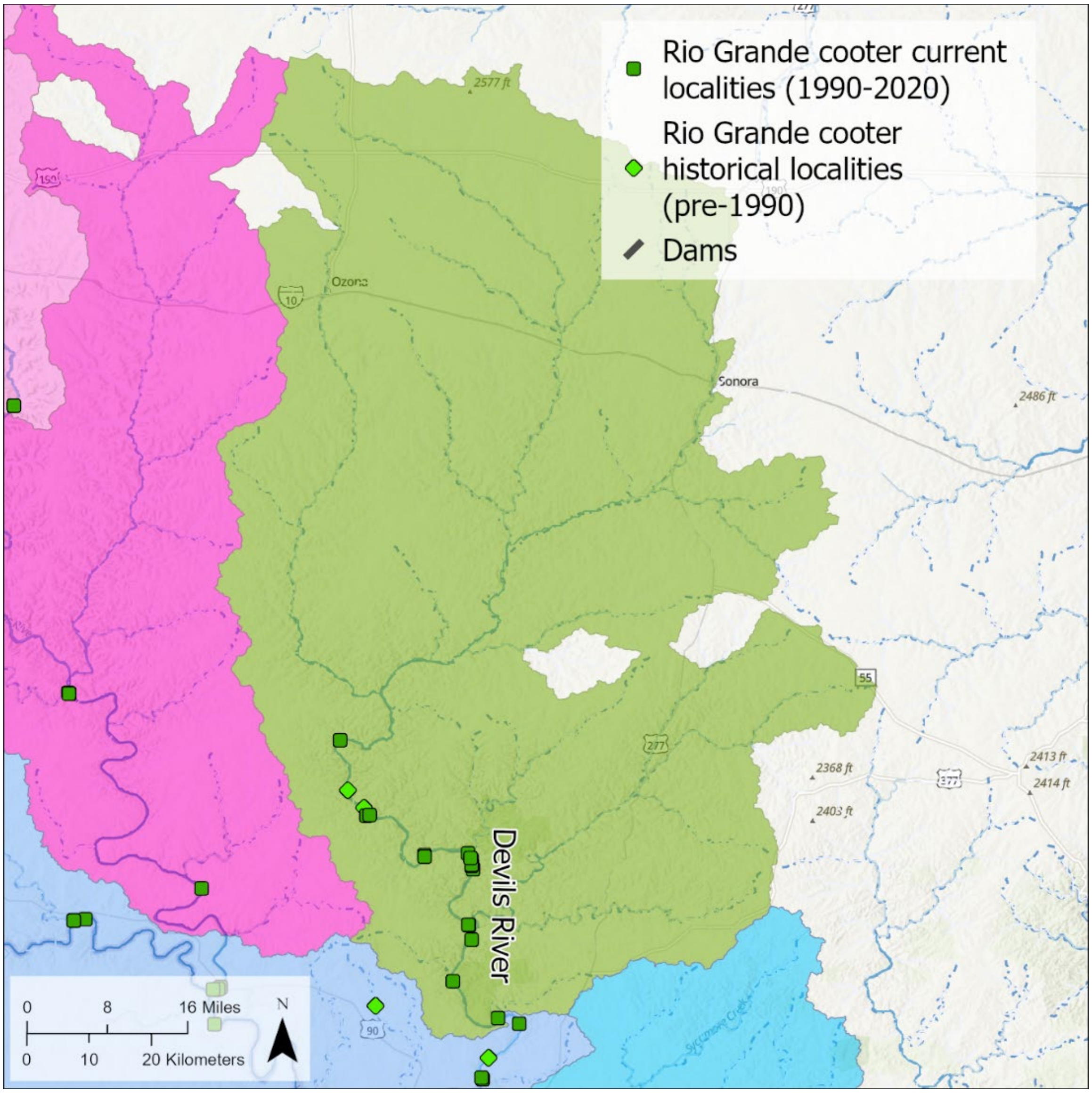


Figure 3.9 Devils River – headwaters to Amistad Reservoir population analysis unit

Rio Grande – Big Bend to Amistad Dam

This unit is comprised of the Rio Grande and its tributaries, from its confluence with Tornillo Creek to Amistad Dam, excluding the Pecos and Devils Rivers (Figure 3.10). It is located in Texas and Coahuila. It includes the area typically flooded by Amistad Reservoir, including approximately up to Deadmans Canyon in the Pecos River drainage and up to Indian Spring in the Devils River drainage. In this region the Rio Grande flows through basins and canyons (Dean and Schmidt 2013, p. 184). The river margins are bedrock where the canyons are narrow, and comprised of sediment with vegetation in wider canyons (Dean and Schmidt 2013, p. 184). Prior to widespread water development, periodic large floods maintained a wide, multi-threaded, sandy channel in this fast-flowing, large river (Edwards et al. 2002, p. 124; Dean and Schmidt 2011, p. 336; 2013, p. 193). Flows have declined from dams and water management, and sediment now accumulates in places from which it would have been flushed downstream in the past (Dean and Schmidt 2011, pp. 333–34). In this unit the Rio Grande river is currently a single-threaded channel that flows through alluvial valleys in basins and canyons (Dean and Schmidt 2011, p. 334). Water quality generally improves from upstream to downstream because of high quality spring inflows (Upper Rio Grande BBEST 2012, pp. 2–7, 3–37, 3–41, 5–6). The surface water is governed by international treaties between the United States and Mexico (J. C. Schmidt et al. 2003, p. 30).

Due to limited public access to the mainstem and the long-held belief that Rio Grande cooter were not present in the Rio Grande upriver from the Pecos River confluence, this area has not been extensively surveyed (Ward 1984, p. 29; Ernst 1990, p. 461.1; Ernst et al. 1994, p. 332; Conant and Collins 1998, p. 179; Bartlett and Bartlett 1999, p. 291; Forstner et al. 2014, pp. 342–45). The first range map including this section of the Rio Grande dates only to 2009 (Ernst and Lovich 2009, p. 378). There is only one historical locality, from Calamity Creek in Brewster County, TX and referenced in Strecker (1915, p. 12) and Conant (1977, p. 472). Calamity Creek is now separated from the mainstem Rio Grande by a long dry segment, but water can be seen in the reach where we have placed the point in Figure 3.10 from satellite imagery. In addition, this stream is referenced in Milstead (Milstead et al. 1950, p. 84) as a locality hosting relict species, along with the Devils River, Independence Creek, and the Río Sabinas in Coahuila. We presume Rio Grande cooter are extirpated from the creek today and have been for some time, but do not rule out the validity of this old record. Trap surveys targeting Big Bend slider in 1997 and 1998 at two locations between the Rio Grande Village campground and Langtry, TX did not capture Rio Grande cooter; we do not have precise details on survey effort at these locations (Forstner et al. 2014, pp. 342–45). The occurrences recorded since 1990 are located in an impoundment by the Rio Grande Village campground within Big Bend National Park and the vicinity of Langtry, TX (Forstner et al. 2014, p. 344; Davis et al. 2020, pp. 8, 35, 37, 67, 61; GBIF.org 2020; Forstner 2020, personal communication).

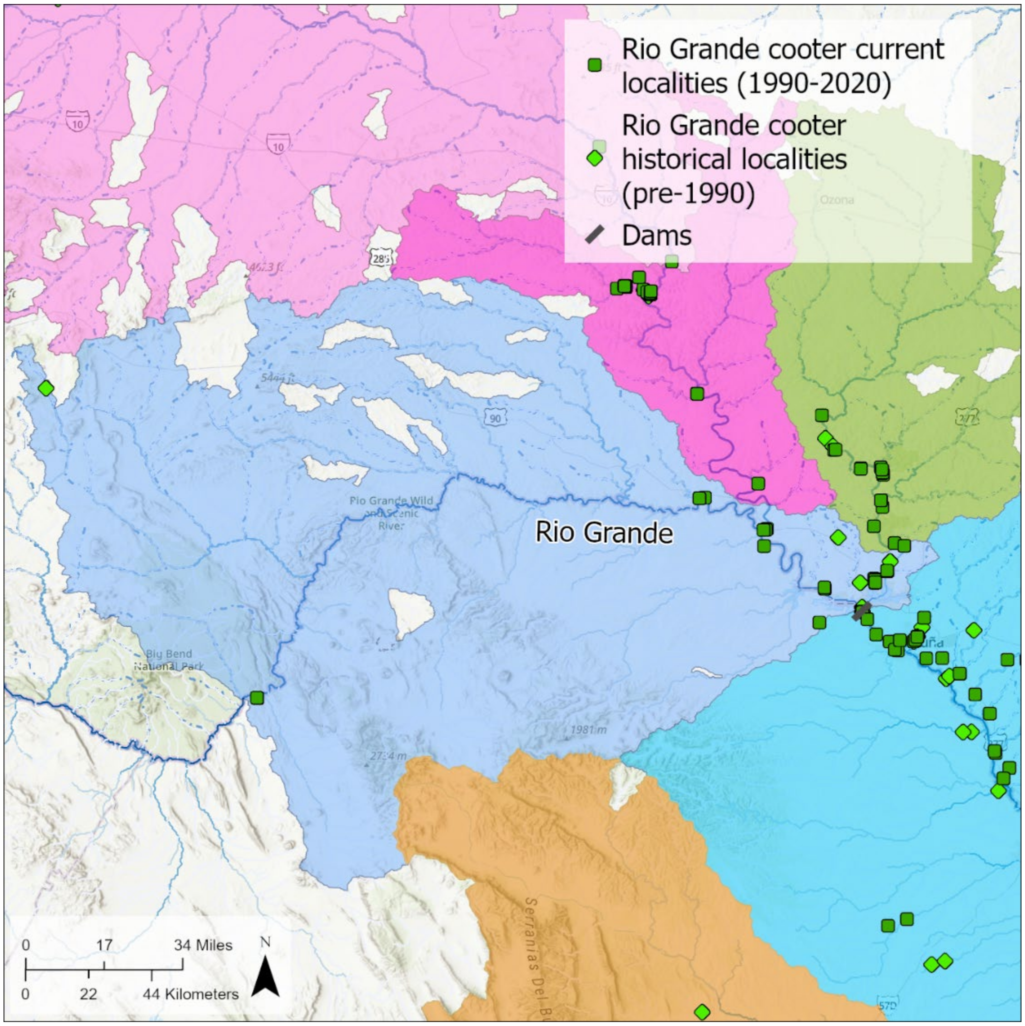


Figure 3.10. Rio Grande – Big Bend to Amistad Dam population analysis unit.

Rio Grande – Amistad Dam to Falcon Dam

This unit is comprised of the Rio Grande and those tributaries that are not part of another population analysis unit, from Amistad Dam to Falcon Dam (Figure 3.11). It is located in Texas, Coahuila, Nuevo León, and Tamaulipas. This unit contains numerous spring-fed streams on both sides of the US-Mexico border, including Las Moras and San Felipe Creeks in the United States, and the Arroyo Escondido in Mexico (Brune 1981, pp. 274–77, 306–7, 454–55). Historically, the channel would have been shifting and subject to large floods as a result of both spring snowmelt runoff and summer-fall tropical storm runoff (Follansbee and Jean 1915, pp. 265, 283–84, 304–10; González Escorcia 2016, pp. 93–94). The numerous dams on the Rio Grande and its tributaries have mostly ameliorated the incidence of any large floods, so contemporary flow patterns in this unit are primarily influenced by dam releases (Lower Rio Grande BBEST 2012, pp. 1-7, 2-13, 4-2–4-4; Sandoval Solis 2019, p. 33). The Edwards-Trinity Plateau Aquifer extends across much of the upper portion of this unit and supports high quality freshwater tributaries to the Rio Grande along this segment in both the United States and Mexico (Brune 1981, pp. 274–77, 449–56; Upper Rio Grande BBEST 2012, pp. 2–8). The surface water is governed by international treaties between the United States and Mexico (J. C. Schmidt et al. 2003, p. 30). There are scattered historical observations from both the mainstem Rio Grande and its tributaries, and numerous recent observations from throughout the unit (Conant 1977, p. 472; Bailey and Forstner 2004, p. 407; Lemos-Espinal and Smith 2007, p. 536; Legler and Vogt 2013a, p. 244; Orrell 2016; Hernandez et al. 2018, p. 502; Bogolin, Davis, and Rahman 2019, p. 775; R. Brown 2019; Cannatella and LaDuc 2019; Gottfried 2019; Grant and Resetar 2019; Laurencio 2019; Prestridge 2019; Rickart and Derieg 2019; Spencer 2019; Zhuang 2019; Davis et al. 2020, p. 8; GBIF.org 2020; Gluesenkamp 2020, personal communication). There have been many observational surveys for Rio Grande cooter in this unit, and the spring-associated Las Moras and San Felipe Creeks are focal areas for Rio Grande cooter studies (Bailey and Forstner 2004, entire; Bohannon 2019b, entire; Davis et al. 2020, pp. 8, 36, 38). Large gaps in observations are attributed to challenges associated with river access through private lands and along the international border (Davis et al. 2020, pp. 5, 16).

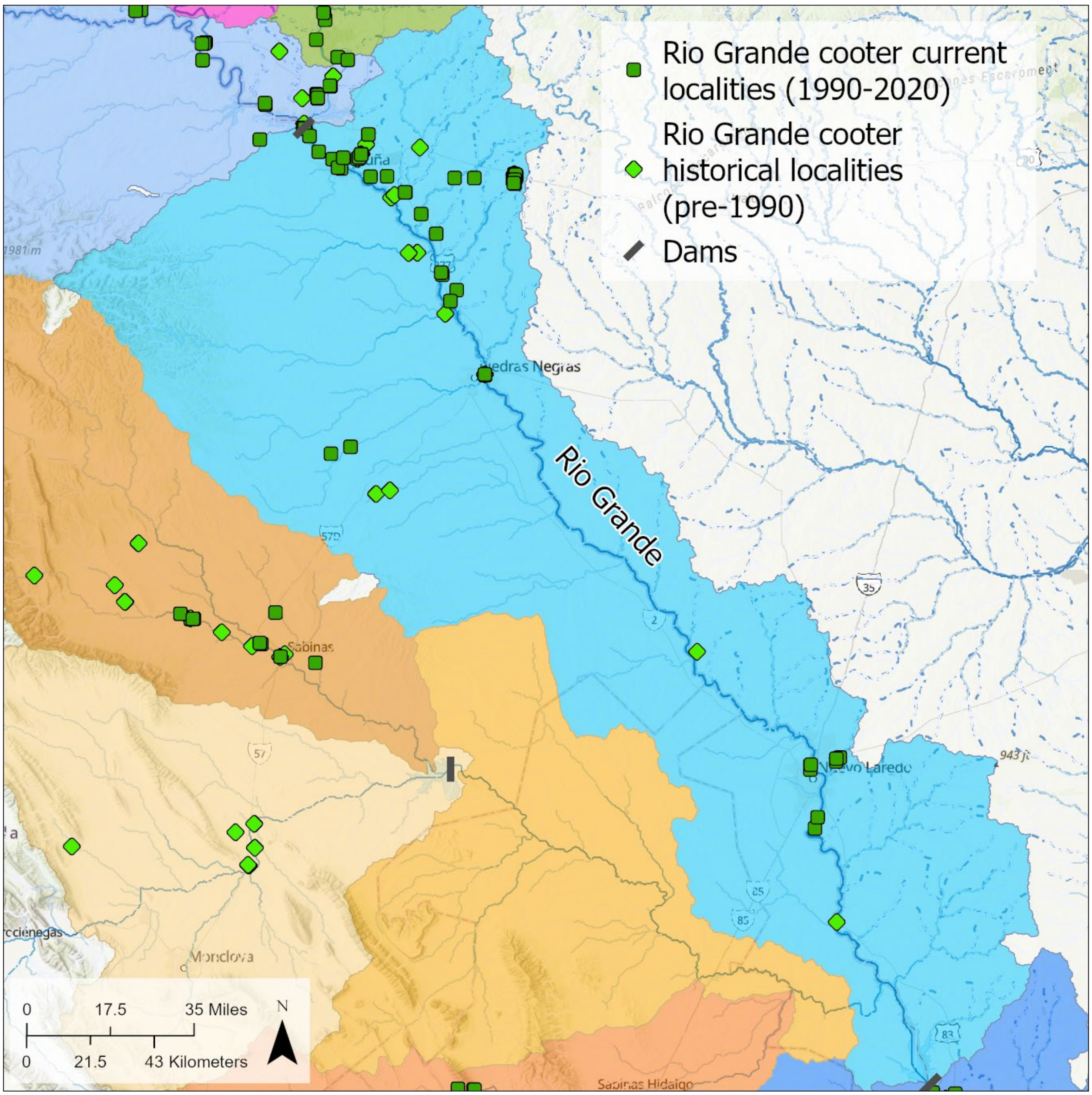


Figure 3.11. Rio Grande – Amistad Dam to Falcon Dam population analysis unit.

Rio Grande – Falcon Dam to Anzalduas Dam

This unit is comprised of the Rio Grande, including tributaries not assigned to another population unit, between Falcon Dam and the downriver extent of the level 12 watershed that includes Anzalduas Dam (Figure 3.12). It is located in Texas, Nuevo León, and Tamaulipas. Compared to the *Rio Grande – Amistad Dam to Falcon Dam* unit, there are fewer perennial tributaries, and all of our historical or recent observations of Rio Grande cooter occur in the mainstem Rio Grande (Gottfried 2019; Davis et al. 2020, pp. 8, 36, 38, 72; GBIF.org 2020). Historically, the river channel in this unit would likely have been shifting and subject to large floods (Follansbee and Jean 1915, pp. 284–310). The influence of spring floods is lower here than further upriver, but late summer and fall tropical storms can also cause flooding (González Escorcia 2016, pp. 93–96). The influence of aquifers and springs is also lower in this unit compared to the *Rio Grande – Amistad Dam to Falcon Dam* unit (Brune 1981, p. 228). Most of the inflow to the Rio Grande in this unit comes from Mexican tributaries, especially the Río Salado. Urban development, irrigated agriculture, and dams and impoundments on the river and some tributaries impact the health of the Rio Grande in this unit (Lower Rio Grande BBEST 2012, pp. 1–7, 2–13, 4-2-4–4; Garrett and Edwards 2014, p. 201). Below Laredo, TX, the Rio Grande is an important source of drinking water for over 11 million people in the border region (Contreras-Balderas et al. 2002, p. 220; González Escorcia 2016, p. 60). The surface water in this unit is governed by international treaties between the United States and Mexico (J. C. Schmidt et al. 2003, p. 30). There are fewer documented observations in this unit compared to the other units. Historical observations are limited to a section of the Rio Grande below Falcon Dam, while recent observations occur there as well as further downriver to Roma, TX, and Rio Grande City, TX (Gottfried 2019; Davis et al. 2020, pp. 8, 36, 38, 72; GBIF.org 2020). Large gaps in observations are attributed to challenges associated with river access through private lands and along the international border (Davis et al. 2020, pp. 5, 16). Researchers detected Rio Grande cooter eDNA near the National Butterfly Center in Mission, TX in 2019, but have not verified the species' presence that far downriver using other survey methods (Davis et al. 2020, pp. 8, 36, 38, 72, 75).

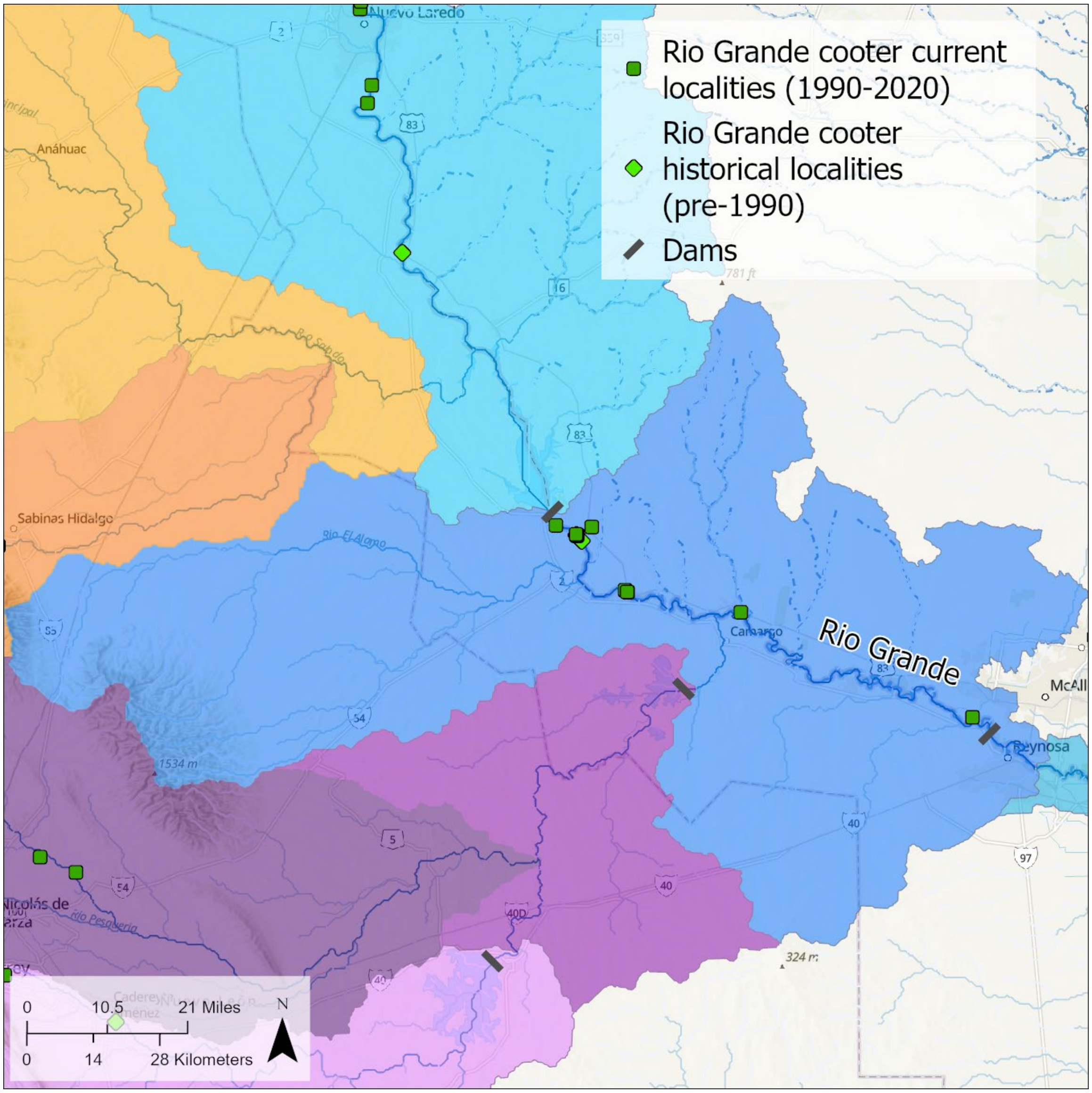


Figure 3.12. Rio Grande – Falcon Dam to Anzalduas Dam population analysis unit

Rio Grande – Anzalduas Dam to Mouth

This unit is comprised of the Rio Grande below Anzalduas Dam (using the level 12 watershed boundary below the dam as the upriver-most boundary of the unit) to the mouth of the river at the Gulf of Mexico (Figure 3.13). It is located in Texas and Tamaulipas. Historically, the river channel at this point would likely have been shifting and subject to large floods, with tropical storms in the late summer and early fall the predominant driver of floods (Follansbee and Jean 1915, p. 328; Lower Rio Grande BBEST 2012, pp. 1–7; González Escorcia 2016, pp. 105–7; Sandoval Solis 2019, p. 33). The hydrology of the Rio Grande in this population analysis unit was dramatically changed by the elimination of most flood events on the river through dams and flood control structures (Lower Rio Grande BBEST 2012, pp. 1–7, 2–13, 4-2-4–4). Below Brownsville, the natural vegetation was a broad riparian woodland and wetland corridor (Lower Rio Grande BBEST 2012, pp. 4–1). This has largely been cleared for agriculture and urban development; 95% of the native vegetation is now gone (Lower Rio Grande BBEST 2012, pp. 4–1). This ecosystem, historically a dynamic river delta, has been reduced to a smaller river that rarely floods (Lower Rio Grande BBEST 2012, pp. 4-1-4–4). Below Laredo, TX, the Rio Grande is an important source of drinking water for over 11 million people in the border region (Contreras-Balderas et al. 2002, p. 220; González Escorcia 2016, p. 60). The surface water in this unit is governed by international treaties between the United States and Mexico (J. C. Schmidt et al. 2003, p. 30). Observations of Rio Grande cooter in this unit are limited to a few in the vicinity of Matamoros that appear to date to the early 20th century; no Rio Grande cooter were found during surveys in this area in 2009, 2018, or 2019 (Altini 1942; Conant 1977, pp. 471–72; D. J. Brown et al. 2012, p. 141; Davis et al. 2020, pp. 8, 36, 38, 72).

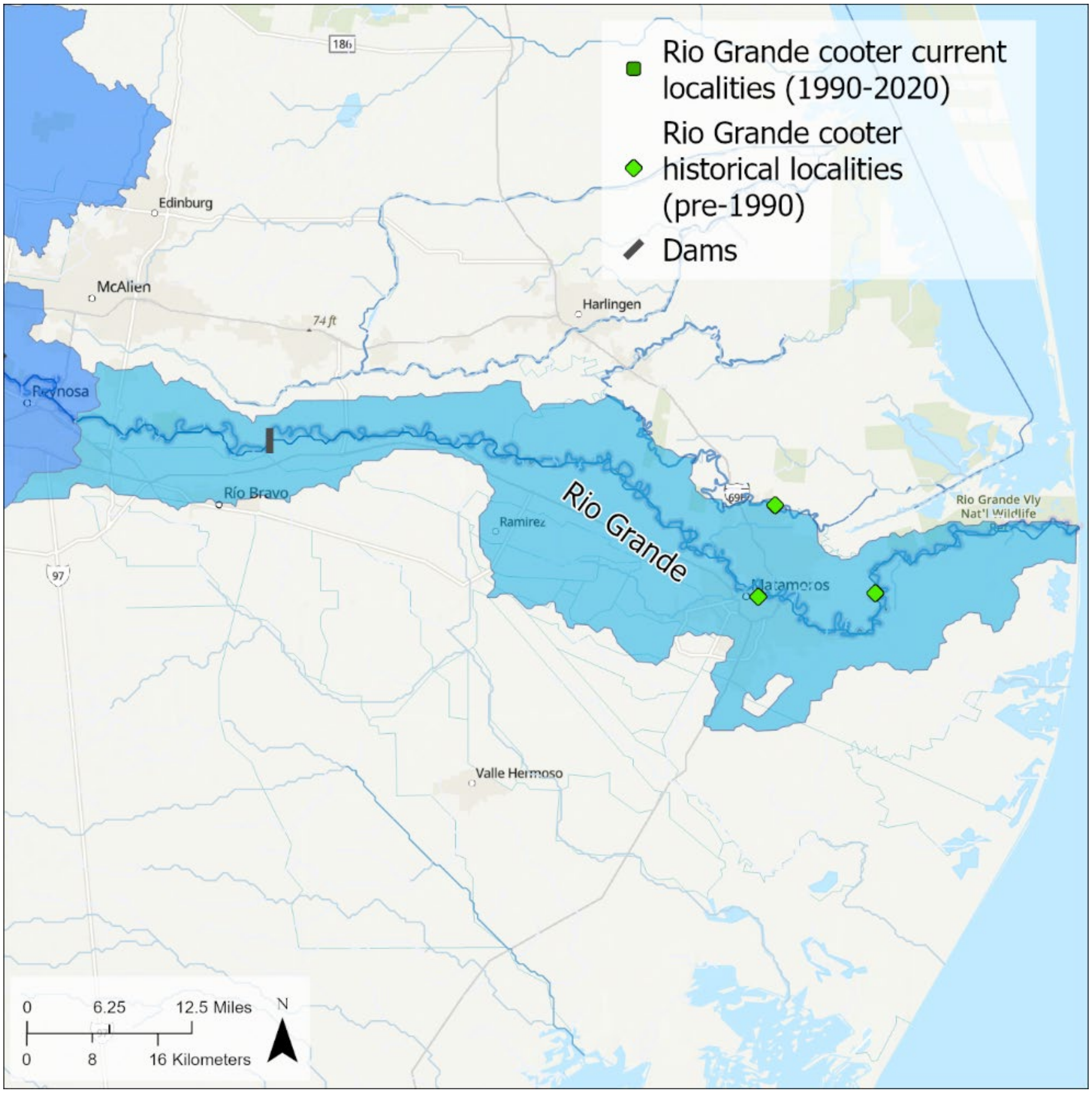


Figure 3.13. Rio Grande – Anzalduas Dam to Mouth population analysis unit

Río Sabinas – headwaters to Don Martin Reservoir

This unit is comprised of the Río Sabinas and its tributaries, from its headwaters in the Sierra Santa Rosa to its confluence with the Don Martin Reservoir (Figure 3.14). It is located in Coahuila. The river flows through private, ejido (a piece of land farmed communally under a system supported by the state), and partially protected lands (Commission for Environmental Cooperation 2014, p. 68). Resource extraction is prohibited in the Don Martin Irrigation District 004, which includes much of the upper watershed (Commission for Environmental Cooperation 2014, pp. 15, 68). Historical observations include localities from the Río Sabinas and its tributaries; most of these are relatively close to the mainstem river (Conant 1977, p. 472; Lemos-Espinal and Smith 2007, p. 536; Legler and Vogt 2013a, p. 244; R. Brown 2019). Current observations were obtained from iNaturalist posts and are all from the Río Sabinas or the Río Alamos, a tributary to the Río Sabinas (Davila Paulin 2020a, personal communication; GBIF.org 2020).

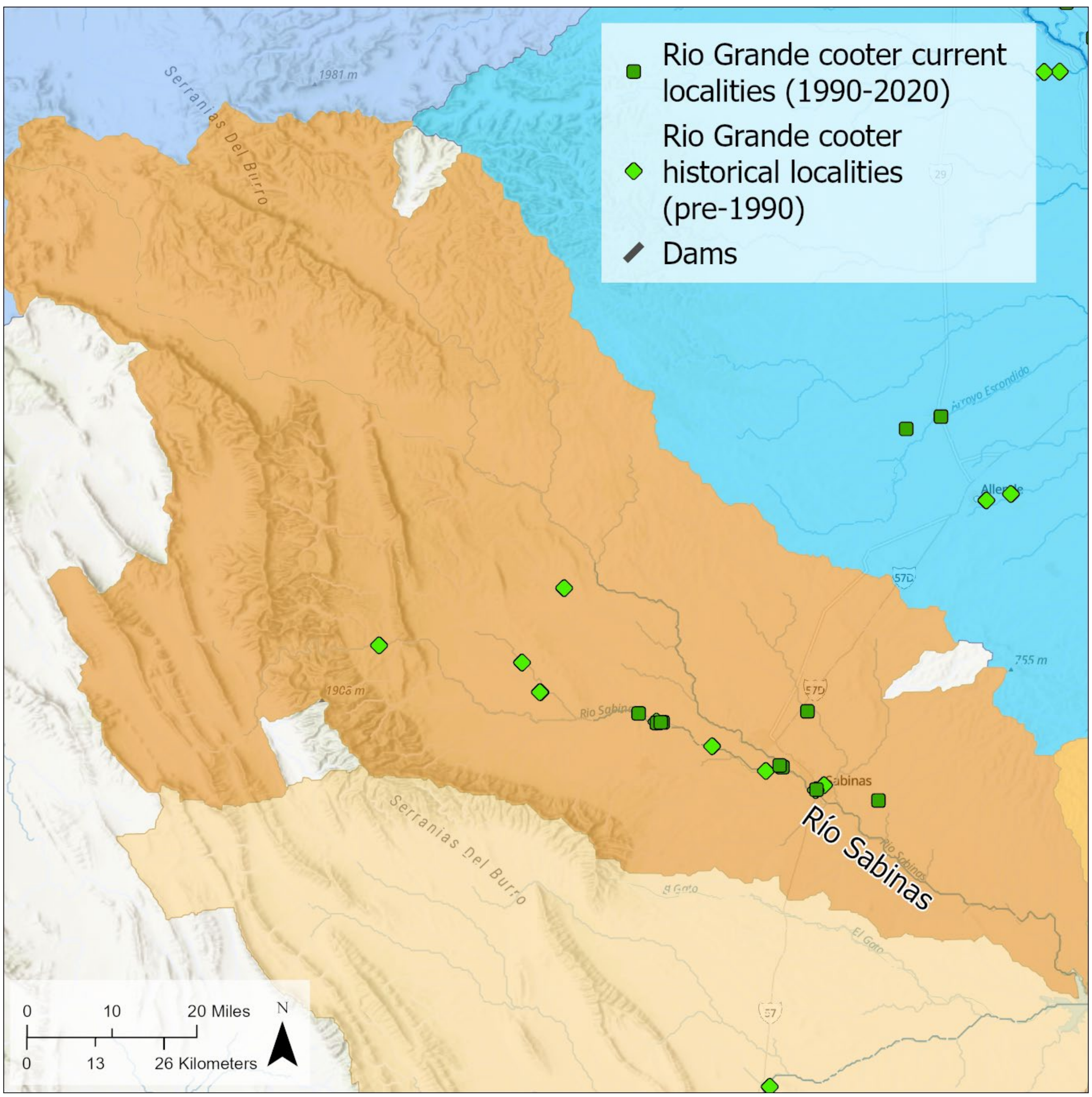


Figure 3.14. Río Sabinas – headwaters to Don Martín Reservoir population analysis unit

Río Salado – headwaters to Don Martin Dam

This unit is comprised of the Río Salado de los Nadadores (a note: the name can be inconsistent; it is always Río Salado below the Don Martín Dam, and is usually Río Salado de los Nadadores above, but the upper section is sometimes simply called the Río Salado) and its tributaries, from its headwaters to the Don Martin Dam, inclusive of the reservoir (Figure 3.15). It is located in Coahuila. Historically, the Río Salado was perennial (Guerra 1952, pp. 1–8). Dr. Ned Strenth from Angelo State University reports that diversions along the river have resulted in part of its upper section (where it is called the Río Salado de los Nadadores locally) becoming intermittent, and that tributaries to the river have dried up over the past few decades (Strenth 2020, personal communication). Historical observations are primarily from the mainstem Río Salado, although one specimen collected in 1939 was from a tributary over 20 km upstream from the river (Conant 1977, p. 472; Lemos-Espinal and Smith 2007, p. 536; Legler and Vogt 2013a, p. 244). There are no recent Rio Grande cooter surveys or observations in this unit, and it is unknown if they are currently present or extirpated. A researcher in the mid-20th century described the Río Salado de los Nadadores as having high salinity, high turbidity, and a lack of aquatic vegetation, which in combination with the barrier to movement presented by the reservoir may explain any potential absence of Rio Grande cooter from this river (Guerra 1952, pp. 1–8).

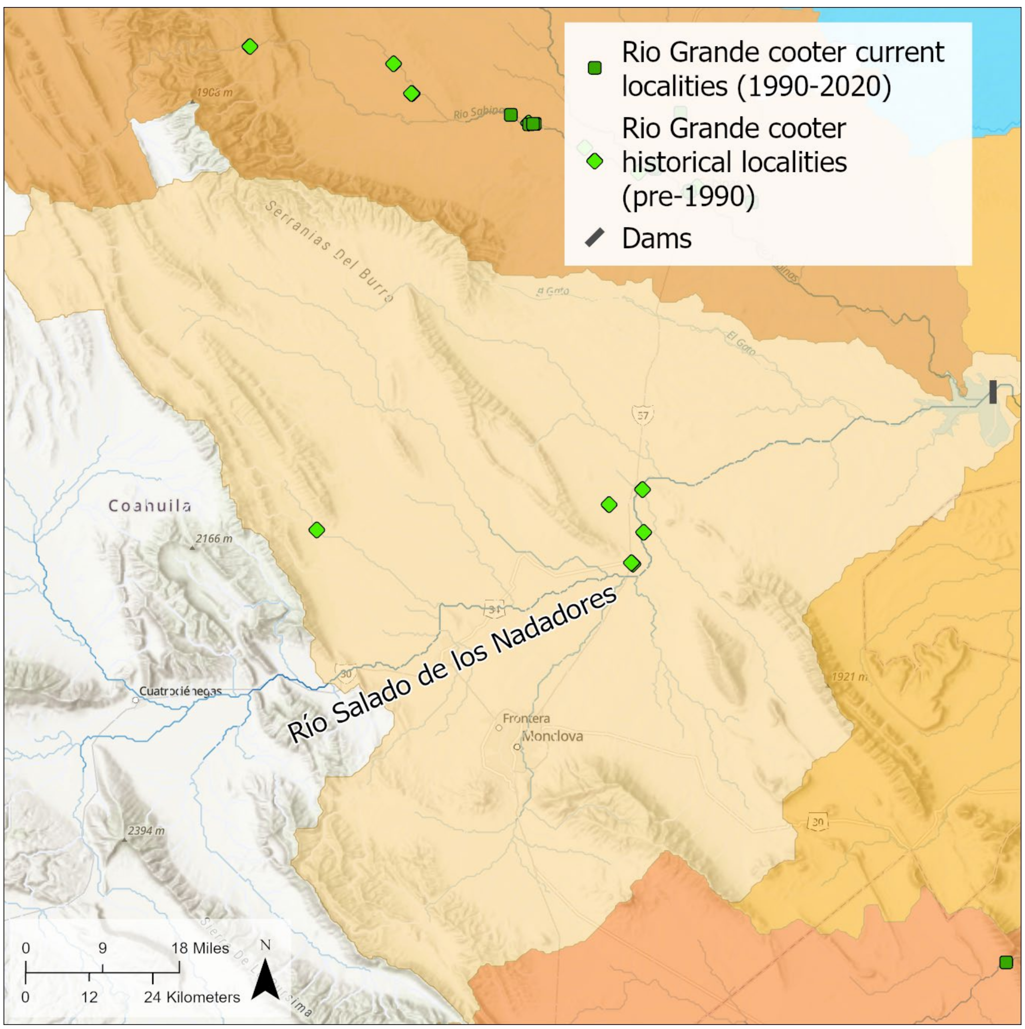


Figure 3.15. Río Salado – headwaters to Don Martín Dam population analysis unit

Río Sabinas Hidalgo – headwaters to cfl Río Salado

This unit is comprised of the Río Sabinas Hidalgo, and its tributaries, to its confluence with the Río Salado (Figure 3.16). It is located in Coahuila and Nuevo León. Its confluence with the Río Salado is near the upper extent of Falcon Reservoir. Little historical information on condition is available. In 1952 it was described as intermittently flowing, but swift water and abundant vegetation were also noted (Guerra 1952, pp. 4–7). A recent observer of Rio Grande cooter along the Río Sabinas Hidalgo described the river as being somewhat polluted due to recreational use, but that overall water quality was high (González 2020, personal communication). The watershed is not well surveyed due to a combination of safety issues in the state and a lack of resources to conduct systematic surveys (González 2020, personal communication). We did not locate any historical Rio Grande cooter observations in this unit. All recent observations are from 2016–2019 and from the mainstem (Nevárez-de los Reyes et al. 2016, p. 631; GBIF.org 2020).

