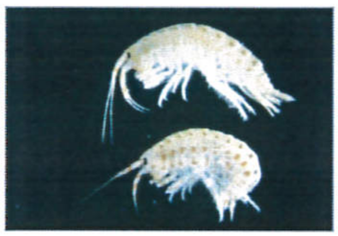
Final Recovery Plan
for
Four Invertebrate Species of the Pecos River Valley: Noel's amphipod (Gammarus desperatus), Koster's springsnail (Juturnia kosteri), Roswell springsnail (Pyrgulopsis roswellensis), and Pecos assiminea (Assiminea pecos)



Noel's amphipod

Roswell springsnail

Koster's springsnail

Pecos assiminea

Photos by Brian Lang, New Mexico Department of Game and Fish

Southwest Region
U.S. Fish and Wildlife Service
Albuquerque, New Mexico

Approved: ______________________
Regional Director, Southwest Region, U.S. Fish and Wildlife Service

Date: July 26, 2019

DISCLAIMER

The Endangered Species Act of 1973 (ESA), as amended (16 U.S.C. 1531 et seq.), requires the development of recovery plans for listed species, unless such a plan would not promote the conservation of a particular species. In accordance with section 4(f)(1) of the ESA and to the maximum extent practicable, recovery plans delineate actions which the best available science indicates are required to recover and protect listed species. Plans are published by the U.S. Fish and Wildlife Service (USFWS), and are sometimes prepared with the assistance of recovery teams, contractors, state agencies, and others. Recovery teams serve as independent advisors to the Service. Plans are reviewed by the public and submitted to additional peer review before they are adopted by the USFWS. The purpose of a recovery plan is to provide a scientifically based, logical, and effective roadmap for the recovery of a species. It explains what is needed for species recovery and how to get there. Recovery plans are advisory documents, not regulatory documents. A recovery plan does not commit any entity to implement the recommended strategies or actions contained within it for a particular species, but rather provides guidance for ameliorating threats and implementing proactive conservation measures, as well as providing context for implementation of other sections of the Endangered Species Act, such as section 7(a)(2) consultations on Federal agency activities, development of Habitat Conservation Plans, or the creation of experimental populations under section 10(j).

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An electronic copy of this recovery plan will be made available at: U.S. Fish and Wildlife Service southwest region Ecological Services website

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DEDICATION

Prior to the completion of this draft recovery plan, the New Mexico Department of Game and Fish (NMDGF) developed a 2005 recovery plan addressing the invertebrates entitled: Recovery and Conservation Plan for Four Invertebrate Species: Noel's amphipod (*Gammarus desperatus*), Koster's springsnail (*Juturnia kosteri*), Roswell springsnail (*Pyrgulopsis roswellensis*), and Pecos assiminea (*Assiminea pecos*). This NMDGF plan, primarily authored by Brian Lang, served as a beacon of information and conservation approaches to benefit the four invertebrates. Brian Lang, a NMGDF biologist, was devoted to the understanding and preservation of these species, as well as other rare invertebrates throughout New Mexico. It was from Brian's efforts over the 22+ years that we know as much as we do about these rare invertebrates. We who worked with Brian over these years dedicate this recovery plan to him.
March 1, 2017. Requiescat in pace.

EXECUTIVE SUMMARY

Current Status of the Species

Noel's amphipod (*Gammarus desperatus*), Koster's springsnail (*Juturnia kosteri*), Roswell springsnail (*Pyrgulopsis roswellensis*), and Pecos assiminea (*Assiminea pecos*) (four invertebrates) were listed as endangered in 2005. Final critical habitat for each species was designated in 2011. In this recovery plan, based on increased understanding of the threats to the species, we change the recovery priority number for each of the four species from a 14, indicating a low degree of threat, a high potential for recovery, and a taxonomic category of full species, to an 8, representing a full species with a moderate degree of threat and a continued high potential for recovery. These four invertebrates are constrained to karst water features including sink holes and springs, reliant on clean groundwater sources, in localized areas of New Mexico and Texas. Noel's amphipod is known to occur in five management units (MUs) in New Mexico; Koster's springsnail is currently found in five MUs in New Mexico; Roswell springsnail is currently found in three MUs in New Mexico; and Pecos assiminea is currently found in three MUs in New Mexico and Texas. Each species' occupation of its respective MUs has remained stable over the past 5 years. The MUs in New Mexico are located on Bitter Lake National Wildlife Refuge. The numbers of individuals for each species are not known.

Habitat Requirements and Threats

Noel's amphipod, Koster's springsnail, Roswell springsnail, and Pecos assiminea are associated with spring systems in desert-grassland in the Roswell Basin in southeastern New Mexico, and in the Toyah and Coyanosa Basins in west Texas. All four species are found on Bitter Lake National Wildlife Refuge. Pecos assiminea is also found at Diamond Y and East Sandia Spring in west Texas on lands administered by The Nature Conservancy. The basins where these four species are found have abundant karst topography, such as sinkholes, caverns, springs, and underground springs, which have created unique settings harboring diverse assemblages of flora and fauna. Within these karst formations, the four invertebrates are found in isolated limestone and gypsum springs, seeps, and wetlands located in and around Roswell, New Mexico, and in Pecos and Reeves Counties, Texas. These aquatic invertebrates require clean, moist habitats; Pecos assiminea requires mud or vegetation very close to flowing water, while Noel's amphipod, Koster's springsnail, and Roswell springsnail require permanent, flowing water. Each invertebrate needs algae, detritus, and bacteria associated with native vegetation and natural spring and seep systems.

As localized endemics, the four invertebrates depend on regional groundwater that often originates at depths and distances far from the habitat protected. The primary threats to the four invertebrates are diminished water quantity due to groundwater pumping and drought (which lowers aquifer levels and subsequently reduces outflow from springs and seeps), and water quality contamination; secondary threats include inadequate existing regulatory mechanisms, localized range, limited mobility, fragmented habitat, and climate change, and tertiary threats may include invasive species, disease, and predation.

This recovery plan discusses all of the threats analyzed when the species were listed. The primary focus is on goals and criteria that will address the major threats and ensure quantity and quality of spring water for these species.

Recovery Strategy

The overall strategy involves preserving, restoring, and managing their aquatic habitat, along with the water resources necessary to support resilient populations of these species and the ecosystems on which they depend. More specifically, the strategy is to:

- Maintain and manage populations and sites throughout each species' range
  - Ensure adequate water quantity and water quality,
  - Protect and restore surface habitats,
  - Control invasive species,
- Collaborate with partners to achieve conservation goals in balance with community water needs, and
- Engage in community outreach to promote the importance and value of Bitter Lake NWR and its diverse array of wildlife, including sensitive, rare aquatic invertebrates, worthy of preserving.

Recovery Goals and Objectives

The recovery goal is to conserve and protect the four invertebrates and their habitats so that each species can be removed from the list of threatened and endangered species (delisted). This will be accomplished by meeting the objectives of: securing the long-term survival of each species with the appropriate number, size, and distribution of within MUs; preserving sites that contain the necessary elements for each species' persistence, such as adequate water quantity and quality; reducing threats within MUs so that the four invertebrate species' are capable of enduring stressors; conducting monitoring and research to understand species patterns, maintain genetic diversity, and identify new sites for species' introductions or repatriation; and working with others to develop long-term management plans and educational approaches that will protect the four invertebrates and inform the community about their habitat needs and ecological importance. We chose persistence as stable to increasing abundance within MUs over 10- and

20-year time frames as surrogates for measures of the resiliency. For example, if the population persists through 10 years, then we know it is resilient enough to withstand typical drought conditions. If the population persists through 20 years, then we know it is resilient enough to withstand major drought conditions (Butler and Tashjian. 2016).

Recovery Criteria

Each species should be considered, separately, for downlisting or delisting when the following objectives and criteria have been met:

Objective 1 – Secure and maintain the long-term survival of each species with the appropriate number, size, and distribution of resilient management units.

Downlisting Criterion 1: Maintain the presence of each species in the occupied management units as of the start of this plan, with a stable or increasing average trend in density over 10 years at currently monitored management units (1 and 3).

Delisting Criterion 1: Maintain the presence of each species in the occupied management units as of the start of this plan, with a stable or increasing average trend in density over 20 years in management units (1 and 3).

Objective 2 – Protect water quantity

Downlisting Criterion 2: Develop, implement, and fulfill a water management plan or equivalent conservation agreement, supported by the local irrigation district and other partners, that ensures adequate surface and groundwater levels to 1) sustain downlisting criteria measured by Criterion 1 above, and 2) meet or exceed BLNWR's minimum federally reserved water right flow (0.0042 m^3/s (0.15 cfs) for 10 years.

Delisting Criterion 2: Develop, implement, and fulfill a water management plan or equivalent conservation agreement, supported by the local irrigation district and other partners, that ensures adequate surface and groundwater levels to 1) sustain delisting criteria measured by Criterion 1 above, and 2) ensure that the flows in Bitter Creek as measured at the Bitter Creek Flume are greater than 0.007 m^3/s (0.25 cfs) for 20 years.

Objective 3 – Protect water quality

Downlisting Criterion 3a: Long-term commitments (Conservation Agreements etc) are in place and will continue to maintain sufficient water quality protections for 10 years, and water quality sustains each species as measured by Criterion 1 above.

Delisting Criterion 3a: Long-term commitments (Conservation Agreements etc) are in place and will continue to maintain sufficient water quality protections for 20 years, and water quality sustains each species as measured by Criterion 1 above.

Downlisting Criterion 3b: Long-term commitments (Conservation Agreements etc) are in place that would specifically address the four invertebrates and reduce the risk of a catastrophic spill occurring within a drainage or recharge area occupied by any of the four invertebrates for 10 years.

Delisting Criterion 3b: Long-term commitments (Conservation Agreements etc) are in place that would specifically address the four invertebrates and reduce the risk of a catastrophic spill occurring within a drainage or recharge area occupied by any of the four invertebrates for 20 years.

Objective 4 – Protect and restore habitat that supports invertebrate populations

Downlisting Criterion 4: A habitat management plan is developed and implemented that ensures that the environment remains as suitable habitat that sustains each species for 10 years.

Delisting Criterion 4: A habitat management plan is developed and implemented that ensures that the environment remains as suitable habitat that sustains each species for 20 years.

Actions Needed

Actions were developed for each objective. Primary actions include ensuring adequate water quantity, protecting and improving water quality, protecting and restoring habitat, designing a long term monitoring strategy, establishing emergency programs necessary to maintain the species in captivity in case of catastrophic events, and designing post-delisting monitoring. Management actions for the Diamond Y Spring system and East Sandia Spring in Texas will be defined in the West Texas Invertebrates Recovery Plan (Service in preparation).

Estimated Date and Cost of Recovery

The Implementation Schedule provides the estimated costs of implementing recovery actions for the first 5 years after the release of the recovery plan, as well as the total cost of recovery. Continual and ongoing costs, as well as the estimated total cost, are based on the projected timeframe of 20 years to recovery and delisting of the four invertebrates. The time estimated to downlist the four invertebrates from endangered to threatened status is 10 years, with an estimated cost of $830,000. The total cost to implement this plan through the year 2038, the estimated recovery (delisting) date for the four invertebrates, is $880,000.


Bitter Lake National Wildlife Refuge, New Mexico, USFWS

TABLE OF CONTENTS

Sunset over Bitter Lake National Wildlife Refuge's wetlands, USFWS

LIST OF TABLES

LIST OF FIGURES IN APPENDIX

1.0 BACKGROUND

This section consists of background information on the distribution, status, habitat requirements, biology, and ecology of the four invertebrate species. This information provides the basis for assessing current status, threats to persistence, and the most effective recovery and conservation strategies for the four invertebrate species.

1.1 Brief Overview

Noel's amphipod (*Gammarus desperatus*), Koster's springsnail (*Juturnia kosteri*), Roswell springsnail (*Pyrgulopsis roswellensis*), and Pecos assiminea (*Assiminea pecos*) (four invertebrates) are associated with spring systems in desert-grassland in the Roswell Basin in southeastern New Mexico and the Toyah and Coyanosa Basins in west Texas (Mace et al. 2001:42; Land and Huff 2010: 455). These basins have abundant karst topography, such as sinkholes, caverns, springs, and underground springs, which has created unique settings harboring diverse assemblages of flora and fauna. The isolated limestone and gypsum springs, seeps, and wetlands located in and around Roswell, New Mexico, and in Pecos and Reeves Counties, Texas, provide the last known habitats in the world for several endemic species of fish, plants, mollusks, and crustaceans, including the four invertebrates (see Figures 1, 6 and 7).

The four invertebrates were listed as endangered species in 2005 (Service 2005a: 46,304) under the Endangered Species Act of 1973 as amended (16 USC 1531 et seq.) (ESA). Critical habitat was designated for the four species in 2011 (Service 2011: 33,036). In this recovery plan, based on increased understanding of the threats to the species, we change the recovery priority number for each of the four species from a 14, indicating a low degree of threat, a high potential for recovery, and a taxonomic category of full species, to an 8, representing a full species with a moderate degree of threat and a continued high potential for recovery. This is based on imminent threats of water withdrawals within the immediate area of the four invertebrates' habitat (Balleau Groundwater, Inc. 1996, 1999; Butler and Tashjian 2016) and on increased potential impacts from drought and climate change, with more accurate predictions of decreasing precipitation and increasing temperatures into the future for this region (Niraula et al. 2017: entire).

To help identify and guide species' recovery needs, section 4(f) of the ESA directs the Secretary of the Interior to develop and implement recovery plans for listed species or populations. Such plans are to include: 1) a description of management actions necessary to conserve the species or population; 2) objective, measurable criteria that, when met, will allow the species or population to be removed from the List of Endangered and Threatened Wildlife; and 3) estimates of the time and funding needed to achieve the plan's goals and intermediate steps. Recovery plans are advisory documents. Recovery recommendations contained in these plans are aimed at lessening or alleviating the threats to the species and ensuring self-sustaining populations in the wild, with the goal of removing the species from the list of federally threatened or endangered species.

Procedures for reclassifying and delisting species are set forth in the ESA and in its implementing regulations. A species may be delisted if it no longer meets the criteria for endangered or threatened status, based on a consideration of the five listing factors. A recovery and conservation plan for the four invertebrate species was developed by the State of New Mexico (NMDGF 2005: entire). This USFWS recovery plan is a revision and expansion of the State's 2005 document, and includes a threats analysis, and objective, measurable criteria for downlisting to threatened, and for full recovery (delisting) of the four species.

1.2 Description and Taxonomy

Noel's amphipod

Noel's amphipod was described in 1981 by Cole from a 1967 collection of amphipods from Chaves County, New Mexico (Cole 1981: 27). The type locality was North Spring on the Roswell Country Club. The North Spring collection appeared to be the same species collected from Lander Springbrook (now an extinct spring due to permanent spring drying) in Chaves County by Noel (1954: 124) and mistakenly identified as *Gammarus fasciatus* (Cole 1981: 27).

Amphipod species are primarily marine, although 900 species occur in freshwater worldwide. Freshwater amphipods are found in subterranean and surface waters, including lakes, ponds, streams, and springs. In the U.S., there are approximately 150 species found in freshwater (Smith 2001: 569). Two families of amphipods, Gammaridae and Hyalellidae, occur in New Mexico (Cole 1981: 27). Noel's amphipod is in the family Gammaridae. It is one of three described and four undescribed *Gammarus* species collectively known as the *Gammarus-pecos* complex (Cole 1985: 93). The *Gammarus-pecos* complex occurs in the Pecos River Basin which extends from Roswell, Chaves County, New Mexico, south to Fort Stockton, Pecos County, Texas. Individuals from other locations were identified as separate species (Lang et al. 2003: 51).

Gammarus in the Chihuahuan Desert contains multiple species within two distinct lineages (Adams *et al.* in review). One lineage is composed of *G. pecos, G. hyalelloides,* the recently described *G. seideli*, and *G. desperatus*. All of these species are allopatric and restricted to individual spring systems. They share a most-recent-common-ancestor with the marine *G. tigrinus*. The second lineage consists of a group of undescribed species found in New Mexico at Hunter Marsh, Sitting Bull Spring, Perch Lake, Malpais Spring, and Lenora Curtain Preserve. This latter group shares a most-recent-common-ancestor with the circumpolar, freshwater *G. lacustris.* Note that Hunter Marsh on BLNWR contains individuals from both lineages.

Gammarus at BLNWR may consists of two species that are sympatric at Hunter Marsh and belong to two different lineages of Chihuahuan Desert *Gammarus.* One of these species is widespread throughout the refuge and, based on morphology, is referable to *Gammarus desperatus* as described by Cole (1981) due to the lack of calceoli on the second antennae of males (Walters and Berg 2015), while the other "species" is undescribed, has only been collected at Hunter Marsh, possesses calceoli on the second antennae of males, (Walters and Berg 2015), and is most closely related to *Gammarus* from other spring systems elsewhere in New Mexico (Adams *et al.* 2018). The Rio Hondo location may contain *Gammarus* that are genetically distinct from *G. desperatus* found on the remainder of the refuge. The Rio Hondo and Upper Snail Unit sites are identified as one of five different genetic "populations" of *Gammarus* based on microsatellite genotypes (Walters and Berg 2017).

Noel's amphipod females are generally smaller than males. Males range in size from 9.45 to 14.8 millimeters (mm) (0.37 to 0.58 inches [in]) while females are 8.5 to 12.6 mm (0.34 to 0.50 in) long (Cole 1981: 28, 31). Noel's amphipods <8.5 mm (smaller than those described by Cole 1981) are regularly observed in monitoring efforts at BLNWR.

Koster's springsnail

Koster's springsnail was described in 1987 from collections made in Chaves County, New Mexico (Taylor 1987: 45). The type locality of the species is Sago Springs on BLNWR. This springsnail is in the family Hydrobiidae, the largest and most diverse family of freshwater snails in North America. The family Hydrobiidae includes approximately 36 genera (Smith 2001: 345). Although initially considered by Taylor (1987: 45) to be in the genus *Tryonia*, the species was reassigned first to the genus *Durangonella* (Hershler 2001: 15) and then to the new genus *Juturnia* (Hershler et al. 2002: 175). Koster's springsnail shell lengths are ≤4.56 mm (0.18 in). Females are larger than males (Taylor 1987: 46). Distinguishing among Koster's and Roswell springsnails in the field is not possible without significant magnification. There is a large amount of overlap in shell shape (Morningstar et al. 2014: 542), but the opercula color differs between the two springsnails (Taylor 1987: 15).

Roswell springsnail

Roswell springsnail was described in 1987 from collections made in Chaves County, New Mexico (Taylor 1987: 16). The type locality of the species was a seep in the Unit 7 spring ditch of BLNWR. As with Koster's springsnail, this springsnail is in the Family Hydrobiidae. Roswell springsnail was initially considered by Taylor to be in the genus *Fontelicella* (Taylor, 1987: 15) but at about the same time, Hershler and Thompson (1987: 25) reassigned the genus *Fontelicella* to *Pyrgulopsis*. Hershler reassigned *Fontelicella roswellensis* to *Pyrgulopsis roswellensis* (Hershler 1994: 63). *Pyrgulopsis* is one of the most abundant and diverse members of the endemic southwestern United States aquatic biota (Hershler et al. 2014: 693).

Operculum color is used to differentiate Roswell springsnail from Koster's springsnail (Taylor et al. 1987: 15; Morningstar et al. 2014: 537). In two studies, individuals were initially assigned to species by operculum color and these assignments were verified using several classes of genetic markers including mitochondrial DNA sequences (Morningstar *et al.* 2014) and microsatellites (Holste *et al.* 2016). In some habitats on the refuge, operculum may be stained leading to difficulty in identifying the two species. Roswell springsnail shell lengths are less than 3.8 mm (0.15 in) with four to five whorls (Hershler 1994: 63).

Pecos assiminea

Pecos assiminea was described in 1987 from collections made in New Mexico, Texas, and México (Taylor 1987: 8). The type locality of the species was a seepage area in the Wetland Unit 7 spring ditch on BLNWR. Pecos assiminea is unique in that it is the most inland species of the primarily marine snail genus *Assiminea*. The species is a very small, golden snail in the family Assimineidae, which comprises mostly marine and brackish-water species (Taylor 1987: 8). The genus *Assiminea* is distinguishable from snails in the family Hydrobiidae by its almost complete lack of tentacles (Taylor 1987: 8). The eyes occur instead in the tips of short eye stalks. Shell lengths of Pecos assiminea range from 1.36 to 2.16 mm (0.05 to 0.08 in) (Taylor 1987: 8). Females are larger than males.

The Mexican population of Pecos assiminea has recently been described as a separate species (*Assiminea cienegensis*) and is no longer considered a disjunct population of *Assiminea pecos* (Hershler et al. 2007: 328).

1.3 Historical and Current Distribution

The physical and biological characteristics of many of the springs mentioned here are described in more detail in Gallo (2013: entire). See Figure 1 for a map of the current Management Units on Bitter Lake NWR. Management units (MUs) are divisions of the listed entity used for monitoring purposes in this plan.

Noel's amphipod

Noel's amphipod was historically known from Lander Springbrook, a tributary of the South Spring River near Roswell (Noel 1954: 124), and North Spring on the Roswell Country Club based on collections made in August 1967 and August 1978 (Figure 2; Cole 1981: 27). Noel's amphipod was also collected from a sinkhole and from Bitter Creek (Lost River) on BLNWR in 1988 (Figure 8; Table 1; Cole, 1988: 2).

The Lander Springbrook location of Noel's amphipod went extinct by 1967 with drying of the spring (Cole 1981: 27; Cole 1988: 2). At the Roswell Country Club North Spring, the Noel's amphipod appears to have been extirpated as a result of habitat modification that occurred prior to May 1988 (Cole 1981: 27; Cole 1988: 2); none were found as recently as 2005 (NMDGF 2005: 1). Noel's amphipod currently persists on BLNWR at: the Snail Unit, the Sago Springs complex including Sinkhole No. 32 (and 31) (these sinkholes are in close proximity to each other and are connected through overland flow to Sago Springs; there is some confusion between historical assignment of numbers for each, so both are combined here); Bitter Creek, including Dragonfly Spring and Lost River Pool; and, Unit 6 spring ditch (Figures 8 and 9; NMDGF 1999: A1; NMDGF 2000: A1; Lang 2002: A2; Lang et al. 2003: 51; tables 6 and 8 in report cited as U.S. Fish and Wildlife Service 2015a). Additionally, it was discovered on property owned by the city of Roswell just outside of BLNWR (Figure 10; Warrick 2005: 1) and within six spring vents flowing into the Rio Hondo within the BLNWR South Tract (Figure 11; Warrick 2006: 1; Service 2013a: 5).

Koster's springsnail

Six extant locations of Koster's springsnail, all from New Mexico, were known when the species was described in 1987 (Taylor 1987: 47). Five of these locations were on BLNWR at the following locations: throughout Bitter Creek; at Sago Springs; in a 0.4-kilometer (km) (0.25-mile [mi]) reach of the Unit 3 spring ditch; study sites A,B,and C in Unit five; and in a seep draining into Unit 6 spring ditch (Figures 8 and 9). The sixth location was known from North Spring on the Roswell Country Club in collections made from 1968 to 1981 (Figure 3; Taylor, 1987: 47).

The current distribution of Koster's springsnail appears to be restricted to BLNWR and at a location found on City of Roswell property near the BLNWR boundary (Figure 3; Warrick 2005: 1). Koster's springsnail was found at the Roswell Country Club North Spring through 1995 (NMDGF 1998: 78) but was not found in 2004 when the location was resurveyed (Lang 2004: 2). Koster's springsnail persists in Lake St. Francis, Dragonfly Spring, Snail Unit, Bitter Creek, the Sago Springs, and Sinkholes No. 31(32) complex, the southwestern corner of Unit 15, City of Roswell adjacent to Hunter Marsh, and in isolated locations in Units 3, 6, and 7 spring ditches (Figures 8, 9, 10, 12, and 13; Mehlhop 1992: 5; Lang 2002: A16; NMDGF 2010: 9). In addition, Koster's springsnail was recently discovered in 2011 in Sinkholes 38 and 59 (Macanowicz et al. 2013: 1108) (Figure 13).

Roswell springsnail

Five locations of Roswell springsnail were known when the species was described in 1987 (Taylor 1987: 16). All of these occurred within Chaves County, and three of them were located outside BLNWR. Twowere located in the Unit 6 and Unit 7 of BLNWR(the type locality) spring ditches, and Sago Springs (Figures 8, 9 and 12). The third location is Landers Springbrook, the fourth location is the North Spring on the Roswell Country Club grounds, and the fifth location was at Berrendo River (Figure 4; Taylor 1987: 16).

Current distribution of Roswell springsnail appears to be restricted to BLNWR and at a location recently found on City of Roswell property near the BLNWR boundary (Figure 4; Sanchez 2009: 1). The Roswell springsnail was last collected at the Roswell Country Club North Spring in 1995 (NMDGF 1998: 69); it was not found during a 2004 survey (Lang 2004: 2). Roswell springsnails are found in Bitter Creek, Sago Springs, Sinkhole No. 31(32), Unit 6 spring ditch (near the beaver dam), Unit 5 site A, and at the City of Roswell location (Figure 4, 8 and 9; Mehlhop 1992: 4; Mehlhop 1993: 6; Lang 2002: A12; Sanchez 2009: 1). Springsnails with amber operculum, characteristic of Roswell springsnail, have also been found in the Snail Unit (Johnson 2017a: 1). The type locality in Unit 7 spring ditch was reported as being dry in 1992 (Figure 12; Mehlhop 1992: 5). However, surveys in 2002 documented the persistence of the Roswell springsnail at this location (NMDGF 2002: A1). Roswell springsnail was also found at the Lost River confluence along Bitter Creek in 1998 (Lang 2002: A12). It has not been found in Hunter Marsh, though sampling intensity may have been too low to detect it (Figure 10; NMDGF 2010: 9).

Pecos assiminea

When Pecos assiminea was described in 1987, snails were found at three isolated localities: in Chaves County on BLNWR in New Mexico; Diamond Y Spring in Pecos County, Texas; and in the Bolsón de Cuatro Ciénegas, Coahuila, Mexico (Taylor 1987: 9). Taylor (1987: 8-9) reported extirpation of two locations in Chaves County: one at North Spring at the Roswell Country Club and the other at the type locality (Unit 7 spring ditch) on BLNWR (Figures 5 and 12). Taylor (1987: 9) reported possible fossil Pecos assiminea from along the Pecos River near Grandfalls, Texas, and the Río Monclova, Coahuila, México. Those in Coahuila were subsequently redescribed as *Assiminea cienegensis*, based on genetic divergence and a distinctly smaller, broader shell (Hershler et al. 2007: 327).

Pecos assiminea occurs at Diamond Y Spring Preserve (Diamond Y Spring source pool, Monsanto Spring, Euphrasia Spring, and John's Pool) owned by The Nature Conservancy, in Pecos County, Texas (Figure 6; NMDGF 2000: A3) and at East Sandia Spring in Reeves County, Texas, on private lands under stewardship of The Nature Conservancy (Figure 7; NMDGF 2000: A3). The species also persists at BLNWR. On BLNWR, Pecos assiminea is currently found in the upper reaches of Bitter Creek near Dragonfly Spring, the lower end of Bitter Creek, the lower reaches of the Sago Spring Complex near Sinkhole No. 32 (and 31), in the Unit 7 spring ditch, in the Snail Unit, and at a spring in the extreme southwestern corner of Unit 15 (Figures 8 12, and 12a; Lang 2002: A5; Roesler 2016: 58). The species was not found at North Spring on the Roswell Country Club during a survey in August 2004 (Figure 5; NMDGF 2005: 1). Pecos assiminea was found (single recent empty shell) in Hunter Marsh in 2009, but subsequent intensive sampling in 2010 did not further identify any individuals (Figure 10; NMDGF 2010: 9).

Additional surveys have been conducted for all four invertebrates. Southeast of Bitter Lake NWR, potential suitable habitat in Bottomless Lakes State Park has been surveyed but none of these species were documented (Mehlhop 1992: 8; Lang 2002: A5). Six locations in the BLM Overflow Wetlands were surveyed in 2003; none of the four invertebrates were found (NMDGF 2003: B1). In 2008, McCrea Spring and South Y Canyon Spring on BLM land were surveyed; none of the four invertebrates were found (NMDGF2008b: 8).

Table 1. Historical locality records of the four endangered invertebrate species in Chaves County, New Mexico, excluding localities at BLNWR.