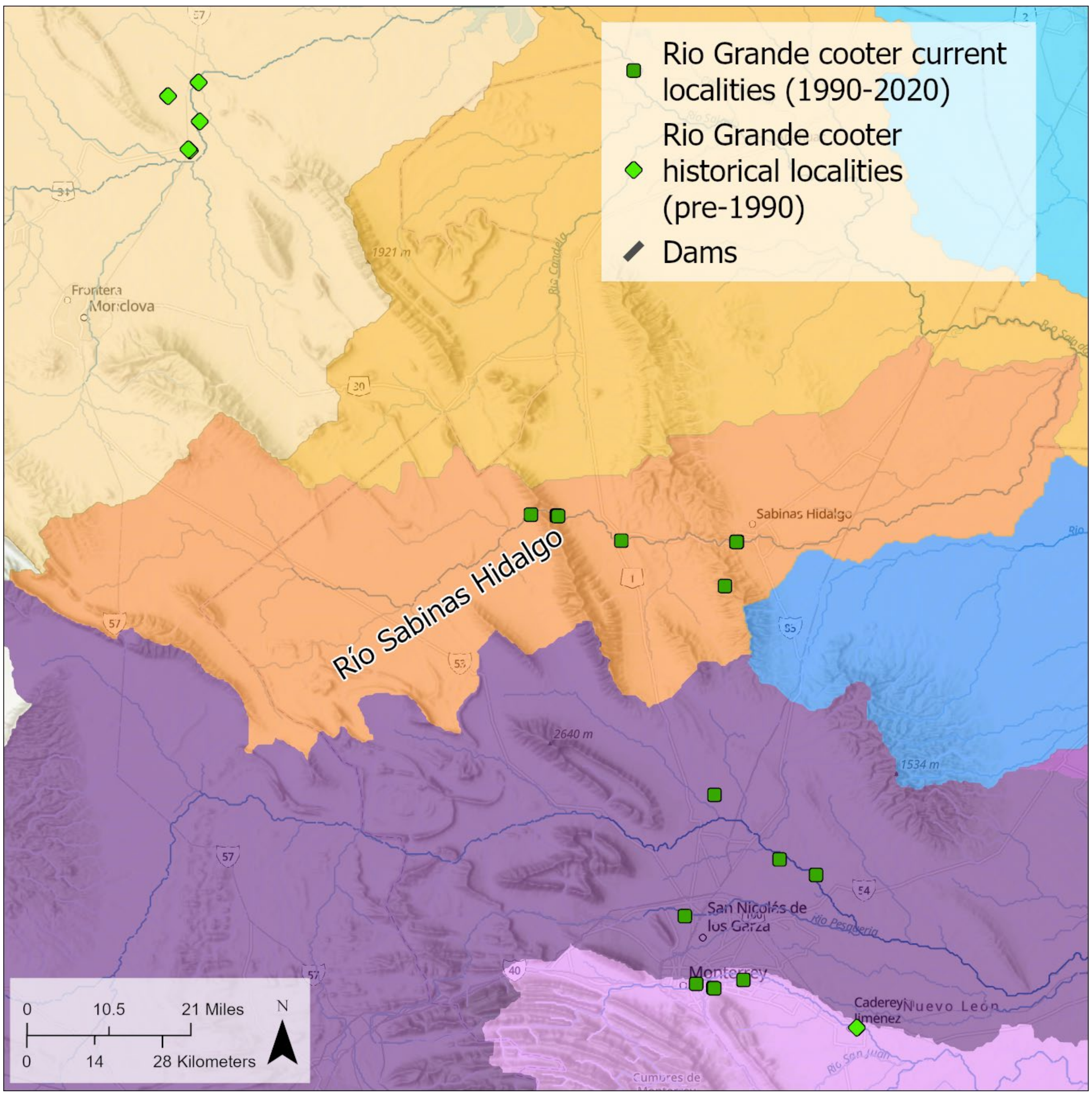


Figure 3.16. Río Sabinas Hidalgo – headwaters to cfl Río Salado population analysis unit.

Río Salado – Don Martin Dam to Falcon Reservoir

This unit is comprised of the Río Salado and its tributaries (except the Río Sabinas Hidalgo), from the Don Martin Dam to the confluence with Falcon Reservoir (Figure 3.17). It is located in Coahuila, Nuevo León, and Tamaulipas. Very little about its character is known prior to construction of the Don Martin Dam. The channel was described in the 1950s as perennial and extremely meandering with brackish tributaries, similar to the historical description of Pecos River conditions in the Toyah Segment (Guerra 1952, pp. 2–6). A detailed understanding of the present character of the river is unavailable due to safety concerns associated with surveying in the state of Nuevo Leon. Flows are described as low, warm, and polluted near the Don Martin Dam outflow, as well as near its confluence with Falcon Reservoir (Berg 2020, personal communication; Hendrickson 2020, personal communication; Strenth 2020, personal communication; Trujillo 2020, personal communication). We did not locate any historical or recent Rio Grande cooter observations in this unit.

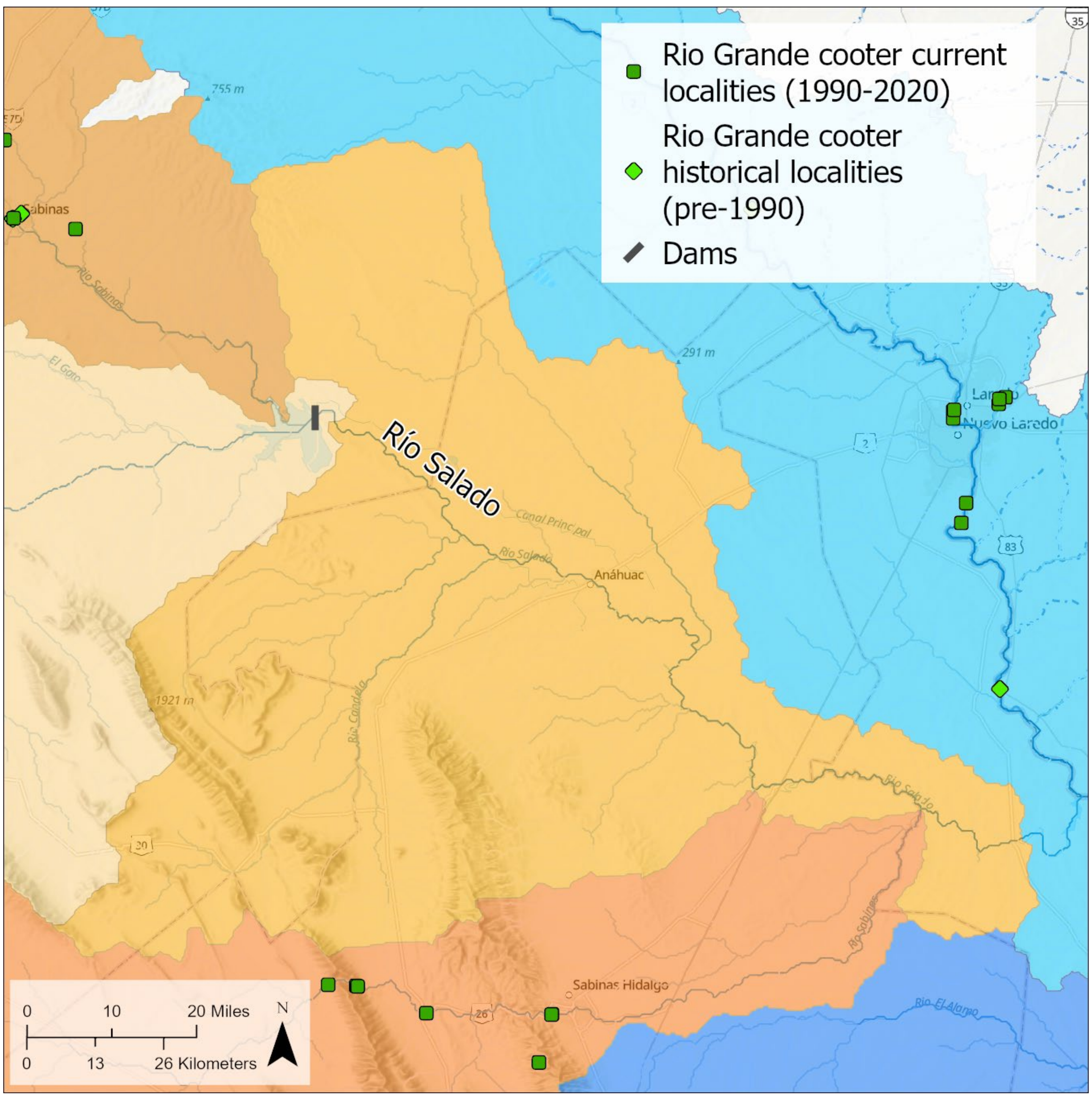


Figure 3.17. Río Salado – Don Martín Dam to Falcon Reservoir population analysis unit.

Río Salinas – headwaters to cfl Río San Juan

This unit is comprised of the Río Salinas and its tributaries, from its headwaters to its confluence with the Río San Juan (Figure 3.18). It is located in Coahuila and Nuevo León. The Río San Juan is normally dry at the location of the confluence (Návar Cháidez 2011, p. 133). The historical character of this river is unknown. Contemporary descriptions of the area suggest that streams and rivers have lower flow, increased pollution, and more diversions than in the first half of the 20th century (Contreras-Balderas and Lozano-Vilano 1994, pp. 381–82; Návar Cháidez 2011, pp. 126–29). We did not locate any historical Rio Grande cooter observations in this unit. Recent observations are sourced from iNaturalist and place Rio Grande cooter in the Río Salinas and a spring in the city of Monterrey (GBIF.org 2020).

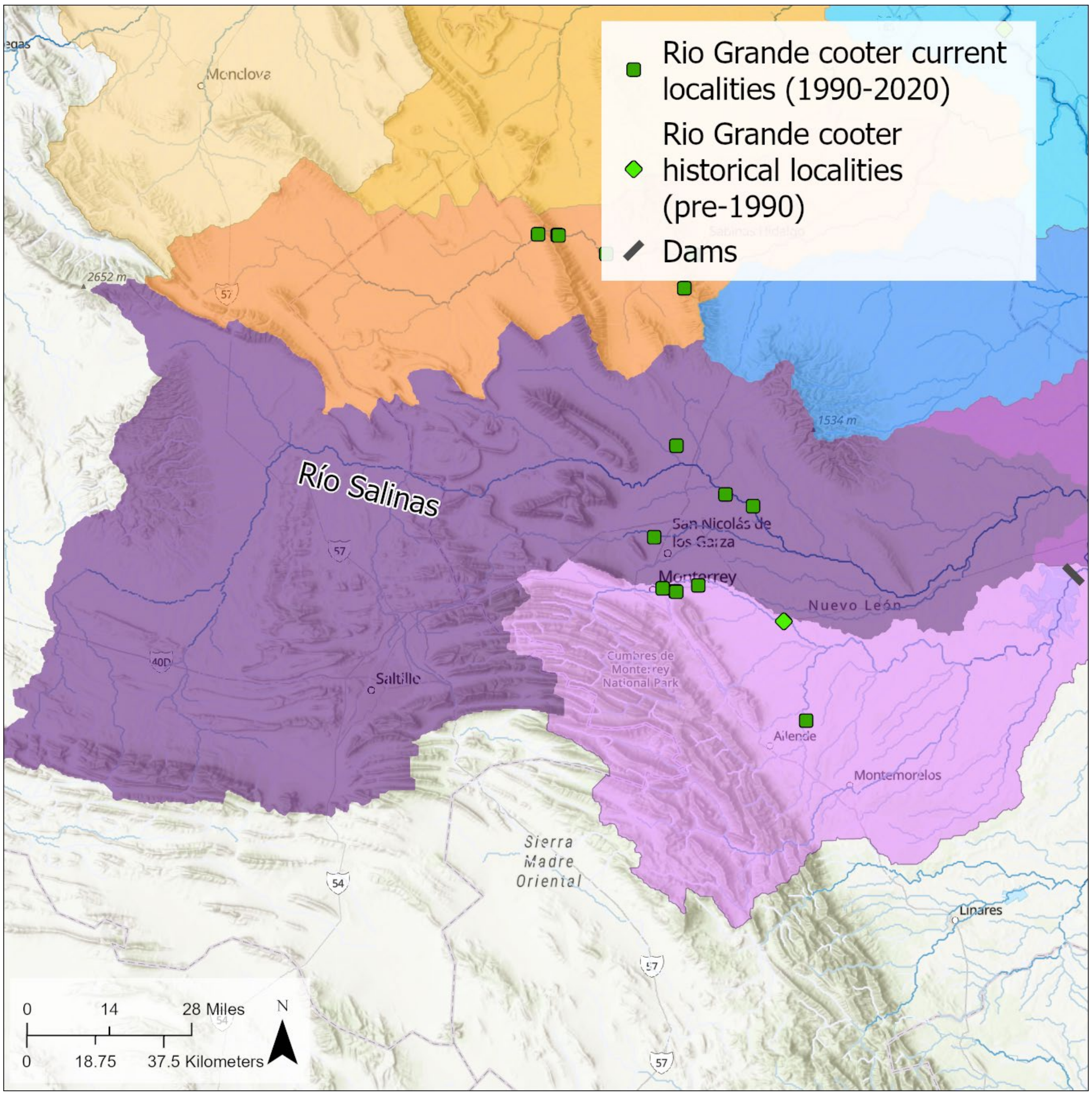


Figure 3.18. Río Salinas – headwaters to cfl Río San Juan population analysis unit.

Río San Juan – headwaters to El Cuchillo Dam

This unit is comprised of the Río San Juan and its tributaries (except the Río Salinas), from its headwaters to the El Cuchillo Dam (Figure 3.19). It is located in Nuevo León. Historically, the Rio San Juan was the largest perennial river in the state of Nuevo León (González Escorcia 2016, p. 86). Since the 1960s, urban and industrial development, including the installation of dams and diversion, have resulted in decreased flows and increased pollution in the unit (Contreras-Balderas and Lozano-Vilano 1994, pp. 381–83; Contreras-Balderas et al. 2002, p. 221; Návar Cháidez 2011, pp. 126–33). There is one historical observation in the unit, a paratype specimen from 1856 (Orrell 2016). Recent observations recorded in 2018 and 2019 are sourced from iNaturalist and place Rio Grande cooter in tributaries to the Río San Juan, but not the mainstem of the river itself (GBIF.org 2020).

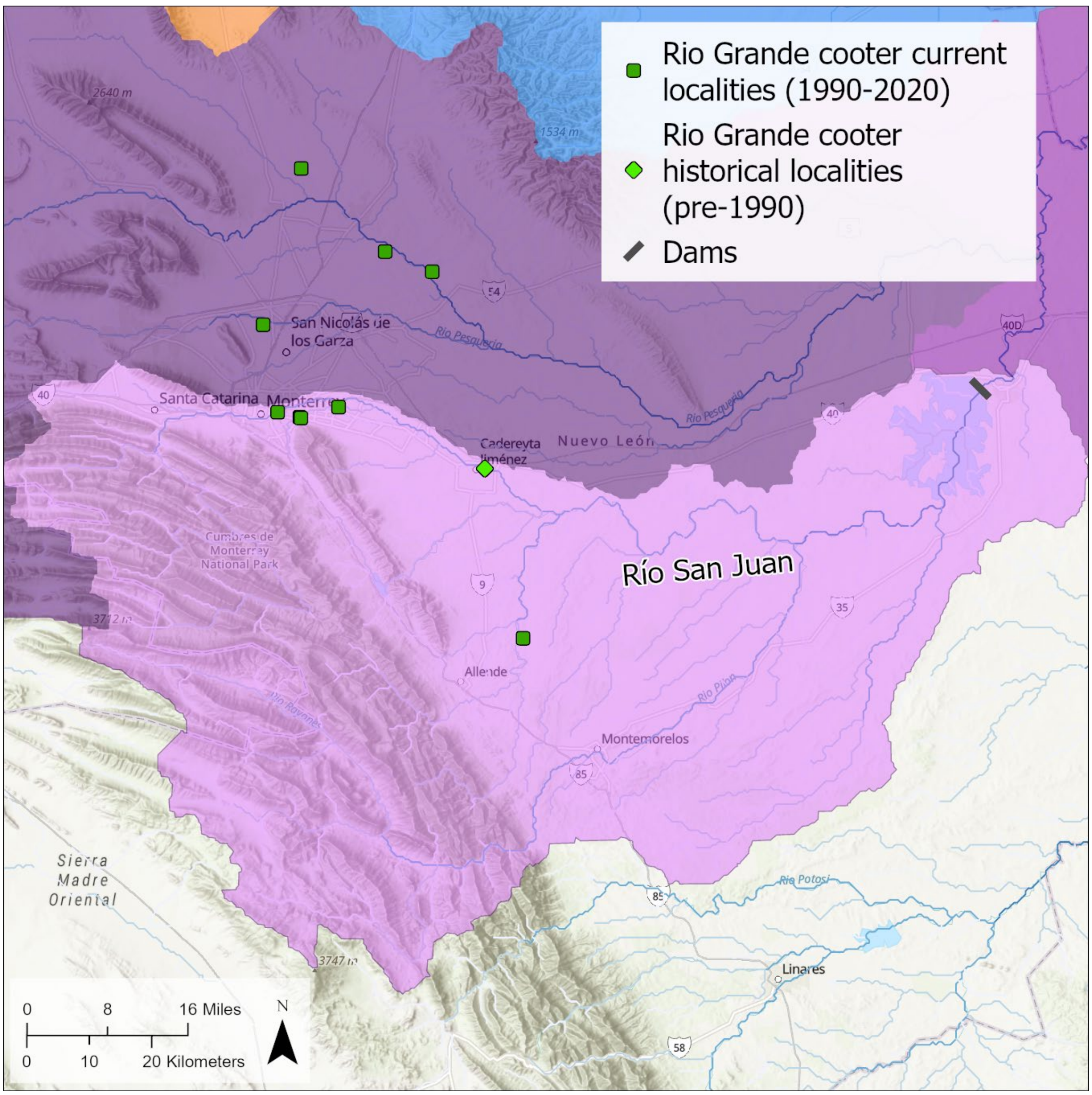


Figure 3.19. Río San Juan – headwaters to El Cuchillo Dam population analysis unit.

Río San Juan – El Cuchillo Dam to Marte R Gomez Dam

This unit is comprised of the Río San Juan and its tributaries between the El Cuchillo and Marte R. Gomez Dams (Figure 3.20). It is located in Nuevo León and Tamaulipas. The El Cuchillo Dam was completed in 1994 and led to the drying of the Río San Juan between the two reservoirs (Návar Cháidez 2011, p. 133). Historically the Río San Juan would have been a large perennial river, but today it has very low to no flow unless there has been a recent rain event (Sanchez 1997, p. 429; Návar Cháidez 2011, p. 133; Berg 2020, personal communication). This unit has no historical or recent observations of Rio Grande cooter, and safety issues associated with surveying in this area preclude the availability of additional information.

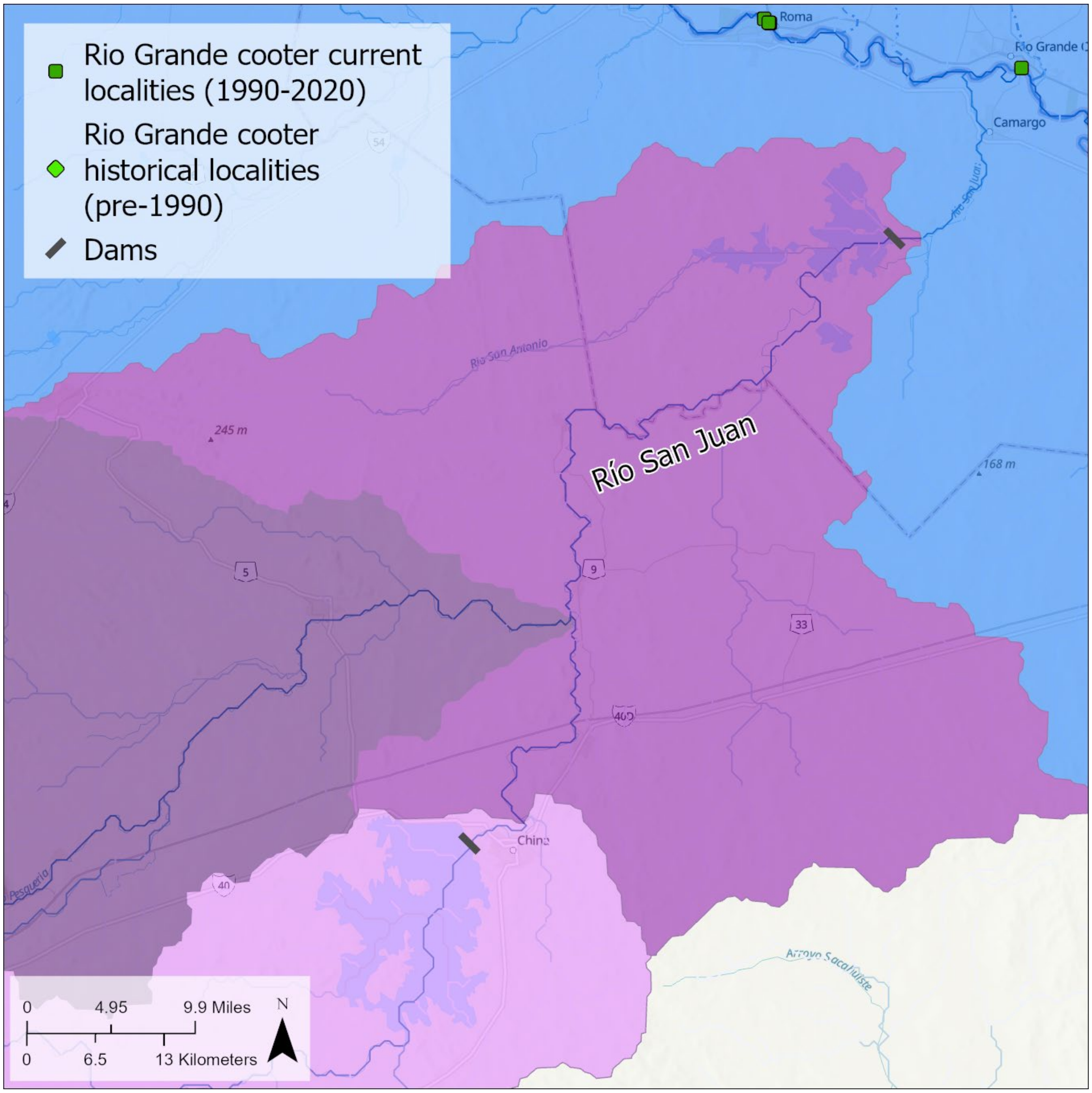


Figure 3.20. Río San Juan – El Cuchillo Dam to Marte R Gomez Dam population analysis unit.

4 Influences on Viability

In this chapter, we consider the historical and current anthropogenic and environmental factors influencing Rio Grande cooter resiliency, representation, and redundancy. These influences affect individual, population, or species needs, ultimately affecting the viability of the species—its ability to sustain populations in the wild over time. The majority of these influences are considered “stressors” to Rio Grande cooter, in that they negatively influence viability. Positive influences on Rio Grande cooter viability, such as conservation efforts, are also covered in this chapter. We acknowledge that there are other factors that influence Rio Grande cooter, but for the purposes of this SSA we focus on those factors that we suggested have population or species-level effects in Chapter 2.

We developed an influence diagram (Figure 4.1) summarizing the ways in which these factors can influence Rio Grande cooter resiliency through their effects on habitat needs or demographic parameters. We analyzed stressors in detail in terms of causes and effects to the species (Appendix A). These tables analyze the pathways by which each stressor affects the species, and each of the causes is examined for its historical, current, and potential future effects on the species’ status. Current and potential future effects, along with current expected distribution and abundance, determine present viability and vulnerability to extinction in the future.

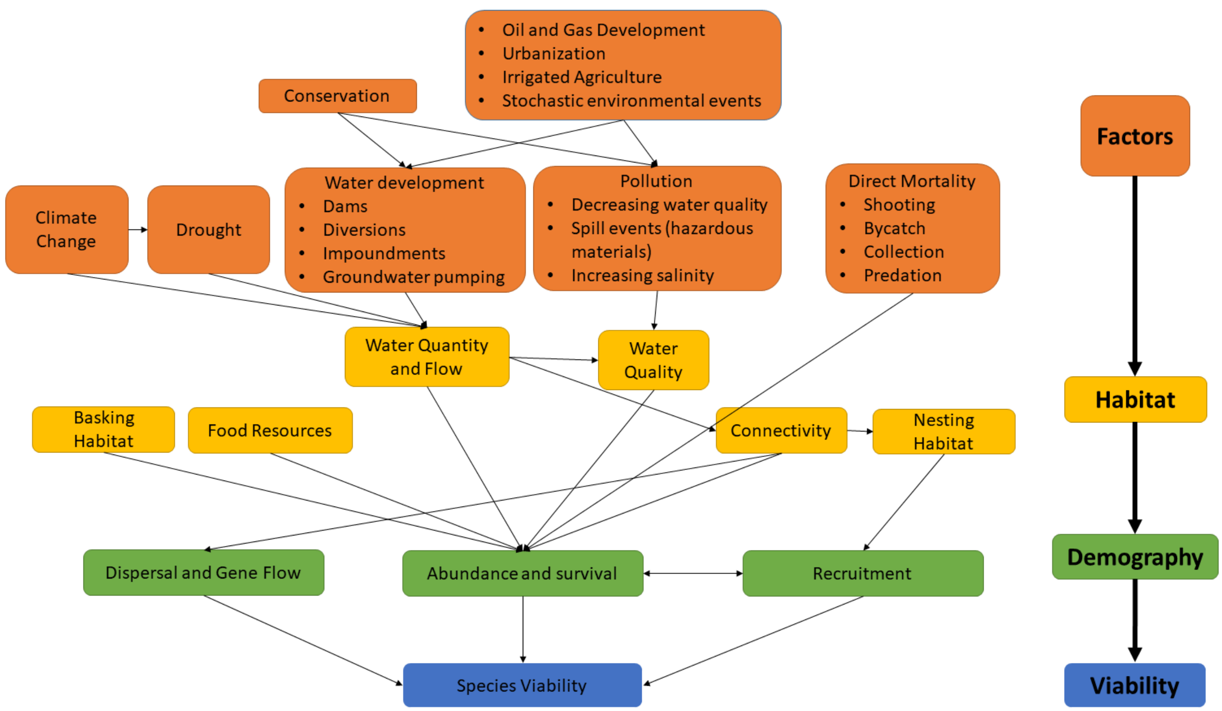


Figure 4.1. Influence diagram that maps the pathways through which environmental and anthropogenic stressors, and conservation efforts, affect demographic parameters and Rio Grande cooter viability.

Stressors

Modified Hydrology

Mechanisms

Water development, including the construction of retention and diversion dams, managed dam releases, diversion of surface water, and groundwater pumping, has transformed most of the aquatic habitat within the range of Rio Grande cooter. Water development has occurred for flood control, irrigation, human consumption, and mining and industrial use. Water development on the Pecos River and Rio Grande began in the late 1800s and on tributaries to the Rio Grande in Mexico by the 1940s, and has continued to the present day (Edwards and Contreras-Balderas 1991, pp. 209–10; Hoagstrom 2003, pp. 93–94; 2009, p. 30; U.S. Army Corps of Engineers 2008, pp. 20–23; Návar Cháidez 2011, p. 133; Arm et al. 2014, p. 28; Rio Grande Regional Water Planning Group 2020, pp. 1-8–1-9). The flow regime and streamflow characteristics of most streams in the Rio Grande watershed have been completely transformed in the last 150 years (Edwards and Contreras-Balderas 1991, entire; Contreras-Balderas and Lozano-Vilano 1994, entire; J. C. Schmidt et al. 2003, entire; Hoagstrom 2003, entire; U.S. Army Corps of Engineers 2008, entire; Hoagstrom et al. 2008, entire; Dean and Schmidt 2011, entire; Hogan 2013, entire; Garrett and Edwards 2014, entire; Miyazono et al. 2015, entire; González Escorcia 2016, entire; Cheek and Taylor 2016, entire).

The installation of dams on lotic (flowing) systems has wide-ranging effects on hydrology and aquatic ecosystems. The construction of dams and impoundments creates artificial lentic (non-flowing) habitat that displaces natural lotic habitat (Bunn and Arthington 2002, p. 496; Moll and Moll 2004, pp. 252–56). Downstream of dams, streamflow is managed for the benefit of human needs, and is therefore altered to be both artificially lower (such as when filling reservoirs or due to diversion) or artificially higher (such as when releasing water for use), than the natural flows under which native species evolved (Hale 1955, p. 9; Cox 1963, p. 19; Bunn and Arthington 2002, pp. 496–98; Hoagstrom et al. 2008, p. 6; Návar Cháidez 2011, p. 126; Rolls et al. 2012, p. 1174; González Escorcia 2016, entire). In addition, the presence of dams that hold back floodwaters changes the distribution of sediment accumulation (Bunn and Arthington 2002, pp. 499–500; Hoagstrom 2003, pp. 93–94; J. C. Schmidt et al. 2003, pp. 34–35; Rolls et al. 2012, p. 1167). This has resulted in stream aggradation, changes to riparian soils and vegetation, and the conversion of sandy-bottomed rivers to muddy ones (Bunn and Arthington 2002, pp. 499–500; Hoagstrom 2003, pp. 93–94; J. C. Schmidt et al. 2003, pp. 34–35; Rolls et al. 2012, p. 1167). Diversion of water from streams reduces streamflows, makes low flows during droughts more likely and more pronounced, and increases the risk that short-term effects from low-flow events become long-term ecosystem-level changes (Rolls et al. 2012, pp. 1164–74).

Groundwater discharge is important to stabilize flow, mediate water temperature, and support riverine ecosystems (Caldwell et al. 2020, p. 1). Groundwater pumping lowers the water table and alters or reduces subsurface flow to rivers (Ashworth 1990, p. 21; Rolls et al. 2012, p. 1176; Arm et al. 2014, p. 19). Because of groundwater pumping for agricultural uses, the water table is highest in late fall and winter and lowest in summer, rather than following precipitation patterns (Rolls et al. 2012, p. 1176; Arm et al. 2014, p. 19). These changes may then result in reduced base flow in streams and rivers (Hoagstrom 2003, pp. 93–94; Rolls et al. 2012, p. 1176). Reduced aquifer recharge is caused both by reduced streamflow and groundwater pumping (Hoagstrom 2003, pp. 93–94). Reduced aquifer levels and lowered water tables can lead to declines in springflow and subsequent streamflow (Thomas 1963, pp. G-11–G-12; Scudday 1977, p. 514; Hoagstrom 2003, pp. 93–94; 2009, pp. 32–34; Gregory and Hatler

2008, pp. 7–10; Rolls et al. 2012, p. 1176; Hogan 2013, p. 6). In Texas, with limited exceptions that do not apply within the Rio Grande cooter range, groundwater is subject to the “rule of capture,” which allows surface landowners to capture any water they can acquire under their land, for any purpose (Mullican and Schwartz 2004, pp. 1–9). As a result, surface springs and streams are vulnerable to drying due to legal groundwater pumping.

Many of the aquifers in the basins that support Rio Grande Cooter in New Mexico are shallow, karst featured alluvial deposits and limestone conglomerate with dynamic subsurface flows that are difficult to forecast (Barroll et al. 2004, p. 8; Arm et al. 2014, pp. 3–4, 13). For example, the aquifer in Eddy County, NM is recharged by components that are poorly measured or quantified (Barroll et al. 2004, pp. 7–9). Natural sources of recharge are precipitation, streamflow events, and possible upward seepage from the Permian-aged limestone Capitan Reef (Barroll et al. 2004, pp. 7–9). Leakage from irrigation canals and laterals, on-farm return flow, and a man-made lake provide large artificial sources of recharge and the magnitude of their contribution can be more easily estimated, though on-farm return flow is the least quantifiable component because few data indicative of its magnitude are available (Barroll et al. 2004, pp. 8–9). There is the potential for recharge reductions from irrigation leaking with efficiency improvements, as well as water designated for agricultural use that is temporarily leased for industrial purposes and where large quantities are withdrawn quickly (Rolls et al. 2012, p. 1176; Hogan 2013, p. 12; Arm et al. 2014, pp. 32–44, 80). Drought also reduces recharge amounts, and the severity of these effects are compounded over periods of years of subsequent drought, to which the state is prone (Bjorklund and Motts 1959, pp. 144, 184; Arm et al. 2014, p. 30). The New Mexico Office of the State Engineer (NMOSE) regulates the quantity, location, timing, frequency, and type of use of both surface and groundwater withdrawals (Arm et al. 2014, pp. 34–36). Appropriations are administered according to statutory surface water and groundwater rules and regulations, and monitoring and enforcement of these withdrawals are led by district water masters (Arm et al. 2014, pp. 32–44).

Unnaturally low flows are a consequence of water development activities such as dam construction, surface water management, surface water diversion, and groundwater pumping. Low flows reduce the total amount of available aquatic habitat and alter that habitat’s extent and structure (Rolls et al. 2012, p. 1167). Low flows increase sediment deposition, alter the substratum, and reduce structural diversity by facilitating the reduction or loss of riffle habitats, swift-water reaches, and/or pools (Moll and Moll 2004, p. 248; Rolls et al. 2012, pp. 1167–68). These changes can impact carrying capacities by increasing the competitive pressure for food resources among individuals as well as the predation pressure on individuals (Rolls et al. 2012, p. 1169). Low flows are an additional stressor for species whose recruitment strategy is hampered by low flows (Rolls et al. 2012, p. 1169). Impacts increase as the frequency and intensity of low flow conditions or events increase (Rolls et al. 2012, p. 1167). Low flows are also correlated with decreased water quality and changes to local vegetation and macroinvertebrate communities (Rolls et al. 2012, pp. 1170–71). Finally, low flows may convert perennial streams and rivers to intermittent or ephemeral waterways, increasing both the importance and vulnerability of refugia (Rolls et al. 2012, pp. 1168–74).

Impacts to species needs

The effects of water development are a potential stressor impacting Rio Grande cooter across all life stages. As a mostly aquatic species, Rio Grande cooter individual needs are inextricably linked to aquatic habitat and the associated riparian uplands. The alteration of flow regimes and reduced water quantity and quality threaten Rio Grande cooter at the individual, population, and species levels. The habitat deterioration or destruction associated with these stressors negatively impacts the development and maintenance of breeding, feeding, and sheltering habitat. Habitat loss due to decreased flows increases competition for food resources, decreases the space available to take cover from predators, and increases the concentration of any toxicants present (Rolls et al. 2012, pp. 1167–71). Increased concentrations of toxicants in the soil and water may cause mortality or reduced vigor of eggs, hatchlings, juveniles, and adults (Hopkins 2000, entire). These stressors may compromise the quantity and quality of available refugia habitat, impairing the capacity of populations to rebound after severe low flow events. Rapid loss of streamflow can strand Rio Grande cooter before they can reach refugia, resulting in increased mortality due to predation or desiccation (Bunn and Arthington 2002, p. 499; Rolls et al. 2012, pp. 1173–74). Changes to the flow regime, including changes to the timing of high and low flood events, as a result of water development can threaten the amount of suitable nesting grounds available to females or the security of nesting grounds for overwintering (Moll and Moll 2004, pp. 24, 54, 248). Females need reliable access to nesting grounds during the late spring and summer, and nests must retain adequate soil moisture content and be free from inundation during incubation (Moll and Moll 2004, pp. 53–54, 248; Legler and Vogt 2013a, p. 245; Bohannon 2019a, pp. 8–11; Mali and Suriyamongkol 2019, pp. 6–7). Nest failure may result from inundation in high flow events, or from the desiccation of eggs during periods of reduced soil moisture content or of hatchlings unable to reach water during low flow events and (Moll and Moll 2004, p. 248; Washington 2008, p. 12). Stream drying and intermittency within the species' range can impede the habitat connectivity and movement that support dispersal of genetic material and allow for successful breeding, feeding, and sheltering (Bunn and Arthington 2002, pp. 498–500). The construction of dams and associated reservoirs adds a partial or total barrier to movement and dispersal in what was likely passable habitat prior to construction (Bunn and Arthington 2002, p. 499; Moll and Moll 2004, pp. 253–55). Therefore, the impacts from water development ultimately include abundance and survival of all life stages, recruitment, and dispersal.

Geographic and Temporal Scope

Pecos River Basin

The impacts of water development on the Pecos River in both Texas and New Mexico have been extensively documented. Mechanisms to extract and use water, including surface water diversion, dams, and groundwater pumping began in the late 1800s, and continue to the present day (Hoagstrom 2003, pp. 93–94; 2009, p. 30). Additional dams were installed along the river regularly for the next 100 years (Hoagstrom 2003, pp. 93–94). These activities reduced or eliminated surface flow along the Pecos River and its tributaries by the mid-1950s, as water use became more intense (Hale 1955, entire; Cox 1963, p. 19; Havenor 1968, p. 5; Hoagstrom 2003, pp. 93–94; 2009, pp. 30, 36). Numerous springs in the basin also dried up or experienced decreased discharge (Brune 1975, pp. 51–82). The potential surface flow in this basin is reduced by evaporation from Fort Sumner and Brantley Reservoirs, diversions for irrigation, decreased inputs from both small and large tributaries, and the cumulative consequences of water management.

Releases from Fort Sumner Reservoir to Brantley Reservoir happened as block releases several times a year for decades, at an interval and timing contrary to the historical flow regime (Hoagstrom et al. 2008, p. 6). When not discharging, no water was released, leading to artificially low flows (Hoagstrom et al. 2008, p. 6). Streamflow intermittence recurs regularly in that segment, as well as below the Brantley Dam and at the inlet to Red Bluff Reservoir, especially during drought (Miyamoto et al. 2005, p. 17; Hoagstrom et al. 2008, p. 6; Arm et al. 2014, pp. 30, 53). The loss of surface flows means that groundwater discharge at springs and irrigation return flows are now the predominant water source for the mainstem (Hoagstrom 2003, p. 93).

Most groundwater pumping occurs to support irrigated agriculture (NMOSE 2016, p. 139; Freese and Nichols, Inc. 2020, p. ES-5). In New Mexico, both groundwater and surface water rights are adjudicated and regulated by the State (NMOSE 2016, pp. 21–43). In Texas, the rule of capture enables private landowners, with very few limitations, to withdraw unlimited amounts of groundwater from their property (Todd 1992, pp. 249–55; International Boundary & Water Commission 1994, p. 1; Kaiser and Skiller 2001, pp. 263–64; Opiela 2002, pp. 97–105; Welles 2013, pp. 486–91; Cook et al. 2015, p. 50; Eoh 2015, pp. 1233–36; Closas and Molle 2018, p. 513). Because the upper Delaware River is in Texas, groundwater pumping can affect the levels of this river downstream when it is within the New Mexico border. The Pecos River and its tributaries below the Red Bluff Dam are also affected by the consequences of the rule of capture as groundwater law. Because of the cost of drilling new wells, groundwater development for irrigated agriculture is not expected to increase significantly in the future (NMOSE 2016, pp. 148–88). However, groundwater pumping to support the water needs of hydraulic fracturing operations has been increasing at a rapid pace (Scanlon et al. 2020, pp. 3510–13). Recent estimates suggest that 3–6% of the cumulative total Permian basin hydraulic fracturing wells have been drilled, and that the development of known oil and gas formation in the Delaware Basin in particular will create demand for tremendous amounts of water in the future, even with aggressive reuse (Scanlon et al. 2020, pp. 3513–15).

Devils River Basin

The Devils River is much less impacted by water development than the other rivers and streams in the Rio Grande cooter range (Upper Rio Grande BBEST 2012, pp. 1-11–1-13). The most significant historical impacts to the Devils River were the loss of 18 km (11.2 mi) of perennial flow due to shifting headwaters, and the inundation of its lower reach by Amistad Reservoir (Brune 1981, pp. 450–52; Upper Rio Grande BBEST 2012, p. 1-11; González Escorcia 2016, pp. 80–81). Reduced recharge to the aquifer locally due to groundwater pumping and soil compaction associated with grazing are the primary causes of the reduced flows (Brune 1981, p. 451). This river is entirely in Texas; thus, it is also subject to the consequences of the rule of capture as described above. Groundwater pumping in the basin is currently stable and occurs at relatively low volumes (Weinberg et al. 2018b, p. 88). Factors that decrease pressure on Devils River surface water and connected groundwater include the fact that multiple ESA-listed species inhabit its waters, the Devils River itself is valued as the most pristine river in Texas, and conservation easements or public ownership apply to nearly 175,000 acres (71,000 hectares) in the watershed (Upper Rio Grande BBEST 2012, pp. 1-15, 2-28, 2-29).

Rio Grande Basin

The Rio Grande within the range of Rio Grande cooter was highly modified by dams and water management starting in the late 1800s, but the character of the river was more or less maintained until the mid-1940s (Dean and Schmidt 2011, p. 341). River management, as of at least the 1970s, has altered the hydrology of the Rio Grande and led to reduced flows and increased river homogeneity (Miyazono et al. 2015, pp. 449–51). The loss of beaches along the reach from below Big Bend National Park to the border of Terrell and Val Verde Counties in Texas is a result of reduced sediment deposition and the increased establishment of riparian vegetation, which are additional symptoms of this altered hydrology (Garrett and Edwards 2014, pp. 396–97, 404). The process of channel narrowing in this upper reach is in a positive feedback loop and expected to continue (Dean and Schmidt 2011, pp. 356–348). There is also a feedback loop of reduced flows in the Rio Grande leading to decreased recharge of the connected alluvial aquifer, stressing nearby spring-fed tributaries and the springs that contribute high quality base flows to the river throughout the Lower Canyons reach (Hogan 2013, p. 6). The portion of the Rio Grande that forms the U.S.-Mexico border in Texas may also be impacted by the consequences of the rule of capture. Groundwater pumping near the Rio Grande in this reach has the potential to reduce spring discharges that are currently critical for baseflows (Brune 1981, pp. 84–94, 423–25; Bennett 2011, pp. 1–2).

Below Amistad, the potential surface flow in the Rio Grande is reduced by evaporation from Amistad and Falcon Reservoirs, diversions for irrigation, decreased inputs from both small and large tributaries (especially the Río Salado and Río San Juan), and the cumulative consequences of water management (Miyamoto et al. 1995, pp. 3–6; Contreras-Balderas et al. 2002, p. 221). However, the most significant change from the historical period may be the lack of large floods rather than the decreased flow, as intermittency does not occur between Amistad Dam and Brownsville (Edwards and Contreras-Balderas 1991, entire). Currently, groundwater pumping primarily serves agricultural and municipal users (New Mexico Office of the State Engineer (NMOSE) 1990–2015; Texas Water Development Board 2020). In the future, demand for water to support hydrofracking in the Eagle Ford play may increase; only 17% of the projected total future wells have been drilled to date (Scanlon et al. 2020, pp. 3513–15).

In the Lower Rio Grande Valley below Anzalduas Dam, water removed from the river for irrigation and municipal use (the largest uses) does not return to the river; it is simply removed from the system (Edwards and Contreras-Balderas 1991, pp. 209–10; Rio Grande Regional Water Planning Group 2020, p. 1-9). The above tidal portion of the Rio Grande in the vicinity of Brownsville has been experiencing decreasing flows for decades, briefly did not reach the Gulf of Mexico in the early 2000s, and remains compromised and subject to the frequent recurrence of extreme low flows (Lower Rio Grande BBEST 2012, pp. 5-1–5-5). It has been suggested that if degradation of the aquatic habitat continues, the Rio Grande in the future could look more like the Pecos River in terms of structure and ecological communities (Hoagstrom 2003, p. 102).

A potentially ameliorating factor for the Rio Grande is the need to deliver water from Amistad Reservoir to the Lower Rio Grande Valley, which is done through reservoir releases into the main channel of the Rio Grande, thus maintaining flows in the river. The Lower Rio Grande Valley accounts for 88% of the land irrigated with Rio Grande surface water in Texas, and 96% of the land irrigated with Rio Grande surface water in Mexico, so a large volume of water is delivered from Amistad Reservoir to the Lower Rio Grande Valley to support irrigated agriculture (Miyamoto et al. 1995, p. 7). The Treaty of 1944 with Mexico mandates that the order of priority use of surface flows for the portion of the Rio Grande that overlaps with Rio Grande cooter's range is based on how that water will be used, not on seniority or the rule of capture (J. C. Schmidt et al. 2003, p. 30; Rio Grande Regional Water Planning Group 2020, pp. 1–8). Municipal users are in the first tier and are guaranteed their full water rights, while irrigators and mining industry users are in a secondary tier, which means they receive less than their full water right allocation in times of decreased flow or drought (Rio Grande Regional Water Planning Group 2020, pp. 1-8–1-9). Over 11 million people rely on Rio Grande surface water for domestic and municipal uses (Contreras-Balderas et al. 2002, p. 220). Because these uses are year-round rather than seasonal in nature (like irrigation demand), the large constituency for surface water deliveries on a regular basis implies some security against river drying for at least some portions of the mainstem Rio Grande, despite the continued disruption to the natural hydrological regime for the river (McKinney and Aparicio

2006, pp. 12–13; Lower Rio Grande BBEST 2012, pp. 2-14, 2-18, 2-31, 2-33, 2-26; Sandoval Solis 2019, p. 33; Rio Grande Regional Water Planning Group 2020, pp. 7-27, 7-32).

Río Salado Basin

Water development in the Río Salado basin occurs as a major dam (Don Martin) at the confluence of the Río Sabinas and the Río Salado de los Nadadores, and as surface water diversion and groundwater pumping, mostly for agriculture and domestic use (Davila Paulin 2020b, personal communication). The former has resulted in low flows and regular intermittency in the mainstem Río Salado from below the Don Martin Dam to the confluence with Falcon Reservoir (Berg 2020, personal communication; Strenth 2020, personal communication; Trujillo 2020, personal communication). The contribution of the Río Salado to Rio Grande flows is currently about 5% of the historical average (Contreras-Balderas et al. 2002, p. 221). Diversions and groundwater pumping have led to decreased flows and periodic intermittency in the Ríos Sabinas, Salado de los Nadadores, and Sabinas Hidalgo (Contreras-Balderas and Lozano-Vilano 1994, p. 381; Davila Paulin 2020b, personal communication; Strenth 2020, personal communication).

Río San Juan Basin

Large dams and reservoirs are also present in the Río San Juan watershed. El Cuchillo, Marte R Gomez, and La Boca Reservoirs fulfill the water needs of agricultural, industrial, and municipal users (Laureano and Návar 2002, p. 1256). Water development in this basin also takes the form of groundwater wells, especially to meet the needs of the city of Monterrey (Scott et al. 2007, pp. 255–56; Mora et al. 2017, pp. 3–4). Decreased flow is evident in the Río Salinas (Contreras-Balderas and Lozano-Vilano 1994, p. 381) and flows between the El Cuchillo Dam and the Marte R Gomez Dam are either absent or very low (Sanchez 1997, p. 429; Návar Cháidez 2011, p. 126). River gage data confirm these low flows. The contribution to Rio Grande flows of the Río San Juan had already declined to 10% of the historical average before the El Cuchillo Dam was completed in 1994; after, discharge dropped to an average of 1% of the historical flows (Sanchez 1997, p. 428; Contreras-Balderas et al. 2002, p. 221).

Pollution

Mechanisms

Water quality is a concern for both humans and animals across the range of Rio Grande cooter. Changes to water quality are common across the landscape due to anthropogenic activities and materials that can introduce a variety of contaminants into the environment, including industry, agriculture, construction, urban stormwater, municipal wastewater, spills or leaks of hazardous materials, and other sources. Often the fate and transport of environmental pollutants is dictated by the presence of water, following the path of natural surface and subsurface flows, resulting in exposures to soil, vegetation, and wildlife (Gregory and Hatler 2008, pp. 7–10). The most commonly reported water quality concerns in the Rio Grande cooter range are contamination and pollution from municipal and industrial wastewater, irrigation return flows, and activities associated with oil and gas development (Campbell 1958, p. 4; Boyer 1986, pp. 308–11; Ashworth 1990, pp. 30–32; Contreras-Balderas and Lozano-Vilano 1994, p. 383; International Boundary & Water Commission 1994, p. 1; Hoagstrom 2003, p. 94; 2009, pp. 35–36; Návar Cháidez 2011, pp. 133–42; Hogan 2013, pp. 10–12; Arm et al. 2014, pp. 26–29; Onsurez 2017; Eaton 2017; Grijalva 2019; Hedden 2020c).

Water Development

Periodic floods can function as a mechanism to flush water with high concentrations of salts and pollutants downstream and out of a watershed; removing floods from a system by capturing runoff in large reservoirs removes this flushing mechanism (Hoagstrom 2009, pp. 31–32). In areas where groundwater is more saline than typical surface water, increases in the proportion of baseflow (the portion of the streamflow that is sustained between precipitation events and fed to streams by delayed pathways) that occur because surface water is diverted for other uses, result in a more saline surface water system (Miyamoto et al. 2005, pp. 17–20; Hoagstrom 2009, pp. 31–32). Evaporation, which is greater from reservoirs than from rivers or streams, increases the concentration of pollutants (Hogan 2013, p. 8). For water bodies with naturally elevated salt loadings, flow reduction due to water development may result in increases in salinity that tip past thresholds like drinking water standards or species tolerance levels (Miyamoto et al. 2005, p. 3; Hoagstrom 2009, pp. 35–36).

Oil and Gas

Prior to the passage and enforcement of clean water laws in the 1970s and later, produced water from oil fields was disposed into unlined surface pits, which allowed this contaminated and highly saline water to percolate into aquifers and streams (Wiebe et al. 1934, pp. 82–85; Campbell 1958, p. 4; Boyer 1986, pp. 308–11; Ashworth 1990, p. 30). Despite regulations, enforcement of laws against surface disposal of oil and gas production-related wastes was not easy and it took time for these practices to be stopped (Boyer 1986, pp. 310–11). Problems with illegal dumping of materials such as produced water remain an issue in oil and gas producing areas (Gregston 2021, personal communication). The injection of brines into wells for brine disposal or secondary recovery continues to present an opportunity for water contamination (Ashworth 1990, p. 31; Scanlon et al. 2020, p. 3515). Such wells can introduce chemical contaminants to surface or groundwater, and the high salinity of the brines can increase aquatic salinity (Houston, Thomas, Jonathan V., Ging, et al. 2019, pp. 30–33). Improperly or inadequately cased oil and gas wells are another source of potential contamination to both surface and groundwater; older wells are riskier because as they age they may fail and contaminate groundwater (Ashworth 1990, pp. 30–31). Contaminants found in water wells include brine, dissolved hydrocarbons, oil on water, and dissolved natural gas (Boyer 1986). Pipelines present another potential route of contamination; they may contain oil, gas, or brines; leaks or ruptures to pipelines can allow these materials to enter underground aquifers (Ashworth 1990, p. 31). In addition, surface spills of oil, brines, or other materials such as drilling mud have contaminated waterways in the past (Arm et al. 2014, pp. 29, 114; Eaton 2017; Hedden 2020c; 2020b).

Municipal and Industrial Use

Inadequate wastewater management by municipal and industrial users can result in contaminants being released directly into waterways. Urban runoff pollution includes garbage, oils and greases, pesticides, heavy metals, and other materials that are carried from impervious surfaces to streams (Contreras-Balderas and Lozano-Vilano 1994, p. 383; Hogan 2013, p. 12). Leaking septic systems, sewer malfunctions, wild and domestic animal waste, and leachate (i.e., leakage) from landfills also contribute to aquatic pollution associated with urban areas (Hogan 2013, p. 10). Heavy metal and toxic chemical accumulation is another stressor associated with industrial development (Návar Cháidez 2011, pp. 133–38) and is often present as legacy contamination in areas with a history of commercial use or industrial manufacturing.

Irrigation

Water used for irrigation becomes more saline due not only to evapotranspiration, but also the accumulation of salts as they are leached from soils with available salt compounds (Ashworth 1990, p. 31; Arm et al. 2014, p. 26). Return water flows from irrigation thus can increase the salinity of underground aquifers when irrigation water percolates to them, or increase the salinity of surface water when irrigation water returns to the closest stream or river (Hoagstrom 2009, pp. 31–32). Irrigation is, by far, the largest water user of both groundwater and surface water across much of the Rio Grande cooter range (NMOSE 2016, pp. 172–78; Far West Texas Planning Group 2020, p. 5-6; Freese and Nichols, Inc. 2020, pp. ES-5, ES-8; Plateau Water Planning Group 2020, p. ES-3; Rio Grande Regional Water Planning Group 2020, p. ES-14). Therefore, irrigation is tied indirectly to the concentration of contaminants from reduced flows and directly to degradation of water quality through increased salinity (Lang and Gordon 2001, p. 9; Miyamoto et al. 2006, pp. 2–4). Irrigation sometimes contributes to decreased salinity by transferring some of the salt loading in surface water to the soils under irrigated crops (Miyamoto et al. 2007, p. 29).

Impacts to Species Needs

Water quality is an integral component of habitats that support aquatic species, with all or some life stages dependent on the presence of water of sufficient quantity and quality to support survival, growth and reproduction. Aquatic species often respond to changes in water quality when they are able to sense undesirable conditions, although not all changes are detectable and may go unnoticed (Agha et al. 2018, p. 1643). Rio Grande cooter tolerance for specific water quality parameters (e.g., temperature, salinity) or xenobiotics (i.e., environmental pollutants) has not been explicitly tested. Thus, its vulnerability to, and hence the level of threat from, various contaminants is unknown. Other species of freshwater turtles have been observed responding to increases in water salinity by moving to fresher water, reducing feeding, or reducing drinking (Agha et al. 2018, p. 1643). The latter two responses can result in poor health or death due to starvation or dehydration, demonstrating the importance of available and accessible freshwater refugia (Cheek and Taylor 2016, pp. 347–48; Agha et al. 2018, p. 1643). Exposure to contaminants including heavy metals and pesticides is known to cause lethal and sublethal harm to reptiles (Yu et al. 2013, p. 555). Specific sublethal effects include increased metabolic rates, disrupted reproduction, decreased swimming performance, sex reversal, and impaired righting ability (Yu et al. 2013, pp. 555–56). Impacts to individuals can lead to population-level effects if there is increased mortality among individuals or if the sexual structure of the population is significantly altered (Yu et al. 2013, pp. 555–56).

Geographic and Temporal Scope

Pecos River Basin

High salinity and the threat of contaminants entering the water system are present throughout the Pecos River, but the area of highest risk is the portion of the watershed that intersects the Permian Basin. Anthropogenic sources of salinity include saltwater disposal associated with oil and gas production, oil field spills, irrigation return flows, and saline water intrusion via aquifers due to groundwater pumping (Houston, Thomas, Jonathan V., Ging, et al. 2019, p. 33). Natural and anthropogenic sources of salinity, in combination with low flows due to river management, have led to high salinity in the mainstem Pecos River above Red Bluff Reservoir, as well as in the reservoir itself (Hoagstrom 2003, pp. 102–3; 2009, pp. 32–39; Miyamoto et al. 2005, entire; Yuan et al. 2007, entire; Houston, Thomas, Jonathan V., Ging, et al. 2019, pp. 25–29). The problem of salt water pollution from oil production has been a long-standing issue for the region, with a 1934 report calling it a “menace” to Texas’s aquatic resources (Wiebe et al. 1934, p. 85). Major pollution events associated with above and below ground oil and produced water spills were an issue for decades before the imposition of increased regulations in the second half of the 20th century, and have long been given as an explanation for the absence of Rio Grande cooter from the Red Bluff Dam to the lower Pecos River in Texas (Campbell 1958, p. 4; Ward 1984; Boyer 1986, p. 32). The focus of contaminants and ecological change research shifted to a focus on salinity by the 1990s and early 2000s (Miyamoto et al. 1995; 2005; 2006; 2007; Hoagstrom 2003; 2009; Gregory and Hatler 2008). This may be due to some recovery of the Pecos River in terms of toxicity; recent sampling by the Texas Commission on Environmental Quality (TCEQ) did not find any toxic contaminants exceeding State water quality criteria (TCEQ 2014, pp. 124–53; 2020a, pp. 85–122). Golden algae first appeared in the Pecos River in the 1960s, followed in the late 1980s by the first of many major fish kills (Jensen et al. 2006, p. 10; Kills and Spills Team 2020). We found no evidence that golden algae blooms harm Rio Grande cooter; Rio Grande cooter inhabit waters that regularly experience blooms, and golden algae impact species with gills (Sallenave 2018, p. 2; Kills and Spills Team 2020). However, such blooms are an indicator of elevated salinity, and their presence and frequency implies that regardless of the remediation of contaminants pollution in this river, elevated salinity has become a perennial problem for the aquatic ecosystem (Arm et al. 2014, p. 29; Sallenave 2018, pp. 1–4). Instances of wastewater dumping onto roadways or ditches, improper handling at disposal facilities, and inadequate or failing storage infrastructure have been observed across the Permian Basin (Gregory and Hatler 2008, p. 86; Fehling 2013; Beal 2017; Mulder 2015). Dozens of hazardous materials spills or leaks totaling thousands of gallons of materials including oil, brines, and other associated materials recur annually in the Permian Basin, resulting in mortality to aquatic life, including fish and turtles (New Mexico Oil Conservation Division 2020; Railroad Commission of Texas 2020; Kills and Spills Team 2020; Tidwell 2021, personal communication).

Devils River Basin

The Devils River does not have a history of contamination, and is at low risk of hazardous materials spills or leaks or high salinity today (Houston, Thomas, Jonathan V., Pedraza, et al. 2019b; Railroad Commission of Texas 2020; TCEQ 2020c). No fish kill events have been recorded since one caused by a sewage spill in the Dry Devils River leading to low DO in 2007 (Kills and Spills Team 2020). The Upper Rio Grande BBEST characterized its water quality as “exceptional” (Upper Rio Grande BBEST 2012, pp. xviii, 1-11–1-13).

Rio Grande Basin

High salinity and the presence of contaminants are also a concern throughout the mainstem Rio Grande basin (Rio Grande Regional Water Planning Group 2020, p. ES-9). Perhaps because the Rio Grande is used not only for irrigation, but also as a source of drinking water for millions of people, its salinity and contaminants have received a great deal of attention and mitigation (Contreras-Balderas et al. 2002, p. 220; U.S. Environmental Protection Agency 2012, entire). Sources of salinity in the Rio Grande stem from loss of water in the river channel due to evapotranspiration and uptake by riparian vegetation, as well as salty irrigation return flows (U.S. Department of the Interior 2002, p. 1; Hogan 2013, p. 8). Increasing salinity in tributaries to the Rio Grande, such as the Río Conchos and especially the Pecos River, also impacts the mainstem river (Miyamoto et al. 2006, pp. 2–9, 20; 2007, pp. 26–29). Evidence of increased salinity in the form of golden alga blooms above Amistad Reservoir recurred from 1985–2007, was absent 2007–2013, and recurred again in 2014 and 2015 (Texas Clean Rivers Program 2013, pp. 25–26; Kills and Spills Team 2020).

Contamination in the Rio Grande basin also comes from sewer malfunctions and illegal wastewater discharges, including from factories along the border, as well as leaking landfills, illegal trash dumping, and mining waste runoff (U.S. Department of the Interior 1998, p. 1; Hogan 2013, pp. 10–12; Grijalva 2019, p. 21; Rio Grande Regional Water Planning Group 2020, p. ES-8). Subreaches of the river near wastewater outfalls, colonias (small communities without basic wastewater infrastructure), and factories are more likely to have concerns for toxicity in the water or sediment (Texas Clean Rivers Program 2013, p. 7; Rio Grande Regional Water Planning Group 2020, pp. ES-8, 1-11). Hazardous materials spills or leaks associated with oil and gas development, fish kills, and leaking underground petroleum storage tanks are consistently present at low levels, and often impact surface or groundwater (TCEQ 2019b; Railroad Commission of Texas 2020; Kills and Spills Team 2020).

Río Salado Basin

Pollution associated with urban and industrial development is the chief concern associated with the rivers in the Río Salado basin (Davila Paulin 2020b, personal communication). Coal mining and its associated effluents are specifically an issue for the Río Sabinas (Davila Paulin 2020b, personal communication). Below the Don Martin Dam, the Río Salado has some contaminant concerns, which are likely exacerbated by the very low flows (International Boundary & Water Commission 1994, pp. 25–26). The Río Salado does not appear to contribute contaminants to the Rio Grande in any significant quantities (Rio Grande Regional Water Planning Group 2020, p. 7-24).

Río San Juan Basin

Urban runoff pollution observed in this river includes trash, oils, pesticides, detergents, and metals (Contreras-Balderas and Lozano-Vilano 1994, p. 383). Pollution in this basin has been a problem for at least the past few decades; in 1998 the Rio San Juan was deemed the third most polluted river in Mexico (Návar Cháidez 2011, p. 133). High concentrations of heavy metals have been observed in its tributaries and bioaccumulation has occurred in the tissue of resident fish (International Boundary & Water Commission 1994, pp. 25–26; Návar Cháidez 2011, pp. 133–38). Wastewater treatment in the basin is unreliable, adding further to contaminant loading in the system (Návar Cháidez 2011, p. 142; Nevárez-de los Reyes 2020, personal communication).

Climate Change

Mechanisms

Greenhouse gas emissions from human activities such as fossil fuel combustion, deforestation, agriculture, and land use change are the primary driver behind the climate changes observed since the industrial revolution of the 19th century (Hayhoe et al. 2018, pp. 76–78). The mean global temperature increased by about 1.0° C from 1901 to 2016, and by 0.65° C from 1986 to 2015, indicating an increase in the rate of change in recent decades (Hayhoe et al. 2018, p. 76). An average increase in temperature manifests locally as higher extremely high temperatures and higher overnight low temperatures, in addition to higher averages (Hayhoe et al. 2018, p. 88). Texas is known for having high variability in both its temperature and its precipitation, which can somewhat mask the effects of climate change, but long-term trends in climate parameters are apparent (Jensen et al. 2006, p. 4; Nielsen-Gammon et al. 2020, p. 3). Temperature increases have occurred and are anticipated throughout the Rio Grande cooter range (Shafer et al. 2014, p. 444; Runkle et al. 2017, pp. 1–2; Kloesel et al. 2018, pp. 992–95, 1003). In terms of precipitation, broadly speaking, wet areas are expected to get wetter and experience more intense precipitation events, while dry areas are expected to get drier and experience more intense drought events (Shafer et al. 2014, pp. 443–45; Runkle et al. 2017, pp. 2–4; Kloesel et al. 2018, pp. 995–96, 1004). Another effect of climate change is exacerbated drought due to feedback loops between high air temperatures, low humidities, and low soil moisture (Cheng et al. 2019, pp. 4437–40). Increased evapotranspiration of surface water and increased demand for water are additional consequences of increased temperatures and droughts (Mace and Wade 2008, p. 658; Shafer et al. 2014, pp. 447–48; Kloesel et al. 2018, p. 999). Decreased surface water reliability is likely to lead to increased groundwater reliance (Kloesel et al. 2018, pp. 1001–4). Karstic aquifers, thought to be more vulnerable to changes in temperature and precipitation, are present in a large portion of Rio Grande cooter's range, including along the Pecos and Devils Rivers in the United States and in the Río San Juan and Río Salado basins in Mexico (Mace and Wade 2008, pp. 659–61; Houston, Thomas, Jonathan V., Ging, et al. 2019, p. 6). Aquifers with high recharge rates, such as the Edwards-Trinity Plateau Aquifer in central and west Texas, and elsewhere within the Rio Grande cooter range, are vulnerable to changes in precipitation and runoff, which makes them less reliable as sources of groundwater (Mace and Wade 2008, p. 657; Kløve et al. 2014, p. 253; NMOSE 2016, pp. 69, 96–102, 136; Far West Texas Planning Group 2020, pp. 3-31–3-32; Freese and Nichols, Inc. 2020, pp. 1-60, 3-4, 3-9, 7-7; Plateau Water Planning Group 2020, pp. 1-10, 1-22, 3-9, 3-13, 3-14, 3-29; Rio Grande Regional Water Planning Group 2020, pp. 3-32, 7-28).

Impacts to Species Needs

The main impact of climate change on Rio Grande cooter has been, and is likely to continue to be, in the form of increasing pressure on the surface and ground water resources that provide or support habitat for the species. It is possible that higher future average temperatures could lead to sex ratios in egg clutches skewed toward females, but we determined that the uncertainty in precisely how and to what extent this would play out in Rio Grande cooter populations was too large to attempt to incorporate this into our analysis (Valenzuela et al. 2019, entire). See the above discussion on impacts from water development for more information on how declines in water availability impact Rio Grande cooter.

Direct Mortality

Mechanisms

Predation, shooting, fish hook ingestion, bycatch, and collection are all mechanisms that can reduce the abundance of Rio Grande cooter populations, and have the potential to impact eggs, hatchlings, juveniles, and adults.

Animals from multiple taxa may depredate Rio Grande cooter during all life stages. Based on direct observations and knowledge of related turtle species, we presume that Rio Grande cooter experience predation from a range of other wildlife, including skunks, coyotes, foxes, and raccoons, birds of prey, ravens, wading birds, bullfrogs, and fire ants (Congdon and Gibbons 1990, p. 52; Forstner et al. 2004, pp. 26–28; Moll and Moll 2004, pp. 76–77; Ernst and Lovich 2009, pp. 209, 375, 379, 407; Pierce et al. 2016, p. 100.8; Bowne et al. 2018, pp. 1151–52; Bogolin, Davis, and Rahman 2019, p. 775). The impact of predators on Rio Grande cooter survival or abundance has not been systematically studied or quantified, nor are estimates of such impacts available for Rio Grande cooter. We did not find any evidence of localized extirpations due to excessive predation.

Humans also kill turtles, both by accident and on purpose. People who are hunting or using guns for recreation, either on shore or in boats, sometimes shoot at turtles, including Rio Grande cooter, for fun, for "target practice," or with the intent of eliminating a potential competitor species (Conant 1977, p. 489; NMDGF 1988, p. 2; Christman and Kamees 2007, p. 8; Pierce et al. 2016, pp. 100.7–100.8; MacLaren, Foley, et al. 2017, p. 48; Mali and Forstner 2017, p. 11; Mali and Suriyamongkol 2019, pp. 11–16; Mahan, Ortega-Berno, et al. 2020, pp. 827–28; Mali et al. 2020a, p. 15). Humans fishing either from shore or by boat sometimes hook Rio Grande cooter on their lines (MacLaren, Foley, et al. 2017, p. 48; Mali and Suriyamongkol 2019, pp. 11–16; Suriyamongkol et al. 2019, pp. 776–77). Rio Grande cooter may die after ingesting the fish hook, or be captured, and then either removed from the hook or killed by the angler (NMDGF New Mexico Department of Game and Fish 1988, p. 2; Pierce et al. 2016, pp. 100.7–100.8; MacLaren, Foley, et al. 2017, p. 48; Waldon et al. 2017, p. 837; Mali and Suriyamongkol 2019, pp. 11–16; Suriyamongkol et al. 2019, pp. 776–77; Letter et al. 2019, p. 207). There are access points and recreational use of the rivers and streams inhabited by Rio Grande cooter throughout its range.

Collection for the pet trade has been cited as a major concern for Rio Grande cooter (Forstner et al. 2004, p. 13; Adkins Giese et al. 2012, p. 125; Bailey et al. 2014, p. 322). The impact on nonmarine turtles of commercial trade is a significant threat to some turtle species (Fitzgerald et al. 2004, p. 4). Individual persons may remove turtles from the wild for personal ownership, the domestic trade, or international trade (Reed and Gibbons 2003, pp. 3–14; Vitt and Caldwell 2014, pp. 423–26). Rio Grande cooter have been present in the domestic pet trade, implying that, at minimum, they were collected in the past in order to found captive populations (reptiledude2 2003; JROOTS 2011; Unknown 2014; 2016; xG8Rx 2014; Snakesatsunset 2016; Nauti-LassCritters 2019; Robert/Trish 2019). The U.S. Fish and Wildlife Service's LEMIS database tracks wildlife exports; a review of Rio Grande cooter exports from 2003–2020 found that on average, about 120 (range 1–451) individuals of this species are exported annually, indicating some international demand (U.S. Fish and Wildlife Service 2020c). We have no information on the source location for Rio Grande cooter used in the pet or wildlife trade.

Restrictions on reptile collection in general and Rio Grande cooter specifically are in place across this species' range. New Mexico state law has prohibited the collection of most native reptiles for commercial purposes, including Rio Grande cooter since 2001 (17-2-4.2 NMSA 1978). Rio Grande cooter was first designated as endangered Group 2 (= Threatened) in the state of New Mexico in 1975, under what as then New Mexico Department of Game and Fish Regulation 563. Species listed as threatened or endangered under the New Mexico Wildlife Conservation Act (17-2-37 through 17-2-46 NMSA 1978), including Rio Grande cooter, are protected against killing, possession, retention or sale without a license or permit under 19.31.10 NMAC. However, there are currently no rules or regulations in place that prohibit the collection of Rio Grande cooter by individuals for personal use, such as to keep as a pet (Baldwin 2021, personal communication). In Texas, restrictions on the commercial collection and sale of nongame wildlife, including turtles, was first implemented in 1998 (31 TAC §§65). The regulations from 1998–2007 required permits for collecting and dealing nongame wildlife, relying on a list of covered species (Texas Parks and Wildlife Department 1998b, pp. 1034–38; 2002, pp. 10041–43). Prior to 2007, this list of covered species did not include Rio Grande cooter (Texas Parks and Wildlife Department 1998a, p. 4223; 2002, pp. 10159–60). In 2007, regulations on the collection of nongame wildlife were modified again (Texas Parks and Wildlife Department 2007, pp. 7472–90). Rio Grande cooter was excluded from any commercial trade by the modified regulations (Texas Parks and Wildlife Department 2007, pp. 7472–90, 7517–22). The regulations also stipulated that individual, noncommercial collectors may collect and possess up to six Rio Grande cooter as long as they are collected from waters on private land (Texas Parks and Wildlife Department 2007, p. 7473). The number of collectors or of individual Rio Grande cooters removed from the wild in Texas, either cumulatively or annually, is not recorded and is unknown. In Mexico, Rio Grande cooter have been listed as Amenezada (Threatened) since 2010, and the capture and possession of wild Rio Grande cooter is only permitted for the purposes of conservation; there are no current permits for such activities (CONABIO 2020, pp. 6–7).

Impacts to Species Needs

Removing adults from a population of turtles has negative effects on recruitment, population growth, and species viability (Ernst et al. 1994, p. xxxii; Ceballos and Fitzgerald 2004, p. 881; Moll and Moll 2004, pp. 175, 275). Population resiliency is decreased because population abundance and fecundity decrease (Moll and Moll 2004, pp. 4, 175, 229, 316–19). The life history strategy of Rio Grande cooter depends on adults who live long enough to reproduce many times; the loss of adults to this stressor impairs that life history strategy (Reed and Gibbons 2003, pp. 16–19; Ceballos and Fitzgerald 2004, p. 881; Moll and Moll 2004, p. 4). Where sufficient numbers of individuals are removed from a population, population-level effects may result (Ceballos and Fitzgerald 2004, p. 881; Fitzgerald et al. 2004, pp. 4, 71; Steen and Robinson 2017, pp. 1334–37).

Geographic and Temporal Scope

All of the mechanisms described in this section potentially act on Rio Grande cooter across its entire range. Because the range of Rio Grande cooter is so large and includes many remote areas, it is difficult to measure and evaluate whether and to what extent the species is impacted by predation, shooting, fish hook ingestion, bycatch, and collection. In addition, due to the lack of studies examining these phenomena systematically, we were unable to meaningfully identify rates of impact to Rio Grande cooter from predation, shootings, or being caught on fishing lines, or differentiate their vulnerability across population analysis units. The observations of death or injury from such events are incidental and opportunistic in nature. Evaluating the impacts of collection was similarly challenging. In a review of the reptile trade in the Chihuahuan Desert Ecoregion, the Pecos and Black Rivers in New Mexico were identified as the primary collection areas for aquatic turtles, and the vicinity of Langtry, Comstock, Sheffield, and Iraan in Pecos and Val Verde Counties were identified as the primary collection area for herptiles in Texas (Fitzgerald et al. 2004, pp. 4, 37, 40–46, 60, 70–71). Although it is possible that illegal collection is taking place but not being witnessed, we were unable to locate a documented instance of legal or illegal collection of Rio Grande cooter taking place. Temporally, increasing restrictions on the legal collection of reptiles, culminating in today’s regulations, which prohibit its commercial collection from its range entirely, should mean that Rio Grande cooter is less threatened by collection today than in the past.