Species	Historical Records	Reference
Noel's Amphipod (Gammarus desperatus)	Lander Springbrook	Noel 1954: 124 Cole 1981:27
	North Spring, Roswell Country Club	Cole 1981: 27
Pecos assiminea (*Assiminea pecos*)	North Spring, Roswell Country Club	Taylor 1987: 8
Koster's Springsnail (*Juturnia kosteri*)	Berrendo River	Taylor 1987: 47
	North Spring River	Taylor 1987: 47
	South Spring River	Taylor 1987: 47
	Pecos River near (1905) bridge at Roswell, west side of river	Taylor 1987: 47
Roswell Springsnail (Pyrgulopsis roswellensis)	Berrendo River	Taylor 1987: 16
	Pecos River northeast of Roswell	Taylor 1987: 16
	Lander Springbrook	Noel 1954: 126
		as Amnicola neomexicana

1.4 Habitat Requirements

Noel's amphipod

Gammarid amphipods typically are found in shallow, cool, well-oxygenated waters of small streams, ponds, ditches, sloughs, and springs (Holsinger 1976: 3; Smith 2001: 574). Acidity is a limiting factor for amphipods, with a pH of 6.0 generally constituting a lower threshold and 8.0 an upper threshold (Smith 2001: 574). Typically, amphipods are found beneath stones and in aquatic vegetation during daylight hours (Smith 2001: 572-574). Noel's amphipod was found mainly on rubble and rubble-sand substrate at Lander Springbrook and less frequently on silt substrate or vegetation (Noel 1954: 124). Habitats on Bitter Lake NWR range from dense beds of emergent aquatic macrophytes to clear, flowing spring-brooks with submerged aquatic vegetation, vegetated banks and margins, and clean substrates. Noel's amphipod occurs in Hunter Marsh where permanent spring sources are located (NMDGF 2010:9). Standing water and silt accumulation appear to constitute unsuitable habitat for the species (NMDGF 2000: A1). Lang (2002: A2) suggested that the addition of stones, which increased stream gradient and current velocity, seemed to improve habitat for Noel's amphipod in the Unit 6 spring ditch. Salinity in habitats occupied by amphipods of the *Gammarus-pecos* complex is low to moderate, ranging from 0.1 to 5.9 parts per thousand (ppt) (Cole 1985: 95; Seidel et al. 2010: 1,165). Comparison among species within the *Gammarus-pecos* complex indicated that this species is in the medium to low maximum salinity range (2.7 to 5.9 ppt) (Seidel et al. 2010: 1,165). Cole (1981: 27) reported chemical composition of the water at North Spring to be similar to that described at Lander Springbrook (Noel 1954: 123): impure gypsum substrate, sulfate- and chloride-rich waters, and calcium as the primary cation.

Koster's springsnail and Roswell springsnail

All nine described hydrobiids from New Mexico (Taylor 1987: iii; Hershler et al. 2002: 180–182) are state endemics that typically occur in small, geographically isolated habitats consisting of eurythermal (i.e., fluctuating temperature) springs and spring-fed wetland systems restricted to the southern half of the state (NMDGF 1998: 77). Habitat of Koster's springsnail consists of soft substrates of springs and seeps (Taylor 1987: 47). Lang (NMDGF 1998: 13) found Koster's springsnail to be most abundant in the deep organic substrates of Bitter Creek. Roswell springsnail, on the other hand, was found to be most abundant on hard, gypsum substrate in Sago Springs outflow channels and pools (NMDGF 1998: 13). Hence, substrate type may be an important factor for these springsnails.

Both springsnails are found throughout Bitter Creek, which varies in water temperature from the headwaters at Dragonfly Spring to the downstream reaches near the mouth at Bitter Lake. The upstream reaches of Bitter Creek are characterized by a relatively stable temperature regime with a narrow range of fluctuation (NMDGF 1998: 15). Water temperature at Dragonfly Spring varied only about 4.6 degrees Celsius (ºC) (8.3 degrees Fahrenheit [ºF]), from 13.6 to 18.2 ºC (56.5 to 64.8 ºF) from October 1996 through June 1998 (NMDGF 1998: 13). Water temperature was much more variable during the same period in the lower reach of Bitter Creek, ranging from 0 to 31 ºC (32 to 87.8 ºF). Water temperature regimes are less variable in the Sago Springs complex than in Bitter Creek (NMDGF 1998: 15). Water temperature varied about 3.5 ºC (6.3 ºF), from 17.0 to 20.5 ºC (62.6 to 68.9 ºF) at the headspring of Sago Springs and about 6.1 ºC

(10.9 ºF) from 15.7 to 21.8 ºC (60.3 to 71.2 ºF) in the outflow at Sago Springs (NMDGF 1998: 20-21). Salinity in Bitter Creek ranged from about 4.5 to near 6 ppt. Dissolved oxygen in Bitter Creek ranged from about 1.0 to over 20 parts per million (ppm) from 1995 to 1998, with lowest levels occurring in summer evening hours and highest levels during daytime hours in spring. Variation in pH was from about 6.7 to 8.2 (NMDGF 1998: 22-24). Koster's springsnail occurs in Hunter Marsh where permanent spring sources are located; the apparent absence of the Roswell springsnail may be an artifact of sampling strategy (NMDGF 2010:9).

Pecos assiminea

Taylor (1987: 9) described habitat of Pecos assiminea as "moist earth beside seepages or spring-brooks; never beside standing water" and occurring "beneath salt grass or sedges, less often on exposed surfaces." Lang (2002: A5) reported that Pecos assiminea was closely associated with wetland habitats characterized by soils saturated at the surface and vegetation dominated by chairmaker's bulrush (*Schoenoplectus americanus*), common reed (*Phragmites australis*), and spike rush (*Eleocharis* spp.), with saltgrass (*Distichlis spicata*) and rushes (*Juncus* spp.) also occurring as common species in the wetland plant community. The snail typically occurs near the surface of the soil beneath litter and vegetation in these habitats. Pecos assiminea occupies wetland habitats along the margin of Bitter Creek, particularly near the mouth at Bitter Lake, at the type locality in the Unit 7 spring ditch, and at Sinkhole No. 32 (which may also be the same as Sinkhole No. 31, due to mapping inconsistency) at the lower end of the Sago Springs complex, where the species is most abundant. Although Pecos assiminea is most common in non-inundated wetland habitat, it may also rarely occur in aquatic habitats of Bitter Creek and Sago Springs (NMDGF 1998: 34). The snail was found in water depths ranging from 5.0 to 21 centimeters (cm) (0.06 to 8.27 inches [in]) in these aquatic habitats (NMDGF 1998: 14). Roesler (2016: 46) found that moisture and temperature were the primary factors determining its presence. Vegetation litter was an important factor in determining habitat suitability though excessive litter output of the common reed had negative effects (Roesler 2016: 47).

1.5 Life History and Ecology

Noel's amphipod

Specific breeding and reproductive characteristics of Noel's amphipod have not been well studied. The following discussion is based largely on characteristics known from other species within the genus.

High population densities in gammarid amphipods are not uncommon and cannibalism may occur at density extremes when food supply becomes limiting (Smith 2001: 575). Amphipods are omnivorous, feeding on a wide variety of plant and animal matter and detritus. Noel's amphipod is often found in beds of submerged aquatic plants, which indicates that they probably browse on a surface film of algae, diatoms, bacteria, and fungi (Smith 2001: 572).

Freshwater amphipods are typically nocturnal, as they are extremely light-sensitive, and are strongly oriented to the substrate (Smith 2001: 574). Amphipods respire primarily through gills (Smith 2001: 572). Predation by fish, birds, and aquatic insects (Smith 2001: 576) may also play a role in regulating population size of Noel's amphipod. Seasonal or long-term movements of amphipods have been reported, indicating that hydrologically connected habitats may be recolonized following local extirpation (Smith 2001: 575).

Most amphipods breed between February and October (Smith 2001: 572). *Gammarus* males and females pair for one to seven days, feeding and swimming together prior to copulation which lasts less than 1 minute (Smith 2001: 573). Fertilized eggs are retained in the female's brood pouch, or marsupium, where they incubate for 1 to 3 weeks (Smith 2001: 573). Young remain in the marsupium for another 1 to 8 days before being released (Smith 2001: 573). The breeding season for Noel's amphipod is likely from February through October and is dependent on water temperature. Most amphipods live 1 year or less (Smith 2001: 574).

Amphipods generally do not tolerate habitat desiccation or other adverse environmental conditions and are thus sensitive to habitat degradation (Smith 2001: 575). Lang (2002: A2) found this to be true in Noel's amphipod. For example, the Sandhill Fire burned over Dragonfly Spring in March 2000. The fire eliminated vegetation shading at the spring and generated a substantial amount of ash input to the system. Subsequently, water temperature fluctuations increased and dissolved oxygen levels decreased at the location (Lang 2002: B4; Haan 2012: 40). Dense algal blooms occurred, forming thick floating mats and blankets on the substrate at the spring. A monotypic, dense stand of common reed (*Phragmites australis*), an invasive grass (Allred 2005: 258), colonized the burned area. This stand of common reed replaced the pre-fire submerged aquatic macrophyte community as the dominant vegetation, perhaps making the location no longer suitable for Noel's amphipod. After these changes in vegetation, temperature, and dissolved oxygen, Noel's amphipod, which requires cool, well-oxygenated water, was absent at many post-fire sample locations (Haan 2012: 22).

Koster's springsnail and Roswell springsnail

Koster's and Roswell springsnails are prosobranch snails, which have internal gills for aquatic respiration. A small amount of oxygen absorption may also occur through the mantle (soft body) surface (Smith 2001: 335, 344). Specific breeding and reproductive characteristics of Koster's springsnail and Roswell springsnail have not been studied. The following discussion is based largely on characteristics known from other species within the genus. Hydrobiid snails are sexually dimorphic (i.e., males and females differ in external appearance) and the male copulatory organ, commonly called a "verge," projects from the vicinity of the neck and cannot be retracted (Smith 2001: 330, 337, 338). Little is known about the specific reproductive habits of Koster's or Roswell springsnails. Both species breed seasonally from March through September (NMDGF 1998: 78). Unlike most hydrobiid snails that lay eggs in adhesive masses, Koster's and Roswell springsnails are ovoviviparous (producing eggs that hatch in the body of a parent, usually the female), with serial production of live young as opposed to broods. Thus, population recruitment is continuous throughout the breeding season. Individuals likely live for less than 1 year (Taylor 1985: 16).

Resource abundance and productivity appear to be important factors in regulating the population size of snails. Increases in population size and increased competition for limited food resources have been associated with reductions in fecundity and juvenile survival for several freshwater taxa (Brown 1991: 295). High incidence of trematode infestation and parasitic castration may regulate reproduction and thus, population size (Taylor 1987: 47).

Substrate preferences may differ for these two springsnails; hard gypsum substrate appears to be preferred by Roswell springsnail at Sago Springs, while Koster's springsnail is found more in association with the soft organic substrates of Bitter Creek. However, Koster's springsnail has been found at Lake Saint Francis (Figure 13), where only gypsum substrate occurs, so presence or lower densities of springsnails could also be due to the lack of consistent springflow, and not substrate. Selection or preference of different substrates is a behavior that is well documented in aquatic snails (Brown 1991: 293), but we are uncertain as to the degree of substrate preference exhibited by Koster's and Roswell springsnails.

Both springsnails in the Sago Springs complex are most active during crepuscular periods perhaps due to the white gypsum substrates characteristic of this site (NMDGF 1998: 26). In the laboratory both springsnails are active throughout the day, but primarily crepuscular (Rogowski and Funhouser 2012: 10).

Freshwater gastropods are chiefly vegetarian, consuming primarily algae, bacteria, and fungi from submerged surfaces. They may also eat dead plant and animal material (Smith 2001: 332). Taylor (1985: 16), studying species of *Tryonia* (including *Juturnia*) other than *kosteri*, found they were "fine-particle feeders on detritus, and presumably on the bacteria and protists in mud and *aufwuchs* [the community of aquatic organisms and detritus coating submerged objects]."

Both species have low within-population mtDNA diversity (Morningstar et al. 2014: 543). Microsatellite markers revealed fine-scale population structure in both species (Holste et al. 2016: 1). Low genetic diversity could be the result of population bottlenecks followed by genetic drift. The occurrence of bottlenecks due to limited gene flow between populations leading to genetic drift is more probable in populations that are isolated from one another by inhospitable habitat (Lesica and Allendorf 1995: 753). Among populations, genetic divergence appeared to be very small; however, there was significant isolation-by-distance in both species (Morningstar et al. 2014: 543), which suggests Roswell springsnail dispersal between sites may be limited (Morningstar et al. 2014: 543). The sharing of one haplotype over all populations by Koster's springsnail suggests some dispersal among populations (Morningstar et al. 2014: 543). While Roswell springsnail has both higher genetic diversity within populations and greater divergence among populations at microsatellite loci (Holste *et al.* 2016, Walters and Berg 2016) than Koster's springsnail, both species do show significant among-population divergence across the refuge (Morningstar *et al.* 2014). Holste *et al.* (2016) estimated genetic effective population sizes (Ne) for both species and found them to be higher for Roswell springsnail.

Pecos assiminea

Specific breeding and reproductive characteristics of Pecos assiminea have not been studied. The following discussion is based largely on characteristics known from other species within the genus.

Pecos assiminea is dioecious (i.e., individual snails are strictly male or female) and fertilization is internal. Eggs are likely deposited in gelatinous masses, as is characteristic of most mesogastropod snails (Barnes 1980: 372). Some gastropods may reach sexual maturity in as little as six months (Barnes 1980: 375); however nothing is known about specific development in

Pecos assiminea. Similarly, nothing is known about the seasonality, frequency of breeding, fecundity, or other aspects of reproduction of Pecos assiminea. Little is known about factors regulating population size of Pecos assiminea. Fluctuating surface water levels and winter freezing of inundated areas appear to limit population size and possibly persistence of the species (NMDGF 2000: A2).

Taylor (1987: 8–9) failed to find Pecos assiminea at two locations in New Mexico: one at the type locality in the Unit 7 spring ditch on BLNWR and another at North Spring on the Roswell Country Club (Figures 5 and 12). Pecos assiminea was subsequently detected at the type locality. Dispersal of the species may rarely occur through downstream transport in stream systems. Lang (NMDGF 1998: 26) reported one live individual in the drift of Sago Springs outflow. However, due to the primarily terrestrial habit of Pecos assiminea and its rarity in aquatic habitat, this mode of dispersal may be limited. Thus, the potential for natural recolonization of suitable habitat following local extinction is not clearly understood, but likely low.

Removal of vegetative cover by burning in habitats of Pecos assiminea has been suggested as an important factor in decline or loss of populations (Taylor 1987: 9). However, Pecos assiminea persisted at Sago Springs despite burning of the habitat in spring 1997 (NMDGF 2000: C3). Pecos assiminea was also discovered at Dragonfly Spring following burning of habitat there during the Sandhill Fire in March 2000. It appears that season of burning, intensity of the fire, vegetation regrowth, and frequency of fire are important determinants of effects on population persistence and abundance (NMDGF 1999: A3). It is likely that Pecos assiminea may survive fire or other vegetation reduction if sufficient litter and ground cover remain to sustain appropriate soil moisture and humidity at a microhabitat scale. Fire can also help maintain and provide additional suitable habitat for Pecos assiminea. Complete combustion of vegetation and litter, high soil temperatures during fire, or extensive vegetation removal resulting in soil and litter drying, may eliminate populations and render habitat unsuitable.

Respiration in Pecos assiminea is by direct air breathing, via trapping of an air bubble in the mantle cavity, and the habitat of the species is amphibious (Taylor 1983: 14; NMDGF 1998: 26). The gills in Pecos assiminea are vestigial (Taylor 1983: 14). Pecos assiminea is probably most active at night (NMDGF 1998: 26).

Mesogastropod snails, which include Pecos assiminea, have a radula, or file-like rasp, situated behind the mouth (Barnes 1980: 348). The radula is used to scrape food from the foraging surface into the mouth. Pecos assiminea likely forage on live and dead vegetation and coarse organic matter, upon which they probably consume bacteria, detritus, fungi, and algae (NMDGF 1988: B-295).

1.6 Abundance and Trends

In 1995 monitoring stations were established at 9 locations: four along Bitter Creek (Dragonfly Spring, Lost River confluence, Bitter Creek flume, downstream of flume) and five in the Sago Springs Complex (NMDGF 1996: 3). At each station, a benthic sample and paired clay tiles were used to sample the invertebrates. A monitoring protocol was developed for the Pecos assiminea (Johnson and Sanchez 2011: entire, Roesler et al. 2015: entire) using quadrats and tiles. Because this species is difficult to detect using visual quadrats (or visual surveys), the placement of wooden tiles, on which Pecos assiminea can be seen, is a more successful survey with respect to finding snails (Roesler 2016). Wooden tiles may be useful in the future to more passively monitor populations of Pecos assiminea; however, they may overestimate density, perhaps limiting their utility to presence-absence sampling only (as discussed in Roesler 2016).

Noel's amphipod

In 2007, amphipods were sampled at four locations, Sago Springs, Bitter Creek, Unit 6 spring ditch, and Hunter Marsh; at all locations but Bitter Creek, the species was detected (NMDGF 2007: 2). In March 2008 amphipods were surveyed at Dragonfly Spring run (Bitter Creek) and Lost River confluence (Bitter Creek); none were found at either location (NMDGF 2008a: 2). In 2009 the amphipod was found in Sago Springs (abundant) while the Bitter Creek location was restricted to the Lost River confluence. In 2010, it was found in the Dragonfly Spring run area of Bitter Creek (NMDGF 2010: 2). The 2011 monitoring effort found the amphipods persisted under drought conditions (NMDGF 2011: 2). Population densities for 2014 and 2015 are found in Table 2.

Table 2. Noel's amphipod population densities reported as number per m^2**, w**ith standard deviations in parentheses, at BLNWR in 2014 and 2015 (based on random sampling; Service 2014: 22; Service 2015a: 34).

Location	Summer 2014	Fall 2014	Winter 2015	Spring 2015	Summer 2015
Bitter Creek	83 (8)	9(1)	120(11)	28(3)	0(0)
Sago Springs	1130 (105)	1630 (15)	1092 (101)	7834 (728)	4223 (392)
Snail Unit	1537 (143)	1667 (155	574 (53)	1519 (141)	685 (64)

Noel's amphipod was discovered at the Rio Hondo in 2006 (NMDGF 2006: 2). In 2014 Rio Hondo population densities ranged from 56 per m^2 (July 2014) to 144 per m^2 (October 2014) before the springs were isolated from the City of Roswell's drainage flow and storm runoff by restoration (Service 2014: 22). Overall Noel's amphipod appears stable at its current locations.

Koster's springsnail

Landye (1981: 10) found no Koster's springsnails at North Spring (Roswell Country Club) in 1967 but in 1973 observed a density of 10,000 per m^2. A return visit in 1980 found a decline in numbers (Landye 1981: 10). Koster's springsnail was still present at North Spring (Roswell Country Club) and Sago Springs run in 1992 (Mehlhop 1992: 4). It was not found on BLNWR in the Unit 3 spring ditch in 1992; no flowing water was found at this site (Mehlhop 1992: 6). In 1993 it was observed at North Spring (Roswell Country Club) and at Sago Springs (8 individuals) (Mehlhop 1993: 6-7).

Koster's springsnail was found in densities ranging from 704 to 89,472 per m^2 (65 to 8,315 per ft^2) in Bitter Creek in 1995 and 1996. At Sago Springs complex, densities ranged from 75 to 512 per m^2 (7 to 48 per ft^2) (NMDGF 1998: 14). It was found at an average abundance of 33,000 per m^2 in 1997-1998 and 68,000 per m^2 in 2000-2003 at Bitter Creek (Haan 2012: 13).

Based on an August 2008 survey Bitter Creek and Sago Spring were occupied, as well as Unit 6 and Unit 7 spring ditches, Lake St. Frances, and Hunter Marsh, and abundant at Bitter Creek and Sago Springs monitoring sites in 2009 (NMDGF 2009: 7-8; NMDGF 2010: 8). The 2011 monitoring effort found Koster's springsnail persisted under drought conditions (NMDGF 2011: 2). Springsnail densities for 2014 and 2015 can be found in Table 3. Overall Koster's springsnail appears stable at its current locations.

Table 3. Springsnail (both Koster's and Roswell) population densities (number per m^2) at BLNWR in 2014 and 2015 (Service 2014: 23; Service 2015a: 34).

Location	Summer 2014	Fall 2014	Winter 2015	Spring 2015	Summer 2015
Bitter Creek	25,537	41,926	31,918	10,398	26,175
Sago Springs	9,537	29,370	15,463	18,518	17,000
Snail Unit	3,815	7,296	3,241	5,167	5,574

Roswell springsnail

Landye (1981: 9) found this snail at North Spring (Roswell Country Club) in 1967, 1971, and 1973. It was found at North Spring (Roswell Country Club), Sago Springs run and Sinkhole 32 in 1992 (Mehlhop 1992:4). In 1993 densities of both springsnails were an estimated 1,390 individuals per m^2 (129 per ft^2) (59 individuals observed) at North Spring (Roswell Country Club) and an estimated 9,560 per m^2 (888 per ft^2) (117 individuals observed) at Sago Springs (Mehlhop 1993: 6-8).

Roswell springsnail occurred at densities ranging from 1,125 to 27,924 per m^2 (104 to 2,595 per ft^2) at Sago Springs and only 64 to 512 per m^2 (6 to 47 per ft^2) at Bitter Creek in 1995 and 1996 (NMDGF 1998: 14). It was found at an average abundance of 27,000 per m^2 (2,508 per ft^2) pre-Sandhill fire (1997-1998) and at 65,000 per m^2 (6,039 per ft^2) post-fire (2000-2003) in Sago Springs (Haan 2012: 13).

During an August 2008 survey, Roswell springsnails were found in Bitter Creek and Sago Spring (NMDGF 2008b: 8). Roswell springsnail was detected in Unit 6 spring ditch and Unit 7 marsh, but not in Unit 7 Spring ditch, and abundant at Bitter Creek and Sago Springs monitoring locations in 2009 (NMDGF 2009b: 7-8; NMDGF 2010: 8). The 2011 monitoring effort found Roswell springsnails persisted under drought conditions (NMDGF 2011: 2). Springsnail densities for 2014 and 2015 can be found in Table 3. Overall, the Roswell springsnail appears stable at its current locations.

Pecos assiminea

Because of their cryptic nature, Pecos assiminea can be hard to find so the lack of observations may be a sampling difficulties (Roesler 2016: 6). Taylor (1987: 8-9) found Pecos assiminea at the type locality (BLNWR Unit 7 spring ditch) in 1981 but it was not detected between 1981 and 1984. It was not found in BLNWR Unit 7 spring ditch in 1992 (Mehlhop 1992: 6). Pecos assiminea was found at Unit 7 spring ditch again in 2014 and 2015 (Johnson 2017b: 1).

Pecos assiminea were found at Bitter Creek and Sago Springs in 1995-1996 (NMDGF 1998: 14). In 1998, the Bitter Creek stream margin (about 1.2 km [0.75 mi]) was surveyed outside of the previously sampled area and only one individual was found (NMDGF 1999: A3). In 1999, no individuals were found during sampling along Bitter Creek, though the species was abundant along the perimeter of a sink hole at the terminus of Sago Springs run (Sinkhole 31). Two live individuals and six recent shells were collected in the Unit 7 spring ditch in 2000; none were found in surveys of the northwest corner of Hunter Marsh (NMDGF 2000: A3). In 2009, Pecos assiminea was still present at Sinkhole 31 (NMDGF 2009: 8). The 2011 monitoring effort found Pecos assiminea densities stable under record drought conditions (NMDGF 2011: 2). From 2013 to 2015 Pecos assiminea was found in quadrats and on tiles at Bitter Creek and Sinkhole 31 (Roesler et al. 2015: 4); no individuals were found in the Rio Hondo system (Service 2014: 23; Service 2015a: 38). Pecos assiminea was found at four of the nine sampling locations in the Snail Unit, and was not detected from the other five locations (Unit 7 and Unit 15 spring ditches and Snail Unit) in 2015 (Service 2015a: 40). In 2016 Pecos assiminea was found in the Sago Springs run and the lower Sago Springs marsh (Johnson 2016: 1). Pecos assiminea occurred at 4 locations (Diamond Y Spring source pool, Monsanto Spring, Euphrasia Spring, and John's Pool) in the Diamond Y Spring in 2000 (NMDGF 2000: A3) and in 2001 (Lang 2002: 5). Overall, the Pecos assiminea status appears stable with new locations within the occupied area being found as sampling methodology is improving.

1.7 Threats

Changes that have occurred in habitat for the four invertebrate species are described in this section, based on available information. Also, an analysis of changes that likely occurred in distribution and abundance of the four invertebrate species is presented. The 2005 listing final rule (Service 2005a: entire) described the threats to the four invertebrate species, categorized by the standard five listing factors. The five listing factors, along with all the identified threats to the species related to each factor, are listed below and remain relevant to each of the species. Not all of the threats are equally significant. All of these issues are discussed in more detail in the following sections.

Listing Factor A. The present or threatened destruction, modification, or curtailment of its habitat or range.

Water Quantity
- Groundwater pumping
- Drought

Water Quality
- Oil and gas development
- Urban development

Train Derailment
Golden algae (not a current threat, only potential)
Nonnative species
Terrestrial plants
Aquatic invertebrates

Listing Factor B. Overutilization for commercial, recreational, scientific, or educational purposes.
This has not been documented as a threat to these species at this time.

Listing Factor C. Disease or predation.
Disease
Infestation of trematodes
Predation
Predation by nonnative fish

Listing Factor D. The inadequacy of existing regulatory mechanisms.
Inadequate protection under Clean Water Act
Inadequate protection under State Law

Listing Factor E. Other natural or manmade factors affecting its continued existence.
Historical BLNWR management
Wildfire (could also have a positive impact if properly implemented)
Localized range, limited mobility, fragmented habitat
Climate change

1.7.1 The present or threatened destruction, modification, or curtailment of its habitat or range.

Water Quantity

Groundwater pumping

Groundwater pumping in the Roswell Basin, New Mexico, and in Pecos and Reeves Counties, Texas, has led to the drying of the major springs associated with the historical regional spring system, many of which are known to have harbored one or more of the four invertebrate species. It is not possible to determine the extent of the loss of invertebrate populations because many springs went dry long before these species were described or surveys could be conducted. In addition, loss cannot be measured simply by the number of artesian springs that are now not flowing. Many of these springs were large enough to form rivers that flowed for several miles, and creeks such as Bitter Creek, BLNWR, while still flowing, are much reduced in flow and length. Most likely there was suitable habitat available for the invertebrates throughout the length of the spring-fed streams.

The source-water area for springs in the BLNWR Middle Tract was determined by Balleau Groundwater, Inc. (1999: Figure 11), is also referred to as the Rio Hondo area. It encompasses

10,711 ha (26,467 acres) west and north of BLNWR (Figure 14). The land ownership of the source-water area is described in Table 4.

Table 4. Land ownership in the BLNWR Middle Tract source-water area.

Owner	Hectares	Acres	Percentage
BLM	1,558	3,851	14.6
Service	1,125	2,779	10.5
State	6,641	16,411	62.0
Private	1,386	3,426	12.9
TOTAL	10,711	26,467	100

<u>Roswell Artesian Basin</u> - Groundwater pumping in the Roswell Artesian Basin increased through the 1950s when approximately 450,000 acre feet/year were extracted (McCord et al. 2005: 22). Rates remained fairly stable through 1966 (McCord et al. 2005: 22). In 1967, water rights were adjudicated in the Roswell Basin, wells were metered, and pumping rates administered by the New Mexico Office of the State Engineer (NMOSE). Groundwater depletion continued until the mid-1970s when it reached its maximum (McCord et al. 2005: 6). Increasing groundwater levels since about 1975 have not restored any lost springs in the Roswell area (Balleau Groundwater, Inc. 1996: 5). Currently, any proposed change in use of water (underground or surface depletion) in the Roswell Basin undergoes analysis by NMOSE to determine if there would be impairment to existing water rights (NMOSE 2005: 14). Additionally, federally reserved water rights for the spring system at BLNWR were finalized with the State in 2008 and provide protection for spring flow at BLNWR within the limits of priority administration.

<u>Berrendo Creek, North Spring, South Spring, Lander Springbrook</u> - In the late 1800s prior to artesian well drilling, flow at North Spring, South Spring, and Berrendo Creek was 2.4 m^3/s (85 cfs), 1.7 m^3/s (60 cfs), and 1.9 m^3/s (66 cfs), respectively (Fiedler and Nye 1933: 251). These systems each provided abundant habitat for the four invertebrate species. Lander Springbrook, a tributary spring to South Spring, harbored Noel's amphipod (Noel 1954: 124). The historical connection of these spring systems to the Pecos River most likely facilitated dispersal of invertebrates throughout the basin downstream of this area.

In the 1880s, irrigated agriculture in the Roswell Artesian Basin was limited to a few small farms (Fielder and Nye 1933: 189). By the end of 1905, 485 artesian wells had been drilled; by 1927, 1,424 wells were pumping water (Fiedler and Nye 1933:191-192). As a result of extensive groundwater pumping, the artesian head in the basin declined (Fiedler and Nye 1933: 193). The amount of decline depended on location within the basin and ranged from 10 to 62 m (32 to 204 ft) from original levels by 1927, and led to a decrease in area within the basin that had artesian flow (Fiedler and Nye 1933: 201).