Each of these stressors directly affects Rio Grande cooter at the individual level. In our analysis, we were unable to determine any potential populations where any of these stressors impacted individuals to a sufficient degree that population-level effects were discernable. In addition, we were unable to find evidence that Rio Grande cooter was more or less threated by any of these mechanisms in one part of its range compared to another. Because of these issues, we did not include a metric evaluating resiliency in the context of direct mortality in the next chapter.

Conservation Efforts

Protected Areas

Mechanisms and impacts to species needs

Protected areas are those in which the upland habitat along a spring, stream, or river are protected from development and managed for conservation. These lands may be privately or publicly held. We are not aware of any lands managed specifically for the benefit of Rio Grande cooter, but anticipate that benefits to the Rio Grande cooter may accrue for areas where the stressors described above are less likely to occur. For example, protected areas will presumably have fewer groundwater pumping operations and fewer activities associated with oil and gas development, and some protected areas may experience less human pressure. Fewer stresses on Rio Grande cooter abundance, reproduction, and dispersal would have positive population-level effects.

Geographic and Temporal Scope

The geographic and temporal scope of the influence of protected areas is fairly small in proportion to the extent of the Rio Grande cooter's range. Most protected areas focus on conserving land rather than water, though protecting watersheds and riparian areas should confer some protection on local surface water. Here we describe the lands and waters protected from development within the species' range.

Pecos River Basin

While the Bureau of Land Management manages a large quantity of land in the Pecos watershed in New Mexico, that management generally provides for multiple uses that result in the presence of all of the stressors described above. A recreational area on the upper Black River currently appears to experience fewer of the stresses associated with water development and pollution than other stream segments in the area, and nearby Rattlesnake Springs is protected from further development due to its National Park Service ownership. In Texas, along Independence Creek near its confluence with the Pecos River, The Nature Conservancy owns a combination of preserve land and easements that protect the creek and its springs. This area includes a long-established Rio Grande cooter population, and is one of the places where reproduction is known to occur.

Devils River Basin

A combination of The Nature Conservancy owned land and easements along the Devils River is complemented by a state preserve; the result is protected aquatic and upland habitat used by Rio Grande cooter. Rio Grande cooter are also known to reproduce in the area.

Rio Grande Basin

There are a few protected areas along the Rio Grande, but their contribution to Rio Grande cooter population health is difficult to describe with confidence. Lands managed for conservation in this basin include Big Bend National Park, Big Bend Ranch State Park, Amistad National Recreation Area, Falcon State Park, and the Santa Ana and Lower Rio Grande Valley National Wildlife Refuges. These areas provide intermittent protection along the Rio Grande, and likely confer the most benefit to Rio Grande cooter if they include nesting habitat (nesting locations for Rio Grande cooter in this basin are unknown). It is also possible that the river's water quality improves near protected areas due to a lack of pollution inputs, but this has not been carefully studied. The Rio Grande between Big Bend National Park and Amistad Reservoir has been designated a Wild & Scenic River. Wild and Scenic Rivers are free of impoundments, have largely undeveloped shorelines, and are characterized by high water quality (U.S. Federal Government n.d.). Big Bend National Park administers the portion of the river designated Wild &

Scenic, of which 69 river miles (111 km) are in the Park and are managed for conservation (National Park Service 2013). An additional 127 river miles (204 km) downriver of the Park boundary are protected through a combination of voluntary stewardship by landowners and river users, and through regulation and government programs (National Park Service 2013; U.S. Federal Government n.d.).

Río Salado Basin

The headwaters of the Río Sabinas and Río Salado de los Nadadores belong to the Distrito Nacional de Riego (National Irrigation District) 004 Don Martín. The protected area includes the Cuatro Ciénegas Basin and the Río Sabinas from the Serranias del Burro (a mountain range) to just above the Don Martin Reservoir. The irrigation district is designated as an Área de Protección de los Recursos Naturales (Natural Resources Protection Area), a special class of lands that protects watershed headwaters, associated forests, and some parts of the watershed (LGEEPA 1988, p. 38). These lands provide an indirect benefit to Rio Grande cooter in the Río Salado de los Nadadores, and a more direct benefit to Rio Grande cooter in the Río Sabinas basin, where the protected area includes the river itself.

Río San Juan Basin

There are three protected areas in the Río San Juan Basin. The headwaters of the Río Pilón, a tributary to the Río San Juan, belong to the Distrito Nacional de Riego 026 Lower Río San Juan. This irrigation district is also an Área de Protección de los Recursos Naturales. In addition, the Cumbre de Monterrey Parque Nacional (National Park) protects a large amount of land in the upper basin, and the Cerro de la Silla Monumento Nacional (National Monument) protects a small amount of land on the edge of the city of Monterrey, Nuevo León. In Mexico, National Parks and National Monuments both provide some protection of the natural resources within their boundaries to the lands so designated (LGEEPA 1988, pp. 37–38). These latter two together support the improved condition of the Río de la Silla, where Rio Grande cooter have been found. These lands benefit Rio Grande cooter indirectly (no Rio Grande cooter have been observed within the boundaries of these specially designated areas).

Carlsbad Project Water Operations and Water Supply Conservation

Mechanisms and impacts to species needs

In 2017, the U.S. Fish and Wildlife Service (USFWS) issued a Biological Opinion (BO) in formal consultation with the Bureau of Reclamation (BOR) for the Carlsbad Project (Project) Water Operations and Water Supply Conservation, 2016–2026 (U.S. Fish and Wildlife Service 2017, entire). This BO evaluated a modified extension of Pecos River water operations for the Project—the storage and release of irrigation water for the Carlsbad Irrigation District (CID). The BO further established certain measures specifically designed to conserve the threatened Pecos bluntnose shiner (*Notropis simus pecosensis*) and Interior Least Tern (*Sternula antillarum athalassos*) that are likely to also benefit Rio Grande cooter. The intent of the modified operational approach is to minimize river drying between Sumner and Brantley Reservoirs, and to help buffer the system against future drought by increasing in-stream/supplemental water supplies and permanent storage capacity in upstream reservoirs.

The range of the Pecos bluntnose shiner in the Pecos River overlaps with that of Rio Grande cooter in the *Pecos River – Sumner Dam to Brantley Dam* population analysis unit (Figure 3.5). In this assessment we consider the contemporary water operations established in the 2017 BO. Under the Project BO, BOR structures their water management actions in order to minimize river drying, especially within Pecos bluntnose shiner critical habitat (U.S. Fish and Wildlife Service 2017, p. 7). A previous BO covering the same area and entities from 2006 to 2016 placed a higher priority on maintaining target flows at certain stream gages than on minimizing drying (U.S. Fish and Wildlife Service 2017, p. 7). The earlier approach (i.e., target flows) tended to quickly deplete supplemental water supplies, leaving little or no buffering capability for hot summer months and drought periods. Maintaining a continuous flow in the mainstem Pecos between Sumner and Brantley Reservoirs will also benefit Rio Grande cooter and its habitat. Current Pecos bluntnose shiner conservation measures tend to mitigate, to some degree, stressors such as decreased water quantity because the preservation of continuous flow allows for movement to refugia where water quantity and water quality conditions are better (see the relevant sections above for a discussion on how those stressors impact Rio Grande cooter).

Geographic and Temporal Scope

The action area covered by the BO includes the Pecos River from Santa Rosa Reservoir downstream to the final delivery point of the CID Main Canal (U.S. Fish and Wildlife Service 2017, p. 7). That canal is located upstream of the city of Carlsbad and below Avalon Reservoir (U.S. Fish and Wildlife Service 2017, p. 50). However, It is important to note that the delivery of supplemental water to minimize river intermittency is only applicable to Pecos bluntnose shiner habitat located from Sumner Reservoir to the Brantley Reservoir inlet (U.S. Fish and Wildlife Service 2017, p. 8). The current BO is valid from 2016 to 2026, and may be extended to 2031 (U.S. Fish and Wildlife Service 2017, p. 39). A 5-year review of the status of Pecos bluntnose shiner was completed in 2020 and noted that water management and conservation like what is described in the BO is needed “in perpetuity” in order to ensure the survival of Pecos bluntnose shiner (U.S. Fish and Wildlife Service 2020d, p. 14). We therefore anticipate that the actions described in the BO will continue into the foreseeable future.

Candidate Conservation Agreements and Candidate Conservation Agreements with Assurances

Mechanisms and impacts to species needs

In 2017, the USFWS signed a Candidate Conservation Agreement (CCA) with the Bureau of Land Management (BLM) and The Center of Excellence (CEHMM) (U.S. Fish and Wildlife Service et al. 2017, entire). At the same time, the USFWS signed Candidate Conservation Agreements with Assurances (CCAAs) with the New Mexico Commissioner of Public Lands and with CEHMM (U.S. Fish and Wildlife Service and New Mexico Commissioner of Public Lands 2017, entire; U.S. Fish and Wildlife Service and The Center of Excellence (CEHMM) 2017, entire). The CCA covers activities on Federal lands, while the CCAAs cover activities on state trust and private lands; collectively, we refer to them as the CCA/As. The purpose of these agreements is to formalize partnerships and provide a mechanism to fund and implement conservation actions to benefit the covered species, which include Rio Grande cooter (U.S. Fish and Wildlife Service et al. 2017, pp. 2, 12). Participants agree to follow the guidance of the USFWS and CHEMM in avoiding or minimizing activities that are identified as threatening the species covered by these agreements (including Rio Grande cooter) and their habitats. The CCA/A conservation measures are designed to reduce negative impacts to water quality and quantity associated with covered activities, and we expect Rio Grande cooter and its habitat to benefit from their implementation (U.S. Fish and Wildlife Service and New Mexico Commissioner of Public Lands 2017, pp. 13–18; U.S. Fish and Wildlife Service and The Center of Excellence (CEHMM) 2017, pp. 25–33; U.S. Fish and Wildlife Service et al. 2017, pp. 26–34)

Participants include oil and gas operators, solid minerals mining companies, water withdrawers, farmers and ranchers, the CID, and other interested stakeholders that hold Federal leases, permits, or other authorizations (U.S. Fish and Wildlife Service and The Center of Excellence (CEHMM) 2017, p. iii; U.S.

Fish and Wildlife Service et al. 2017, p. iii). The key conservation measures in the agreements are designed to limit oil and gas development to areas outside of the Black and Delaware River floodplains, minimize erosion due to surface disturbance, and maintain minimum water flows in the rivers by reducing or ceasing water withdrawals when river gages drop below certain levels (U.S. Fish and Wildlife Service et al. 2017, pp. 26–34, 53). These measures counteract stressors such as low water flows and pollution; see the relevant sections above for a discussion on how those stressors impact Rio Grande cooter.

Geographic and Temporal Scope

The total geographic extent potentially covered by one of the three agreements includes approximately 575,000 acres (230,000 hectares). Substantial acreage under federal, state, and private ownership is enrolled in the CCA/As, but the proportion of the potential total is unknown due to the way enrollments are characterized in publicly available reports (CEHMM-Center of Excellence and State of New Mexico Commissioner of Public Lands 2020, p. 5). The potential aquatic extent covered by the CCA/As includes portions of the Black and Delaware Rivers in New Mexico and Texas and associated ephemeral streams. Lands covered by the CCA/As include the floodplains of the Black and Delaware Rivers, and a portion of the Pecos River (U.S. Fish and Wildlife Service and New Mexico Commissioner of Public Lands 2017, p. 34; U.S. Fish and Wildlife Service and The Center of Excellence (CEHMM) 2017, pp. 53–54; U.S. Fish and Wildlife Service et al. 2017, pp. 52–53). The CCA/As were signed in 2017 and are valid for 30 years (U.S. Fish and Wildlife Service and New Mexico Commissioner of Public Lands 2017, p. 24; U.S. Fish and Wildlife Service and The Center of Excellence (CEHMM) 2017, p. 41; U.S. Fish and Wildlife Service et al. 2017, p. 40). The Delaware River portion will be reassessed in 2026 to determine if a self-sustaining population of Texas hornshell have been established (U.S. Fish and Wildlife Service and The Center of Excellence (CEHMM) 2017, p. 19; U.S. Fish and Wildlife Service et al. 2017, p. 19). If such a population is not established, conservation measures required for CCA/A participants for the Delaware River and its associated USGS 100-year floodplain may potentially be revised (U.S. Fish and Wildlife Service and The Center of Excellence (CEHMM) 2017, p. 19; U.S. Fish and Wildlife Service et al. 2017, p. 19).

5 Current Condition

In this chapter, we present the results of Rio Grande cooter current condition in terms of resiliency, redundancy, and representation.

Current Resiliency

Resiliency Analysis Methodology

Resiliency is the ability of a species to withstand environmental and democraphic stochasticity: periodic disturbances within the normal range of variation. We gauge resiliency by evaluating population-level characteristics. We sought to include both habitat and demographic factors because our conceptual model (Figure 4.1) identified both as influencing viability. To do this, we assessed available data to quantify or qualitatively describe the intersection between species needs and factors influencing viability. We reviewed online databases, reports, scientific publications, books (including field guides), hydrological spatial datasets, water quality datasets, unpublished datasets, and newspaper articles, and interviewed individual researchers in an effort to locate information that could be standardized and applied to Rio Grande cooter population analysis units across its entire range. Our Cause and Effects Tables (Appendix A) also informed this assessment by serving as the basis by which we decided what metrics to include in the resiliency analysis.

After considering the available data and the stressors described in Chapter 4, we selected two demographic factors (*Occurrence* and *Subadult Presence*) and three habitat factors (*Occurrence Complexity*, *Water Quantity*, and *Water Quality*) for our resiliency analysis. Based on the available data and our understanding of Rio Grande cooter ecology, we developed a basis for assigning a risk category for each metric at the population analysis unit level. The risk category reflects a qualitative determination of the likelihood that the species response to the conditions described in each individual metric, over the 30-year period following the year 2020, would be extirpation from a given population analysis unit. This 30-year timeframe correlates with two approximately 15-year generations, or slightly longer than the presumed average Rio Grande cooter lifespan of 20–25 years. Table 5.1 summarizes the risk categories used. We assigned a combined risk category (e.g., Low-Moderate Risk) for some metrics or areas where we had greater uncertainty in our estimate of the true risk.

We used a quantitative, repeatable approach to determine an overall risk category for each population analysis unit considering the impacts to the species across all the demographic and habitat factors. We first calculated the midpoint value for the range of each risk category. For example, if a population analysis unit was assigned Low Risk for *Occurrence*, then the value used was 5, the midpoint between 0 and 10, the range provided in Table 5.1. When combined risk categories were used, we calculated the midpoint value for the full range; for example, a Low-Moderate Risk used the value 16.5, the midpoint between 0 and 33. We then calculated the geometric mean of those values across all the metrics, which resulted in a final value between 0 and 100 that was converted to the matching risk category for that value. For example, if the geometric mean for a given population analysis unit was 18, it would be assigned a final risk category of Moderate Risk in the current resiliency analysis. For the population analysis units that were not assigned a risk (i.e., were "Undetermined") we omitted that metric from the calculation of the geometric mean.

Table 5.1. Qualitative and quantitative descriptions of the three risk categories used in the resiliency analysis. We include a crosswalk to resiliency categories because many SSAs use that language in their analyses, but this assessment uses risk categories throughout the resiliency discussion.

Risk Category	Estimated chance of extirpation over 30 years	Numerical description of estimate	Resiliency Category
Low Risk	Extirpation is very unlikely	<10%	High Resiliency
Moderate Risk	Extirpation is unlikely	10–33%	Moderate Resiliency
High Risk	Extirpation risk ranges from being about as likely as not to being very likely	>33%	Low Resiliency

Metrics

Occurrence

As mentioned in Chapter 3, the majority of available Rio Grande cooter records are presence-only occurrence data, obtained from a wide range of source material, including museum records, citizen science databases, grant and contract reports, field guides, journal articles, and personal communications reporting observations of the species. We incorporate occurrence based on these data into our resiliency model. This metric is a basic measure of Rio Grande cooter demography and is the best available substitute for abundance as described in our conceptual model (Figure 4.1). While it would be preferable to include additional or other types of demographic population data, a simple measurement of occurrence was available for the entire species' range and is based on empirical evidence. For example, while limited data are available on abundance or population size, density, sex ratios, or age structures for small areas within a few population analysis units (Sirsi et al. 2017, p. 10; Mali, Duarte, et al. 2018, p. 8), our resiliency analysis is intended to evaluate population analysis units using the same criteria in each unit to the maximum extent possible. We lack long-term trend data for persistence or abundance of Rio Grande cooter within any of the population analysis units. Although abundance estimates, coupled with trend information, would be an ideal way to measure current conditions and population trajectories, those data are not available. However, evidence of the presence of Rio Grande cooter in a given population analysis unit is meaningful; not all population analysis units have such evidence. Rio Grande cooter presence on the landscape reflects its ability to persist despite the influence of the stressors discussed and diagrammed in Chapter 4. It therefore also reflects the impact of stressors for which we lack information to study directly, such as direct mortality, which impacts abundance and potentially occurrence, but for which there is not information on geographic extent, temporal extent, frequency, or magnitude of impacts. In addition, assuming our estimate of Rio Grande cooter lifespan as averaging 20–25 years is correct, we believe that, in the absence of a catastrophic event, population analysis units where Rio Grande cooter have been found between 1990 and 2020 will likely continue to have Rio Grande cooter for the next 30 years.

We considered, but did not adopt, an assumption about the trend in occurrence for Rio Grande cooter. As discussed above, we do not have the information necessary to make judgements about Rio Grande cooter abundance. An attempt to assign a trend would require us to determine whether Rio Grande cooter will continue to be observed in a unit or not, and our assessment at that level would be difficult to separate from our overall risk assignment to the population analysis unit as a whole. This is not to suggest that we have no information about Rio Grande cooter presence; we do. The extent and intensity of survey effort for Rio Grande cooter has increased substantially in the last several years. A naïve interpretation of the data from these efforts might lead us to suggest that the discovery of new geographic distribution data for Rio Grande cooter means that it is expanding its range, or that the increased number of recorded observations reflects an underlying increase in absolute abundance. However, the new data are, with rare exception, presence-only data. The lack of *absence* data or prior surveys meant to establish presence and absence on the landscape means that there is insufficient evidence that Rio Grande cooter was absent from the “new” localities recently reported in the literature to prove that a shift has occurred. Moreover, a combination of increased funding for research efforts, and the development of the iNaturalist platform, reasonably explains the increased numbers of occurrence data points since 2010.

We developed quantitative rules for assigning risk to each population analysis unit based on the *Occurrence* metric, allowing for modification if warranted based on information from the literature or knowledge of species experts. The rules are as follows:

- If there have been zero observations of Rio Grande cooter since 1990, then the unit is assigned **High Risk**.
- If the population unit is at least partially in the United States and there are one to five observations or localities with Rio Grande cooter since 1990, then we consulted with researchers familiar with the population analysis units to select a risk assignment.
- If the population unit is at least partially in the United States and there are six or more observations and localities of Rio Grande cooter since 1990, then the unit is assigned **Low Risk**.
- If the population unit is entirely in Mexico, and there are one or more observations of Rio Grande cooter since 1990, then the unit is assigned **Low-Moderate Risk**. In general, observation counts in Mexico are a fraction of those in the United States, but we do not know whether low numbers are a true reflection of a small or unstable population, or if these units simply lack the search effort needed to confirm population persistence.

Subadult Presence

Data on successful nesting, hatching, and hatchling emergence are scant to non-existent. The methods used in previous studies of Rio Grande cooter differ on the degree to which hatchling and juvenile observations were a likely outcome (for example, some surveys employed traps with netting too large to capture the smallest turtles). Consequently, we incorporated into our resiliency model a more basic measure: *Subadult Presence*, based on reports of hatchlings or juveniles, to serve as evidence (albeit not proof) of reproduction. As with *Occurrence*, we acknowledge that it would be preferable to include additional or other types of data to demonstrate more conclusively the extent to which Rio Grande cooter are nesting, hatchling, and growing into sexually mature individuals. However, nesting surveys to date are very limited, not all turtle traps are able to capture all size classes of turtles, very young turtles cannot be easily sexed, and most of the range has not been systematically surveyed. That said, evidence of recruitment in the form of subadult presence is meaningful on its own; it indicates successful nesting within a population analysis unit, and not all population analysis units have evidence of subadult presence. It is the best available proxy for recruitment from our conceptual model, and reflects the ability to reproduce despite the influence of all of the stressors discussed in Chapter 4, as well as those that were not. It therefore serves to incorporate the impact of stressors for which we lacked information to study directly, such as nesting habitat availability.

Our *Subadult Presence* metric is binary: either we located evidence of the presence of hatchlings, juveniles, or subadults in a given population analysis unit, or we did not. We reviewed our occurrence database and the sources used to build it to collect this evidence. We assume that Rio Grande cooter live 20–25 years (see Chapter 2) and that evidence of reproduction in the last 15 years provides a stronger indicator of species persistence over the next 30 years than if we looked at the last 30 years. Using more recent data ties the current conditions to the current generation of Rio Grande cooter. Therefore, this metric is informed by observations from the period 2005–2020. It is theoretically possible that there are populations of Rio Grande cooter successfully producing hatchlings and juveniles that do not mature into adults, but we are not aware of any evidence that this is occurring.

We developed quantitative rules for assigning risk to each population analysis unit based on the *Subadult Presence* metric. Because there have been so few efforts to find hatchling and juvenile Rio Grande cooter, our uncertainty in interpreting zero values is high. We address this by collapsing the Moderate and High Risk categories for population analysis units with no hatchling or juvenile observations. Because so few observations of any kind are available for Mexico, and no studies have been conducted beyond the Rio Grande, population analysis units entirely within Mexico were not evaluated. The final rules are as follows:

- If there are zero observations of Rio Grande cooter hatchlings or juveniles since 2005, then the unit is assigned **Moderate-High Risk**.
- If there are one or more observations of Rio Grande cooter hatchlings or juveniles, then the unit is assigned **Low Risk**.
- If the unit is located in Mexico, we did not attempt to assign a rating, so the risk is Undetermined.

Occurrence Complexity

Rio Grande cooter are known to inhabit a wide variety of habitat types (Pierce et al. 2016, pp. 100.4–100.6; Bogolin 2020, pp. 116–33; Davis et al. 2020, pp. 6–8, 23). Our occurrence database includes observations from spring pools, small-order streams, large rivers, ponds located near flowing water, and reservoirs. These aquatic habitats include a range of temperatures, pollutants, and turbidities. We infer from the natural landscape conditions under which Rio Grande cooter evolved, and the places where it appears in abundance, that springs, streams, and rivers are all potentially important habitat. It is unknown whether subpopulations of Rio Grande cooter need all three, or if they prefer or have greater fitness in one habitat type versus the others. We suggest that when spring pools, streams, and rivers are available to Rio Grande cooter in a population analysis unit, one or more of these may serve as refugia if a stochastic environmental or anthropogenic event makes some portion of their range uninhabitable for a period of time. Since resiliency is a measure of the ability to recover from stochastic perturbations in the environment, access to appropriate refugia should enhance Rio Grande cooter resiliency. To reflect the uncertainty in the true preference of Rio Grande cooter for spring, stream, and river habitat, and to capture the potential benefit of access to refugia, we used the occurrence database described above and hydrological spatial datasets to determine Rio Grande cooter occurrence in spring pools, streams, and rivers. *Occurrence Complexity* reflects the diversity of aquatic habitats in which Rio Grande cooter are documented to occur within a single plpulation analysis unit..

The Pecos River, Devils River, Rio Grande, Río Sabinas, Río Salinas, Río Salinas Hidalgo, Río Salado, and Río San Juan are considered rivers when evaluating this metric. These rivers are waterbodies with historically significant and perennial flows that drain large watersheds. Streams are defined as any other linear water feature (e.g., Black River, Las Moras Creek) that flows into a river. Springs, spring runs, and spring pools are the natural areas or artificial impoundments surrounding a spring that are not reasonably considered a stream or river (e.g., Rattlesnake Springs). We use collapsed risk categories to reflect uncertainty about the true risk of extirpation of the Rio Grande cooter at the population analysis unit level, as defined in these rules:

- If Rio Grande cooter have not been observed in spring pools, streams, or rivers since 1990, then the unit is assigned **High Risk**.
- If Rio Grande cooter have been observed in only one of spring pools, streams, or rivers, since 1990, then the unit is assigned **Moderate-High Risk**.
- If Rio Grande cooter have been observed in any two of spring pools, streams, or rivers, since 1990, then the unit is assigned **Low-Moderate Risk**.
- If Rio Grande cooter have been observed in all three of spring pools, streams, or rivers, since 1990, then the unit is assigned **Low Risk**.

Water Quantity

Rio Grande cooter is an aquatic species that needs water for the majority of its life cycle. The exceptions are that it nests on land, eggs develop in terrestrial nests, and hatchlings may overwinter in nests before emerging and entering the water. Thus, the presence of water is the fundamental building block of Rio Grande cooter habitat. Throughout the Rio Grande cooter range, various anthropogenic activities stress the abundance and supply of water, potentially impacting the springs, streams, and rivers where they are currently found. The drying of these habitats, and the consequent reduction in available habitat for Rio Grande cooter, increases the risk of extirpation of this species at the population analysis unit level. However, there is a great deal of uncertainty about the magnitude of this increase. This uncertainty is amplified by the difficulty of separating the interconnected and synergistic influences of habitat loss, water quality, and occurrence complexity reductions on the overall risks to Rio Grande cooter in a population unit. Reductions in flow and conversions of springs and streams from perennial to intermittent or ephemeral flows have occurred throughout the range, yet Rio Grande cooter have been observed since 1990 in 11 of 16 population analysis units. In the absence of more information, we conclude that Rio Grande Cooter are likely more robust to declines in flow and periodic stream intermittency at the population analysis unit level analyzed here with respect to extirpation than other aquatic species like fishes (e.g., Pecos bluntnose shiner) and mussels (e.g., Texas hornshell). This does not mean that Rio Grande cooter do not suffer harm from drying, but rather that they are not likely to be extirpated from an entire population analysis unit because a river or stream reach goes dry for a short period. The basis for risk assignments for the *Water Quantity* metric are developed from this conclusion:

- A population analysis unit that is **High Risk** due to water quantity is characterized in this way: Springs, streams, and rivers within the population unit are generally dry. Flow is irregular and/or discontinuous throughout the unit.
- A population analysis unit that is **Moderate Risk** due to water quantity is characterized in this way: Springs, streams, and rivers within the population unit that have flow are subject to intermittent drying, either regularly or irregularly, and a large proportion of the springs, streams, and rivers within the unit are already generally dry, with irregular and/or discontinuous flow.
- A population analysis unit that is **Low Risk** due to water quantity is characterized in this way: There may be losses of spring or stream habitat in the unit, or the springs, streams, and rivers in the unit may experience intermittent but irregular drying events, but long-term drying events are not recorded/known.

Water Quality

Water quality is an integral component of habitats that support aquatic species, with all or some life stages dependent on the presence of water of sufficient quantity and quality to support survival, growth, and reproduction. Aquatic species often respond to changes in water quality when they sense undesirable conditions, although not all changes are detectable and may go unnoticed. Changes to water quality are common across the landscape due to anthropogenic activities that can introduce a variety of contaminants into the environment, including industry, agriculture, constructions, urban stormwater, municipal wastewater, hazardous materials spills or leaks, and other sources. These contaminants are frequently transported via water, resulting in exposures to wildlife that inhabit aquatic systems. The Rio Grande cooter has not been tested systematically for tolerances to any particular water quality parameter (e.g., temperature, salinity) or xenobiotic (i.e., environmental pollutants like trace metals or pesticides) so its vulnerability to the threat posed by various contaminant levels is unknown. Water quality sampling across the range of Rio Grande cooter is highly variable. New Mexico, Texas, and the Mexican states use different strategies to complete water quality testing, and public availability of results differs across entities. We elected to assess risk to Rio Grande cooter from water quality degradation in the United States and Mexico differently due to the differences in available information.

After reviewing available water quality data across the species' range, specific conductance, which is related to salinity, and is a reliable indicator of overall water quality (Spellman 2020, pp. 410–11) (U.S. Environmental Protection Agency 2021), is the parameter most consistently available that also shows some correlation with Rio Grande cooter presence across population analysis units in the United States. Specific conductance is a measure of water quality with established correlations to habitat suitability for other aquatic species. In general, this abiotic parameter tends to increase in watersheds impacted by various anthropogenic activities, degrading water quality over time, thereby influencing biotic communities (Williams 1999, entire). For example, adult Texas hornshell mussels (*Popenaias popeii*) cannot tolerate salinity levels of about 12,250 µS/cm for more than short periods of time (Lang and Altenbach 2001, pp. 3–4). A laboratory study of another mussel, Eastern elliptio (*Elliptio complanata*) found sublethal effects on metabolic rate at about 3,800 µS/cm and on development at about 5,600 µS/cm; lethal effects were observed at about 7,300 µS/cm or higher (Blakeslee et al. 2013, pp. 2850–52). Research suggests many freshwater turtles can tolerate relatively high salinities for short periods of time (Dunson and Seidel 1986, entire; Agha et al. 2018, pp. 1642–46). We also know that *Pseudemys* turtles have some level of tolerance to brackish water, but do not know the specific limits to their ability to thrive under acute or chronic salinity levels (Agha et al. 2018, pp. 1637, 1642–46).

Given this information, we assessed specific conductance at the population analysis unit level as one component of our *Water Quality* metric. To do this, we collected all historical measurements of specific conductance from USGS and TCEQ taken from the Pecos River, Rio Grande, and relevant tributaries (Houston, Thomas, Jonathan V., Pedraza, et al. 2019b; 2019a; TCEQ 2020c). We calculated the median and mean values for specific conductance for the periods 1990–2005 and 2005–2020. We lacked the laboratory research studies needed to perfectly assign relative impacts to Rio Grande cooter from varying levels of specific conductance in their aquatic habitat. We used benchmarks from the U.S. Geological Survey to create two thresholds for interpreting the mean and median specific conductance values in a given population analysis units into high, moderate, and low categories (U.S. Geological Survey n.d.). Specific conductance median and mean values less than 5,500 µS/cm are considered fresh to slightly saline (U.S. Geological Survey n.d.), and we assume that waters in these conditions place no or low levels of stress on Rio Grande cooter. Values between 5,500 µS/cm and 9,000 µS/cm are considered moderately saline (U.S. Geological Survey n.d.), and we assume waters in these conditions place increased, or moderate levels of stress on Rio Grande cooter. Values greater than 9,000 µS/cm are moderately to highly saline (U.S. Geological Survey n.d.), and we assume waters in these conditions place higher levels of stress on Rio Grande cooter. For additional detail on the specific conductance analyses and results, refer to Appendix B. Information about salinity in Mexican waterways was gleaned from the literature where possible, but was generally unavailable and thus not formally categorized.

We also assessed the risk to Rio Grande cooter from contaminants within our *Water Quality* metric because impacts to other forms of aquatic life resulting from aquatic contamination events have been established. Hazardous spills or leaks (e.g., leaking underground storage tanks), and existing contamination in groundwater, soils, or surface water could impact Rio Grande cooter. We used information from the TCEQ online database to identify sources of industrial and hazardous waste sites and leaking petroleum storage tanks (TCEQ 2019b; 2019a), spill information from the New Mexico Oil Conservation Division (New Mexico Oil Conservation Division 2020), spill information from the Texas Railroad Commission (Railroad Commission of Texas 2020), and the Texas Parks and Wildlife Department's (TPWD) Kills and Spills database (Kills and Spills Team 2020) to inform our best professional judgement of the influence of contaminants on Rio Grande cooter habitat for population analysis units in the United States. Information about water quality in Mexican waterways was gleaned from the literature and conversations with individuals who have recorded observations of Rio Grande cooter in Mexico (these personal communications are cited as applicable in the specific analysis of each population analysis unit, below).

Finally, we integrated our assessment of specific conductance and risk of contaminants and sources of pollution to determine the overall risk to Rio Grande cooter associated with *Water Quality* within a given population analysis unit. We recognize that this approach is not a comprehensive water quality or ecological risk assessment, but it is our attempt to utilize the best available information to assess water quality using a commonly measured parameter, along with the history of hazardous materials spills or leaks, and known hazardous waste sites in areas currently occupied by the species, across its range. This is a limited analysis that does not include, or attempt to fully capture the impacts of, all point and non-point sources of environmental contamination that may be affecting the species. The rules used to assign risk levels for water quality for population analysis units in the United States are as follows:

- If mean and median values of specific conductance from 1990–2005 and 2005–2020 are greater than 9,000 µS/cm and/or there are ongoing or increasing numbers of hazardous waste incidents indicating a high risk of contaminants impacting surface or groundwater, then the unit is assigned **High Risk**.
- If mean and median values of specific conductance from 1990–2005 and 2005–2020 are between 5,500 µS/cm and 9,000 µS/cm, and/or there are ongoing incidents indicating a moderate risk of contaminants impacting surface or groundwater, then the unit is assigned **Moderate Risk**.
- If mean and median values of specific conductance from 1990–2005 and 2005–2020 are less than 5,500 µS/cm, and there is little indication of contaminants impacting surface or groundwater, then the unit is assigned **Low Risk**.

The rules used to assign risk levels for water quality for population analysis units in Mexico are as follows:

- If water quality is regarded by experts or those with personal knowledge as poor, or there are ongoing or increasing numbers of hazardous waste incidents indicating a high risk of contaminants impacting surface or groundwater, then the unit is assigned **High Risk**.
- If water quality is regarded by experts or those with personal knowledge as moderately impaired, and/or there are ongoing incidents indicating a moderate risk of contaminants impacting surface or groundwater, then the unit is assigned **Moderate Risk**.
- If water quality is regarded by experts or those with personal knowledge as good, and there is little indication of contaminants impacting surface or groundwater, then the unit is assigned **Low Risk**.

Summary

Table 5.2 describes the basis for assigning risk to each population analysis unit, by metric, for the resiliency analysis.

Table 5.2. This table summarizes the information presented in the preceding section on the methods used to assign risk category rating for each metric used in the resiliency analysis. Some risk assignments, reflecting our uncertainty, are assigned to a combined risk category: Low-Moderate Risk or Moderate-High Risk. Where applicable, we indicate this by noting the combined category in brackets following the rule.

Metric	High Risk	Moderate Risk	Low Risk
Occurrence	Zero observations, 1990–2020; fewer than six observations and expert opinion	US: Fewer than six observations, 1990–2020 and based on expert opinion Mexico: At least one observation, 1990–2020 [Low-Moderate Risk]	US: Six or more observations, 1990–2020
Subadult Presence (United States only)	Zero observations of Rio Grande cooter hatchlings or juveniles, 2005–2020 [Moderate-High Risk]	Not Used	One or more observations of Rio Grande cooter hatchlings or juveniles, 2005–2020
Occurrence Complexity	Not observed in spring pools, streams, or rivers, 1990–2020	Observations in only one of spring pools, streams, or rivers, 1990–2020 [Moderate-High Risk] Observations in any two of spring pools, streams, or rivers, 1990–2020 [Low-Moderate Risk]	Observed in spring pools, streams, and rivers, 1990–2020
Water Quantity	Springs, streams, and rivers within the population unit are generally dry. Flow is irregular and/or discontinuous throughout the unit.	Springs, streams, and rivers within the population unit that have flow are subject to intermittent drying, either regularly or irregularly, and a large proportion of the springs, streams, and rivers within the unit are generally dry, with irregular and/or discontinuous flow.	There may be losses of spring or stream habitat in the unit, or the springs, streams, and rivers in the unit may experience intermittent but irregular drying events, but long-term drying events are not known/recorded.
Water Quality	There are ongoing or increasing numbers of hazardous waste incidents indicating a high risk of contaminants impacting surface or groundwater, and/or – Mean and median values of specific conductance from 1990–2005 and 2005–2020 are greater than 9,000 µS/cm. [United States] – Water quality is regarded by experts or those with personal knowledge as poor. [Mexico]	There are ongoing incidents indicating a moderate risk of contaminants impacting surface or groundwater, and/or – Mean and median values of specific conductance from 1990–2005 and 2005–2020 are between 5,500 µS/cm and 9,000 µS/cm. [United States] – Water quality is regarded by experts or those with personal knowledge as moderately impaired. [Mexico]	There is little indication of contaminants impacting surface or groundwater, and/or – Mean and median values of specific conductance from 1990–2005 and 2005–2020 are less than 5,500 µS/cm. [United States] – Water quality is regarded by experts or those with personal knowledge as good. [Mexico]

Current Resiliency Results

Pecos River – Sumner Dam to Brantley Dam

Rio Grande cooter were not known to be extant in this population analysis unit prior to 2018, when a member of the public reported seeing them along Berrendo Creek, a tributary to the Rio Hondo, itself a tributary to the Pecos River. Following this sighting, a total of seven unique Rio Grande cooter were trapped in 2018 and 2019 (Suriyamongkol et al. 2020, pp. 536–37; Mali and Suriyamongkol 2019, pp. 11–16). The only other recent indication that Rio Grande cooter could be present in this unit is a carcass found on Bitter Lake National Wildlife Refuge in 2008 (Giermakowski and Pierce 2016, p. 656). Subsequent trapping on the refuge yielded no Rio Grande cooter (Suriyamongkol et al. 2020, pp. 536–37). Dr. Ivana Mali of Eastern New Mexico University, who has several years of experience studying Rio Grande cooter in the area, suggested that Low Risk would not be an appropriate designation for this population analysis unit (Mali 2020, personal communication). However, the presence of several Rio Grande cooter individuals at the Berrendo Creek site is well documented (Suriyamongkol et al. 2020, pp. 536–37), so the High Risk category is also not appropriate. Therefore, we assigned a rating of **Moderate Risk** to this unit for the *Occurrence* metric. There are no observations of hatchling or juvenile turtles in this unit, so we assigned a rating of **Moderate-High Risk** to this unit for the *Subadult Presence* metric. All the observations of Rio Grande cooter in this unit are in Berrendo Creek, so we assigned a rating of **Moderate-High Risk** to this unit for the *Occurrence Complexity* metric.