Berrendo Springs was down to 12 percent of its original flow in 1926 (Balleau Groundwater, Inc. 1996: 13). By 1926, South Spring was dry (Balleau Groundwater, Inc. 1996: 13). Lander

Springbrook went dry in the late 1950s or early 1960s (Cole 1981: 27), extirpating the population of Noel's amphipod, which in the early 1950s had been described by Noel (1954: 124) as the most abundant animal in the spring. Discharge patterns at North Spring are unclear. Balleau Groundwater, Inc. (1996: 13) list North Spring's flow as zero in 1926, but Cole (1981) described three small separate brooks that entered a pond on a private golf course in 1967. Invertebrate surveys in 1995 found flows sufficient to support springsnails (Lang 2005a: 33). In 2004 North Spring was still flowing but was substantially modified (Lang 2005a: 33).

Salt Creek, Bitter Creek, Middle Tract Springs - Surface flow at BLNWR was also diminished by artesian pumping. Springs adjacent to Salt Creek no longer flow and surface flow from the BLNWR Middle Tract (at South Weir) was 0.4 m^3/s (15 cfs) in 1937 and 0.14 m^3/s (5 cfs) in 1995 (Balleau Groundwater, Inc. 1996: Addendum 1: 1-2). Modern aerial photos of Bitter Creek show the meanders of the historic spring system. The meandering channel is evidence of much higher flows than the modern system, which does not have the energy to meander within the alluvium.

Diamond Y Spring - The primary threat to Pecos assiminea in Texas is the potential failure of spring flow due to excessive groundwater pumping or drought, which would result in total habitat loss for the species. Pumping of the regional aquifer system for agricultural production of crops has resulted in the drying of most other springs in this region (Brune 1981: 38). There have been no continuous records of spring flow discharge at Diamond Y Spring by which to determine any trends in spring flow. Sharp et al. (2003: 8) believed the spring flow at Diamond Y Spring may come from the Rustler aquifers located west of the spring outlets. One significant factor that influences flows at the spring is the large groundwater withdrawals for agricultural irrigation of farms to the southwest in the Belding-Fort Stockton areas. Although The Nature Conservancy (TNC) of Texas owns and manages the property surrounding the Diamond Y Spring system, it has no control over groundwater use that affects spring flow (Kargas 2003: 143).

San Solomon-Balmorhea Spring Complex - Sandia Springs are at the base of the Davis Mountains just east of Balmorhea, Texas, and are part of the San Solomon-Balmorhea Spring Complex, the largest remaining desert spring system in Texas (Sharp et al. 2003: 60-61). Source waters are in the Delaware and Apache Mountains to the west (Texas Water Development Board (TWDB) 2005: 105). The Sandia Springs are part of the 97-hectare (ha) (240-acre) Sandia Springs Preserve owned and managed by TNC (Karges 2003: 145). Sandia Springs have the lowest discharge rate of the major springs in the Complex (Schuster 1997: 80). Sandia Spring flows from clays overlaying the alluvium and provide water primarily for ranching (Schuster 1997: 92). Measured discharges ranged from 0.013 to 0.11 m^3/s (0.45 to 4.07 cfs) in 1995 and 1996 (Schuster 1997: 94). West Sandia Springs has ceased to flow (TWDB 2005: 9). Water chemistry at East Sandia Spring indicates it is not directly hydrologically connected with the other springs in the San Solomon Spring Complex in the nearby area (Schuster 1997: 92-93). The average temperature ranged from 19.3 to 22.3 °C, pH levels from 7.0 to 7.8 and conductivity from 4000 to 4880 µS at East Sandia Springs (TWDB 2005: 38-40). In 2005, East Sandia Spring discharge was determined to be stable (TWDB 2005: 107)

Drought

A drought in the 1950s likely affected the recharge of the groundwater in the Roswell Basin, New Mexico. Despite controls on pumping initiated in 1968 and increased precipitation near Roswell in the 1960s and 1970s, artesian groundwater levels continued to decline until 1975 (McCord et al. 2005: 6). There has been extreme to exceptional drought in the area in 2000, 2002, 2004, 2006, 2008, and an extended period from 2011 to 2014 (National Drought Mitigation Center 2016: 1). Groundwater pumping is currently much less than it was during the drought of the 1950s and by 2005, artesian groundwater levels had recovered to the levels they were in 1950s (McCord et al. 2005: 20, 22). Consequently, we expect that the aquifer has the capacity to rebound from drought.

The length or severity of the current drought cycle is not known, and the Southwest may be entering a period of prolonged drought (McCabe et al. 2004: 4140). More severe droughts have occurred over the past 2000 years and we can expect these to occur in the future (Woodhouse and Overpeck 1998: 2709; Piechota et al. 2004: 308). Certainly, without groundwater pumping or with pumping at reduced volume, there would be a greater margin of safety for the springs.

As part of the current, worldwide collaboration in climate modelling under the IPCC, climate assessments of the full dataset of 30 climate models for historical and 21st century comparisons provide predictions at scales ranging from global to county level in the U.S. (USGS National Climate Change Viewer 2015; *http://www.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp*). This global climate information has been recently downscaled by NASA to scales relevant to our region of interest, and projected into the future under two different scenarios of possible emissions of greenhouse gases (Alder and Hostetler 2014: 2). From this dataset, precipitation and evaporative deficit (water lost to evaporative processes) were analyzed across the ranges of the four invertebrate species.

These analyses of precipitation and evaporative deficit predict that the ranges of the four invertebrates will experience a decrease in available water. At the county level, precipitation changes are expected to decrease by approximately 11 % ((Butler, and Tashjian 2016). Model means in Chaves County, NM, in which most of the four invertebrates reside, indicate a slight loss in precipitation. In Reeves and Pecos Counties, Texas, each of which hosts one population of Pecos assiminea, no change was predicted in the amount of precipitation. However, predicted increase in the annual mean evaporative deficit will lead to drier overall conditions in both situations. This indicates that even with constant precipitation or only slight decreases in these counties, the increase in evaporative deficit is expected to reduce the amount of available water.

Drought and decreases in available water could affect the springs through decreased flow. The springs do not have to dry out completely to have an adverse effect on the biota. Drought impacts both surface and groundwater resources and can lead to diminished water quality and disturbed riparian habitats (Woodhouse and Overpeck 1998: 2693). During the record drought of 2011 water levels at many springhead vents were very low and the uppermost part of Unit 7 spring ditch had dried up (NMDGF 2011: 2). Decreased flow could lead to a decrease in habitat availability and connectivity, increased water temperatures, lower dissolved oxygen levels, and an increase in salinity. Any of these factors, alone or in combination, could lead either to the reduction or extirpation of a population.

Table 5. Annual mean precipitation and evaporative deficit changes across the range of the four invertebrates based off of USGS National Climate Change Viewer models.

County	Analysis	1950-2005	2025-2049	2050-2074	2075-2099	Total Change
Chaves	Precipitation (in/day x100)	3.5	3.5	3.5	3.1	-0.4
	Evaporative Deficit (in/month)	1.6	2	2.4	2.8	1.2
Reeves	Precipitation (in/day x100)	2.8	2.8	2.8	2.8	0
	Evaporative Deficit (in/month)	2.4	2.8	3.2	3.7	1.3
Pecos	Precipitation (in/day x100)	3.5	3.5	3.5	3.5	0
	Evaporative Deficit (in/month)	2.1	2.6	3	3.4	1.3

Water Quality

Groundwater Contamination

The four invertebrate species depend upon clean water for their survival. Therefore, water contamination (either groundwater or surface water) is a serious threat. The sources and magnitudes of potential contaminants have been previously detailed (NMDGF 2005: 18; Service 2005a: 46,314; Service 2010a: 8). Here we describe changes in conditions since 2005.

The Roswell Basin is characterized by karst topography. Groundwater flow in karst aquifers is significantly different from that of other aquifers because the large conduits are formed by the dissolution of carbonate rocks. In typical aquifers, groundwater moves slowly as laminar flow (on the order of 10 to 100 feet per year), but in karst aquifers groundwater flows are considerably faster (on the order of 100 to 1000 feet per year). Because of the potential for rapid transfer of water, karst areas are extremely vulnerable to groundwater contamination.

The groundwater source area for the BLNWR Middle Tract lies in karst formations north and west of the area and was delineated by Balleau Groundwater, Inc. (1999: Figure 14). Karst formations are known for rapid water transport and associated contaminants (Eberts et al. 2013: 69). Recent evaluations of groundwater residence time suggest that at least a portion of the water is recharged within the last 10 to 50 years (Land and Huff 2010: 455). Short residence time of water in the aquifer does not allow for remediation of contaminants through biodegradation or sorption (National Research Council 2000: 79).

Oil and Gas Development

The Roswell Basin is within the western border of the Permian Basin, one of the major oil and gas regions in the United States (U.S. Energy Information Administration 2015: 6). Based on the intentions to drill applications in Chavez County, the rate of drilling has dropped off in the last 10 years (GoTech 2016: web site query). No new wells have been permitted in the BLM Habitat Protection Zone (HPZ) (see description in Management Plans section below) (Figure 14).

Drilling and associated actions (e.g., pipelines, storage facilities, surface pits) can threaten surface and groundwater quality. For example, oil and other contaminants from drilling activities throughout the basin could enter the aquifer supplying the springs when the limestone layers are pierced by drilling activities. Dye tracer studies were used to determine if drilling fluids might be contaminating nearby water wells (Goodbar 2009a: 1,510). Contamination was found, leading BLM to institute more stringent drilling regulations on Federal land wells in karst area (Goodbar 2009b: 1,098). These enhanced drilling measures are not required on State and private lands.

Currently there are 84 active wells within the BLNWR Middle Tract source water area (New Mexico Oil Conservation Division 2016: web site query) that are potential sources of contamination. Twenty natural gas wells are currently active within the BLM HPZ, which encompasses 5,093 ha (12,585 acres) of Federal mineral estate within the BLNWR source water area; no new wells have been permitted since 2010. There were 728 (355 on Federal, 240 on State, and 133 on Private lands) "intentions to drill" (pursuit of required permits has been initiated by an applicant) filed for oil or natural gas on Federal lands in Chavez County, from 2004 through 2015 (GoTech 2016: entire).

Petroleum-product contamination of groundwater from underground leaks in well casings may occur in the future, but existing drilling and casing regulations by the Oil Conservation Division and requirements of the BLM for oil and gas drilling and operation in cave and karst areas (BLM 1997: Appendix 3) are likely to substantially reduce this probability. However, even when oil and gas operations have employed regulatory standards, groundwater contamination occurs (New Mexico Water Quality Control Commission 2002: 90). To remediate (clean) the aquifer is extremely expensive should it become contaminated. In most cases contamination of an underground aquifer is treated at the source. Rarely do remediation efforts pump water from the aquifer and treat it before sending it back. This is largely because these techniques are very costly and difficult to apply. Ground and surface water contamination can adversely impact aquatic mollusks and amphipods (Eisler 1987: 24; Shales et al. 1989: 137). Because the invertebrates are sensitive to contaminants, efforts to clean up pollution source sites after the aquifer has been contaminated may not be sufficient to protect the species and the aquatic habitat on which they depend.

Operations associated with oil and gas drilling such as exploration, storage, transfer, and refining are potential threats to the four invertebrates and their habitat (Brittingham et al. 2014: 11,306; Burton et al. 2014: 1,681). Such extractive processes and industry operations are known to contaminate ground and surface waters (Richard 1988: 14; Richard and Boehm 1989: 6; Goodbar 2009a: 1,509). Moreover, large volumes of water are produced concurrently with oil and gas extraction, especially in southeastern New Mexico (Boyer 1986: 297; Guerra et al. 2011: 1). About 1,060 to 1,514 liters (280 to 400 gallons) of water are produced for every barrel of crude oil (Guerra et al. 2011: 5). This water may be injected into the ground in some areas to recover more oil, but can also be disposed of in permitted surface pits (Boyer 1986: 309). Most produced water is reinjected into the ground for disposal (Boyer 1986: 289). This is the industry preferred alternative for disposal (Guerra et al. 2011: 7).

Oil and gas activities also threaten the Pecos assiminea in Texas because of the potential groundwater or surface water contamination from pollutants (Veni 1991: 1). The Diamond Y Spring system is within an active oil and gas extraction field. At this time there are still many active wells and pipelines located within a hundred meters of surface waters. In addition a natural gas refinery is located within 0.8 km (0.5 mi) upstream of Diamond Y Spring. There are also old brine pits associated with previous drilling within feet of surface waters. Oil and gas pipelines cross the spring outflow channels and marshes where the species occurs, creating a constant potential for contamination from pollutants from leaks or spills. These activities pose a threat to the habitat of the Pecos assiminea by creating the potential for pollutants to enter underground aquifers that contribute to spring flow or by point sources from spills and leaks of petroleum products on the surface.

There was a crude oil spill (approximately 10,600 barrels) from a pipeline that traverses Leon Creek above its confluence with Diamond Y Draw in 1992. Remediation initially involved aboveground land farming of contaminated soil and rock strata to allow microbial degradation. To date, no impacts on the rare fauna of Diamond Y Spring have been observed, but no specific monitoring of the effects of the spill was undertaken (Service 2005a: 46,315).

<u>Other Contamination Sources</u>

Trichloroethylene and perchloroethylene contamination is known occur around the BLNWR dating back to the 1960s (Aragon v. United States 1998: 2; EPA 2016a: 1; EPA 2016b: 1). Although there is no indication that these contaminants have entered water sources of springs occupied by the four invertebrate species, these examples demonstrate that groundwater contamination can easily occur and have long-lasting effects.

Urban development

Recent (last 15 years) population growth in the Roswell area is around the State average (New Mexico Department of Workforce Solutions 2011: 5; 2015: 8). Urban development on the west side of BLNWR poses a risk to ground and surface water quality from sewage contamination (i.e., septic system discharge). The largest source of groundwater contamination in New Mexico is from household septic systems (New Mexico Water Quality Control Commission 2014: x). Common pollutants associated with septic tank contamination include total dissolved solids, iron, manganese, sulfides, nitrate, organic chemicals, and microbiological contaminants such as bacteria, viruses, and parasites (NM Water Quality Control Commission 2002: 85). Groundwater contamination from septic systems has not been documented near BLNWR; however, west of BLNWR, unregulated dumping of domestic refuse in sinkholes has been documented. The extent of groundwater contamination generated from septic systems and illegal dumping near the BLNWR is unknown.

Train Derailment and Spill

A train right-of-way crosses the Bitter Creek watershed on BLM land, which is a groundwater source area for the springs on BLNWR. A train derailment and spill of hazardous materials could potentially contaminate Bitter Creek or other drainages. Depending on the toxicity and amount of material spilled, invertebrates in Bitter Creek could be impacted.