We assigned a rating of **Moderate Risk** to this unit for the *Water Quantity* metric because a large proportion of the streams in the unit are generally dry, and the river in the unit has regular issues with severe low flows and intermittency (Follansbee and Jean 1915, p. 452; Hatch et al. 1985, p. 561; Hoagstrom et al. 2008, p. 6; U.S. Fish and Wildlife Service 2010, pp. 5–7; 2020d, pp. 7–14; Davenport 2019, pp. 24–28; Tetra Tech, Inc. 2020, pp. 18–22). We have no information on whether springs were present historically that would have supported Rio Grande cooter, so this remains unknown. The Rio Hondo is the only remaining perennial or mostly perennial tributary in the unit, and has likely been so for several decades (Follansbee and Jean 1915, pp. 578–79; Tetra Tech, Inc. 2020, pp. 3, 6, 18–22). The Pecos River has experienced repeated instances of intermittency since at least 1985 (Hatch et al. 1985, p. 561; Hoagstrom et al. 2008, p. 6; Davenport 2019, pp. 2, 24–28; U.S. Fish and Wildlife Service 2020d, pp. 7–14). Because this threatens the persistence of the Federally Threatened Pecos bluntnose shiner, conservation measures are in place by the Bureau of Reclamation under a Biological Opinion to minimize river intermittency (U.S. Fish and Wildlife Service 2017, entire; Davenport 2019, pp. 3–4). These measures buffer the threat of river drying for Pecos bluntnose shiner and, by extension, Rio Grande cooter.

We assigned a rating of **Low Risk** to this unit for the *Water Quality* metric because the water in this unit has low salinity and low impacts from contaminants. The median and mean values for specific conductance during the periods 1990–2004 and 2005–2020 are between approximately 3,500 and 5,000 µS/cm. While there are produced water and oil spills or leaks that occur within the unit (New Mexico Oil Conservation Division 2020), their impacts to the Pecos River are low enough that such hazardous materials spills or leaks, or other industrial contamination, do not threaten the Pecos bluntnose shiner (Davenport 2019, entire; U.S. Fish and Wildlife Service 2020d, entire), and we infer from this that contaminant risk to Rio Grande cooter is also low.

The overall conditions in this unit currently present a **High Risk** to Rio Grande cooter.

Pecos River – Brantley Dam to Red Bluff Dam

Rio Grande cooter in this unit include some of the most closely studied localities across the entire species' range. Our occurrence database contains hundreds of observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **Low Risk** to this unit for the *Occurrence* metric. There are also dozens of observations of hatchlings and juveniles in this unit between 2005 and 2020, indicating that reproduction is occurring successfully and that the study design employed in this unit is able to pick up that signal. As a result, we assigned a rating of **Low Risk** to this unit for the *Subadult Presence* metric. In this unit, Rio Grande cooter have been observed in springs (e.g., Rattlesnake Springs), streams (e.g., Rocky Arroyo, Black River), and the Pecos River, so we assigned a rating of **Low Risk** to this unit for the *Occurrence Complexity* metric.

We assigned a rating of **Moderate Risk** to this unit for the *Water Quantity* metric because a large proportion of the springs and streams in the unit are generally dry, and the river in the unit has regular issues with severe low flows and intermittency. The springs in this unit from which Rio Grande cooter are known still flow, but likely at reduced levels due to groundwater pumping in the area (Cox 1963, pp. 2–3, 22–24; Thomas 1963, pp. G-11–G-12; Arm et al. 2014, pp. 19, 28, 41). The Black River, Delaware River, and Rocky Arroyo, which were historically perennial, have been reduced to intermittent streams (Hale 1955, p. 2; Bjorklund and Motts 1959, p. 39; Cox 1967, pp. 3, 10, 19; Arm et al. 2014, pp. 21, 26; Inoue et al. 2014, p. 1881; Bonner and Littrell 2016, p. 3). The Pecos River is frequently dry between Avalon Dam and Carlsbad Springs, and has been so since at least 1959 (Bjorklund and Motts 1959, p. 40; Hoagstrom et al. 2008). It is also periodically dry in the inlet to Red Bluff Reservoir (Miyamoto et al. 2005, p. 17).

We assigned a rating of **Moderate Risk** to this unit for the *Water Quality* metric because the water in this unit has elevated salinity and increasing, ongoing impacts from contaminants. The median and mean values for specific conductance across the unit as a whole during the periods 1990–2004 and 2005–2020 are between 7,600 µS/cm and 8,000 µS/cm. Specific conductance values in the Black and Delaware Rivers are usually lower (Lang and Gordon 2001, p. 9; Bonner and Littrell 2016, p. 4). Hazardous materials spills or leaks associated with oil and gas production are a major issue in this unit (Hedden 2020b). The count and volume of hazardous materials spills or leaks has been increasing since the late 1990s (New Mexico Oil Conservation Division 2020; Railroad Commission of Texas 2020). Produced water is the primary contaminant, followed by crude oil (New Mexico Oil Conservation Division 2020; Railroad Commission of Texas 2020). Water in the unit has also been impacted historically by the disposal of contaminants to unlined grounds or directly into the water (Boyer 1986, pp. 302–11). A contamination event, whose exact origin and makeup remains unresolved, killed an estimated 120 red-eared sliders (*Trachemys scripta elegans*) in April 2020, illustrating the vulnerability of aquatic turtles to such events (Texas Parks and Wildlife Department 2020, pp. 1–2).

The overall conditions in this unit currently present a **Moderate Risk** to Rio Grande cooter.

Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment

This unit is typically portrayed as currently unoccupied in field guides and species accounts (A. E. Brown 1903, pp. 543–44; Milstead 1960, p. 551; Conant 1977, p. 472; Ward 1984, p. 29; Hibbitts and Hibbitts 2016, pp. 134–37). Our occurrence database contains two observations from 1990–2020 for this unit. The metadata for one observation indicates that the true location is uncertain (Zhuang 2019), and less than 2 km (1.24 mi) from the boundary between the Toyah and Edwards Segments. The other is an eDNA detection that was not corroborated by visual, drone, or trapping surveys (Bogolin, Davis, and Rahman 2019, p. 46). Repeated surveys in this area have not yielded evidence that Rio Grande cooter persist in this segment, and a species expert familiar with the area does not believe they occur there (Forstner 2020, personal communication). Consequently, we assigned a rating of **High Risk** to this unit for the *Occurrence* metric. There are no observations of hatchling or juvenile turtles in this unit, so we assigned a rating of **Moderate-High Risk** to this unit for the *Subadult Presence* metric. The observations of Rio Grande cooter in this unit are exclusively in the mainstem Pecos River, so we assigned a rating of **Moderate-High Risk** to this unit for the *Occurrence Complexity* metric.

We assigned a rating of **High Risk** to this unit for the *Water Quantity* metric because the springs and streams within the population analysis unit are generally dry. The flow of the Pecos River is subject to frequent and ongoing intermittency issues, regularly experiencing no flow events, especially during the irrigation season and during periods of drought (Collins and Riffenburg 1927, p. 80; Campbell 1958, p. 4; Grozier et al. 1966, pp. 1–8; Yuan et al. 2007, p. 1801; Hoagstrom 2009, pp. 30–36; Upper Rio Grande BBEST 2012, pp. 2-21–2-27). Most of the springs in this basin are dry, and those that have flowing water are impounded, such that they do not connect to the tributaries or mainstem of the Pecos River (Campbell 1958, pp. 3–4; Brune 1975, pp. 23, 57–62, 356; 1981, pp. 139–131, 139–42, 382–84, 422–24, 442–44, 450–55; Hoagstrom 2009, pp. 30–36). Due to the loss of springs as well as groundwater pumping, these tributary streams are no longer reliably perennial (Brune 1975, pp. 23, 57–62; 1981, pp. 139–42, 356–58, 382–84).

We assigned a rating of **High Risk** to this unit for the *Water Quality* metric because the water in this unit has very high salinity and increasing, ongoing impacts from contaminants. The median and mean values for specific conductance during the periods 1990–2004 and 2005–2020 are between 13,000 µS/cm and 16,000 µS/cm. Hazardous materials spills or leaks associated with oil and gas production are an ongoing problem in this unit and may be increasing in both number and volume (Railroad Commission of Texas 2020). Crude oil is the primary contaminant, but natural gas, well liquids, and produced water are also significant components (Railroad Commission of Texas 2020). Fish kill events and hazardous materials spills or leaks are regularly reported in this population analysis unit (Kills and Spills Team 2020). Most of these are associated with golden alga or low DO, which do not directly impact Rio Grande cooter (Gregory and Hatler 2008, p. 76; U.S. Army Corps of Engineers 2008, p. 29; Kills and Spills Team 2020). However, turtles were reported among the dead wildlife associated with a 40-mile long kill event in 1996 (Kills and Spills Team 2020). Water in the unit has also been impacted historically by the disposal, spillage, and leaking of contaminants to groundwater and surface water (Wiebe et al. 1934, pp. 81–83; Campbell 1958, p. 4; Brune 1981, pp. 21–22; Boyer 1986, pp. 302–11; Ashworth 1990, p. 3032; TCEQ 2019b).

The overall conditions in this unit currently present a **High Risk** to Rio Grande cooter.

Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment

Our occurrence database contains dozens of observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **Low Risk** to this unit for the *Occurrence* metric. There are also a small number of observations of hatchlings and juveniles in this unit in the area of Independence Creek between 2005 and 2020, indicating that reproduction is occurring successfully. As a result, we assigned a rating of **Low Risk** to this unit for the *Subadult Presence* metric. In this unit, Rio Grande cooter have been observed in springs (e.g., the spring pools in Independence Creek preserve), streams (Independence Creek), and the Pecos River, so we assigned a rating of **Low Risk** to this unit for the *Occurrence Complexity* metric.

We assigned a rating of **Low Risk** to this unit for the *Water Quantity* metric because while there have been declines in spring and stream habitat in the unit, significant drying events are not recorded or anticipated in the near future. The springs in this segment are likely reduced in volume from their historical flow levels but are not dry (Brune 1975, pp. 23, 57–62, 70–71; 1981, pp. 422–24). Independence Creek is still perennial to its confluence with the Pecos River, although its perennial length may be reduced compared to its historical condition, like other streams in the region (Brune 1981, pp. 139–131, 139–42, 382–84, 422–24, 442–44, 450–55; Upper Rio Grande BBEST 2012, pp. 1-11, 2-34). Finally, there are no known no-flow events in this segment; in fact, flow generally increases in the Pecos River from Independence Creek downriver due to the additive flows of springs (Campbell 1958, p. 4; Upper Rio Grande BBEST 2012, pp. 2-24–2-25; Houston, Thomas, Jonathan V., Pedraza, et al. 2019b, p. 55).

We assigned a rating of **Low Risk** to this unit for the *Water Quality* metric because the water in this unit has low salinity and low impacts from contaminants. The median and mean values for specific conductance during the periods 1990–2004 and 2005–2020 are between 3,200 µS/cm and 4,200 µS/cm. In addition, there is little indication of negative impacts from contaminants in this segment: hazardous materials spills or leaks are infrequent and the last brine spill recorded in this portion of the river is from 1981 (Hoagstrom 2003, p. 104; Kills and Spills Team 2020; Railroad Commission of Texas 2020). It is possible that contaminated waters from the Toyah Segment could flow into this segment, but we did not find evidence of this being a problem currently.

The overall conditions in this unit currently present a **Low Risk** to Rio Grande cooter.

Devils River – headwaters to Amistad Reservoir

Our occurrence database contains hundreds of observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **Low Risk** to this unit for the *Occurrence* metric. There are also a small number of observations of hatchlings and juveniles in this unit between 2005 and 2020, indicating that reproduction is occurring successfully. As a result, we assigned a rating of **Low Risk** to this unit for the *Subadult Presence* metric. In this unit, Rio Grande cooter have been observed in springs along the Devils River, tracked moving into and back out of Dolan Creek, and observed extensively in the mainstem, so we assigned a rating of **Low Risk** to this unit for the *Occurrence Complexity* metric.

We assigned a rating of **Low Risk** to this unit for the *Water Quantity* metric because while there have been declines in spring and stream habitat in the unit, significant drying events are not recorded or anticipated in the near future. The springs that fed the historical headwaters of the Devils River are now dry, and those along the river downstream from that area have lower flows than they did historically, although they still flow (Brune 1981, pp. 173, 415–16, 450–52). Dolan Creek is the main tributary feeding the Devils River, and its flow remains perennial (Upper Rio Grande BBEST 2012, p. 2-28). Finally, although the headwaters of the river may have shifted downstream in the early 20th century, despite the slight decline in flows, there are no dry stretches below Pecan Springs or known no-flow events (Brune 1981, pp. 450–52; González Escorcia 2016, pp. 80–81; Sandoval Solis 2019).

We assigned a rating of **Low Risk** to this unit for the *Water Quality* metric because the water in this unit has low salinity and low impacts from contaminants. The median and mean values for specific conductance during the periods 1990–2004 and 2005–2020 are between approximately 400 µS/cm and 450 µS/cm. In addition, there is little indication of negative impacts from contaminants in this unit. Spills or leaks of hazardous materials are rare, in keeping with the Devils River's reputation as one of the most healthy rivers in Texas (Upper Rio Grande BBEST 2012, p. 1-11; TCEQ 2019b; Kills and Spills Team 2020; Railroad Commission of Texas 2020).

The overall conditions in this unit currently present a **Low Risk** to Rio Grande cooter.

Rio Grande – Big Bend to Amistad Dam

Our occurrence database contains a few dozen observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **Low Risk** to this unit for the *Occurrence* metric. There are no observations of hatchlings or juveniles in this unit between 2005 and 2020, indicating uncertainty as to whether reproduction is occurring successfully. As a result, we assigned a rating of **Moderate-High Risk** to this unit for the *Subadult Presence* metric. In this unit, Rio Grande cooter have been observed in a spring-fed impoundment in Big Bend, in small tributaries to the Rio Grande near Langtry, and in the Rio Grande itself, so we assigned a rating of **Low Risk** to this unit for the *Occurrence Complexity* metric.

We assigned a rating of **Low Risk** to this unit for the *Water Quantity* metric. While there have been declines in spring and stream habitat in the unit, no-flow events are not recorded or anticipated in the near future. It is highly likely that springs along the Rio Grande flow at reduced levels compared to the past (Brune 1981, pp. 84–94, 423–25, 449–56). Eagle Nest Creek and Pump Canyon have perennial flow, though their perennial length may be reduced compared to historical levels (Brune 1981, pp. 84–94, 423–25; Forstner 2020, personal communication). Significant diversions and impoundments of the Rio Grande above this unit occur (U.S. Army Corps of Engineers 2008, entire; Dean and Schmidt 2011, p. 336). The Rio Grande in this population analysis unit is undergoing channel narrowing and bed aggradation in its upstream reaches, and experiences significant reductions in flow during severe drought with some instances of very low flows, but is not known to have gone dry (Dean and Schmidt 2011, pp. 333–36; Garrett and Edwards 2014, p. 397; Blythe and Schmidt 2018, p. 1214; Sandoval Solis 2019, p. 33).

We assigned a rating of **Low Risk** to this unit for the *Water Quality* metric because the water in this unit has low salinity and low impacts from contaminants. The median and mean values for specific conductance during the periods 1990–2004 and 2005–2020 are between approximately 1,000 µS/cm and 1,200 µS/. In addition, there is little indication of negative impacts from contaminants in this unit. Contaminant issues are not highlighted in reports on this area, and hazardous materials spills and leaks are uncommon (Upper Rio Grande BBEST 2012, pp. 1-5, 1-14; TCEQ 2019b; 2020d, p. 179; 2020b, p. 116; Kills and Spills Team 2020; Railroad Commission of Texas 2020).

The overall conditions in this unit currently present a **Moderate Risk** to Rio Grande cooter.

Rio Grande – Amistad Dam to Falcon Dam

Our occurrence database contains a few dozen observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **Low Risk** to this unit for the *Occurrence* metric. There are a small number of observations of hatchlings and juveniles in this unit between 2005 and 2020, indicating that reproduction is occurring successfully. As a result, we assigned a rating of **Low Risk** to this unit for the *Subadult Presence* metric. In this unit, Rio Grande cooter have been observed in multiple spring-fed pools, streams, and in the Rio Grande itself, so we assigned a rating of **Low Risk** to this unit for the *Occurrence Complexity* metric.

We assigned a rating of **Low Risk** to this unit for the *Water Quantity* metric because while there have been declines in spring and stream habitat in the unit, no-flow events are not recorded or anticipated in the near future. Some springs in this unit are intermittently dry, others have experienced reductions in flow, but a few have higher flows now than historically due to changes in hydrostatic pressure after the development of Amistad Reservoir (Brune 1981, pp. 167, 274–77, 306–7, 452–55, 463–66, 487–88). Some perennial streams are likely now intermittent or flowing at decreased levels due to spring drying, but a study of this phenomenon has not been done (Brune 1981, pp. 274–77, 306–7, 452–55). It seems likely that many tributaries were intermittent even prior to European settlement, especially in the lower reaches of the unit (Brune 1981, pp. 167, 464–66, 487–88). Several tributaries continue to flow perennially, such as Las Moras Creek, San Felipe Creek, Sycamore Creek, Mud Creek and Pinto Creek in Texas (El-Hage and Moulton 2001, pp. 28–36, 48–49; Naismith Engineering, Inc. 2012, p. 22; TCEQ 2020b, pp. 116–18), and the Río San Diego and part of the Río San Antonio in Coahuila (Berg 2020, personal communication; Gluesenkamp 2020, personal communication; Strenth 2020, personal communication; Trujillo 2020, personal communication). Although the Rio Grande in this unit flows at a fraction of its historical volume, extreme low flows or intermittency has not been observed (Follansbee and Jean 1915, pp. 265, 283–84, 304–10; González Escorcia 2016, pp. 93–94; Sandoval Solis 2019, p. 33).

We assigned a rating of **Moderate Risk** to this unit for the *Water Quality* metric because the water in this unit has low salinity but experiences continuing impacts from certain contaminant sources. The median and mean values for specific conductance during the periods 1990–2004 and 2005–2020 are between approximately 900 µS/cm and 1,100 µS/cm. However, there are indications of negative impacts from contaminants in this unit. Hazardous materials spills or leaks are an issue in Webb County, and there is a history of fish kills related to oil or gas operations (Kills and Spills Team 2020; Railroad Commission of Texas 2020). Leaking petroleum storage tanks frequently impact groundwater or surface water (TCEQ 2019b). In addition, there are several active Industrial and Hazardous Waste Corrective Action sites near the Rio Grande in this unit (TCEQ 2019a). Incidents have declined since the 1990s but continue to recur (TCEQ 2019b; 2019a; Railroad Commission of Texas 2020; Kills and Spills Team 2020).

The overall conditions in this unit currently present a **Low Risk** to Rio Grande cooter.

Rio Grande – Falcon Dam to Anzalduas Dam

Our occurrence database contains dozens of observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **Low Risk** to this unit for the *Occurrence* metric. There are no observations of hatchlings or juveniles in this unit between 2005 and 2020, indicating uncertainty as to whether reproduction is occurring successfully. As a result, we assigned a rating of **Moderate-High Risk** to this unit for the *Evidence of Reproduction* metric. In this unit, Rio Grande cooter have only been observed in the Rio Grande itself, so we assigned a rating of **Moderate-High Risk** to this unit for the *Occurrence Complexity* metric.

We assigned a rating of **Low Risk** to this unit for the *Water Quantity* metric because the available evidence suggests that perennial flows have persisted where they were present historically. Our research suggests that the type of springs that would have supported Rio Grande cooter were never present in this unit (Brune 1981, pp. 228, 409–10). Tributaries to the Rio Grande are uncommon in this unit, but the Arroyo Los Olmos and Río San Juan continue to contribute flows, albeit to a lesser degree than in the past (International Boundary & Water Commission 1994, p. 16; Miyamoto et al. 1995, p. 14; Contreras-Balderas et al. 2002, p. 221; TCEQ 2020d, p. 177). Although the Rio Grande in this unit flows at a fraction of its historical volume, extreme low flows or intermittency has not been observed (González Escorcia 2016, p. 99; Sandoval Solis 2019, p. 33).

We assigned a rating of **Moderate Risk** to this unit for the *Water Quality* metric because the water in this unit has low salinity but experiences continuing impacts from contaminants. The median and mean values for specific conductance during the periods 1990–2004 and 2005–2020 are between approximately 1,100 µS/cm and 1,500 µS/cm. There is some indication of negative impacts from contaminants in this unit. Hazardous materials spills or leaks such as leaking petroleum storage tanks frequently impact groundwater or surface water (TCEQ 2019b; Kills and Spills Team 2020; Railroad Commission of Texas 2020). In addition, there are several active Industrial and Hazardous Waste Corrective Action sites near the Rio Grande in this unit (TCEQ 2019a). Incidents have declined since the 1990s but continue to recur (TCEQ 2019b; 2019a; Railroad Commission of Texas 2020; Kills and Spills Team 2020).

The overall conditions in this unit currently present a **Moderate Risk** to Rio Grande cooter.

Rio Grande – Anzalduas Dam to Mouth

Our occurrence database contains no observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **High Risk** to this unit for the *Occurrence* and *Occurrence Complexity* metrics. There are no observations of hatchlings or juveniles in this unit between 2005 and 2020, so we assigned a rating of **Moderate-High Risk** to this unit for the *Subadult Presence* metric, but note that the risk is likely toward the High end given the lack of adult observations.

We assigned a rating of **Moderate Risk** to this unit for the *Water Quantity* metric because intermittency has been an issue in this unit in recent decades, and gages show regular recurrences of very low flow conditions (Lower Rio Grande BBEST 2012, pp. 1-7, 4-4; Sandoval Solis 2019, p. 33). Our research suggests that the type of springs that would have supported Rio Grande cooter were never present in this unit (Brune 1981, p. 105), and there are no tributaries to the Rio Grande in this unit (Lower Rio Grande BBEST 2012, p. 3-3), so our conclusions on water quantity are based on the mainstem Rio Grande only.

We assigned a rating of **Moderate Risk** to this unit for the *Water Quality* metric because the water in this unit has low salinity but experiences continuing impacts from contaminants. The median and mean values for specific conductance during the periods 1990–2004 and 2005–2020 are between approximately 1,300 µS/cm and 1,400 µS/cm. There is some indication of negative impacts from contaminants in this unit. Hazardous materials spills or leaks such as leaking petroleum storage tanks frequently impact groundwater or surface water (TCEQ 2019b; Kills and Spills Team 2020; Railroad Commission of Texas 2020). In addition, there are several active Industrial and Hazardous Waste Corrective Action sites near the Rio Grande in this unit (TCEQ 2019a). Incidents have declined since the 1990s but continue to recur (TCEQ 2019b; 2019a; Railroad Commission of Texas 2020; Kills and Spills Team 2020).

The overall conditions in this unit currently present a **High Risk** to Rio Grande cooter.

Río Sabinas – headwaters to Don Martin Reservoir

Our occurrence database contains several observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **Low-Moderate Risk** to this unit for the *Occurrence* metric. In this unit, Rio Grande cooter have been observed in a tributary to the Río Sabinas named the Río Los Álamos, as well as in the Río Sabinas itself, so we assigned a rating of **Low-Moderate Risk** to this unit for the *Occurrence Complexity* metric. We assigned a rating of **Low Risk** to this unit for the *Water Quantity* metric because the Río Sabinas is fed by springs and is normally perennial, despite flowing at lower volumes than in the past (Contreras-Balderas and Lozano-Vilano 1994, p. 381; Davila Paulin 2020a; 2020b, personal communication; Hendrickson 2020, personal communication; Ochoa Espinoza 2020, personal communication). We assigned a rating of **Low Risk** to this unit for the *Water Quality* metric because the water in this unit is reported to have good quality, and impacts from contaminants appear localized and non-severe (Berg 2020, personal communication; Davila Paulin 2020a; 2020b, personal communication; Hendrickson 2020, personal communication; Ochoa Espinoza 2020, personal communication; Strenth 2020, personal communication; Trujillo 2020, personal communication). The overall conditions in this unit currently present a **Moderate Risk** to Rio Grande cooter.

Río Salado – headwaters to Don Martín Dam

Our occurrence database contains no observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **High Risk** to this unit for the *Occurrence* and *Occurrence Complexity* metrics. We assigned a rating of **Low Risk** to this unit for the *Water Quantity* metric because the Río Salado de los Nadadores is perennial for most of its length below the Cuatro Ciénegas basin to the Don Martín dam, despite flowing at lower volumes than in the past (Contreras-Balderas and Lozano-Vilano 1994, p. 381; Strenth 2020, personal communication). We assigned a rating of **Low Risk** to this unit for the *Water Quality* metric because the water in this unit is reported to have good quality despite being somewhat saline, and it is very rural with few sources of contamination (Guerra 1952, p. 6; Berg 2020, personal communication; Davila Paulin 2020b, personal communication; Strenth 2020, personal communication; Trujillo 2020, personal communication). The overall the conditions in this unit currently present a **High Risk** to Rio Grande cooter.

Río Sabinas Hidalgo – headwaters to cfl Río Salado

Our occurrence database contains several observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **Low-Moderate Risk** to this unit for the *Occurrence* metric. In this unit, Rio Grande cooter have only been observed in the mainstem Río Sabinas Hidalgo, so we assigned a rating of **Moderate-High Risk** to this unit for the *Occurrence Complexity* metric. We assigned a rating of **Moderate Risk** to this unit for the *Water Quantity* metric because the Río Sabinas Hidalgo, despite being fed by springs and supplying a reservoir, is reported to flow at lower volumes in the past, and we are uncertain as to whether it is normally perennial or intermittent (Guerra 1952, p. 7; Contreras-Balderas and Lozano-Vilano 1994, p. 381; Ochoa Espinoza 2020, personal communication). We assigned a rating of **Low Risk** to this unit for the *Water Quality* metric because the water in this unit is reported to have good quality, and impacts from contaminants appear localized and non-severe (Davila Paulin 2020b, personal communication; Ochoa Espinoza 2020, personal communication). The overall conditions in this unit currently present a **Moderate Risk** to Rio Grande cooter.

Río Salado – Don Martin Dam to Falcon Reservoir

Our occurrence database contains no observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **High Risk** to this unit for the *Occurrence* and *Occurrence Complexity* metrics. We assigned a rating of **High Risk** to this unit for the *Water Quantity* metric because the Río Salado has very low flows in the areas where it has been observed recently, and is likely prone to intermittency (Berg 2020, personal communication; Strenth 2020, personal communication). We assigned a rating of **High Risk** to this unit for the *Water Quality* metric because the water in this unit is reported to have poor quality (Berg 2020, personal communication; Hendrickson 2020, personal communication; Strenth 2020, personal communication; Trujillo 2020, personal communication). The overall conditions in this unit currently present a **High Risk** to Rio Grande cooter.

Río Salinas – headwaters to cfl Río San Juan

Our occurrence database contains several observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **Low-Moderate Risk** to this unit for the *Occurrence* metric. In this unit, Rio Grande cooter have been observed in a spring pool in Monterrey, a stream named the Río Pesquería, as well as in the Río Salinas itself, so we assigned a rating of **Low Risk** to this unit for the *Occurrence Complexity* metric. We assigned a rating of **Low-Moderate Risk** to this unit for the *Water Quantity* metric because we did not find evidence that river drying is a major issue, despite evidence that it flows at lower volumes than in the past (Contreras-Balderas and Lozano-Vilano 1994, p. 381). We assigned a rating of **Moderate Risk** to this unit for the *Water Quality* metric because the water in this unit is reported to have good quality upriver from urban areas, but impacts from contaminants are common around Monterrey and downstream, especially in the Río Pesquería (Contreras-Balderas and Lozano-Vilano 1994, p. 382; Sanchez 1997, p. 429; Cubero 2016; Montemayor 2020, personal communication). The overall conditions in this unit currently present a **Moderate Risk** to Rio Grande cooter.

Río San Juan – headwaters to El Cuchillo Dam

Our occurrence database contains several observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **Low-Moderate Risk** to this unit for the *Occurrence* metric. In this unit, Rio Grande cooter have been observed in tributaries to the Río San Juan (Río de la Silla, Río Pilón, and Río Santa Catarina), so we assigned a rating of **Moderate-High Risk** to this unit for the *Occurrence Complexity* metric. We assigned a rating of **Moderate Risk** to this unit for the *Water Quantity* metric because some tributaries are reported to have good flow, but others have experienced low or no-flow events, especially during drought (Návar Cháidez 2011, p. 131; Montemayor 2020, personal communication; Nevárez-de los Reyes 2020, personal communication; Vallejo Valdez 2020, personal communication). We assigned a rating of **Moderate Risk** to this unit for the *Water Quality* metric because the water in this unit is reported to have good quality upriver from urban areas, but impacts from contaminants are common around Monterrey and downstream, especially in the mainstem Río San Juan (Contreras-Balderas and Lozano-Vilano 1994, p. 383; Návar Cháidez 2011, p. 133; Hernández 2018; Chantaka Lucio 2019; Montemayor 2020, personal communication; Nevárez-de los Reyes 2020, personal communication; Vallejo Valdez 2020, personal communication). The overall conditions in this unit currently present a **Moderate Risk** to Rio Grande cooter.

Río San Juan – El Cuchillo Dam to Marte R Gomez Dam

Our occurrence database contains no observations of Rio Grande cooter from 1990–2020, so we assigned a rating of **High Risk** to this unit for the *Occurrence* and *Occurrence Complexity* metrics. We assigned a rating of **High Risk** to this unit for the *Water Quantity* metric because the Río San Juan is reported to have no flow most of the time (Sanchez 1997, p. 429; 1997, p. 429; Návar Cháidez 2011, p. 133). We assigned a rating of **High Risk** to this unit for the *Water Quality* metric because the water in this unit was reported to have poor quality prior to the construction of the El Cuchillo dam, and we have no expectation that conditions have improved (Contreras-Balderas and Lozano-Vilano 1994, p. 383; Robinson 2000, p. 9; Návar Cháidez 2011, p. 133). The overall conditions in this unit currently present a **High Risk** to Rio Grande cooter.

Summary of Current Resiliency

The current resiliency of Rio Grande cooter population analysis units based on demographic and habitat factors is presented in Table 5.3. Generally speaking, resilient population analysis units are characterized by having enough individuals within habitat patches to survive and reproduce despite disturbance. Based on our analysis of the 16 population analysis units evaluated across the Rio Grande cooter's range, we determined that three of these units have a current overall condition of **Low Risk**, seven have a current overall condition of **Moderate Risk**, and six have a current overall condition of **High Risk**. Within the population analysis units currently categorized as High Risk, meaning these populations have a limited ability to respond to stochastic events, there is no evidence that self-sustaining populations are present. Overall, given the current conditions of the population analysis units for the Rio Grande cooter, the majority of populations have the ability to withstand stochastic events (e.g., disturbance).

Table 5.3. Current condition analysis results by population analysis unit, individual metrics, and overall risk. The factor-level risk rating is presented in addition to our determination of the overall risk to species viability based on resiliency. The values in parentheses are the midpoints of the range of extirpation risk (as described in detail in the methodology section). The order of the population analysis units is roughly north to south and west to east.

Population Analysis Unit	Demographic Factors		Habitat Factors			Overall Risk
	Occurrence	Subadult Presence	Occurrence Complexity	Water Quantity	Water Quality	
Pecos River – Sumner Dam to Brantley Dam	Moderate (21.5)	Moderate-High (55)	Moderate-High (55)	Moderate (21.5)	Low (5)	High Risk
Pecos River – Brantley Dam to Red Bluff Dam	Low (5)	Low (5)	Low (5)	Moderate (21.5)	Moderate (21.5)	Moderate Risk
Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment	High (66.5)	Moderate-High (55)	Moderate-High (55)	High (66.5)	High (66.5)	High Risk
Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment	Low (5)	Low (5)	Low (5)	Low (5)	Low (5)	Low Risk
Devils River – headwaters to Amistad Reservoir	Low (5)	Low (5)	Low (5)	Low (5)	Low (5)	Low Risk
Rio Grande – Big Bend to Amistad Dam	Low (5)	Moderate-High (55)	Low (5)	Low (5)	Low (5)	Moderate Risk
Rio Grande – Amistad Dam to Falcon Dam	Low (5)	Low (5)	Low (5)	Low (5)	Moderate (21.5)	Low Risk
Rio Grande – Falcon Dam to Anzalduas Dam	Low (5)	Moderate-High (55)	Moderate-High (55)	Low (5)	Moderate (21.5)	Moderate Risk
Rio Grande – Anzalduas Dam to Mouth	High (66.5)	Moderate-High (55)	High (66.5)	Moderate (21.5)	Moderate (21.5)	High Risk
Río Sabinas – headwaters to Don Martin Reservoir	Low-Moderate (16.5)	Undetermined	Low-Moderate (16.5)	Low (5)	Low (5)	Moderate Risk
Río Salado – headwaters to Don Martín Dam	High (66.5)	Undetermined	High (66.5)	Low (5)	Low (5)	High Risk
Río Sabinas Hidalgo – headwaters to cfl Río Salado	Low-Moderate (16.5)	Undetermined	Moderate-High (55)	Moderate (21.5)	Low (5)	Moderate Risk
Río Salado – Don Martin Dam to Falcon Reservoir	High (66.5)	Undetermined	High (66.5)	High (66.5)	High (66.5)	High Risk
Río Salinas – headwaters to cfl Río San Juan	Low-Moderate (16.5)	Undetermined	Low (5)	Low-Moderate (16.5)	Moderate (21.5)	Moderate Risk
Río San Juan – headwaters to El Cuchillo Dam	Low-Moderate (16.5)	Undetermined	Moderate-High (55)	Moderate (21.5)	Moderate (21.5)	Moderate Risk
Rio San Juan – El Cuchillo Dam to Marte R Gomez Dam	High (66.5)	Undetermined	High (66.5)	High (66.5)	High (66.5)	High Risk

Current Redundancy

Redundancy is the ability of a species to withstand catastrophes. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population health and for which adaptation is unlikely (Mangel and Tier 1993, p. 1083). We gauge redundancy by analyzing the number and distribution of populations relative to the timing and intensity of anticipated species-relevant catastrophic events (e.g., drought, severe water contamination events, over-collection) that could act on an entire river basin simultaneously.

We identified catastrophic events that could possibly act on Rio Grande cooter at the species level (we address very local catastrophic events in our resiliency analysis, particularly through our *Occurrence Complexity* metric). The first type of event is a widespread, severe contamination event impacting water quality such that any turtle unable to leave the area of contamination dies. The most conceivable format for this would be a major industrial spill into a waterway that leaves the habitat uninhabitable for an extended period of time. The presence of many dams and impoundments within each basin may provide some protection against a catastrophic event of this degree because they inhibit the passage of contaminants throughout a given watershed. The reverse may also be true, as the same water management structures may inhibit the flushing of contaminants from an area and allow for the buildup of toxic materials. The second type of catastrophe is a widespread, severe drought that results in major drying of occupied Rio Grande cooter habitat, and that is so severe it leads to widespread mortality of Rio Grande cooter due to stranding, dehydration, or predation. Mechanisms to cause this would likely be a combination of an extreme lack of rainfall combined with intensive groundwater pumping and high temperatures. As with a severe contamination event, the presence of reservoirs throughout the species' range could provides some protection against such widespread drying occurring, particularly given the reliance of human populations on surface water, which is stored in the reservoirs and delivered via the rivers themselves. However, drought conditions could also lead to river drying if accumulating reservoir storage is given priority over maintaining instream flows. A potential mitigating factor for this type of catastrophic event is that in both Texas and New Mexico, state-mandated regional water planning processes require communities to plan and prepare for the recurrence of severe drought. The third type of possible catastrophic event is a major collection event, in which Rio Grande cooter are illegally removed from the wild in large numbers, having the same impact on the population as the sudden death of a large number of adult turtles.