Golden alga

Golden alga (*Prymnesium parvum*) occurs in brackish waters and under certain environmental conditions produces toxins that cause massive fish kills. The toxin is toxic to gill breathing fish, mollusks, arthropods, and to the gill-breathing stage of amphibians (Paster 1973: 261). The toxin targets the permeability of the gill (Yariv and Hestrin 1961: 165). Golden alga has caused fish kills in Texas and New Mexico in the Pecos River and isolated water bodies in the basin (Watson 2001: 5; Denny 2011: 10-11). Over the last few years it has spread upstream, with the most upstream kill being documented at Spring River Park in Roswell (Denny 2011: 10). In 2010 several sinkholes and outlets to three impoundment units on BLNWR were sampled for golden algae; none were found (Denny 2016: 1). Golden alga blooms occur most often under saline conditions in lentic (still, non-moving) waters (Watson 2001: 7; Denny 2011: 13). A vegetated edge to the water body appears to limit the risk of a bloom (Denny 2016: 1). Based on these conditions, sinkholes are the most at risk habitat inhabited by the four invertebrates.

We found no published reports of mortality in freshwater snails or amphipods from golden alga, but because some of the water where the invertebrates occur is brackish, there is concern that the three invertebrates which are gill breathers (Koster's springsnail, Roswell springsnail, and Noel's amphipod) could be killed if there was a golden algae bloom in habitat they occupy. Because Pecos assiminea does not depend on gills for respiration and is not always immersed in water it is unlikely that it would be affected by a bloom. The current risk of golden alga occurring in these habitats is considered to be low. However, projected increases in evaporative deficits (Table 5) due to climate change could result in higher saline conditions increasing the potential for Golden algae blooms in the future.

A risk assessment and monitoring plan should be developed for the complete range of contaminant threats to track if and when these contaminant sources show up at BLNWR.

Nonnative species

Introduced species are one of the primary threats contributing to extinctions (Pimentel et al. 2000: 53), and are one of the most serious threats to native aquatic species (Williams et al. 1989: 3; Lodge et al. 2000: 8; Lydeard et al. 2004: 324), especially in the Southwest (Miller et al. 1989 34; Minckley and Douglas 1991: 17). It is estimated that approximately 50,000 non-native species have been introduced into the United States (Pimentel et al. 2000: 53). Although a few of these introductions have been beneficial, many have caused dramatic declines in populations of native plants and animals (Pimentel et al. 2000: 58). Because the distribution of the four invertebrate species is so limited, and their habitat so restricted, introduction of a nonnative species into their habitat could be devastating. Several nonnative species have been very successful in invading spring ecosystems in the Southwest. For that reason we discuss several invasive terrestrial plants and aquatic animal species that are present in the invertebrates' habitat or are not yet present but have caused problems in other similar habitats in the Southwest and would pose a threat to the four invertebrate species if they were introduced.

Terrestrial plants

Several invasive terrestrial plant species that may affect the invertebrates occur on BLNWR, including saltcedar (*Tamarix* spp.), common reed (*Phragmites australis*), kochia (*Kochia scoparia*), and Russian thistle (tumbleweeds) (*Salsola* spp.). These plants present unique challenges and threats to the habitat occupied by the four invertebrate species.

Saltcedar **-** Saltcedar is seen as a threat to the spring habitats primarily through the amount of water it consumes and from the chemical composition of the leaves it drops on the ground and into the springs. Overall, they appear to have a negligible impact on water resources in the river at this time (McDonald et al. 2015: 5,117). Invertebrates in small spring ecosystems depend on food from two sources: that which grows in or on the substrate (aquatic plants, algae, and periphyton) and that which falls or is blown into the system (primarily leaves). Leaves from nonnative plants that fall into the water are often less suitable food sources for invertebrates, due to their resins or physical structure (Bailey et al. 2001: 446). Saltcedar leaves add salt to the soil through its leaf litter (the leaves contain salt glands) (DiTomaso 1998: 334). Because saltcedar grows along the edge of water courses, it is possible that this could affect the soil chemistry of areas inhabited by Pecos assiminea. However, no research has been conducted specifically on the effect of saltcedar on Pecos assiminea. Eradication of saltcedar is an ongoing management effort at BLNWR. The species is removed mechanically by hand (young sprouts), with heavy equipment, by cutting and burning, and spraying with herbicides. In addition, salt cedar leaf beetle (*Diorhabda carinulata:* Chrysomelidae) has been reported at BLNWR (Tamarisk Coalition 2014: Map).

Common reed - Common reed distribution at BLNWR has been increasing over the last few years; it increased significantly in Bitter Creek after the Sandhill fire in 2000 (Lang 2005a: 18). Both the native strain and nonnative strains of common reed occur on BLNWR (Sanchez 2015: 1). Both strains are considered invasive. Common reed grows in dense patches and reproduces primarily through an underwater rhizome (an elongated, horizontal stem). Dense stands of the plant choke the channel, slowing water velocity and creating more pool-like habitat. Pool-like habitat is less suitable for the Roswell and Koster's springsnails, which prefer lotic (flowing) water. In addition, the dense stands of the plant can completely shade the water, inhibiting algal growth, one of the food items for the springsnails. The dense roots and stems also inhibit sampling, making it more difficult to track population trends. Refuge staff is currently treating and removing common reed from Bitter Creek following the infestation post-Sandhill fire (Roesler et al. 2015: 11).

Tumbleweed - Russian thistle (tumbleweed) is another introduced plant species that can create problems within the spring ecosystem. Russian thistle is not a riparian species like saltcedar and common reed; however, it often ends up in the springs because wind blows the tumbleweeds into the spring channels. Noel (1954: 124) noted that she had to pull Russian thistle out of Lander Springbrook so that she could take samples. In 2005, BLNWR conducted an emergency section 7 consultation for the removal of tumbleweeds from the Area 6 spring ditch (Service 2005b: entire). Wind had blown the tumbleweeds into the channel to a depth of 0.9 to 1.2 m (3-4 ft), completely shading the water and overloading the small channel with organic material. While some amount of organic material from outside the spring ecosystem is necessary, it is not desirable to overload the system with so much organic material that it cannot be processed by decomposers. In such situations, dissolved oxygen can drop to dangerously low levels as the material decomposes. Primary productivity (growth of algae and native aquatic plants) would be greatly reduced or prevented because of shading. Control of introduced terrestrial plant species is an ongoing management activity at BLNWR that will have to be conducted carefully to have the least impact on the four invertebrate species and their habitat (Service 1998: 5).

Kochia – Kochia is another highly invasive annual broadleaf weed that can dominate ground cover in an area (Casey 2009: 1) and has an allelopathic (chemical inhibition of one species by another) effect on grasses (Karachi and Pieper 1987: 380). Once dried it also can be blown into water ways and clog the spring systems (Sanchez 2015: 8).

Aquatic invertebrates

Nonnative mollusks have affected the distribution and abundance of native mollusks in the United States. Of particular concern for three of the invertebrates (Noel's amphipod, Roswell springsnail, and Koster's springsnail) are *Melanoides tuberculata* (red-rim melania) and *Potamopyrgus antipodarum* (New Zealand mudsnail). Both of these snails are excellent colonizers, reach tremendous population sizes, and have been found in isolated springs in the West (Richards et al. 2001: 375; Ladd and Rogowski 2012: 287).

Red-rim melania - *Melanoides* has become established in isolated desert spring ecosystems in Utah, Nevada, Texas, and Mexico, including Diamond Y Spring (Contreras-Arquieta 1998: 283; McDermott 2000: 15; Rader et al. 2003: 648; Ladd and Rogowski 2012: 287). It has caused the decline and local extirpation of native snail species and it is considered a threat to endemic aquatic snails that occupy springs and streams in Utah (Rader et al. 2003: 648). It is easily transported on gear or aquatic plants, and because it reproduces asexually (individuals can develop from unfertilized eggs), a single individual is capable of founding a new population. Introduction into remote springs in Texas has been attributed to the transport of scientific equipment that was not adequately disinfected (Karatayev et al. 2009: 188). It has become the most abundant snail in the upper watercourse of the Diamond Y Spring system (Echelle 2001: 26). *Melanoides* has been implicated in the decline of native spring snails in Nevada (Williams et al. 1985: 36); however, because it is aquatic it probably has less effect on Pecos assiminea than on the other endemic aquatic snails present in the spring.

New Zealand mudsnail - *Potamopyrgus* is also a potential threat to the endemic aquatic snails at BLNWR. It was discovered in the Snake River, Idaho, in the mid-1980s and has quickly spread to every Western state except New Mexico and Texas (Benson et al. 2016: 1). Like *Melanoides*, *Potamopyrgus* has an operculum (a lid to close off the shell opening), can withstand periods of drying up to 8 days (thereby facilitating transport) and can reproduce either sexually or asexually (Alonso and Castro-Diez 2008: 108). Thus, new populations can be established with transport of a single individual. In addition, *Potamopyrgus* is tiny [3 mm (0.12 in] in height), is easily overlooked on gear or shoes, and can be transported unknowingly by people visiting various recreational sites. Considering its current rate of expansion, and the availability of suitable habitat, it is highly likely that *Potamopyrgus* will soon be discovered in New Mexico.

Potamopyrgus tolerates a wide range of conditions including brackish water. Densities are usually highest in systems with high primary productivity, constant temperatures, and constant flow (typical of spring systems) (Alonso and Castro-Diez 2008: 108). It has reached densities exceeding 500,000 per m^2 (46,000 per ft^2) (Richards et al. 2001: 375), to the detriment of native invertebrates. Not only can it dominate the invertebrate assemblage (97 percent of invertebrate biomass) it can also eat nearly all of the algae and diatoms growing on the substrate, altering ecosystem function at the base of the food web (food is no longer available for native animals) (Hall et al. 2003: 407). If *Potamopyrgus* becomes introduced into the spring systems harboring the four invertebrate species, control would most likely be impossible because the snails are so small and because any chemical treatment would also affect the native species. The impact could be devastating.

Fishes

In many areas of the West, nonnative fishes have detrimental effects on native faunas (Cucherousset and Olden 2011; entire). Of the numerous nonnative fish in the Pecos River Basin, the Common Carp (*Cyprinus carpio*) (carp) can be singled out as the most troublesome to the four invertebrates. Introduced in the latter part of the 19th century, it is now found in all 50 states (Nico et al. 2016: 2). It is an omnivore but does most of its damage by disturbing the substrate and water column (Nico et al. 2016: 3). It uproots aquatic plants, increases turbidity of the water, and consumes any invertebrates on the plants (Miller and Crowl 2006: 90-91); all of these effects are detrimental to the four invertebrates. Historically, carp have been found in Bitter Creek, and are currently found in spring ditches along the impoundment units, as well as the Rio Hondo. Davenport (2016: 1) reports high numbers of carp in the spring ditches along Units 6, 7, and 15 occupied by the four invertebrates. Removal of carp from the spring ditches and the Rio Hondo would be advantageous to the four invertebrates but would be hard to maintain given the reintroduction potential from the Pecos River.
There are no nonnative fish reported from sinkhole habitats occupied by the four invertebrates (Watts and Kodric-Brown 2004: 17; Swaim and Boeing 2008: 23).

1.7.2 Overutilization for commercial, recreational, scientific, or educational purposes.

Roswell springsnail, Koster's springsnail, Pecos assiminea, and Noel's amphipod may occasionally be collected as specimens for scientific study, but these uses probably have a negligible effect on total population numbers. These species are currently not known to be of commercial value, and overutilization has not been documented. However, as their rarity becomes known, they may become more attractive to collectors. Although scientific collecting is not presently identified as a threat, unregulated collecting by private and institutional collectors could pose a threat to these locally restricted populations. We are aware of unregulated overcollection being a potential threat with other snails (e.g., armored snail (*Pyrgulopsis* (*Marstonia) pachyta*) (65 FR 10033); Bruneau hot springsnail (*P. bruneauensis*) (58 FR 5938); and Socorro springsnail *(P. neomexicana*) and Alamosa springsnail (*Tryonia* *alamosae*) (56 FR 49646)), due to their rarity, restricted distribution, and generally well known locations. Due to the small number of localities for the snails and the amphipod, these species are vulnerable to unrestricted collection, vandalism, or other disturbance. There is no documentation of collection as a significant threat to any of the species. Therefore, we believe that collection of the animals has a low likelihood of occurring, and at this time is not considered a significant threat.

1.7.3 Disease or predation.

Disease

Trematodes - Infestation by trematodes (a flatworm or fluke, phylum Platyhelminthes) was noted by Taylor (1987: 47) in populations of Koster's springsnail at Sago Springs, BLNWR. Digenetic trematodes (trematodes in the order Digenera) are parasitic and have the most complicated life histories in the animal kingdom, involving two to four intermediate (vertebrate and/or invertebrate) hosts (Hickman et al. 1974: 209). The first larval stage of the trematode nearly always uses a mollusk (snail or bivalve) as the first intermediate host (Hickman et al. 1974: 210). Larval trematode parasites reduce or completely inhibit snail reproduction through castration (Minchella et al. 1985: 851). The effect of the trematodes on the springsnail population is not known.

Predation

Springsnails and amphipods are a food source for other aquatic animals. Juvenile springsnails appear vulnerable to a variety of predators. Damselflies (Zygoptera) and dragonflies (Anisoptera) were observed feeding upon snails in the wild (Mladenka 1992: 81-82). Damselflies and dragonflies are native to and abundant at BLNWR and most likely prey upon both the springsnails and Noel's amphipod. Predation on the invertebrates from animals they have evolved with is not seen as a threat.

Land snails - The terrestrial land snail (*Rumina decollata,* also known as the dellocate snail) was introduced from Europe to the United States in the early 1800s and it spread westward (Selander and Kaufman 1973: 1,186). It has not been previously reported from New Mexico but was recently found in the Roswell area along the Rio Hondo (Lang 2005b: 1). The predatory snail inhabits gardens and agricultural areas but has also invaded riparian and other native habitats (Selander and Kaufman 1973: 1,186). It is used in California as a biological control agent against the exotic brown garden snail (*Helix aspera*) (Cowie 2001: 27). It will consume native snails (Cowie 2001: 23). For this reason, *Rumina* is a potential threat to Pecos assiminea.

Crayfish - Nonnative aquatic species, such as crayfish, are also a potential threat to the four invertebrate species. There are only two native species of crayfish in New Mexico, but their distributions currently do not overlap with those of the four invertebrate species (Taylor et al. 1996: 30, 32). Crayfish are typically opportunistic generalists (they will eat anything and everything) (Hobbs 1991: 840). Predation on snails is well-documented (Lodge et al. 1994: 1,265; Dorn 2013: 1,298). However, because they also feed on organic debris and vegetation and reduce algal biomass (Lodge et al. 1994: 1265), they could potentially compete with Roswell springsnail, Koster's springsnail, and Noel's amphipod for food resources. Although nonnative crayfish are not present at BLNWR, crayfish have created major problems in aquatic systems in Arizona (Hyatt 2004: 71), and there is no physiological reason why some species of crayfish could not survive in the habitats that now support the four invertebrate species. Eradication of crayfish once they are established is extremely difficult (Hyatt 2004: 64).