We judged whether Rio Grande cooter has redundancy rangewide and at the river basin level. The river basins used for this assessment are those where the turtle historically occurred: the Pecos River, Devils River, Rio Grande, Río Salado, and Río San Juan basins. Currently, the Rio Grande cooter occurs in population analysis units considered Low Risk or Moderate Risk in our resiliency analysis in all five of these major river basins (Table 5.4; Figure 5.1). Therefore, it has redundancy rangewide. In addition, within each river basin save the Devils River, which only has one population analysis unit, there is more than one population analysis unit considered Low Risk or Moderate Risk in our resiliency analysis. So, the Rio Grande cooter also has redundancy within four of five river basins. When we consider the distribution of population analysis units by political boundaries such as states or participation in the Pecos River Compact or Rio Grande Water Treaty, we also find that the level of risk is distributed among the risk categories. None of these potential groupings of population analysis units result in a population analysis unit existing in a singular management or regulatory situation, or where all of the population analysis units in a group were assigned High Risk in our resiliency analysis. Thus, the Rio Grande cooter also has redundancy when considering potential political groupings. Because Rio Grande cooter currently has redundance at multiple scales, there is a lower likelihood of catastrophic events having an impact across the range of the species.

Table 5.4. Current conditions analysis results by river basin and count of population analysis units in each risk category.

River Basin	Number of Low Risk Population Analysis Units	Number of Moderate Risk Population Analysis Units	Number of High Risk Population Analysis Units	Total Number of Population Analysis Units
Pecos River	1	1	2	4
Devils River	1	0	0	1
Rio Grande	1	2	1	4
Río Salado	0	2	2	4
Río San Juan	0	2	1	3
All Basins	3	7	6	16

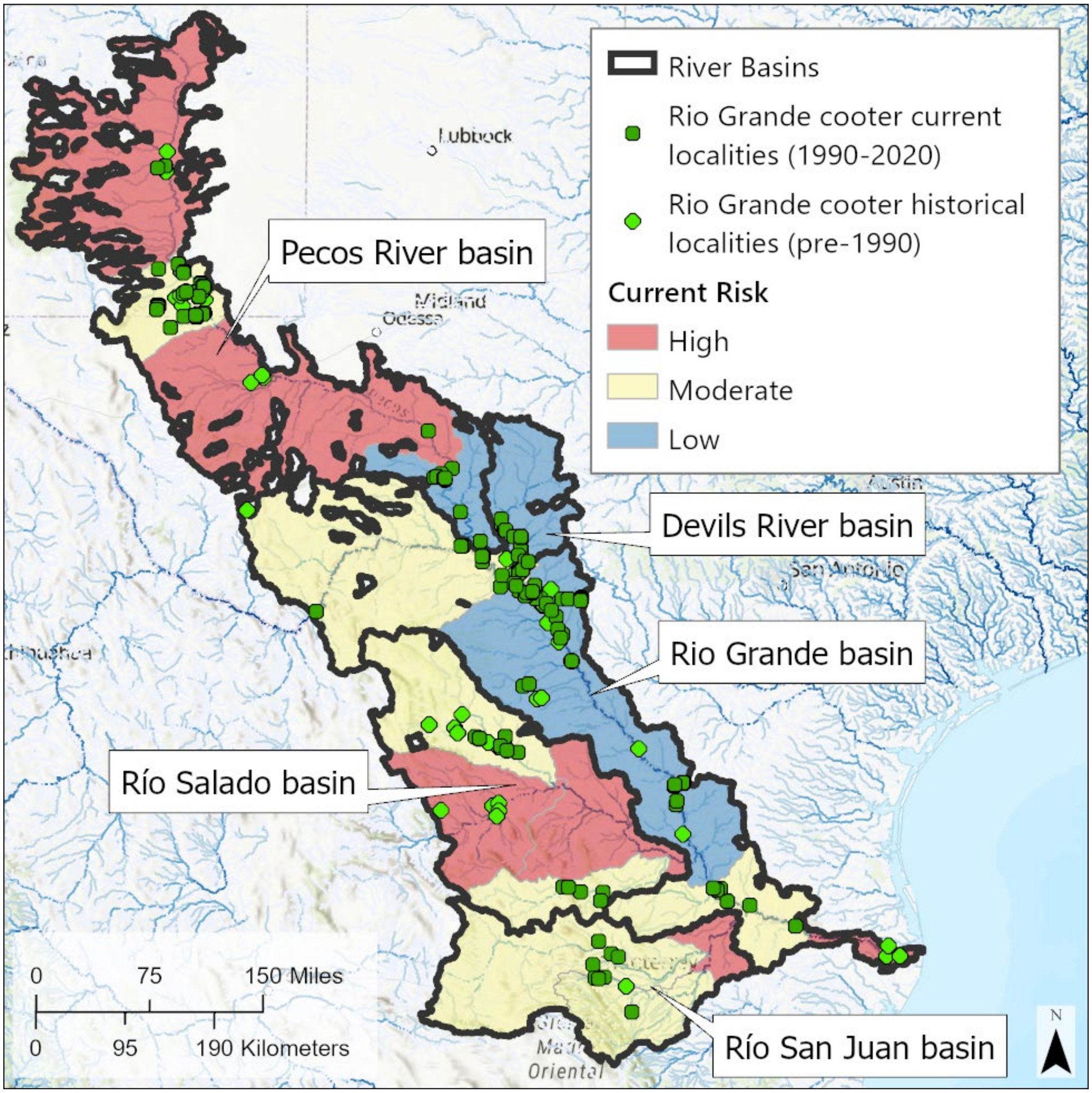


Figure 5.1. Rio Grande cooter population analysis units colored by current risk category assignment (red for high risk, yellow for moderate risk, and blue for low risk). The five major river basins are labeled and have thick black borders (see Figure 3.4 for population analysis units color coded by river basin).

Current Representation

Representation is the ability of Rio Grande cooter to adapt to both near-term and long-term changes in its physical and biological environments. This ability to adapt to new environments—referred to as adaptive capacity—is essential for viability, as all species need to continually adapt to changing environments (Nicotra et al. 2015, p. 1269). Rio Grande cooter may adapt to novel changes in their environment by moving to new, suitable environments or by altering their physical or behavioral traits to match the new environmental conditions through either plasticity or genetic change (Nicotra et al. 2015, p. 1270; Beever et al. 2016, p. 132).

We can best gauge representation by examining the breadth of genetic, phenotypic, and ecological diversity found within a species and its ability to disperse and colonize new areas. In assessing the breadth of variation, it is important to consider both larger-scale variation (such as morphological, behavioral, or life history differences which might exist across the breadth of environmental and ecological variation across the species range), and smaller-scale variation (which might include measures of interpopulation genetic diversity). Regarding representative characters, Rio Grande cooter exist as a single genetic population throughout their distribution in the United States (Bailey et al. 2008, pp. 408–10) and no studies have found evidence for spatial patterns in behavioral, morphological, or life history diversity. Thus, to assess representation, we focused on whether the species exists across a large area with diversity of environmental conditions (e.g., climatic conditions, geology, stream type) and we assume that the risk of loss of adaptive potential can be minimized by maintaining a broad distribution of the species across its known historical range. Current representation for Rio Grande cooter is characterized by its occurrence within all five of the historically occupied river basins, and by the fact that the resiliency analysis determined that the Overall Risk for 10 of 16 population analysis units is either Low Risk or Moderate Risk. Therefore, we assume that because it is present throughout its known historical range and the majority of population analysis units are classified as Low Risk or Moderate Risk, the Rio Grande cooter has some capacity to adapt to changing future conditions.

6 Species Viability

In this chapter, we describe how the current viability of Rio Grande cooter may change as a response to the conditions outlined in our future scenarios. We consider the potential contributions of sources on stressors in the future, and correspondingly, how those stressors may negatively impact the species' habitat and demographic needs. Where appropriate, we consider any existing efforts to conserve the species or its habitat. As in the current conditions chapter, we evaluate the species' viability in terms of resilience at the population scale, and representation and redundancy at the species scale. We describe two plausible future scenarios and project the response of Rio Grande cooter to the environmental conditions at two future timesteps in terms of the three Rs, and ultimately, species viability.

Future Resiliency

Future Resiliency Analysis Methodology

As with the current conditions analysis, the future condition risk assessment reflects our judgement of the likelihood that the species' response to the conditions described in each individual metric, over the 30-year period following a given timestep, would be extirpation from a given population analysis unit. This 30-year timeframe correlates with two approximately 15-year generations, and is slightly longer than the presumed average Rio Grande cooter lifespan of 20–25 years. We carry forward the framework used in the current resiliency analysis with respect to the risk categories and associated estimates of extirpation. As a starting point, we sought to evaluate the species' response to the conditions in each scenario using the same metrics and basis for assigning risk that were used in the current condition resiliency analysis.

We consider two future timesteps: 2040 and 2060. Risk categories assigned to each scenario at timestep 2040 reflect a qualitative determination of the likelihood that the species response to the conditions described in each individual metric, from 2040 to 2070, would be extirpation from a given population analysis unit. The risk categories at timestep 2060 reflect that determination for the period 2060-2090. Thus, the full projection time for the species response presented in this SSA report encompasses the entire period from 2020–2090. The future condition of Rio Grande cooter is expected to be driven largely by water quantity and water quality, as these habitat characteristics have been observed to change over time and to correlate with Rio Grande cooter occupancy and relative abundance (Chapters 2–5). Management of Rio Grande cooter habitat, and the associated resources that create and sustain that habitat (e.g., the Edwards-Trinity Plateau Aquifer), further influence the future condition of the species.

To construct plausible future scenarios, we used existing, published projections of relevant future conditions to develop our scenarios where available. Scenarios of changes to the climate are available from the Intergovernmental Panel on Climate Change (IPCC), and forecast conditions out to the year 2100 (U.S. Federal Government 2020). We projected impacts to water supply and demand from climate change, focusing on impacts from increasing temperatures and the associated potential changes in drought frequency, severity, and duration (Shafer et al. 2014, entire; Kloesel et al. 2018, entire; Cheng et al. 2019, entire; U.S. Federal Government 2020). We considered Representative Concentration Pathways (RCPs) 4.5 and 8.5. RCPs are scenarios that allow for diverse interactions between human population size, economic activity, energy and land use, technology, and climate policy that produce a particular emissions outcome (Intergovernmental Panel on Climate Change (IPCC) 2014, p. 8). Given an emissions trajectory, trajectories for associated variables such as temperature are also modeled, and there is a strong, almost linear correlation between emissions and temperature change (Intergovernmental Panel on Climate Change (IPCC) 2014, p. 8). Increasing air temperatures are associated with higher high and low temperatures, decreased soil moisture, increased evapotranspiration rates, more severe heat waves, and longer and more intense droughts (Wehner et al. 2017, entire; Cheng et al. 2019, pp. 4433–34).

Regional water plans in both Texas and New Mexico also forecast water demand and supply across different user groups and subregional areas. These forecasts are decadal and extend to the year 2070 for Texas and the year 2060 for New Mexico. We relied primarily on the regional water plans from Texas and New Mexico that overlapped our population analysis units to evaluate the likelihood that springs, streams, or rivers within the population analysis units might be subject to drying in the future (NMOSE 2016, entire; Far West Texas Planning Group 2020, entire; Freese and Nichols, Inc. 2020, entire; Plateau Water Planning Group 2020, entire; Rio Grande Regional Water Planning Group 2020, entire). Within these, we specifically considered surface and groundwater availability, projected changes to demand, and identified gaps between supply and demand. We cross-referenced the counties, basins, and aquifers from the water plan summaries to the population analysis units to project future impacts to habitat.

For some parts of the Rio Grande cooter range, additional projections of impacts on water resources from oil and gas operations were available (Figure 6.1). The summary projections available from these sources are based on rigorous modeling efforts and constitute the best available scientific information on future conditions for the metrics they analyzed. We considered potential increases in water demand associated with hydraulic fracturing in the Permian Basin and Eagle Ford play, using projections developed by Scanlon et al. (2020, entire). To do this we compared the water use projected by regional water plans (NMOSE 2016, entire; Far West Texas Planning Group 2020, entire; Freese and Nichols, Inc. 2020, entire; Plateau Water Planning Group 2020, entire; Rio Grande Regional Water Planning Group 2020, entire) and increased the total demand to match that projected by Scanlon et al. (2020, supporting information, entire), to determine if the increase resulting in a gap between projected supply and demand. In parts of Mexico associated with the Eagle Ford formation, projections of current water stress were compared to future water stress if additional oil and gas development were to occur to infer whether and to what extent such activities might impact water quantity (Hernández-Espriú et al. 2019, entire).

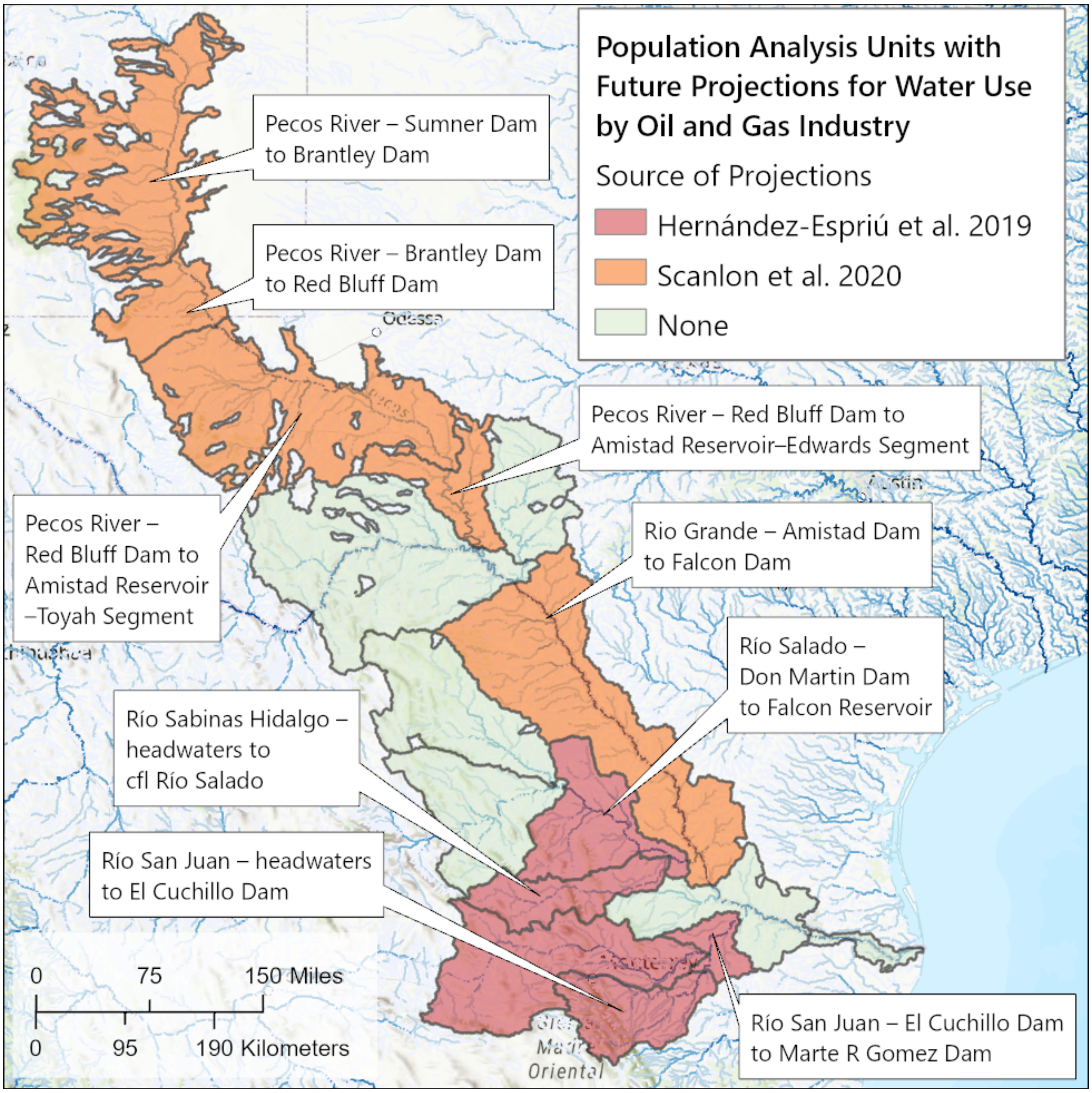


Figure 6.1. Population analysis units for which future projections of water demand by the oil and gas industry were available. Water demand is largely for activities associated with hydrofracking. Projections for the United States are from Scanlon et al. (2020, entire, and supplementary information). Projections for Mexico are from Hernández-Espriú et al. (2019, entire, and supplementary information).

The final influence on water quantity we considered is that of existing conservation efforts in New Mexico (i.e., the CCA/As for Texas Hornshell and Other Species and the Bureau of Reclamation's Carlsbad Water Project Biological Opinion conservation measures), particularly with respect to their goals of maintaining instream flow and minimizing river intermittency (U.S. Fish and Wildlife Service 2017, entire; U.S. Fish and Wildlife Service and New Mexico Commissioner of Public Lands 2017, entire; U.S. Fish and Wildlife Service and The Center of Excellence (CEHMM) 2017, entire; U.S. Fish and Wildlife Service et al. 2017, entire). Much of New Mexico is currently experiencing severe to exceptional drought (National Integrated Drought Information System 2021), which, in combination with human demand for water, leads to reduced flows and increased potential for river intermittency. In the last several years, localized drying in the area covered by these conservation efforts indicates that it is possible that the goals will not be met (CEHMM-Center of Excellence 2019, entire; U.S. Fish and Wildlife Service 2019, entire; 2020a, entire; 2020b, entire; CEHMM-Center of Excellence and New Mexico State Land Office 2020, pp. 9–19; R. Schmidt 2020; Horner 2021, personal communication). To account for this, we considered the implications of the success or failure of these agreements.

As with the current resiliency analysis (Chapter 5), we integrated our assessment of specific conductance and risk of contaminants and sources of pollution to determine the overall risk to Rio Grande cooter within a given population analysis unit associated with water quality. We continued to use the specific conductance dataset assembled to assess current risk in our future conditions analysis for population analysis units in the United States. We created our own future projections by fitting a linear model to the dataset of specific conductance measurements used in the current condition analysis. We created two alternative future scenarios for specific conductance by varying the reference period used to calculate the model fit. Specifically, we calculated the mean specific conductance at the population analysis unit level using the entire period of record, and again using the data only from 1990 to 2020, which is the period of record that informed the current condition analysis. We did this for both timesteps. For each unit, we used the lower final mean specific conductance value for Scenario 1, and the higher value for Scenario 2 (regardless of the input dataset) to ensure that our scenarios best reflected the full range of plausible future outcomes. For a more detailed overview of the specific conductance analyses and results, refer to Appendix B.

To project future risk from hazardous materials spills or leaks and contaminants, we relied on the same qualitative assessment of trends as with the current condition (Chapter 5). In Scenario 2, we also considered a marginal increase in the risk of contamination events associated with an increase in hydraulic fracturing activities, as there is a potential risk to surface and groundwater in the Permian Basin and Eagle Ford Play from the large volumes of produced water that result from oil and gas production (Hernández-Espriú et al. 2019, entire; Scanlon et al. 2020, entire). Information about water quality in Mexican waterways was gleaned from the literature and from conversations with researchers and individuals who have recorded observations of Rio Grande cooter in Mexico, as with the current condition (Chapter 5).

We chose future timesteps that fit within the timeframes of existing future projections and link the current and future conditions: the years 2040 and 2060. When constructing the scenarios, we grouped the outcomes from projections that were more favorable for Rio Grande cooter into Scenario 1 and the outcomes that were less favorable into Scenario 2. In combination, these two scenarios represent the full potential range of resiliency outcomes for Rio Grande cooter (Table 6.1).

We used the same metrics and rules as the current resiliency analysis to project the response of Rio Grande cooter at the population analysis unit level over the 30 years from each timestep. Modifications to the metrics were minor and are described below. We also used the quantitative, repeatable approach to determine an overall risk category for each population analysis unit considering the impacts to the species across all the demographic and habitat factors that was used in the current resiliency analysis. When we could not tabulate occurrence data to inform the *Occurrence*, *Subadult Presence*, or *Occurrence Complexity* metrics, we used the most recently available risk assignment as the null value when computing the geometric mean. This was done in order to not artificially influence the mean, which would otherwise happen in any instance where the value for the metric differed from the mean.

Table 6.1. Description of the conditions projected to occur for each influencing factor in the two future scenarios. We also identify the primary metric impacted by a given influencing factor.

Habitat Metric	Influencing Factor	Scenario 1	Scenario 2
Water Quantity	Climate change	Representative Concentration Pathway (RCP) 4.5 (moderate increase in greenhouse gas emissions)	RCP 8.5 (severe increase in greenhouse gas emissions)
	Water demand vs. availability	United States: Regional Water Plan projections accurately predict future water demand and availability. Mexico: Current trends continue.	United States: Regional Water Plan projections accurately predict future water demand and availability for most places, but underestimate water demand from mining in the Permian Basin and Eagle Ford play. Mexico: Current trends continue, with increased water stress in the Eagle Ford play.
	Conservation measures	Existing CCA/As on the lower Pecos River and permit conditions for the Bureau of Reclamation's management of the upper Pecos River succeed in maintaining instream flows and minimizing river and stream intermittency for population analysis units in New Mexico.	Existing CCA/As on the lower Pecos River and permit conditions for the Bureau of Reclamation's management of the upper Pecos River fail to maintain instream flows or minimize river and stream intermittency for population analysis units in New Mexico.
Water Quality	Specific conductance	Current trends continue; lower projected mean specific conductance.	Current trends continue; higher projected mean specific conductance.
	Hazardous materials spills or leaks; presence of contaminants	Current trends continue.	United States: Current trends continue, with increased risks from hazardous materials spills in the Permian Basin and Eagle Ford play. Mexico: Decreased water quality compared to current conditions with increased risks from hazardous materials spills in the Eagle Ford play.

Metrics

We reviewed the demographic and habitat metrics used in the current condition analysis and assessed whether and how they could be carried over into the future condition analysis in order to ensure consistency in our approach to the current and future species condition. The *Occurrence*, *Subadult Presence*, and *Occurrence Complexity* metric rules for assigning risk categories are associated with specific timeframes, so these rules were modified to be congruent with the future timesteps. When the timeframes were entirely in the future (i.e., 2021 or later), then we used the most recent risk assignment as a null value. See Table 5.2 for a summary of the rules for evaluating risk for the *Water Quantity* and *Water Quality* metrics, and Table 6.2 for a summary of the rules for evaluating risk for the future *Occurrence* and *Occurrence Complexity* metrics.

The *Occurrence* metric is based on observational, presence-only data that we compiled into a database and mapped on the landscape. As for the current resiliency analysis, information on abundance, occupancy, or on the trends associated with either of these is not widely available. Consequently, we are unable to project increases or decreases in *Occurrence* outside of the context of water quantity and water quality. The goal of the metric is to measure the influence of each factor on its own, while the overall population analysis unit risk category rating reflects the totality of conditions. For the year 2040, we can use the same conceptual rule to characterize risk: the number of observations in our database for the 30 years prior to the timestep in question. In this case, the years 2010–2040 are used to characterize the category rating assigned for 2040. However, we are unable to use this strategy for timestep 2060, as the entire period of 2030–2060 is in the future. Because we do not have data for the period 2030–2060, we adopt the values for 2040 when making the future risk determination for this metric; that is, we assume that risk for the *Occurrence* metric is stable, though we note that a determination of high risk for the *Occurrence* metric indicates the turtles in a given population analysis unit have the corresponding level of vulnerability to extirpation.

The *Subadult Presence* and *Occurrence Complexity* metrics rest on the same observational database as the *Occurrence* metric, and have the same limitations. We do not have the capacity to make fine-scale projections about Rio Grande cooter occupancy of individual springs, streams, or rivers within a unit. As with the *Occurrence* metric, we use the period 2010–2040 to inform projections for timestep 2040, and adopt the risk categories assigned to 2040 for 2060. The *Subadult Presence* metric is based on the 15-year period prior to the year of evaluation, so the timeframes of both future timestep are outside the existing dataset (2025–2040 and 2045–2060). Thus, we use the value for the current resiliency analysis as a null value for calculating the overall mean in both timesteps.

Table 6.2. A summary of the rules used to assign a risk category to the *Occurrence* and *Occurrence Complexity* metrics for the future resiliency analysis. The *Occurrence* and *Occurrence Complexity* metrics are not calculated for 2060; the results from 2040 are used as null values when determining the overall risk for 2060. The *Subadult Presence* metric is not calculated for the future timesteps; the result from 2020 is used as a null value when determining the overall risk for 2060.

Risk Category	Occurrence, 2040	Occurrence Complexity, 2040
High Risk	Zero observations, 2010–2020 *or* fewer than six observations and expert knowledge	Not observed in spring pools, streams, or rivers, 2010–2040
Moderate-High Risk	Not used	Observations in only one of spring pools, streams, or rivers, 2010–2020
Moderate Risk	United States: Fewer than six observations, 2010–2020 unless expert knowledge can resolve	Not used
Low-Moderate Risk	Mexico: At least one observation, 2010–2020	Observations in two of spring pools, streams, or rivers, 2010–2020
Low Risk	United States: Six or more observations, 2010–2020	Observed in spring pools, streams, and rivers, 2010–2020

Scenario 1

Overview

In Scenario 1, climate change proceeds as projected by the RCP 4.5-associated models. This scenario assumes that the regional water plans in the United States accurately project future water supply and demand in 2040 and 2060, while current trends in water supply and demand continue in Mexico. The conservation measures associated with CCA/As and BOs in New Mexico for management of the upper Pecos River succeed in maintaining instream flows and minimizing river and stream intermittency at both timesteps. For population analysis units in the United States, existing trends in specific conductance continue to 2040 and 2060. Trends in the rate and volume of hazardous materials spills and leaks continue to 2040 and then stabilize. For population analysis units in Mexico, current trends in overall water quality continue.

Occurrence, Occurrence Complexity, and Subadult Presence

As described above in the metrics section, we used occurrence database records from 2010 to 2020 to evaluate the *Occurrence* and *Occurrence Complexity* metrics for the 2040 timestep. For every population analysis unit, most or all of the observations in that unit come from 2010 or later. Thus, there was no change to the risk category rating for these metrics between 2020 and 2040. The *Occurrence* and *Occurrence Complexity* metrics for the 2060 timestep, and the *Subadult Presence* metric for both the 2040 and 2060 timesteps, could not be evaluated anew as part of the future scenario, as explained above. We use the most recent risk assignment value (from either 2020 or 2040, as appropriate) as a null value when computing the geometric mean in order to not artificially influence the mean, which could happen if we simply removed one of the variables from consideration.

Factors Influencing Water Quantity

We anticipate increased water stress as a result of heat and drought impacts associated with climate change projections, particularly rising temperatures, under the RCP 4.5 scenario. RCP 4.5 is a scenario with some efforts to constrain emissions, in which annual anthropogenic CO_2 emissions stabilize around 2050 and then decline (Intergovernmental Panel on Climate Change (IPCC) 2014, pp. 8–9). Projected increases in temperatures and associated negative effects are small in 2040 and small to moderate in 2060 (Shafer et al. 2014, entire; Wehner et al. 2017, entire; Kloesel et al. 2018, entire; Cheng et al. 2019, pp. 4433–34; U.S. Federal Government 2020). For 2040, we project a small increase in demand for water and small decrease in the availability of surface water due to the impacts from climate change, leading to increased water stress across the board. For 2060, we project a small to moderate increase in demand for water and small to moderate decrease in the availability of surface water due to the impacts from climate change and increased water stress overall. In Mexico, regional water plans were unavailable, so the influence of climate change is the primary driver of any changes to projected water quantity.

Projected pressure on water quantity based on regional water plans varied across population analysis units. In general, irrigation demand is stable or declining, but mining[3] demand is rising, sometimes sharply (NMOSE 2016, pp. 172–78; Far West Texas Planning Group 2020, p. 5-6; Freese and Nichols, Inc. 2020, pp. ES-4, ES-5; Plateau Water Planning Group 2020, pp. ES-5, 2-23, 2-24; Rio Grande Regional Water Planning Group 2020, pp. ES-14, ES-18, ES-19). In absolute terms, mining water usage is typically a small fraction of agricultural usage, so its rate of increase does not necessarily translate to water shortages (NMOSE 2016, pp. 172–78; Far West Texas Planning Group 2020, p. 5-6; Freese and Nichols, Inc. 2020, pp. ES-5, ES-8; Plateau Water Planning Group 2020, p. ES-3; Rio Grande Regional Water Planning Group 2020, p. ES-14). There is a risk to surface water supplies in the *Pecos River – Brantley Dam to Red Bluff Dam, Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment,* and *Rio Grande – Big Bend to Amistad Dam* population analysis units from groundwater pumping to supply oil and gas operations, if those pumps are installed in an area where the groundwater and surface water are closely connected (NMOSE 2016, pp. 172–75; Far West Texas Planning Group 2020, pp. 2-7–2-22, 3-2–3-9, 4-2–4-4, 5-5–5-29; Freese and Nichols, Inc. 2020, Appendix I; Plateau Water Planning Group 2020, ES-Appendix). In the *Rio Grande – Big Bend to Amistad Dam* population analysis unit, a shortage of water is projected for the mining industry for the future timesteps (Far West Texas Planning Group 2020, pp. 2-7–2-22, 3-2–3-9, 4-2–4-4, 5-5–5-29; Plateau Water Planning Group 2020 ES-Appendix). The Plateau Regional Water Plan indicates that the shortage exists because the Kinney County Groundwater Conservation District's Desired Future Conditions for the area limited the amount of modeled available water (Plateau Water Planning Group 2020, pp. 1-6, 3-11, 5-35). This means that the water is in the aquifer and could be exploited by mining interests, which are exempt from water extraction limits and most reporting requirements (2 TAC §36.117; Bracken 2010, pp. 182–83; Rahm 2011, p. 2979; Galant

[3] "Mining" as used in regional water plans is inclusive of, but not limited to, oil and gas development and operations. Hydrofracking is the most common use for water, though it is not the only use. Projections of water demand associated with oil and gas are specific to hydrofracking, but projections of future water demand by the mining industry are not limited to only these. The proportion of water demand under the mining category that belongs to oil and gas, or to hydrofracking, is either unknown or unspecified.

2012, pp. 828–32; Freyman 2014, pp. 34, 56; Lashmet and Miller 2015, pp. 252–53; Backstrom 2019, pp. 5–6). We do not have any information on locations of future groundwater pump installations, so our assessment is necessarily generalized to the county level.

Three population analysis units overlap Val Verde County, TX, which contains the city of Del Rio and Laughlin Air Force Base: the *Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment, Rio Grande – Big Bend to Amistad Dam*, and *Devils River – headwaters to Amistad Reservoir* population analysis units. The city of Del Rio and Laughlin Air Force Base get their fresh water supplies from the springs connected to the Edwards-Trinity Plateau Aquifer at San Felipe Springs in the city of Del Rio (Plateau Water Planning Group 2020, pp. 1-19, 2-19, 3-18, 4-3, 5A-46, ES-Appendix). As a result, if they decide to address shortages through groundwater development, we assume that they are unlikely to do so in a way that will compromise their water supply further (Plateau Water Planning Group 2020, pp. ES-Appendix). The aquifer can likely be tapped in an area that will not result in the drying of surface water, so additional pumping does not necessarily mean surface drying—it depends on where the pumping takes place (Brune 1975, pp. 32–41; Fratesi et al. 2019, pp. 13–17; Toll et al. 2017, pp. 43–47). Because we have no specific locations where future groundwater pumping will occur, we have limited ability to forecast surface drying as a result, which is the basis by which we assign risk categories under the *Water Quantity* metric.

The Rio Grande from Amistad Reservoir to the Gulf of Mexico is governed by the Water Treaty of 1944 between the United States and Mexico (J. C. Schmidt et al. 2003, p. 30). This treaty includes a special system of water rights that differs from elsewhere in Texas or New Mexico (Rio Grande Regional Water Planning Group 2020, p. ES-9). Under this system, municipal and industrial users are guaranteed their full rights, and irrigation and mining users split the remaining available water (Rio Grande Regional Water Planning Group 2020, p. ES-9). Today it is common for the latter users to not receive the full share for which they hold a water right (Rio Grande Regional Water Planning Group 2020, p. ES-18). Although the shortages will be exacerbated in the future due to the impacts of climate change, intermittency in the Rio Grande is not anticipated above Anzalduas Dam due to the continued need to deliver year-round water to municipal users in the lower Rio Grande Valley (Contreras-Balderas et al. 2002, p. 221; Rio Grande Regional Water Planning Group 2020, pp. ES-17–ES-18). In the *Rio Grande – Anzalduas Dam to Mouth* population analysis unit, however, there are currently issues with intermittency near the mouth of the river, and water quantity problems here are expected to continue to recur under declining flows or drought conditions (Lower Rio Grande BBEST 2012, p. 1-7). Based on the regional water plan, little change from the status quo is expected in total demand for water, but the consumers of water are expected to continue transitioning from irrigation to municipal use, further shoring up demand for perennial water in the river (Rio Grande Regional Water Planning Group 2020, pp. ES-27, 2-18, 2-19, 3-10, 3-17, 5.2-68–5.2-78, ES-Appendix).

Currently, there are conservation measures associated with a U.S. Fish and Wildlife Service Biological Opinion for Bureau of Reclamation management of the Pecos River and its dams in New Mexico, which affects the *Pecos River – Sumner Dam to Brantley Dam* population analysis unit (U.S. Fish and Wildlife Service 2017, entire). There are also ongoing conservation efforts associated with the CCA/As covering Rio Grande cooter and other species inhabiting the Black, Delaware, and Pecos Rivers in a portion of Eddy County, NM and Culberson County, TX, which affect the *Pecos River – Brantley Dam to Red Bluff Dam* population analysis unit (U.S. Fish and Wildlife Service and New Mexico Commissioner of Public Lands 2017, entire; U.S. Fish and Wildlife Service and The Center of Excellence (CEHMM) 2017, entire;

U.S. Fish and Wildlife Service et al. 2017, entire). Under this scenario, these measures continue to be in place in both 2040 and 2060, *and* are successful in minimizing river intermittency and maintaining instream flows. We assume in this scenario that this is the case regardless of other factors, since their purpose is to achieve these results despite the challenges in doing so.

Factors Influencing Water Quality

In this scenario, existing trends in specific conductance are projected to continue as described in our analysis methodology section. Existing trends in hazardous materials spills or leaks and presence of contaminants continue. We held increasing or decreasing trends concerning the rate and volume of hazardous materials spills and leaks constant at the levels projected for 2040 because we did not have data to support projecting these trends further into the future, and because, for example, exponentially increasing spills for the next 40 years did not meet our plausibility standard for scenario inclusion. Similarly, if continuing a declining trend would imply zero future spills, such a trend would not meet our plausibility standard for scenario inclusion.

These trends were not uniform across all population analysis units. In the United States, where specific conductance data were available, we projected stable or declining trends in specific conductance everywhere except the *Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment* and the *Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment* population analysis units. Data on hazardous materials spills or leaks and the presence of contaminants suggest increasing concerns about declining water quality in the *Pecos River – Brantley Dam to Red Bluff Dam* and *Pecos River – Red Bluff Dam to Amistad Reservoir*, *Toyah Segment* units (TCEQ 2019a; 2019b; Kills and Spills Team 2020; New Mexico Oil Conservation Division 2020; Railroad Commission of Texas 2020). In the *Pecos River – Red Bluff Dam to Amistad Reservoir*, *Edwards Segment* population analysis unit, indirect pollution from the Toyah Segment is the source of our concerns about water quality (TCEQ 2019a; 2019b; Kills and Spills Team 2020; Railroad Commission of Texas 2020). Contaminants remain a concern even if they are not increasing in three of the population analysis units on the Rio Grande: *Rio Grande – Amistad Dam to Falcon Dam*, *Rio Grande – Falcon Dam to Anzalduas Dam*, and *Rio Grande – Anzalduas Dam to Mouth* (TCEQ 2019a; 2019b; Kills and Spills Team 2020; Railroad Commission of Texas 2020). Three population analysis units in the United States are projected to remain stable with good water quality: *Pecos River – Sumner Dam to Brantley Dam*, *Devils River – headwaters to Amistad Reservoir*, and *Rio Grande – Big Bend to Amistad Dam* (TCEQ 2019a; 2019b; Kills and Spills Team 2020; Railroad Commission of Texas 2020). In Mexico, we project that water quality conditions will continue to be good into the future for three units in the Río Salado basin (*Río Sabinas – headwaters to Don Martin Reservoir, Río Salado – headwaters to Don Martin Dam, Río Sabinas Hidalgo – headwaters to cfl Rio Salado*), and that they will decline into the future for two units in the Río San Juan basin (*Río Salinas – headwaters to cfl Río San Juan, Río San Juan – headwaters to El Cuchillo Dam*); the two units with currently degraded water quality are not projected to improve (*Río Salado – Don Martin Dam to Falcon Reservoir, Río San Juan – El Cuchillo Dam to Marte R Gomez Dam*) (Guerra 1952, p. 6; Contreras-Balderas and Lozano-Vilano 1994, pp. 382–83; Sanchez 1997, p. 429; Robinson 2000, p. 9; Návar Cháidez 2011, p. 133; Cubero 2016; Hernández 2018; Chantaka Lucio 2019; Berg 2020, personal communication; Davila Paulin 2020a; 2020b, personal communication; Hendrickson 2020, personal communication; Montemayor 2020, personal communication; Nevárez-de los Reyes 2020, personal communication; Ochoa Espinoza 2020, personal communication; Strenth 2020, personal communication; Trujillo 2020, personal communication; Vallejo Valdez 2020, personal communication).

Changes to Metric Risk Assignments

Compared to the current conditions, there was no change in the risk assignment for the *Occurrence, Subadult Presence,* or *Occurrence Complexity* metrics for any population analysis unit for either 2040 or 2060.

When we considered projected changes to *Water Quantity* over time, it is clear that water stress is increasing, but for most population analysis units we did not determine that the changes were sufficient to shift population analysis unit hydrology from its current characterization and associated risk category determination. The exception at timestep 2040 was the *Río Salinas – headwaters to cfl Río San Juan* population analysis unit in Mexico. This unit was designated **Low-Moderate Risk** for *Water Quantity* for 2020 due to uncertainty, and shifted to **Moderate Risk** for 2040 given the increased stress due to climate and the lack of any information about increasing water supplies in the units. At timestep 2060, the *Water Quantity* metric result for all but three population analysis units remained in the same category of risk as for 2040. For the *Pecos River – Sumner Dam to Brantley Dam* unit, we projected that even if the current conservation measures continue into the future, the pressure on water supplies is severe enough that we project an increased risk of Berrendo Creek drying, as it is not actually protected by those conservation measures. Because Berrendo Creek contains the only known current localities for Rio Grande cooter, the risk to the species is increased to **High Risk** for *Water Quantity* at 2060. In addition, the continuation of current trends, including the effects of climate change, lead us to project an increase from **Low Risk** to **Moderate Risk** for the *Río Sabinas – headwaters to Don Martin Reservoir* and *Río Salado – headwaters to Don Martin Dam* population analysis units due to increasing river intermittency.

When we considered projected changes to *Water Quality* over time, the fine-scale results were mixed, but overall the effects were small across both timesteps, and did not result in a change to the *Water Quality* metric risk category assignment for most population analysis units. The only exception was the *Pecos River – Red Bluff Dam to Amistad Reservoir*, *Edwards Segment* at the 2060 timestep, which was projected to shift from **Low Risk** to **Moderate Risk** due to increasing specific conductance within the unit and the increasing risks to the *Pecos River – Red Bluff Dam to Amistad Reservoir*, *Toyah Segment*, which flows unimpeded into the Edwards Segment.

After evaluating each metric for a given scenario and year, we projected an overall future risk level for each population analysis unit (Table 6.3 and

Table 6.4). We did not project any changes to the overall risk category at the population analysis unit level for either timestep 2040 or timestep 2060.

Summary of Scenario 1 Resiliency

Compared to the results of the current resiliency analysis, we do not project any changes to the *Overall Risk* to Rio Grande cooter in any of the population analysis units under Scenario 1 at timestep 2040 or timestep 2060 (Table 6.3 and Table 6.4). Under this scenario, at both future timesteps, the overall resiliency of Rio Grande cooter is characterized by having six populations in the **High Risk** category, seven populations in the **Moderate Risk** category, and three populations in the **Low Risk** category. Overall, under both timesteps of this scenario, the majority (10 of 16) of population analysis units are categorized as either **Low Risk** or **Moderate Risk**, and have the ability to withstand stochastic events (e.g., disturbance).

Table 6.3. Summary of future resiliency analysis for Scenario 1 at timestep 2040. Risk categories reflect the outcomes from the species response to the conditions present in 2040 over the period 2040–2070. Arrows pointing up denote increases compared to the current resiliency.

Population Analysis Unit	Demographic Factors		Habitat Factors			Overall Risk
	Simple Occurrence	Subadult Presence	Occurrence Complexity	Water Quantity	Water Quality	
Pecos River – Sumner Dam to Brantley Dam	Moderate	Moderate-High	Moderate-High	Moderate	Low	High
Pecos River – Brantley Dam to Red Bluff Dam	Low	Low	Low	Moderate	Moderate	Moderate
Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment	High	Moderate-High	Moderate-High	High	High	High
Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment	Low	Low	Low	Low	Low	Low
Devils River – headwaters to Amistad Reservoir	Low	Low	Low	Low	Low	Low
Rio Grande – Big Bend to Amistad Dam	Low	Moderate-High	Low	Low	Low	Moderate
Rio Grande – Amistad Dam to Falcon Dam	Low	Low	Low	Low	Moderate	Low
Rio Grande – Falcon Dam to Anzalduas Dam	Low	Moderate-High	Moderate-High	Low	Moderate	Moderate
Rio Grande – Anzalduas Dam to Mouth	High	Moderate-High	High	Moderate	Moderate	High
Río Sabinas – headwaters to Don Martin Reservoir	Low-Moderate	Undetermined	Low-Moderate	Low	Low	Moderate
Río Salado – headwaters to Don Martín Dam	High	Undetermined	High	Low	Low	High
Río Sabinas Hidalgo – headwaters to cfl Río Salado	Low-Moderate	Undetermined	Moderate-High	Moderate	Low	Moderate
Río Salado – Don Martin Dam to Falcon Reservoir	High	Undetermined	High	High	High	High
Río Salinas – headwaters to cfl Río San Juan	Low-Moderate	Undetermined	Low	Moderate ↑	Moderate	Moderate
Río San Juan – headwaters to El Cuchillo Dam	Low-Moderate	Undetermined	Moderate-High	Moderate	Moderate	Moderate
Río San Juan – El Cuchillo Dam to Marte R Gomez Dam	High	Undetermined	High	High	High	High

Table 6.4. Summary of future resiliency analysis for Scenario 1 at timestep 2060. Risk categories reflect the outcomes from the species response to the conditions present in 2060 over the period 2060–2090. The categorization for Subadult Presence is carried over from the current conditions analysis. Arrows pointing up denote increases compared to the current resiliency.

Population Analysis Unit	Demographic Factors		Habitat Factors			Overall Risk
	Occurrence	Subadult Presence	Occurrence Complexity	Water Quantity	Water Quality	
Pecos River – Sumner Dam to Brantley Dam	Moderate	Moderate-High	Moderate-High	High ↑	Low	High
Pecos River – Brantley Dam to Red Bluff Dam	Low	Low	Low	Moderate	Moderate	Moderate
Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment	High	Moderate-High	Moderate-High	High	High	High
Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment	Low	Low	Low	Low	Moderate ↑	Low
Devils River – headwaters to Amistad Reservoir	Low	Low	Low	Low	Low	Low
Rio Grande – Big Bend to Amistad Dam	Low	Moderate-High	Low	Low	Low	Moderate
Rio Grande – Amistad Dam to Falcon Dam	Low	Low	Low	Low	Moderate	Low
Rio Grande – Falcon Dam to Anzalduas Dam	Low	Moderate-High	Moderate-High	Low	Moderate	Moderate
Rio Grande – Anzalduas Dam to Mouth	High	Moderate-High	High	Moderate	Moderate	High
Río Sabinas – headwaters to Don Martin Reservoir	Low-Moderate	Undetermined	Low-Moderate	Moderate ↑	Low	Moderate
Río Salado – headwaters to Don Martín Dam	High	Undetermined	High	Moderate ↑	Low	High
Río Sabinas Hidalgo – headwaters to cfl Río Salado	Low-Moderate	Undetermined	Moderate-High	Moderate	Low	Moderate
Río Salado – Don Martin Dam to Falcon Reservoir	High	Undetermined	High	High	High	High
Río Salinas – headwaters to cfl Río San Juan	Low-Moderate	Undetermined	Low	Moderate ↑	Moderate	Moderate
Río San Juan – headwaters to El Cuchillo Dam	Low-Moderate	Undetermined	Moderate-High	Moderate	Moderate	Moderate
Río San Juan – El Cuchillo Dam to Marte R Gomez Dam	High	Undetermined	High	High	High	High

Scenario 2

Overview

In Scenario 2, climate change proceeds as projected by the RCP 8.5-associated models. The regional water plans in the United States accurately project future water supply and demand in 2040 and 2060, but underestimate water demand from mining in the Permian Basin and Eagle Ford Play. Current trends in water supply and demand continue in Mexico, with increased water stress in the Eagle Ford Formation associated with oil and gas development. The conservation measures associated with CCA/As and BOs in New Mexico for management of the upper Pecos River fail to maintain instream flows and minimize river and stream intermittency at both timesteps. For population analysis units in the United States, existing trends in specific conductance continue to 2040 and 2060. Trends in the rate and volume of hazardous materials spills and leaks continue to 2040 and then stabilize, with increased risks in the Permian Basin and Eagle Ford play. For population analysis units in Mexico, water quality is decreased compared to the current conditions, and there are elevated risks from hazardous materials spills in the Eagle Ford play.

Occurrence, Occurrence Complexity, and Subadult Presence

The *Occurrence, Occurrence Complexity,* and *Subadult Presence* metrics were treated the same in Scenario 1 and Scenario 2. See Scenario 1 section on these metrics above for more detail.

Factors Influencing Water Quantity

We anticipated increased water stress as a result of heat and drought impacts associated with projections of climate change, particularly rising temperatures, under the RCP 8.5 scenario. In the RCP 8.5 scenario, there are no efforts to constrain emissions, and annual anthropogenic CO_2 emissions stabilize after 2100 (Intergovernmental Panel on Climate Change (IPCC) 2014, pp. 8–9). Projected increases in temperatures and associated negative effects are small in 2040 and moderate in 2060. Air temperature metrics for our two scenarios are similar at the year 2040, but diverge by 2060 (Shafer et al. 2014, entire; Wehner et al. 2017, entire; Kloesel et al. 2018, entire; Cheng et al. 2019, pp. 4433–34; U.S. Federal Government 2020). For 2040, we project a small increase in demand for water and small decrease in the availability of surface water due to the impacts from climate change, leading to increased water stress across the board. For 2060, we project a moderate increase in demand for water and moderate decrease in the availability of surface water due to the impacts from climate change and increased water stress overall. In Mexico, regional water plans were unavailable, so the influence of climate change is the primary driver of any changes to projected water quantity for the population analysis units not associated with the Eagle Ford play.

Information about projected future water supply, demand, and shortages from regional water plans for population analysis units in the United States, detailed in this section in Scenario 1 above, also applies to Scenario 2. For population analysis units in Mexico, we assume the same continuation of current trends outlined in Scenario 1. However, in Scenario 2, we incorporate additional stresses on water quantity based on projections for demand associated with oil and gas development, especially hydrofracking, in portions of the Rio Grande cooter range associated with the Permian Basin and Eagle Ford formation (Hernández-Espriú et al. 2019, entire, and supplementary information; Scanlon et al. 2020, entire, and supplementary information). These projections covered an area that overlapped with the following population analysis units: *Pecos River – Sumner Dam to Brantley Dam, Pecos River – Brantley Dam to Red Bluff Dam, Pecos River – Red Bluff Dam to Amistad Reservoir, Rio Grande – Amistad Dam to Falcon*

Dam, Río Sabinas Hidalgo – headwaters to cfl Río Salado, Río Salado – Don Martin Dam to Falcon Reservoir, Río Salinas – headwaters to cfl Río San Juan, Río San Juan – headwaters to El Cuchillo Dam, and *Río San Juan – El Cuchillo Dam to Marte R Gomez Dam* (Figure 6.1). For the population analysis units in the United States, we incorporated these projections by calculating the marginal difference in demand by the mining user group from the regional water plans and future oil and gas demand projections (NMOSE 2016, pp. 172–75; Freese and Nichols, Inc. 2020, Appendix I; Plateau Water Planning Group 2020, ES-Appendix; Scanlon et al. 2020, entire, and supplementary material; Rio Grande Regional Water Planning Group 2020, Appendix A), and then calculated a new total water demand. We then compared that value to the available water supply to determine whether any increases in demand would result in projected shortages of water (NMOSE 2016, pp. 172–75; Freese and Nichols, Inc. 2020, Appendix I; Plateau Water Planning Group 2020, ES-Appendix; Scanlon et al. 2020, entire, and supplementary material; Rio Grande Regional Water Planning Group 2020, Appendix A). For the population analysis units in Mexico, we considered the change in groundwater stress and total water stress for the analysis areas used by Hernández-Espriú et al. (2019, entire, and supplementary material).

Finally, we assume that the conservation measures in New Mexico described above are not successful in reliably minimizing river intermittency and maintaining instream flows, and that portions of the *Pecos River – Brantley Dam to Red Bluff Dam* and the *Pecos River – Sumner Dam to Brantley Dam* units are subject to drying that was not projected to occur in Scenario 1.

Factors Influencing Water Quality

In Scenario 2, in the United States, existing trends in water quality parameters are projected to continue. The trends for hazardous materials spills and leaks and the presence of contaminants are described in detail under Scenario 1. In Scenario 2, we additionally assumed that the risk of contamination events associated with oil and gas development, especially hydrofracking, would increase in areas projected for that development by Scanlon et al. (2020, entire) and Hernández-Espriú et al. (2019, entire). Most of the risk stems from the generation of large volumes of produced water and the need to dispose of it safely, which can be challenging (Scanlon et al. 2020, p. 3515). As with Scenario 1, trends varied among the population analysis units, and most are projected to remain at the same risk level they are designated currently. In the United States, where specific conductance data were available, we projected increasing mean specific conductance for all of the Pecos River population analysis units, while the Devils River and Rio Grande population analysis units were all stable, except for the *Rio Grande – Falcon Dam to Anzalduas Dam* unit, which was declining. The concerns about contaminants and pollution from Scenario 1 also apply to this scenario. In addition, the risk is exacerbated for the population analysis units identified in Figure 6.1 due to the increased risk of contamination events or hazardous materials spills or leaks associated with oil and gas development (Scanlon et al. 2020, p. 3515). This scenario also assumes that declining trends in water quality in Mexico are stronger than in Scenario 1.

Changes to Risk Assignments

Compared to the current conditions, there was no change in the risk assignment for the *Occurrence, Subadult Presence,* or *Occurrence Complexity* metrics for any population analysis unit for either 2040 or 2060.

When we considered projected changes to *Water Quantity* over time, the additional water stress from oil and gas development activities, and the more severe climate change impacts in 2060, we determined that several of the population analysis units should be assigned to a higher risk category for the *Water*

Quantity metric, relative to the current conditions. For the 2040 timestep, we projected increases in the *Water Quantity* risk category for four population analysis units. The *Pecos River – Sumner Dam to Brantley Dam* population analysis unit increased from **Moderate Risk** to **High Risk** due to impacts from climate change and the loss of effective conservation measures. The *Pecos River – Brantley Dam to Red Bluff Dam* population analysis unit also increased from **Moderate Risk** to **High Risk** due to those factors as well as impacts from additional water demand associated with oil and gas development. The *Rio Grande – Amistad Dam to Falcon Dam* population analysis unit increased from **Low Risk** to **Moderate Risk** due to several factors: in addition to climate change impacts and demand associated with oil and gas development, we also projected an increase to the water deficit in Maverick County, TX, and we know this unit has vulnerable occupied habitat outside of the mainstem Rio Grande. Finally, in 2040 we projected an increase from **Low-Moderate Risk** to **Moderate Risk** for the *Río Salinas – headwaters to cfl Río San Juan* population analysis unit due to the combination of increased water stress associated with climate change and increased demand for water by the oil and gas industry.

All units that increased in risk from 2020 to 2040 remained in that same risk category in timestep 2060. Additional changes to the risk category for units in 2060 occurred six population analysis units. The *Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment* and *Rio Grande – Big Bend to Amistad Dam* population analysis units increased from **Low Risk** to **Moderate Risk** due to the marginal impacts from the consequences of climate change. The *Rio Grande – Anzalduas Dam to Mouth* population analysis unit increased from **Moderate Risk** to **High Risk**, and the *Río Sabinas – headwaters to Don Martin Reservoir* and *Río Salado – headwaters to Don Martin Dam* population analysis units increased from **Low Risk** to **Moderate Risk**, due to the marginal impacts from the consequences from climate change in addition to the continuation of existing trends. The *Río Sabinas Hidalgo – headwaters to cfl Río Salado* population analysis unit was projected to increase from **Moderate Risk** to **High Risk** due to the combination of increased water stress associated with climate change and with increased demand for water by the oil and gas industry, on an already intermittent river.

Some units (such as *Pecos River – Red Bluff Dam to Amistad Reservoir, Río Salado – Don Martin Dam to Falcon Reservoir*, and *Río San Juan – El Cuchillo Dam to Marte R Gomez Dam*) are likely to have increased water stress in the future, but are already in the **High Risk** category for the *Water Quantity* metric, and so we cannot project a change to the risk category.

We project changes to the *Water Quality* risk category designation for two population analysis units that occur in timestep 2040 and continue to timestep 2060. First, we project that *Pecos River – Red Bluff Dam to Amistad Reservoir*, *Edwards Segment* will increase from **Low Risk** to **Moderate Risk** for 2040 and remain so for 2060. This shift is due to the current increasing trend in specific conductance and the threat of pollution from the upstream and adjacent Toyah Segment, since there are no barriers to the flow of degraded water into the Edwards Segment. Second, we project an increase from **Low Risk** to **Moderate Risk** for the *Río Sabinas Hidalgo – headwaters to cfl Río Salado* that occurs at the 2040 timestep and continues through the 2060 timestep, due to the additional risks from oil and gas development, as well as the decreased water quality that is assumed for this scenario.

Summary of Scenario 2 Resiliency

Compared to the results of the current resiliency analysis, we project changes to the *Overall Risk* to Rio Grande cooter in three of the population analysis units under Scenario 2: one unit shifts at timestep 2040 (this change is maintained at timestep 2060) and two units shift at timestep 2060 (Table 6.5 and

Table 6.6). In timestep 2040, the *Rio Grande – Amistad Dam to Falcon Dam* unit's *Overall Risk* increases from **Low Risk** to **Moderate Risk**. It remains at **Moderate Risk** at 2060. At timestep 2060, the *Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment* unit's *Overall Risk* increases from **Low Risk** to **Moderate Risk**. Also at timestep 2060, the *Río Sabinas Hidalgo – headwaters to cfl Río Salado* unit's *Overall Risk* increases from **Moderate Risk** to **High Risk.** We never projected an improvement to any of the metrics or overall rating for any population analysis unit.

Under this scenario, at timestep 2040, the overall resiliency of Rio Grande cooter is characterized by having six populations in the **High Risk** category, eight populations in the **Moderate Risk** category, and two populations in the **Low Risk** category. The *Overall Risk* designation increases for one unit; the others remain the same as under the current conditions. At timestep 2060, the overall resiliency of Rio Grande cooter is characterized by having seven populations in the **High Risk** category, eight populations in the **Moderate Risk** category, and one population in the **Low Risk** category. *Overall Risk* increases for three units; the other units retain the same risk category level as under the current conditions. Overall, under both timesteps of this scenario, the majority (either 9 or 10 of 16) of population analysis units are categorized as either **Low Risk** or **Moderate Risk**, and have the ability to withstand stochastic events (e.g., disturbance).

Table 6.5. Summary of future resiliency analysis for Scenario 2 at timestep 2040. Risk categories reflect the outcomes from the species response to the conditions present in 2040 over the period 2040–2070. The categorization for Subadult Presence is carried over from the current conditions analysis. Arrows pointing up denote increases compared to the current resiliency.

Population Analysis Unit	Demographic Factors		Habitat Factors			Overall Risk
	Occurrence	Subadult Presence	Occurrence Complexity	Water Quantity	Water Quality	
Pecos River – Sumner Dam to Brantley Dam	Moderate	Moderate-High	Moderate-High	High ↑	Low	High
Pecos River – Brantley Dam to Red Bluff Dam	Low	Low	Low	High ↑	Moderate	Moderate
Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment	High	Moderate-High	Moderate-High	High	High	High
Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment	Low	Low	Low	Low	Moderate ↑	Low
Devils River – headwaters to Amistad Reservoir	Low	Low	Low	Low	Low	Low
Rio Grande – Big Bend to Amistad Dam	Low	Moderate-High	Low	Low	Low	Moderate
Rio Grande – Amistad Dam to Falcon Dam	Low	Low	Low	Moderate ↑	Moderate	Moderate ↑
Rio Grande – Falcon Dam to Anzalduas Dam	Low	Moderate-High	Moderate-High	Low	Moderate	Moderate
Rio Grande – Anzalduas Dam to Mouth	High	Moderate-High	High	Moderate	Moderate	High
Río Sabinas – headwaters to Don Martin Reservoir	Low-Moderate	Undetermined	Low-Moderate	Low	Low	Moderate
Río Salado – headwaters to Don Martín Dam	High	Undetermined	High	Low	Low	High
Río Sabinas Hidalgo – headwaters to cfl Río Salado	Low-Moderate	Undetermined	Moderate-High	Moderate	Moderate ↑	Moderate
Río Salado – Don Martin Dam to Falcon Reservoir	High	Undetermined	High	High	High	High
Río Salinas – headwaters to cfl Río San Juan	Low-Moderate	Undetermined	Low	Moderate ↑	Moderate	Moderate
Río San Juan – headwaters to El Cuchillo Dam	Low-Moderate	Undetermined	Low-Moderate	Moderate	Moderate	Moderate
Río San Juan – El Cuchillo Dam to Marte R Gomez Dam	High	Undetermined	High	High	High	High

Table 6.6. Summary of future resiliency analysis for Scenario 2 at timestep 2060. Risk categories reflect the outcomes from the species response to the conditions present in 2060 over the period 2060–2090. The categorization for Subadult Presence is carried over from the current conditions analysis. The categorization for Occurrence and Occurrence Complexity is carried over from timestep 2040. Arrows pointing up denote increases compared to the current resiliency.

Population Analysis Unit	Demographic Factors		Habitat Factors			Overall Risk
	Occurrence	Subadult Presence	Occurrence Complexity	Water Quantity	Water Quality	
Pecos River – Sumner Dam to Brantley Dam	Moderate	Moderate-High	Moderate-High	High ↑	Low	High
Pecos River – Brantley Dam to Red Bluff Dam	Low	Low	Low	High ↑	Moderate	Moderate
Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment	High	Moderate-High	Moderate-High	High	High	High
Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment	Low	Low	Low	Moderate ↑	Moderate ↑	Moderate ↑
Devils River – headwaters to Amistad Reservoir	Low	Low	Low	Low	Low	Low
Rio Grande – Big Bend to Amistad Dam	Low	Moderate-High	Low	Moderate ↑	Low	Moderate
Rio Grande – Amistad Dam to Falcon Dam	Low	Low	Low	Moderate ↑	Moderate	Moderate ↑
Rio Grande – Falcon Dam to Anzalduas Dam	Low	Moderate-High	Moderate-High	Low	Moderate	Moderate
Rio Grande – Anzalduas Dam to Mouth	High	Moderate-High	High	High ↑	Moderate	High
Río Sabinas – headwaters to Don Martin Reservoir	Low-Moderate	Undetermined	Low-Moderate	Moderate ↑	Low	Moderate
Río Salado – headwaters to Don Martín Dam	High	Undetermined	High	Moderate ↑	Low	High
Río Sabinas Hidalgo – headwaters to cfl Río Salado	Low-Moderate	Undetermined	Moderate-High	High ↑	Moderate ↑	High ↑
Río Salado – Don Martin Dam to Falcon Reservoir	High	Undetermined	High	High	High	High
Río Salinas – headwaters to cfl Río San Juan	Low-Moderate	Undetermined	Low	Moderate ↑	Moderate	Moderate
Río San Juan – headwaters to El Cuchillo Dam	Low-Moderate	Undetermined	Low-Moderate	Moderate	Moderate	Moderate
Río San Juan – El Cuchillo Dam to Marte R Gomez Dam	High	Undetermined	High	High	High	High

Summary/Synthesis

Overall, after projecting the response of Rio Grande cooter to changing habitat conditions under the two plausible future scenarios, the resiliency of Rio Grande cooter individual population analysis units is fairly stable (Table 6.7). Specifically, estimates of current resiliency for the Rio Grande cooter population analysis units categorize three units as **Low Risk**, seven units as **Moderate Risk**, and six units as **High Risk**. Under Scenario 1, the estimated future resiliency does not change from the current condition at either timestep despite an increase in the potential threats within some units. However, estimates of future resiliency slightly declined under Scenario 2. Under Scenario 2, at timestep 2040, the overall resiliency of Rio Grande cooter is characterized by having six populations in the **High Risk** category, eight populations in the **Moderate Risk** category, and two populations in the **Low Risk** category. At timestep 2060, the overall resiliency of Rio Grande cooter is characterized by having seven populations in the **High Risk** category, eight populations in the **Moderate Risk** category, and one population in the **Low Risk** category. The number of population analysis units categorized as **Low** or **Moderate Risk** is ten at timestep 2040 and nine at timestep 2060; in both instances these reflect a majority of the population analysis units. Populations in **Low** or **Moderate Risk** have the ability to withstand stochastic events (e.g., disturbance).

We suggest that one reason we project little change to Rio Grande cooter resiliency in the future is that most of the significant changes to Rio Grande cooter habitat occurred in the 20th century, and while change of course continues, Rio Grande cooter individuals and populations have already responded to many of the impacts from water development. The scenarios reflect the fact that large-scale new changes, such as large new dams, are not projected over the course of the next several decades. Another factor behind the projected future stability is that Rio Grande cooter also appears to benefit by inhabiting surface waters that humans also rely on for municipal water supplies (particularly the Rio Grande). In the United States, drinking water standards for water quality (Texas Clean Rivers Program 2003, entire; Miyamoto et al. 2007, p. 29), along with major efforts to address pollution in the last 50 years (U.S. Environmental Protection Agency 2012, entire; Lower Rio Grande BBEST 2012, p. 5-4; Rio Grande Regional Water Planning Group 2020, pp. 1-11, 3-18), have resulted in relatively good water quality in the mainstem Rio Grande, in contrast to the Pecos River, which is generally not used for human consumption and does not meet standards to do so (TCEQ 2000, entire; 2014, entire; 2020a, entire; Gregory and Hatler 2008, pp. 24–29). Similarly, because water deliveries are needed year-round, some parts of the Rio Grande are more protected against drying events than a river like the Pecos River, that is used principally for irrigation and therefore the demand for water in that river changes dramatically over the course of a year (McKinney and Aparicio 2006, pp. 12–13; Gregory and Hatler 2008, pp. 15–17, 68–75; Lower Rio Grande BBEST 2012, pp. 2-14, 2-18, 2-31, 2-33, 2-26; Arm et al. 2014, p. 19; Rio Grande Regional Water Planning Group 2020, pp. 7-27, 7-32). That said, the municipal demand that guarantees water deliveries to the Lower Rio Grande Valley also leads to a decrease in flows in the most downstream reach below diversions for municipal use (Lower Rio Grande BBEST 2012, pp. 2-2, 2-32). Finally, we note that, in comparison to the United States, we had relatively little information on both current and likely future conditions for the population analysis units in Mexico. Because of this, we often relied on personal observations to inform the resiliency analysis in those units. Consequently, we have more confidence in the accuracy of our projections and the resulting risk assignments for population analysis units within the United States. The assessment for Mexican population analysis units is the most likely to change based on new information.

Table 6.7. *Overall Risk* categories for Rio Grande cooter population analysis units. The current risk designations are the same as those for both timesteps under Scenario 1. In Scenario 2, one unit changes in timestep 2040 and two units change in timestep 2060.

Population Analysis Unit	Current	Scenario 1 – 2040	Scenario 1 – 2060	Scenario 2 – 2040	Scenario 2 – 2060
Pecos River – Sumner Dam to Brantley Dam	High	High	High	High	High
Pecos River – Brantley Dam to Red Bluff Dam	Moderate	Moderate	Moderate	Moderate	Moderate
Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment	High	High	High	High	High
Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment	Low	Low	Low	Low	Moderate ↑
Devils River – headwaters to Amistad Reservoir	Low	Low	Low	Low	Low
Rio Grande – Big Bend to Amistad Dam	Moderate	Moderate	Moderate	Moderate	Moderate
Rio Grande – Amistad Dam to Falcon Dam	Low	Low	Low	Moderate ↑	Moderate
Rio Grande – Falcon Dam to Anzalduas Dam	Moderate	Moderate	Moderate	Moderate	Moderate
Rio Grande – Anzalduas Dam to Mouth	High	High	High	High	High
Río Sabinas – headwaters to Don Martin Reservoir	Moderate	Moderate	Moderate	Moderate	Moderate
Río Salado – headwaters to Don Martín Dam	High	High	High	High	High
Río Sabinas Hidalgo – headwaters to cfl Río Salado	Moderate	Moderate	Moderate	Moderate	High ↑
Río Salado – Don Martin Dam to Falcon Reservoir	High	High	High	High	High
Río Salinas – headwaters to cfl Río San Juan	Moderate	Moderate	Moderate	Moderate	Moderate
Río San Juan – headwaters to El Cuchillo Dam	Moderate	Moderate	Moderate	Moderate	Moderate
Río San Juan – El Cuchillo Dam to Marte R Gomez Dam	High	High	High	High	High

Future Redundancy

Currently, Rio Grande cooter has redundancy rangewide and at the river basin level. We project that Rio Grande cooter will continue to have redundancy at both of these scales across the two future scenarios and timesteps, despite the fact that we did not forecast improvements to conditions or associated resiliency risk levels (see the current redundancy analysis section in Chapter 5 for more details on how we determine redundancy at the river basin level). Under Scenario 1, we projected no changes to the *Overall Risk* to Rio Grande cooter at the population analysis unit level in our resiliency analysis, so Rio Grande cooter is projected to maintain redundancy within the major river basins and across the species' range for this scenario (Table 6.8; Figure 6.2). Under Scenario 2, Rio Grande cooter resiliency declines for three population analysis units. Compared to the current conditions, at timestep 2040, one unit declines to **Low Risk** from **Moderate Risk.** At timestep 2060, two units decline to **Low Risk** from **Moderate Risk**, and one unit declines to **High Risk** from **Moderate Risk**. Although the species is at slightly increased risk to catastrophic events within the Pecos and Rio Grande basins because of declining resiliency, the species maintains redundancy through the range at both timesteps within Scenario 2 (Table 6.9; Table 6.10; Figure 6.2).

Table 6.8. Future conditions analysis results by river basin and count of population analysis units in each risk category for Scenario 1, timesteps 2040 and 2060. All counts are the same as in the current conditions analysis; see Table 5.4.

River Basin	Number of Low Risk Population Analysis Units	Number of Moderate Risk Population Analysis Units	Number of High Risk Population Analysis Units	Total Number of Population Analysis Units
Pecos River	1	1	2	4
Devils River	1	0	0	1
Rio Grande	1	2	1	4
Río Salado	0	2	2	4
Río San Juan	0	2	1	3
Total	3	7	6	16

Table 6.9. Future conditions analysis results by river basin and count of population analysis units in each risk category for Scenario 2, timestep 2040. Changes from the current conditions analysis indicated with arrows; see Table 5.4.

River Basin	Number of Low Risk Population Analysis Units	Number of Moderate Risk Population Analysis Units	Number of High Risk Population Analysis Units	Total Number of Population Analysis Units
Pecos River	1	1	2	4
Devils River	1	0	0	1
Rio Grande	0 ↓	3 ↑	1	4
Río Salado	0	2	2	4
Río San Juan	0	2	1	3
Total	2 ↓	8 ↑	6	16

Table 6.10. Future conditions analysis results by river basin and count of population analysis units in each risk category for Scenario 2, timestep 2060. Changes from the current conditions analysis indicated with arrows; see Table 5.4.

River Basin	Number of Low Risk Population Analysis Units	Number of Moderate Risk Population Analysis Units	Number of High Risk Population Analysis Units	Total Number of Population Analysis Units
Pecos River	0 ↓	2 ↑	2	4
Devils River	1	0	0	1
Rio Grande	0 ↓	3 ↑	1	4
Río Salado	0	1 ↓	3 ↑	4
Río San Juan	0	2	1	3
Total	1 ↓	8 ↑	7 ↑	16

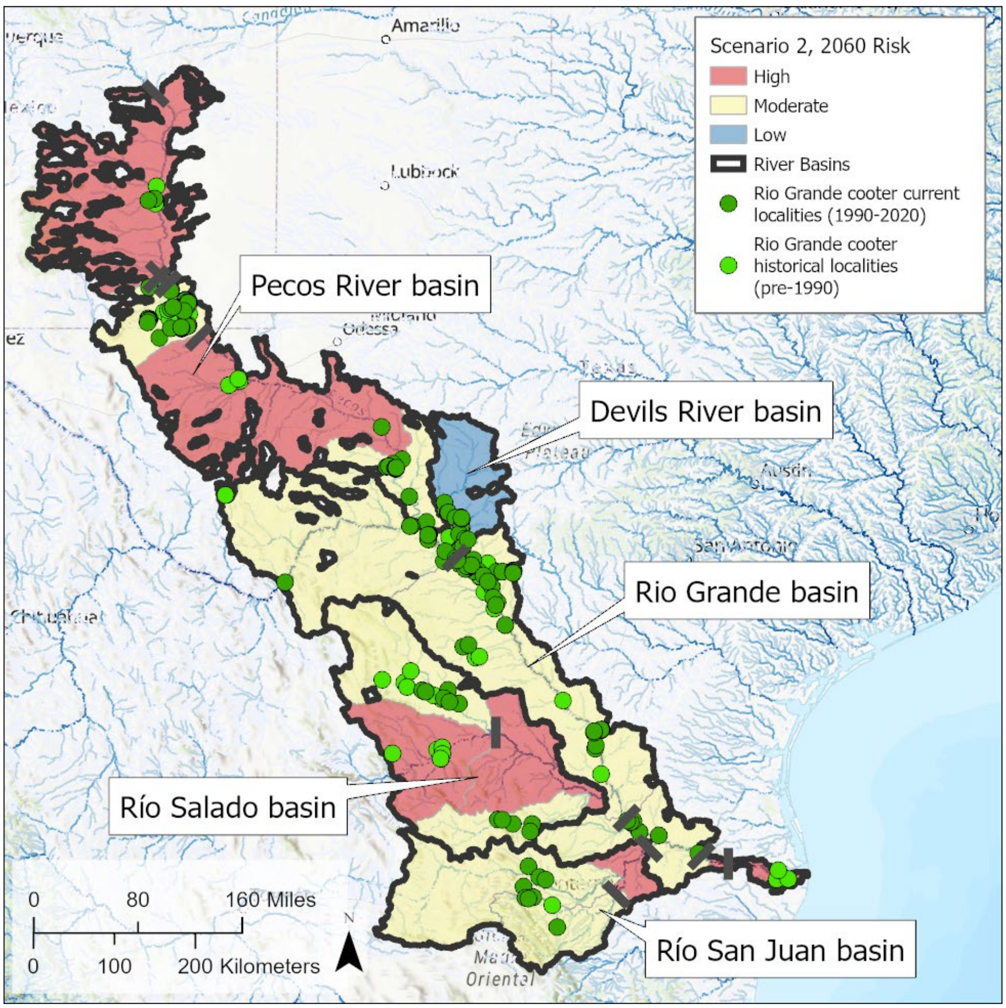


Figure 6.2. Rio Grande cooter population analysis units colored by risk category assignment for Scenario 2, timestep 2060 (red for high risk, yellow for moderate risk, and blue for low risk). The five major river basins are labeled and have thick black borders (see Figure 3.4 for population analysis units color coded by river basin).

Future Representation

As with current condition, we assume that the risk of loss of adaptive potential (i.e., representation) can be minimized by maintaining a broad distribution of the Rio Grande cooter across its known historical range. In Scenario 1, our projected risk categorizations do not change from the current condition and thus, we project that the future representation will not change from the current under this scenario. In Scenario 2, we project a decrease in population resiliency for two or three of the 16 population analysis units, depending on the timestep. Despite the increase in risk under Scenario 2, if resiliency and redundancy are maintained into the future, the Rio Grande cooter will continue to have representation because it will continue to occur throughout its historic range.

Summary of Species Viability

This assessment describes the viability of Rio Grande cooter in terms of resiliency, representation, and redundancy using the best available commercial and scientific information. We used these concepts to describe current and potential future conditions regarding the species' viability. To address the uncertainty associated with potential future impacts and how they will affect the species' resource needs, we assessed potential future conditions using two plausible scenarios. These scenarios were based on identified negative and positive influences on the species across its range, allowing us to predict potential changes in population and habitat parameters.

Current Conditions

The species is well distributed across its range, despite the fact that Rio Grande cooter have not been observed in four population analysis units for many decades, presumably due to degraded water quantity and water quality (A. E. Brown 1903, pp. 543–44; Collins and Riffenburg 1927, p. 80; Wiebe et al. 1934, pp. 81–83; Campbell 1958, p. 4; Milstead 1960, p. 551; Grozier et al. 1966, pp. 1–8; Conant 1977, p. 472; Brune 1981, pp. 21–22; Ward 1984, p. 29; Boyer 1986, pp. 302–11; Ashworth 1990, p. 3032; Contreras-Balderas and Lozano-Vilano 1994, p. 383; Sanchez 1997, p. 429; Robinson 2000, p. 9; Yuan et al. 2007, p. 1801; Hoagstrom 2009, p. 303; 2009, pp. 30–36; Návar Cháidez 2011, p. 133; Upper Rio Grande BBEST 2012, pp. 2-21–2-27; Lower Rio Grande BBEST 2012, pp. 1-7, 4-4; Hibbitts and Hibbitts 2016, pp. 134–37; TCEQ 2019b; 2019a; Sandoval Solis 2019, p. 33; Railroad Commission of Texas 2020; Kills and Spills Team 2020; Trujillo 2020, personal communication; Hendrickson 2020, personal communication; Strenth 2020, personal communication). It occupies varying habitat types in terms of spring pools and streams of varying sizes and depths, and occurs across a wide range of temperature and precipitation regimes. The resiliency of Rio Grande cooter is characterized by having three population analysis units in the **Low Risk** category, seven in the **Moderate Risk** category, and six in the **High Risk** category. Given the current conditions of the population analysis units for Rio Grande cooter, the majority of populations have the ability to withstand stochastic events. The species currently has redundancy within the major river basins and across the species' range, and it currently has representation in that the species is distributed throughout its known historical range.