Fishes - Springsnails and amphipods are vulnerable to predation by fishes. The extent to which predation from fishes affects population size of the three aquatic invertebrates is not known. The native Comanche Springs pupfish (*Cyprinodon elegans*) is known to feed on springsnails and amphipods (Kennedy 1977: 100; Winemiller and Anderson 1997: 209), while the co-occurring native *Cyprinodon pecosensis* does not appear to feed on either snails or amphipods (Davis 1981: 535). Mladenka (1992: 81) observed guppies (*Poecilia reticulata*) feeding on springsnails in the laboratory. The Common Carp could ingest some of the invertebrates based on their feeding mode (see section on Nonnative Species – Fishes for further discussion). Mosquitofish (*Gambusia affinis*) is also present in some of the spring systems. This fish is native to portions of New Mexico but has also been widely introduced to control mosquitoes (Sublette et al. 1990: 271). It has negatively impacted or extirpated many species of fishes and invertebrates (e.g., through predation) (Meffe and Carroll 1994: 223). The extent to which mosquitofish are affecting the three species of aquatic invertebrates is unknown.

1.7.4 The inadequacy of existing regulatory mechanisms.

Primary causes of decline of the Roswell springsnail, Koster's springsnail, Pecos assiminea, and Noel's amphipod are the loss, degradation, and fragmentation of wetland habitat due to human activities. Federal and State laws have been insufficient to prevent past and ongoing losses of the limited habitat of the four invertebrate species, and are unlikely to prevent further declines of the species.

Federal

Clean Water Act

Pursuant to section 404 of the Clean Water Act (CWA) (33 USC 1344), the U.S. Army Corps of Engineers (USACE) regulates the discharge of dredged or fill material into all waters of the United States, including wetlands. In general, the term ''wetland'' refers to areas meeting the USACE criteria of having hydric soils, hydrology (either a defined minimum duration of continuous inundation or saturation of soil during the growing season), and a plant community that is predominantly hydrophytic vegetation (plants specifically adapted for growing in a wetland environment).

Any discharge of dredged or fill material into waters of the United States, including wetlands, requires a permit from the USACE. These include individual permits which would be issued following a review of an individual application, and general permits that authorize a category or categories of activities in a specific geographical location or nationwide (33 CFR parts 320–330). General and special permit conditions may vary among individual USACE Districts and the various general permits. However, the use of any individual or general permit requires compliance with the ESA.

While the CWA provides a means for the USACE to regulate the discharge of dredged or fill material into waters and wetlands of the United States, it does not provide complete protection. Many applicants are required to provide compensation for wetlands losses (i.e., no net loss) and many smaller impact projects remain largely unmitigated unless specifically required by other environmental laws such as the ESA. Moreover, we are not aware of any USACE permits that have been issued for the spring complexes where these species occur or historically occurred, indicating that there is little protection provided to these species through the CWA.

Recent court cases limit the USACE's ability to utilize the CWA to regulate the discharge of fill or dredged material into the aquatic environment within the current range of the four invertebrate species (Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers, 531 US 159 (2001). For these reasons, we conclude that regulation of wetlands filling by the USACE under Section 404 of the CWA is inadequate to protect the four invertebrate species from further decline.

Management Plans

Revisions made to the BLM Roswell Approved Resource Management Plan prompted a formal section 7 consultation with the Service regarding the endangered Pecos gambusia (*Gambusia nobilis*), which resides on BLNWR. The BLM designated a habitat protection zone (HPZ) for Pecos gambusia to protect from potential groundwater contamination by oil and gas well drilling operations (BLM 2002: entire) (Figure 14). The HPZ includes a portion of the source water area for the springs in the northern part of the BLNWR Middle Tract, where Pecos gambusia co-occurs with the four invertebrate species. The HPZ includes 5,093 ha (12,585 acres) of the Federal mineral estate and 4,025 ha (9,945 acres) of the Federal surface estate that are within the BLNWR source water area, wherein special requirements for oil and gas well development are managed to protect the ground and surface water resources (BLM 2002: 33). For example, stipulations for oil and gas wells in the HPZ include storage of drilling muds in steel tanks and use of cement to seal the entire length of the well casing.

Endangered Species Act

The four invertebrate species co-exist with other federally endangered species on the BLNWR in New Mexico and at Diamond Y and East Sandia Springs in Texas. Any habitat protections provided to the Pecos gambusia, Leon Springs pupfish (*Cyprinodon bovinus*), Diamond tryonia (*Pseudotryonia adamantina*), Gonzales tryonia (*Tryonia circumstriata*), Pecos amphipod (*Gammarus pecos*), or Pecos sunflower (*Helianthus paradoxus*) would only provide partial protection for the Roswell springsnail, Koster's springsnail, Pecos assiminea, and Noel's amphipod; their presence does not overlap completely. As a result, invertebrate habitat may not be afforded protection under current management actions or consultations which address conservation for the listed fish and sunflower in the same area.

Federal Water Right

Federal water rights for the BLNWR were secured in 2008 through a consent order (Service 2008: entire). This order protects minimal flow levels in Bitter Creek within the priority administration system of New Mexico. The order is based on a stipulated agreement between

New Mexico and the United States where flows in Bitter Creek are protected from further degradation in order to protect invertebrate, fish, and bird populations. Where this water right provides assurances of minimal flows in the Bitter Creek spring system, it provides no protection from contamination, or no guarantee that the flows will persist. In addition, we need to determine if the flows provided by the water right are adequate for the persistence of the species.

State

New Mexico

New Mexico Wildlife Conservation Act - Existing New Mexico State regulatory mechanisms are inadequate to protect the Roswell springsnail, Koster's springsnail, Pecos assiminea, and Noel's amphipod. All four species are listed as New Mexico State endangered species, Group 1, which are those species "...whose prospects of survival or recruitment within the State are in jeopardy." This designation provides the protection of the New Mexico Wildlife Conservation Act, but only prohibits direct take of these species, except under issuance of a scientific collecting permit. New Mexico State statutes do not address habitat protection, indirect effects, or other threats to these species. New Mexico State status as an endangered species only conveys protection from collection or intentional harm. There is no formal consultation process to address the habitat requirements of the species or how a proposed action may affect the needs of the species. Because most of the threats to these species are from effects to habitat, protecting individuals will not ensure the long-term protection of the species.

New Mexico Department of Game and Fish (NMDGF) - The NMDGF recognizes the importance of Roswell springsnail, Koster's springsnail, Pecos assiminea, and Noel's amphipod conservation at the local population level and has the authority to consider and recommend actions to mitigate potential adverse effects to these species during its review of development proposals. As noted, NMDGF's primary regulatory venue is under the New Mexico Wildlife Conservation Act. NMDGF prepared a state recovery plan for the four invertebrates that has helped guide conservation of the species since 2005 (NMDGF 2005: entire). There are no statutory requirements under NMDGF's jurisdiction that serve as an effective regulatory mechanism for reducing or eliminating the threats (see Factors A and C above) that may adversely affect Roswell springsnail, Koster's springsnail, Pecos assiminea and their habitat.

Oil Conservation Division of the New Mexico Energy, Minerals, and Natural Resources Department (NMOCD) - The NMOCD regulates oil and gas well drilling and casing in part to prevent contamination of groundwater (19 NMAC 15.16). Although there are no known instances of groundwater contamination by leaking oil or gas wells in the BLNWR Middle Tract source-water area, there is a well-documented history of oil and gas industry operations on and adjacent to BLNWR, which has resulted in the spillage of oil and brine onto the BLNWR (Service 2005a: 46,306). In addition, the NMOCD regulates spacing of wells. Currently the spacing is set at one well per 65 ha (160 acres). However, this could be changed to 1 per 16 ha (40 acres), increasing the number of well pads, roads, pipelines, and infrastructure on the landscape within the source-water area, and thus increasing the chances for an accidental spill. State land is checker-boarded within BLM land in the source-water capture zone but the State does not require the same level of safe-guards for drilling or waste material handling that are required within the HPZ. Although State regulations provide some protection to the four invertebrate species, they do not minimize the threat of oil spills through accidents or equipment malfunctions.

New Mexico Office of the State Engineer (OSE) - Water rights are adjudicated in the Roswell Basin, wells are metered, and pumping rates are administered by the NMOSE (NMOSE 2005: 10). Spring flows within habitat occupied by the four invertebrates at BLNWR are protected by existing Federal water rights (Service 2008). These water rights should ensure a minimum surface water discharge of Bitter Creek. However, if this water is contaminated, the Federal water right alone does not provide adequate protection for these species.

Currently, any proposed change in use of water (underground or surface depletion) in the Roswell Basin undergoes analysis by NMOSE to determine if there would be impairment to existing water rights (NMOSE 2005: entire). This analysis can protect the BLNWR water right from impairment. Thus the spring flows on BLNWR should be protected from any changes in nearby groundwater pumping. This provides a regulatory benefit to the four invertebrate species.

1.7.5 Other natural or manmade factors affecting its continued existence.

Historical Management

BLNWR was established in 1937, as wintering and breeding grounds for migratory birds (Service 1998: 10). At the time, the four invertebrate species were unknown to science. Consequently, management was directed primarily at creating dikes and ponding water year round for the benefit of waterfowl. Some of the ponds created would seasonally flood springs that flowed into these ponds naturally. Management for waterfowl has moved away from permanent flooded and now focuses on providing seasonal wetlands through moist soil management techniques, where water is managed to follow a natural, seasonal regime. BLNWR implemented moist-soil management in 1994 and does not allow water in seasonally ponded areas to inundate springs (Service 1998: 23). It is unclear how historical management prescriptions impacted the four invertebrates.

Fire

BLNWR is characterized by sinkhole/karst terrain (Gallo 2013: entire). This terrain poses safety threats to fire crews and suppression equipment. As a result, fire suppression efforts are largely restricted to established roads. This severely limits management ability to quickly suppress fires that threaten fragile aquatic habitats on the BLNWR. In 2000, the Sandhill fire, a wildfire that occurred during the Spring, burned 405 ha (1,000 acres) on the Bitter Creek area of BLNWR Middle Tract. The fire burned through Dragonfly Springs, eliminated vegetation shading the spring, and generated a substantial amount of ash in the spring system (NMDGF 2000: B5, Lang 2005a: 21). Subsequently, dense algal mats formed, water temperature fluctuations and maximum temperatures increased, while dissolved oxygen levels decreased (Lang 2005a: 18). The pre-fire dominant vegetation of submerged aquatic plants and mixed native grasses within the burned area had also been replaced by the invasive common reed (Lang 2005a: 18). Shortly after the fire, a reduction in Noel's amphipod was observed, and Koster's springsnail occurred at lower densities than were observed prior to the fire (Lang 2002: 5, 7). After the fire, in 2000-2003 Koster's springsnail increased and were found at 68,000 per m^2 (6,317 per ft^2) in Bitter

Creek (Haan 2012: 13). In addition, the Roswell Springsnail persisted at Bitter Creek following the fire (Hann 2012: 13), though there have never been large numbers at this site.

Alternatively, Pecos assiminea has been found to persist in areas following fires (NMDGF 2000: C3). Pecos assiminea was also documented at Dragonfly Spring following burning of habitat there during the Sandhill Fire (Lang 2005a: 32). Pecos assiminea is potentially more vulnerable to fires than the springsnails because the assiminea resides at or near the surface of the water compared to springsnails living in the substrate of springs, channels and pools. However, Pecos assiminea may survive fire or other vegetation reduction if sufficient litter and ground cover remain to sustain appropriate soil moisture and humidity at a microhabitat scale (Service 2004: 3).

After the Sandhill Fire, a dense stand of common reed developed in most reaches of Bitter Creek, including in habitat occupied by the four invertebrate species (Lang 2005a: 21) (see also “Factor C” section above). Prior to the Sandhill Fire, common reed occurred only sporadically along Bitter Creek (Lang 2005a: 19). These dense stands of common reed have increased the fuel load and threat of wildfire on BLNWR. Standing dead canes of common reed and associated litter often constitute twice as much biomass as living shoots (Gunker 2008: 22). This abundant dead fuel carries fire well, allowing stands to burn even when the current year’s shoots are green (Gunker 2008: 22). An on-going restoration project has removed common reed from 2.8 ha (7 acres) of Bitter Creek to reduce the threat of wildfire (Sanchez 2015: 10).

Prescribed fire can be an important vegetation management tool that should be incorporated into a habitat management plan. Controlled burns have been implemented on BLNWR to burn grass, sedge, cattail, and nonnative vegetation (e.g., Russian thistle) in an attempt to reduce the risk of large uncontrolled wildfires or to remove excessive amounts of Russian thistle from a spring run (Service 2004: entire). Controlled burns with appropriate conservation measures do not adversely affect Koster’s springsnail, Pecos assiminea, or Roswell springsnail (Service 2004: 4). On the other hand, controlled burns to remove Russian thistle may have indirectly affected Noel’s amphipod through the release of common reeds, which can reduce water flow and result in decreased dissolved oxygen levels (Service 2005b: 5). Surveys conducted immediately post-fire indicate that Noel’s amphipod is still found throughout the burned area, with little to no direct effects (Service 2005b: 5). Completing a risk assessment for the four invertebrates for proposed controlled burns would be an important part of a habitat management plan.

Localized range, limited mobility, fragmented habitat

Several biological traits of a population have been identified as putting a species at risk of extinction. Some of these characteristics include having a localized range, limited mobility, and fragmented habitat (O’Grady et al. 2004: 514). The four invertebrate species have all of these characteristics. Having a small, localized range means that any perturbation, either natural (e.g., drought) or anthropogenic (e.g., water contamination) can eliminate many or all of the existing populations. Having a high number of individuals at a site provides no protection against extinction. Noel (1954: 124) noted that the Noel’s amphipod was the most abundant animal in Lander Spring; however, it was subsequently extirpated when the spring dried up (Cole 1981: 27). For Koster’s springsnail, Pecos assiminea, and Roswell springsnail, fossil records indicate that at least one of these snail species were historically found at Berrendo Creek, North Spring, South Spring Rivers, and along the Pecos River (Taylor 1987: 16, 47), which suggests a historical decline in the range and distribution of these species.

Limited mobility restricts the ability of the invertebrates to disperse to other suitable habitats or to move out of habitat that becomes unsuitable. Consequently, they are unable to avoid contaminants or other unfavorable changes to their habitat. Fragmented (unconnected) habitat restricts gene flow among populations and limits the ability of the invertebrates to recolonize habitats that have been disturbed but then recover. For example, three springs once contributed to Berrendo Creek in the Roswell Basin. If springsnails in one of the springs was eliminated because of a toxic spill, after the habitat had recovered, the spring could have been colonized naturally by dispersal of animals from the other springs. In the currently fragmented habitats, dispersal is highly unlikely and if springsnails are extirpated from a site the habitat probably will not be recolonized, further restricting the range.