Scenario 1

In Scenario 1, we do not project any changes to the *Overall Risk* to Rio Grande cooter in any of the population analysis units at either timestep 2040 or timestep 2060 (Table 6.3 and Table 6.4). The overall resiliency of Rio Grande cooter is characterized at both timesteps by having six populations in the **High Risk** category, seven populations in the **Moderate Risk** category, and three populations in the **Low Risk** category. In total, 10 of 16 population analysis units (the majority) are categorized as **Low Risk** or **Moderate Risk**, and have the ability to withstand stochastic events (e.g., disturbance). This distribution is the same as the current conditions. We also project that the species will continue to have redundancy within the major river basins and across the species' range, and maintain current levels of representation at both future timesteps of the scenario (Table 6.8).

Scenario 2

In Scenario 2, we project increases to the *Overall Risk* to Rio Grande cooter in three population analysis units over the two timesteps (Table 6.5 and Table 6.6). At the 2040 timestep, the overall resiliency of Rio Grande cooter is characterized by having six populations in the **High Risk** category, eight populations in the **Moderate Risk** category, and two populations in the **Low Risk** category. The *Overall Risk* designation increases for one unit; the others remain the same as under the current conditions. At the 2060 timestep, the overall resiliency of Rio Grande cooter is characterized by having seven populations in the **High Risk** category, eight populations in the **Moderate Risk** category, and one population in the **Low Risk** category. *Overall Risk* increases for three units; the others remain the same as under the current conditions. In total, the number of population analysis units categorized as **Low Risk** or **Moderate Risk** is 10 of 16 at timestep 2040, and 9 of 16 at timestep 2060; the majority thus have the ability to withstand stochastic events. As with Scenario 1, we project that the species will continue to have redundancy within the major river basins and across the species' range, and maintain current levels of representation at both future timesteps (Table 6.9; Table 6.10; Figure 6.2).

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Appendix A. Cause and Effects Tables

Template for Cause and Effects Evaluation

ESA Factor(s): ?	Analysis	Confidence / Uncertainty	Supporting Information
Source(s)	*What is the ultimate source of the actions causing the stressor? Ie, Urban Development, Oil and Gas Development, Agriculture*	See next page for confidences to apply at each step.	Literature Citations, with page numbers for each step. Use superscript to delineate which statement goes with which citation. These can be repeated per theme, but not within a theme.
- Activity(ies)	*What is actually happening on the ground as a result of the action? Be specific here.*		
Stressor(s)	*What are the changes in environmental conditions on the ground that may be affecting the species? For example, removal of nesting habitat, increased temperature, loss of flow*		
- Affected Resource(s)	*What are the resources that are needed by the species that are being affected by this stressor? Or is it a direct effect on individuals?*		
- Exposure of Stressor(s)	*Overlap in time and space. When and where does the stressor overlap with the resource need of the species (life history and habitat needs)? This is not the place to describe where geographically it is occuring, but where in terms of habitat.*		
- Immediacy of Stressor(s)	*What's the timing and frequency of the stressors? Are the stressors happening in the past, present, and/or future?*		
Changes in Resource(s)	*Specifically, how has(is) the resource changed(ing)?*		
Response to Stressors: - Individuals	*What are the effects on individuals of the species to the stressor? (May be by life stage)*		
- Population & Species Responses	*[Following analysis will determine how do individual effects translate to population and species-level responses, and what is the magnitude of this stressor in terms of species viability?]*		
Effects of Stressors: - Populations [Resiliency]	*What are the effects on population characteristics (lower reproductive rates, reduced population growth rate, changes in distribution, etc)?*		
- Geographic Scope	*What is the geographic extent of the stressor relative to the range of the species/populations? In other words, this stressor effects what proportion of the rangewide populations?*		
- Magnitude	*How large of an effect do you expect it to have on the populations?*		
Summary	*What is the bottom line- is this stressor important to carry forward in your analysis, or is it only having local effects, or no effects?*		

Confidences

This table of Confidence Terminologies explains what we mean when we characterize our confidence levels in the cause and effects tables on the following pages.

Confidence Terminology	Explanation
Highly Confident	We are more than **90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by documented accounts or research and/or strongly consistent with accepted conservation biology principles.
Moderately Confident	We are **70 to 90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Somewhat Confident	We are **50 to 70% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Low Confidence	We are less than **50% sure** that this relationship or assumption accurately reflects the reality in the wild, as there is little or no supporting available information and/or uncertainty consistency with accepted conservation biology principles. Indicates areas of high uncertainty.

Cause and Effects Tables for Rio Grande Cooter

Theme: Hydrologic Change (flow regime alteration and water quantity)

Hydrologic Change ESA Factor(S): A, D, E	**Analysis**	**Confidence/ Uncertainty**	**Supporting Information**
Source(s)	Agricultural, oil and gas, urban, rural, and industrial development [1] Meteorological and hydrological drought are exacerbating factors, as is climate change [2-6]	Highly confident	[1] Dieter et al. 2018, entire [2] National Weather Service, n.d. [3] Shafer et al. 2014, pp. 443-448 [4] Runkle et al. 2017, pp. 1–2 [5] Kloesel et al. 2018, pp. 992–1003 [6] Cheng et al. 2019, pp. 4437–4440
- Activity(ies)	Surface and groundwater resources are developed using a variety of techniques. These include the construction of dams and reservoirs, surface water diversions, wells, and groundwater pumping [7-10]. The sectors above use both surface and groundwater. — Agricultural users apply water to crops and pastures [1]. — Oil and gas users apply water during the drilling process for lubrication, cooling, and cleaning of equipment. Hydraulic fracturing operations use water in the slurries injected during the fracturing process and to facilitate the movement of oil or gas into collection wells. Water is used during drilling to lubricate and cool the drill and remove drilling mud and rock debris. For hydraulic fracturing operations, water is mixed with chemicals that improve its ability to create fractures in the rock, and with sand to hold the fractures open and allow oil or gas to flow into the well [1,11]. — Urban and rural users predominantly use freshwater resources for domestic and light industrial purposes [1]. — Industrial users apply water to fabricating, processing, washing, diluting, cooling, or transporting a product, incorporating into a product, and sanitation [1]. Meterological drought is a combination of dryness, rainfall deficit compared to precipitation normals, and the length of a dry period. Hydrological drought incorporates the effect of rainfall deficit compared to precipitation normals on surface and groundwater levels [2]. Climate change is associated with increased temperatures, lower humidity, lower soil moisture, increased evapotranspiration increased dry period length, and irregularities in rainfall [3-6].	Highly confident	[1] Dieter et al. 2018, pp. 18–25, 26–31, 36–41 [7] Poff and Zimmerman 2010, pp. 196–197 [8] Arm et al. 2014, p. 19 [9] Hoagstrom 2003, pp. 93–94, 103 [10] Brune 1981, entire [11] Allison and Mandler 2018, p. 1
Stressor(s)	Removal of water from surface and subsurface environment [12]. Alteration of flow regimes, including magnitude, frequency, duration, timing and rate-of-change [7, 12] Geomorphic changes to rivers and streams [13–14] Creation of artificial lentic (non-flowing) and lotic (flowing) habitat [15-16] Altered pathways for water movement [9] Alteration of riparian vegetation and soils [13-14]	Highly confident	[7] Poff and Zimmerman 2010, pp. 196–197 [9] Hoagstrom 2003, p. 93 [12] Rolls et al. 2012, entire [13] Dean and Schmidt 2011, pp. 333–336 [14] Garrett and Edwards 2014, p. 397 [15] Bunn and Arthington 2002, p. 496 [16] Moll and Moll 2004, pp. 252–256

Hydrologic Change ESA Factor(S): A, D, E	**Analysis**	**Confidence/ Uncertainty**	**Supporting Information**
- Affected Resource(s)	The aquatic habitat in which Rio Grande cooter carry out most of their resource functions, including breeding, feeding, sheltering, dispersal, thermoregulation, and survival is directly affected by these stressors, indirectly affecting: — Sheltering habitat: cover from predators, refugia during adverse conditions in a subset of the range [17-18] — Aquatic connectivity enabling individuals to find potential mates [12] — Aquatic connectivity enabling females to travel to nesting sites [12] — Foraging habitat The riparian habitat where Rio Grande cooter nest may also be affected by these stressors	Highly confident	[12] Rolls et al. 2012, pp. 173 [17] Pierce et al. 2016, pp. 100.5-100.8 [18] Cheek and Taylor 2016, p. 249
- Exposure of Stressor(s)	All life stages and habitats are exposed to and affected by these stressors.	Highly confident	
- Immediacy of Stressor(s)	The stressors began over 100 years ago in some parts of the species' range, are present currently, and are anticipated to continue into the foreseeable future. Although demand for water fluctuates seasonally for some users (particularly for agricultural and cooling-related uses), the management of water resources occurs year-round, and the impacts on Rio Grande cooter also occur year-round [8, 19-26]	Highly confident	[8] Arm et al. 2014, pp. 28, 30, 40-14, 53, 63 [19] Ashworth 1990, p. 21 [20] Brune 1975, pp. 51-82, 202 [21] Cox 1963, pp. 19 [22] Edwards et al. 2002, pp. 124-126 [23] Hale 1955, pp. 1-2, 9-10 [24] Hoagstrom et al. 2008, pp. 6 [25] Hoagstrom 2009, pp. 30, 36 [26] Navar-Chaidez 2011, pp. 126, 131, 133, 137, 140
Changes in Resource(s)	Numerous changes in the habitat resources associated with this stressor can occur [8-10,12,13,15,24,25,27,29-31]: — Alteration of flow regimes may take the form of the elimination of flood events, stream drying, asychronous flow volumes compared to seasonal historical normals — Increased incidence of very low flows and intermittency; alteration of streams and rivers from perennial to intermittent or ephemeral — Elimination or unreliability of deeper pool habitat — Geomorphic changes to rivers and streams. Reduced flows are likely to result in narrowed channel widths. Channel aggradation is observed in some areas, while channel deepening and increased bank steepness is observed in other areas. Channel substrate may become rocky (leading to surface intermittency) or muddy (due to sedimentation and low flows in an erosive geology) — Some stream reaches converted into impounded lentic habitat — Irrigation ditches contain some characteristics of habitat, but not all — Alteration of base flows due to lowering of water tables and return flows from agricultural or urban/domestic uses — Creation of artificial lentic (non-flowing) habitat that displaces natural lotic habitat — Lowering of water tables that impacts base flows — Reduced connectivity among rivers, streams, and springs	Highly confident	[8] Arm et al. 2014, pp. 28, 30, 40-14, 53, 63 [9] Hoagstrom 2003, pp. 93–94, 103 [10] Brune 1981, entire [12] Rolls et al. 2012, entire [13] Dean and Schmidt 2011, pp. 346 [15] Bunn and Arthington 2002, entire [24] Hoagstrom et al. 2008, pp. 11-12 [25] Hoagstrom 2009, pp. 30-34 [27] Hogan 2013, p. 6 [29] Thomas 1963, entire [30] Contreras-Balderas and Lozano-Vilano 1994, p. 381 [31] Edwards and Contreras-Balderas 1991, pp. 209-210

Hydrologic Change ESA Factor(S): A, D, E	**Analysis**	**Confidence/ Uncertainty**	**Supporting Information**
	— Reduction or change in subsurface flow to rivers — Reduction of aquifer recharge rates. — Changes to riparian vegetation and soils, varying depending on the nature of alterations to the flow regime and water levels — Loss of large debris suitable for basking previously delivered by flood events — Unreliable or inconsistent water levels during the nesting season — Reduction in total habitat available		
Response to Stressors: **- Individuals**	— Increased competition for high quality food, space, and nesting habitat, reducing fitness and increasing risk of mortality [12] — Individuals can be stranded by low flow and become weak and/or die [12,15] — Increased vulnerability to predation, particularly for juveniles and hatchlings [12,15] — Access to nesting habitat may be cut off or minimized, potentially reducing nesting frequency [16] — Nest failure from inundation or desiccation [16]	Moderately confident (inference based)	[12] Rolls et al. 2012, entire [15] Bunn and Arthington 2002, entire [16] Moll and Moll 2004, pp. 64. 248, 251, 262
- Population & Species Responses			
Effects Of Stressors: **- Populations [Resiliency]**	— Reduced abundance due to less supporting habitat and direct mortality. — Reduced recruitment and lower reproductive rates due to less available nesting habitat and increased nest failure — Extirpation or displacement due to elimination or deterioration of suitable habitat — Loss of connectivity that lowers genetic exchange and reduces effective population size	Moderately confident (inference based)	
- Geographic Scope	Rangewide: water quantity reduction and flow regime alteration affects every population unit, and generally affects springs, streams, and rivers within each unit. Populations have increased vulnerability where flow is maintained by small, shallow aquifers that are sensitive to the effects of withdrawals, drought, and extreme temperatures [8,32]	Highly confident	[8] Arm et al. 2014, p. 28 [32] Klove et al. 2014: 253
- Magnitude	The magnitude of this threat varies from small to severe depending on the spatial scale of interest (e.g., the individual spring or river/stream reach, individual population analysis units, groups of population analysis units in a river basin, or the range as a whole).	Highly confident	
Summary	Recommend carrying this stressor forward as its impacts vary over the range and examining it in the resiliency framework should yield insights into species viability.		

Theme: Water Quality Change

Water Quality Change ESA Factor(S): A, D, E	Analysis	Confidence/ Uncertainty	Supporting Information
Source(s)	Agricultural, oil and gas, urban, rural, and industrial development [1] Meteorological and hydrological drought are exacerbating factors, as is climate change [2-6]	Highly confident	[1] Dieter et al. 2018, entire
- Activity(ies)	Agricultural users apply water to soils with high salt contents. Some water is lost to evaporation. The applied water picks up salts from the soil and the evaporation concentrates the salts in the remaining water that returns to the hydrological system [1-10]. Water comes into contact with contaminants such as fertilizers and pesticides when it falls as precipitation on areas where those chemicals are available for dissolution into water or transport by water. As that water runs off the lands into surface water, or percolates underground to an aquifer, those toxicants and contaminants are transported along with the water [11-12]. Spills or leaks involving hazardous materials and contaminants are associated with oil and gas industry operations, as well as other human activities. These spills may occur directly into surface water, percolate into groundwater, or move into aquatic systems as runoff [2,9,11-17]. Removal of water from surface and subsurface environment. Water moves through altered pathways across land and back to hydrological system Oil and gas wells are drilled and then hydraulic fracturing is applied. Bores may hit fractures in the rock that allow leakage of the slurry into groundwater or an aquifer. The injection of brines into wells for brine disposal or secondary recovery continues to present an opportunity for water contamination, as do improperly or inadequately cased oil and gas wells. Pipelines present another potential route of contamination; they may contain oil, gas, or brines, and leaks or ruptures to pipelines can allow these materials to enter underground aquifers [1,2,7,12,13,15,18].	Highly confident	[1] Dieter et al. 2018, entire [2] Arm et al. 2014: 26, 28-29, 114 [3] Cheek and Taylor: 2016 [4] Hogan 2013: 8, 10-12 [5] Miyamoto et al. 2005, pp. 17–20 [6] Hoagstrom 2009, pp. 31–32 [7] Ashworth 1990, p. 30-31 [8] Lang and Gordon 2001, p. 9 [9] Miyamoto et al. 2006, pp. 2–4 [10] Miyamoto et al. 2007, p. 29 [11] Gregory and Hatler 2008: 7-10 [12] Boyer 1986: 302, 308 [13] Campbell 1958: 4 [14] Hedden 2020 [15] Gregston 2020, entire [16] Contreras-Balderas and Lozano-Vilano 1994: 383 [17] Eaton 2017 [18] Scanlon et al. 2020, p. 3515
Stressor(s)	These activities lead to chronic or acute elevated salinity, toxicants, and other problematic water quality parameters that affect wildlife [2,4,7,11-14,16-30] Increased concentrations of contaminants occur due to declines in water quantity [4,5,18,19] Contaminated soil may occur [2,4,14,17]	Highly confident	[2] Arm et al. 2014: 26-29 [4] Hogan 2013: 8, 10-12 [7] Ashworth 1990, p. 30-31 [11] Gregory and Hatler 2008: 7-10 [12] Boyer 1986: 302, 308-311 [13] Campbell 1958: 4 [14] Hedden 2020 [16] Contreras-Balderas and Lozano-Vilano 1994, p. 383 [17] Eaton 2017 [18] Hoagstrom 2009, pp. 31–36 [19] Hoagstrom 2003, p. 94 [20] Návar Cháidez 2011, pp. 133–142 [21] Onsurez 2017

Water Quality Change ESA Factor(S): A, D, E	Analysis	Confidence/ Uncertainty	Supporting Information
			[22] International Boundary & Water Commission 1994, p. 1 [23] Grijalva 2019 [24] Miyazono et al. 2015: 452 [25] Houston et al. 2019, pp. 30–33 [26] Yu et al. 2013, p. 555-556 [27] New Mexico Oil Conservation Division 2020 [28] Railroad Commission of Texas 2020 [29] TCEQ 2020a [30] Kills and Spills Team 2020
- Affected Resource(s)	Presumed direct effect on individuals [26,31] — Increased susceptibility to disease — Suppressed growth — Developmental problems for eggs and subadults	Somewhat confident (lack of studies)	[26] Yu et al. 2013, p. 555-556 [31] Agha et al. 2018, p. 1643
- Exposure of Stressor(s)	All life stages and habitats are exposed to and affected by these stressors.	Moderately confident	
- Immediacy of Stressor(s)	The timing and frequency of the stressors varies over the species' range. The trend over the entire historical period in the intensity of the stressors is variable. In some areas the stressor peaked several decades in the past, while in other areas the current period is the worst, with the stressor increasing. The stressor is expected to continue into the future in most of the range, although the intensity is expected to vary widely across the range [5-7,9,11,12,19,20,25,30,32-35].	Highly confident	[5] Miyamoto et al. 2005: 2 [6] Hoagstrom 2009: 35-36 [7] Ashworth 1990: 30-31 [9] Miyamoto et al. 2006: 20 [11] Gregory and Hatler 2008: 76-77 [12] Boyer 1986: 302, 308 [19] Hoagstrom 2003: 94 [20] Návar Cháidez 2011, p. 133 [25] Houston et al. 2019, pp. 30–33 [30] Kills and Spills Team 2020 [32] Wiebe et al. 1934: 81-85 [33] Spiers and Hejl 1970: 2 [34] Edwards and Contreras-Balderas. 1991: 203 [35] Jensen et al. 2006, p. 10
Changes in Resource(s)	Specific conductance, a proxy for salinity, is higher in some segments where Rio Grande cooter are found than they are presumed to have been historically [25,36]. Surface water flow volumes are decreased compared to their historical condition [37,38]. Surface waters, stream and river sediments, and riparian soils are not necessarily free of toxicants and pollutants [25,27-30].	Highly confident	[25] Houston et al. 2019 [27] New Mexico Oil Conservation Division 2020 [28] Railroad Commission of Texas 2020 [29] TCEQ 2020a

Water Quality Change ESA Factor(S): A, D, E	Analysis	Confidence/ Uncertainty	Supporting Information
			[30] Kills and Spills Team 2020 [36] TCEQ 2020b [37] González Escorcia 2016, entire [38] Sandoval Solis 2019, entire
Response to Stressors: **- Individuals**	Highly saline or contaminated environments cause individual behavioral responses, including reduction in feeding, drinking, and movement to locations with better water quality. Prolonged exposure may decrease individual fitness and frequency and success of nesting. Mortality may occur due to starvation, dehydration, or barriers to accessing alternative suitable habitat [26,31,39,40]	Moderately confident (species-specific threshholds unknown)	[26] Yu et al. 2013, p. 555-556 [31] Agha et al. 2018, p. 1643 [39] Lang and Altenbach 2001, pp. 3–4 [40] Blakeslee et al. 2013, pp. 2850–2852
- **Population & Species Responses**			
Effects Of Stressors: **- Populations [Resiliency]**	We infer the following potential population-level effects [12,15,31]: — Reduced abundance due to poor nutrition, fitness, and health from poor habitat quality — Changes to composition in age class structure from effects to juvenile development — Reduced recruitment and lower reproductive rates due to less available nesting habitat and increased nest failure — Extirpation or displacement due to elimination or deterioration of suitable habitat	Somewhat confident	[12] Rolls et al. 2012, entire [15] Bunn and Arthington 2002, entire [31] Agha et al. 2018, p. 1643
- Geographic Scope	Rangewide: water quality issues are found in nearly every population analysis unit, and may affect multiple springs, streams, and rivers within each unit.	Highly confident	
- Magnitude	The magnitude of this threat varies from small to severe depending on the spatial scale of interest (e.g., the individual spring or river/stream reach, individual population analysis units, groups of population analysis units in a river basin, or the range as a whole).	Highly confident	
Summary	Recommend carrying this stressor forward as its impacts vary over the range and examining it in the resiliency framework should yield insights into species viability.	Highly confident	

Theme: Direct Mortality

Direct Mortality ESA Factor(S): B, D, E	Analysis	Confidence/ Uncertainty	Supporting Information
Source(s)	Outdoor recreation by humans Desire by humans to own and keep turtles Urban development Invasive/overabundant predators	Highly confident	
- Activity(ies)	Human-Rio Grande cooter conflict [1-7] Collection for personal or commercial use [8-15] Predation by invasive or overabundant predators, such as racoons, foxes, coyotes, skunks, or bullfrogs [8,16-20] Predation by pet dogs or cats	Highly confident	[1] Conant 1977, p. 489 [2] NMDGF 1988, p. 2 [3] Christman and Kamees 2007, p. 8 [4] Pierce et al. 2016, p. 100.7-100.8 [5] MacLaren et al. 2017a, p. 48 [6] Mali and Forstner 2017, p. 11 [7] Mali and Suriyamongkol 2019, pp. 11–16 [8] Forstner et al. 2004, p. 13, 26-28 [9] Adkins Giese et al. 2012, p. 125 [10] Bailey et al. 2014, p. 322 [11] U.S. Fish and Wildlife Service 2020a [12] Reed and Gibbons 2003, pp. 3–5 [13] Vitt and Caldwell 2014, pp. 423–426 [14] Fitzgerald et al. 2004: 3-4 [15] Ceballos and Fitzgerald 881-888 [16] Congdon and Gibbons 1990, p. 52 [17] Moll and Moll 2004, pp. 76–77 [18] Ernst and Lovich 2009, pp. 209, 375, 379, 407 [19] Pierce et al. 2010, p. 100.8; [20] Bowne et al. 2018, pp. 1151–1152
Stressor(s)	Not applicable - direct mortality	Highly confident	
- Affected Resource(s)	Direct effect on individuals	Highly confident	
- Exposure of Stressor(s)	All life stages and habitats are exposed to and affected by these stressors.	Highly confident	
- Immediacy of Stressor(s)	The short-term timing and frequency of direct mortality to Rio Grande cooter from these sources and activities is not known. — The killing of Rio Grande cooter by hunters and anglers has been reported in the past, continues to be observed in the present, and will likely continue into the future. We do not have insights into trends.	Moderately confident	See sources in Activities row

	— The extent of past, present, and likely future collection of Rio Grande for personal or commercial use is unknown. However, we presume that the trend in this is decreasing due to increased regulation of wildlife collection rangewide. — The extent of past, present, and likely future predation of Rio Grande by invasive or overabundant predators is unknown. However, we presume that this may be increasing due to urban growth.		
Changes in Resource(s)	Individuals either die from wounds or suffer decreased fitness until/if they are able to recover, or are removed from wild population.	Highly confident	
Response to Stressors: **- Individuals**	Individuals either die from wounds or suffer decreased fitness until/if they are able to recover, or are removed from wild population.	Highly confident	
- **Population & Species Responses**			
Effects Of Stressors: **- Populations [Resiliency]**	We identified the following potential population-level effects [8,12,14,17,21,22]: — Removing adults from a population of turtles has negative effects on recruitment, population growth, and species survival. — Population abundance is decreased. — Population resiliency is decreased because population abundance and fecundity decrease. The life history strategy depends on long-lived adults who reproduce many times; the loss of adults to this stressor impairs that life history strategy.	Highly confident	[8] Forstner et al. 2004 (entire) [12] Reed and Gibbons 2003: 3-4, 15-22 [14] Fitzgerald et al. 2004, pp. 4, 37, 40–46, 60, 70–71 [17] Moll and Moll: 175, 208-209, 228-230 [21] Steen and Robinson 2017: 1334-1337 [22] Ceballos and Fitzgerald 2004: 881
- Geographic Scope	Although there is evidence that Rio Grande cooter are shot, caught on fishhooks, predated by animals associated with humans, and collected for personal and commercial use, we have no information on the relative likelihood that Rio Grande cooter will be impacted by these sources or activities in one location compared to another. Because the range of Rio Grande cooter is so large and includes many remote areas, it is difficult to measure and evaluate whether and to what extent the species is impacted by predation, shooting, fish hook ingestion, bycatch, and collection. In addition, due to the lack of studies examining these phenomena systematically, we were unable to meaningfully identify rates of impact to Rio Grande cooter from predation, shootings, or being caught on fishing lines, or differentiate their vulnerability across population analysis units.	Moderately confident	
- Magnitude	It is difficult to calculate the effect because we do not know how many turtles per year are being removed from the population due to these effects, or their age class. Due to the life history strategy of the species, cumulative impacts vary depending on what turtles are removed, and how their removal alters natural survival rates.	Low confidence	
Summary	There is concern from researchers studying this species and herpetologists in the region, but a lack of information and evidence to support analysis of these sources and activities in detail. Recommend discussing narratively but not incorporating into a resiliency metric because impacts have not been measured and we therefore lack a basis to assess population level impacts (and therefore interpret viability).	Highly confident	

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Appendix B. Specific Conductance Data Analysis

Data Acquisition and Processing

We acquired specific conductance data from a U.S. Geological Survey (USGS) project and from the Texas Commission on Environmental Quality (TCEQ). The TCEQ dataset was accessed using the Clean Rivers Program Data Tool (TCEQ 2020c), while the USGS dataset was available from ScienceBase as part of the Pecos River Basin Salinity Assessment project (Houston, Thomas, Jonathan V., Pedraza, et al. 2019b). We removed TCEQ data points from the USGS dataset to eliminate double-counting data, and merged the two tabular datasets into a single file. The TCEQ specific conductance data was mapped to surface water quality stations in order to obtain spatial coordinates for each measurement; the USGS dataset already included coordinates. We used ArcGIS software to manually remove data points not located along waterways used by Rio Grande cooter (e.g., located at wells or unoccupied impoundments). We also used ArcGIS to assign each measurement to the appropriate population analysis unit. We used R software to bin the data into 15-year increments of time (e.g., 1990–2004, 2005–2020) to review whether there had been changes over time in specific conductance measurements within each population analysis unit (R Core Team 2020).

For the current resiliency analysis, we calculated the median and mean values for specific conductance for the periods 1990–2005 and 2005–2020. Specific conductance median and mean values less than 5,500 µS/cm are considered fresh to slightly saline, and place low levels of stress on Rio Grande cooter (U.S. Geological Survey n.d.). Values between 5,500 µS/cm and 9,000 µS/cm are considered moderately saline, and place moderate levels of stress on Rio Grande cooter. Values greater than 9,000 µS/cm are moderately to highly saline, and place higher levels of stress on Rio Grande cooter.

For the future resiliency analysis, we extrapolated the trends in the dataset using simple linear regression to compute the arithmetic mean for the year 2040 and the year 2060. As described in Chapter 6, we conducted the extrapolation twice: once using the data from 1938–2020, and once using the data from 1990–2020. The dataset from 1938–2020 contained 13 extreme outlier values that were omitted from the dataset. One outlier was an observation from 1939 from station “10S.25E.11.3 BTR LKS” in the *Pecos River – Sumner Dam to Brantley Dam* population unit with a value of 119,400 µS/cm. The other 12 were from station “24S.29E.16.133 USGS NO 8” in the *Pecos River – Brantley Dam to Red Bluff Dam* population unit, taken between 1970 and 1976, with values ranging from 185,000 µS/cm to 230,000 µS/cm. We question the quality of these data since they are an order of magnitude higher than the maximum value with them removed, and omitted them from our calculation of the mean and median at the population analysis unit level. For some population analysis units, the projected future mean value did not differ between the two scenarios, but where they did, we applied the lower specific conductance value to Scenario 1 and the higher specific conductance value to Scenario 2. We do not know whether using the full dataset or the recent dataset will more accurately predict future specific conductance values; so, by including both we seek to describe the range of plausible future outcomes. The same ranges of specific conductance values used for current condition correspond to low, medium, and high levels of presumed stress on Rio Grande cooter.

Results

Tables B.1-B.9 summarize specific conductance for each population analysis unit. The salinity category is provided to assist readers with interpretation and is based on the ranges described above. Table B.10 summarizes the categories by population analysis unit to facilitate comparisons between units.

Table B.1. Specific conductance means and medians for the *Pecos River – Sumner Dam to Brantley Dam* population analysis unit. Included are the results from the current resiliency analysis and both scenarios of the future resiliency analysis. The current analysis includes both median and mean values in µS/cm for the timeframe identified in the Years column. The future analysis includes the projected mean value based on extrapolating the dataset forward in time to the year 2040 or 2060, as described above. The method for determining the salinity category is also described above, and may be Low, Moderate, or High.

Resiliency Analysis	Years	Mean (µS/cm)	Median (µS/cm)	Salinity category
Current	1990–2004	5,009	3,900	Low
	2005–2020	4,620	3,537	Low
Future Scenario 1	2040	3,369	—	Low
	2060	3,130	—	Low
Future Scenario 2	2040	5,356	—	Low
	2060	5,627	—	Moderate

Table B.2. Specific conductance means and medians for the *Pecos River – Brantley Dam to Red Bluff Dam* population analysis unit. Included are the results from the current resiliency analysis and both scenarios of the future resiliency analysis. The current analysis includes both median and mean values in µS/cm for the timeframe identified in the Years column. The future analysis includes the projected mean value based on extrapolating the dataset forward in time to the year 2040 or 2060, as described above. The method for determining the salinity category is also described above, and may be Low, Moderate, or High.

Resiliency Analysis	Years	Mean (µS/cm)	Median (µS/cm)	Salinity category
Current	1990–2004	7,902	7,648	Moderate
	2005–2020	7,995	7,625	Moderate
Future Scenario 1	2040	5,344	—	Low
	2060	3,944	—	Low
Future Scenario 2	2040	8,558	—	Moderate
	2060	8,893	—	Moderate

Table B.3. Specific conductance means and medians for the *Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment* population analysis unit. Included are the results from the current resiliency analysis and both scenarios of the future resiliency analysis. The current analysis includes both median and mean values in µS/cm for the timeframe identified in the Years column. The future analysis includes the projected mean value based on extrapolating the dataset forward in time to the year 2040 or 2060, as described above. The method for determining the salinity category is also described above, and may be Low, Moderate, or High.

Resiliency Analysis	Years	Mean (µS/cm)	Median (µS/cm)	Salinity category
Current	1990–2004	13,935	13,150	High
	2005–2020	15,929	15,500	High
Future Scenario 1	2040	15,510	—	High
	2060	16,110	—	High
Future Scenario 2	2040	20,825	—	High
	2060	24,124	—	High

Table B.4. Specific conductance means and medians for the *Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment* population analysis unit. Included are the results from the current resiliency analysis and both scenarios of the future resiliency analysis. The current analysis includes both median and mean values in µS/cm for the timeframe identified in the Years column. The future analysis includes the projected mean value based on extrapolating the dataset forward in time to the year 2040 or 2060, as described above. The method for determining the salinity category is also described above, and may be Low, Moderate, or High.

Resiliency Analysis	Years	Mean (µS/cm)	Median (µS/cm)	Salinity category
Current	1990–2004	3,441	3,220	Low
	2005–2020	4,201	3,640	Low
Future Scenario 1	2040	4,633		Low
	2060	4,963		Low
Future Scenario 2	2040	5,394		Low
	2060	6,287		Moderate

Table B.5. Specific conductance means and medians for the *Devils River – headwaters to Amistad Reservoir* population analysis unit. Included are the results from the current resiliency analysis and both scenarios of the future resiliency analysis. The current analysis includes both median and mean values in µS/cm for the timeframe identified in the Years column. The future analysis includes the projected mean value based on extrapolating the dataset forward in time to the year 2040 or 2060, as described above. The method for determining the salinity category is also described above, and may be Low, Moderate, or High.

Resiliency Analysis	Years	Mean (µS/cm)	Median (µS/cm)	Salinity category
Current	1990–2004	404	399	Low
	2005–2020	437	440	Low
Future Scenario 1	2040	450	—	Low
	2060	461	—	Low
Future Scenario 2	2040	490	—	Low
	2060	529	—	Low

Table B.6. Specific conductance means and medians for the *Rio Grande – Big Bend to Amistad Dam* population analysis unit. Included are the results from the current resiliency analysis and both scenarios of the future resiliency analysis. The current analysis includes both median and mean values in µS/cm for the timeframe identified in the Years column. The future analysis includes the projected mean value based on extrapolating the dataset forward in time to the year 2040 or 2060, as described above. The method for determining the salinity category is also described above, and may be Low, Moderate, or High.

Resiliency Analysis	Years	Mean (µS/cm)	Median (µS/cm)	Salinity category
Current	1990–2004	1,076	1,020	Low
	2005–2020	1,151	1,040	Low
Future Scenario 1	2040	1,153	—	Low
	2060	1,163	—	Low
Future Scenario 2	2040	1,208	—	Low
	2060	1,257	—	Low

Table B.7. Specific conductance means and medians for the *Rio Grande – Amistad Dam to Falcon Dam* population analysis unit. Included are the results from the current resiliency analysis and both scenarios of the future resiliency analysis. The current analysis includes both median and mean values in µS/cm for the timeframe identified in the Years column. The future analysis includes the projected mean value based on extrapolating the dataset forward in time to the year 2040 or 2060, as described above. The method for determining the salinity category is also described above, and may be Low, Moderate, or High.

Resiliency Analysis	Years	Mean (µS/cm)	Median (µS/cm)	Salinity category
Current	1990–2004	1,006	1,010	Low
	2005–2020	956	947	Low
Future Scenario 1	2040	898	—	Low
	2060	852	—	Low
Future Scenario 2	2040	914	—	Low
	2060	862	—	Low

Table B.8. Specific conductance means and medians for the *Rio Grande – Falcon Dam to Anzalduas Dam* population analysis unit. Included are the results from the current resiliency analysis and both scenarios of the future resiliency analysis. The current analysis includes both median and mean values in µS/cm for the timeframe identified in the Years column. The future analysis includes the projected mean value based on extrapolating the dataset forward in time to the year 2040 or 2060, as described above. In this unit, the extrapolated mean value when regressing against the full dataset was below 0. Because this is impossible, we used the 1990–2020 dataset extrapolated values in both scenarios. The method for determining the salinity category is also described above, and may be Low, Moderate, or High.

Resiliency Analysis	Years	Mean (µS/cm)	Median (µS/cm)	Salinity category
Current	1990–2004	1,425	1,140	Low
	2005–2020	1,312	1,130	Low
Future Scenario 1 and Scenario 2	2040	864	—	Low
	2060	588	—	Low

Table B.9. Specific conductance means and medians for the *Rio Grande – Anzalduas Dam to Mouth* population analysis unit. Included are the results from the current resiliency analysis and both scenarios of the future resiliency analysis. The current analysis includes both median and mean values in µS/cm for the timeframe identified in the Years column. The future analysis includes the projected mean value based on extrapolating the dataset forward in time to the year 2040 or 2060, as described above. The method for determining the salinity category is also described above, and may be Low, Moderate, or High.

Resiliency Analysis	Years	Mean (µS/cm)	Median (µS/cm)	Salinity category
Current	1990–2004	1,395	1,319	Low
	2005–2020	1,380	1,320	Low
Future Scenario 1	2040	1,373	—	Low
	2060	1,364	—	Low
Future Scenario 2	2040	1,430	—	Low
	2060	1,453	—	Low

Table B.10. The current and future salinity categories, based on underlying specific conductance measurements and projections, for the population analysis units in the United States. Specific conductance data for the population analysis units in Mexico was not available.

Population Analysis Unit	Current	Scenario 1, 2060	Scenario 2, 2060
Pecos River – Sumner Dam to Brantley Dam	Low	Low	Moderate
Pecos River – Brantley Dam to Red Bluff Dam	Moderate	Low	Moderate
Pecos River – Red Bluff Dam to Amistad Reservoir, Toyah Segment	High	High	High
Pecos River – Red Bluff Dam to Amistad Reservoir, Edwards Segment	Low	Low	Moderate
Devils River – headwaters to Amistad Reservoir	Low	Low	Low
Rio Grande – Big Bend to Amistad Dam	Low	Low	Low
Rio Grande – Amistad Dam to Falcon Dam	Low	Low	Low
Rio Grande – Falcon Dam to Anzalduas Dam	Low	Low	Low
Rio Grande – Anzalduas Dam to Mouth	Low	Low	Low