Climate Change

Based on the evidence of warming of the Earth's climate from observations of increases in average global air and ocean temperatures, widespread melting of glaciers and polar ice caps, and rising sea levels recorded in the Intergovernmental Panel on Climate Change Report (IPCC 2007a: entire, 2013: entire), climate change is now a consideration for Federal agency analysis (Government Accounting Office 2007: entire). The earth's surface has warmed by an average of 0.74 ºC (1.3 ºF) during the 20th century (IPCC 2007b: 30). The IPCC (2013: 7) projects that there will very likely be an increase in the frequency of hot extremes, heat waves, and heavy precipitation events as a result of climate change. Thus for species that may become impacted by changes in climate, the Service will incorporate climate change into recovery guidance to incorporate the most realistic management in order to achieve recovery (Service 2010b: entire). This global climate information has been downscaled to our region of interest, and projected into the future under two different scenarios of possible emissions of greenhouse gases (Alder and Hostetler 2014: 2). Climate predictions for the four invertebrates area include a 5 to 6 percent increase in maximum temperature (up to 4 ºC (7.2 ºF)), 11 percent decrease in precipitation, and a 25 percent increase in evaporative deficit over the next 25 years (Butler, and Tashjian 2016).

In 11 of the last 15 years (2001-2015) there has been moderate to exceptional drought conditions in the four invertebrates' habitat with 10 percent of the time in exceptional drought (National Drought Mitigation Center 2016, Chaves County Data). The 2002-2003 drought spanned all of the southwestern North America and was anomalously dry with unusually high temperatures (Breshears et al. 2005: 15,144); similar conditions occurred in 2009-2013.

The BLNWR spring flow is closely connected to the artesian aquifer groundwater level (Butler and Tashjian 2016: 4). The 2009-2013 drought conditions resulted in a marked decline in available spring habitat on the BLNWR (Butler and Tashjian 2016: 8). A similar drought will likely deepen groundwater levels, assuming groundwater extraction continues at levels commensurate with current rates (Butler and Tashjian 2016: 8). The threshold at which ground water depletion would result in significant loss of the invertebrate populations is unclear, but the downward trend in groundwater levels indicates that some action will be needed to stabilize groundwater levels to maintain spring flow.

Summary of Threats

Though there are many threats listed, the most significant threats to all four species are those that impact water quality and quantity. These include:

- Ground water withdrawal
- Urbanization
- Oil and gas development
- Drought
- Climate change
- Limited habitat availability

The following threats are considered secondary to water quality and quantity, and should be considered for recovery after the immediate threats of water quantity and quality are resolved:

- Wildfire
- Predation
- Nonnative invasive species
- Invasive plants
- Train derailment or catastrophic/toxic spills
- Golden algae(threat is only a potential and is undocumented)

Our Recovery Criteria and Objectives are focused on the threats that most impact water quantity and quality. Other threats may be exacerbated with the loss of water quantity and quality, and thus become more prevalent.

1.8 Critical Habitat

In 2011, the Service designated critical habitat for the four invertebrate species (Service 2011: entire). Pecos assiminea had critical habitat units designated on BLNWR in Chaves County, New Mexico, and Pecos and Reeves Counties, Texas (Service 2011: 33,053). There are four units: two at BLNWR, Sago/Bitter Creek Complex (Unit 1) and Assiminea Impoundment Complex (Unit 2b), and two in Texas, Diamond Y Springs Complex (Unit 4), Pecos County; and East Sandia Spring (Unit 5), Reeves County, Texas. The Diamond Y Springs Complex critical habitat overlaps with Pecos sunflower, Diamond tryonia, Gonzales tryonia, and Pecos amphipod (Service 2013b: 40,990 and 40,996). The East Sandia Spring (Unit 5) overlaps with designated critical habitat for Diminutive Amphipod, Phantom springsnail, and Phantom tryonia (Service 2013b: 40,987 and 40,993).

The primary constituent element of critical habitat for the Pecos assiminea is moist or saturated soil at stream or spring run margins that:

- consist of wet mud or occurs beneath mats of vegetation;
- are within 2 to 3 cm (1 in) of flowing water;
- have native wetland plant species, such as salt grass or sedges, that provide leaf litter, shade, cover, and appropriate microhabitat;
- contain wetland vegetation adjacent to spring complexes that supports the algae, detritus, and bacteria needed for foraging; and
- have adjacent spring complexes with:

    - permanent, flowing, fresh to moderately saline water with no or no more than low levels of pollutants; and stable water levels with natural diurnal and seasonal variations (Service 2011: 33,053).

Koster's springsnail and Roswell springsnail have designated critical habitat only in New Mexico at BLNWR in two units (Service 2011: 33,059).

The primary constituent element of critical habitat for the Koster's springsnail and Roswell springsnail is springs and spring-fed wetland systems that:

- have permanent, flowing water with no or no more than low levels of pollutants;
- have slow to moderate water velocities;
- have substrates ranging from deep organic silts to limestone cobble and gypsum;
- have stable water levels with natural diurnal (daily) and seasonal variations;
- consist of fresh to moderately saline water;
- vary in temperature between 10-20 °C (50-68 °F) with natural seasonal and diurnal variations slightly above and below that range; and
- provide abundant food, consisting of:
    - algae, bacteria, and decaying organic material; and submergent vegetation that contributes the necessary nutrients, detritus, and bacteria on which these species forage (Service 2011: 33,058).

Noel's amphipod has designated critical habitat only in New Mexico at BLNWR in three units (Service 2011: 33,062).
The primary constituent element of critical habitat for Noel's amphipod is springs and spring-fed wetland systems that:

- have permanent, flowing water with no or no more than low levels of pollutants;
- have slow to moderate water velocities;
- have substrates including limestone cobble and aquatic vegetation;
- have stable water levels with natural diurnal (daily) and seasonal variations;
- consist of fresh to moderately saline water;
- have minimal sedimentation;
- vary in temperature between 10-20 °C (50-68 °F) with natural seasonal and diurnal variations slightly above and below that range; and
- provide abundant food, consisting of:
    - submergent vegetation and decaying organic matter;
    - a surface film of algae, diatoms, bacteria, and fungi; and
    - microbial foods, such as algae and bacteria, associated with aquatic plants, algae, bacteria, and decaying organic material (Service 2011: 33,060).

Critical habitat for all four species does not include manmade structures (such as buildings, aqueducts, runways, roads, and other paved areas) and the land on which they are located within the legal boundaries.

1.9 Conservation Efforts

BLNWR has a Final Comprehensive Conservation Plan (CCP) that was approved in 1998 (Service 1998: entire). The CCP serves as a management tool to be used by the Refuge staff and its partners in the preservation and restoration of the ecosystem's natural resources. The plan is intended to guide management decisions and sets forth strategies for achieving Refuge goals and objectives within that 20 year timeframe. Key goals of the CCP related to the four invertebrate species include the following: 1) Restore, enhance, and protect the natural diversity on the BLNWR including threatened and endangered species by a) appropriate management of habitat and wildlife resources on refuge lands and b) by strengthening existing, and establishing new cooperative efforts with public and private stakeholders and partners; and, 2) Restore and maintain selected portions of a hydrological system that more closely mimics the natural processes along the reach of the Pecos River adjacent to the BLNWR by a) restoration of the river channel, as well as restoration of threatened, endangered, and special concern species; and b) control of exotic species and management of trust responsibilities for maintenance of plant and animal communities and to satisfy traditional recreational demands.

Specific objectives related to these goals include: 1) Restoration of populations of aquatic species designated as endangered, threatened, or of special concern to a sustainable level (aquatic species in these categories include the four invertebrate species); and, 2) Monitoring of wildlife populations including endemic snails. Though the CCP is dated, the BLNWR annual operating plan works off of these general goals and objectives.

In 2003, a dike rehabilitation project was begun on BLNWR. Two dikes running the length of Units 6 and 7 were constructed. This isolated the spring systems from the main body of the impoundments allowing the areas to be flooded in the winter without inundating the springs occupied by the invertebrates. This project created and protected habitat that had been lost by the previous management of the Units. Potential habitat for the invertebrates was created in a new ditch designed to carry water to Unit 7. Current management of BLNWR recognizes and includes the invertebrates in its planning, maintenance, and operations. BLNWR has an adjudicated Federal reserved water right that helps preserve spring flow on the Refuge.

As discussed above under "The inadequacy of existing regulatory mechanisms," revisions to the BLM Roswell Approved Resource Management Plan made in 1997 prompted a formal section 7 consultation with the Service regarding Pecos gambusia, which occurs on BLNWR (BLM 1997, Appendix 11: 32). The BLM in consultation with the Service designated a HPZ to protect Pecos gambusia from potential groundwater contamination by oil and gas well drilling operations (BLM 2002: 25). Because Pecos gambusia co-occurs with the four invertebrate species, the invertebrates benefit from these protections. The protection provided does not eliminate the chance of accidents and groundwater contamination related to oil and gas drilling from occurring but it does reduce the probability.

In 2013, a major restoration effort was undertaken on the Rio Hondo. In 2006, Noel's amphipod was found in a spring vent along the west side of the Rio Hondo (Warrick 2006: 1). In 2010, six vents were found to have amphipods (Sanchez 2010: 1). Water quality sampling indicated the river flow was not suitable for Noel's amphipods and high flow events inundate the springs impacting amphipods (Service 2013a: 5). BLNWR proposed to reroute the Rio Hondo channel to isolate the springs and make a Rio Hondo spring run suitable for the four invertebrates and other species of concern (Service 2013a: 5). During initial mapping for the restoration more than 20 spring vents were identified that may provide suitable habitat for the four invertebrates. Work was carried out in 2014 and a 3.3 km (2.05 mi) spring run was restored and protected from Rio Hondo and Pecos River high flows (with the help of a Cooperative Recovery Initiative grant). Following restoration, 94 spring vents were found (Service 2014: 13). In addition, invasive vegetation was removed via prescribed burn and herbicide treatment along the spring run. There are several locations where Noel's amphipods are found along the spring run, but Pecos assiminea have not been found adjacent to the Rio Hondo through 2018. BLNWR translocated approximately 7,000 of both Roswell and Koster's springsnails from 2015-2018 to a section of the Rio Hondo with comparable water chemistries. Preliminary results indicate there has been an 18-fold increase in abundance at the release location.

A recovery and conservation plan for the four invertebrate species was finalized by the State of New Mexico in 2005 (NMDGF 2005: entire). The plan provides details about the natural history of the invertebrates, a historical perspective of habitat and population trends, and habitat assessment. The goal of the plan is to ensure that the invertebrates occur in sufficient numbers within populations and in a sufficient number of discrete and independent populations, that downlisting and eventual delisting under the Wildlife Conservation Act is warranted (NMDGF 2005: 32). The plan outlines three parameters to meet the goal: 1) maintenance or expansion of the existing distribution and abundance of the invertebrates at BLNWR; 2) repatriation of the invertebrates to restored suitable habitat at two or more sites within their known historical range; and 3) establishment and stocking of an artificial and secure refugium to protect against catastrophic loss in the wild (NMDGF 2005: 33). The State's recovery plan does not ensure any long-term protection for these species because there are no mandatory elements to ensure proposed projects do not adversely affect these species or their habitat.

1.10 Biological Constraints and Needs

The four invertebrates occur in a very restricted range, have limited mobility, and their habitat is fragmented. All of these characteristics make them susceptible to local extirpation and extinction (McKinney 1997: 499; O'Grady et al. 2004: 514). Any perturbation, either natural (e.g., drought) or anthropogenic (e.g., water contamination) can eliminate many or all of the existing populations. Having a high number of individuals at a site provides no protection against extinction. Noel (1954: 124) noted that the amphipod in Lander Spring was the most abundant animal present. It was extirpated from that site when the spring dried up (Cole 1985: 94). Small size and limited mobility restrict the ability of the invertebrates to disperse if habitat becomes unsuitable. Consequently, they are unable to avoid contaminants or other unfavorable changes to their habitat. Fragmented (unconnected) habitat restricts gene flow among locations and limits the ability of the invertebrates to recolonize habitats that have been disturbed but then recover. Dispersal among habitats may be difficult given the invertebrates limited mobility and if one location is extirpated the habitat may not be recolonized, further restricting the range.

Although the habitat where they occur can be protected through conservation measures, they depend on groundwater that originates far from the habitat protected. The amount and quality of that water can be protected to some extent but not completely. It is highly likely that if one spring or sinkhole at BLNWR is affected by a contaminant others would be affected as well because of the groundwater connection. In addition, any regional disturbance such as widespread drought would affect all of the habitat simultaneously. Although some of the threats can be adequately addressed, the inherent problems associated with narrow endemics in fragmented habitat will always be present. The best management and recovery plans possible are incapable of preventing stochastic events that could eliminate the species.

1.11 Research Needs

1.11.1 Information about population dynamics of the four invertebrates and information to precisely define suitable habitat (for the purposes of habitat restoration or replication) is not available. The following research topics should be addressed:

- Determine specific habitat requirements for each species as they relate to cover and food availability.
- Investigate the relationship between stream flow and abundance dynamics.
- Investigate demographic parameters for each species including: estimation of effective population size, extinction probabilities, reproduction rates, longevity, survival rates, mortality rates, and density-dependence.
- Identify the preferred metrics for water quality characteristics (i.e., water temperature, pH, hardness, conductivity, salinity, etc.) to help determine the range of conditions necessary to maintain the invertebrates.
- Determine sensitivity to commonly used pesticides that may be used to control nonnative terrestrial vegetation adjacent to occupied habitat.
- Determine the sensitivity to potential contaminants, such as polycyclic aromatic hydrocarbons, polychlorinated biphenyl, benzene, toluene, and xylene.
- Determine springsnail species presence ratios in each system.
- Determine if federally reserved water right is sufficient to allow population persistence.
- Investigate dispersal rates and the capacity for migration.
- Conduct surveys for additional population locations in the Country Club area and other sinkhole locations to the north in BLM land and at spring locations at Bottomless Lakes.
- Investigate methods to ensure refugium populations, including emergency response capacity and options for captive rearing.

2.0 RECOVERY GOALS, STRATEGY, OBJECTIVES, AND CRITERIA

The following sections present a broad strategy for achieving the recovery of Noel's amphipod, Koster's springsnail, Roswell springsnail, and Pecos assiminea. The goal is to achieve a level of recovery for each of the invertebrate species such that they no longer require protections under the Endangered Species Act and are able to be removed from the list of federally threatened and endangered species.

2.1 Recovery Strategy

The overall strategy involves preserving, restoring, and managing their aquatic habitat, along with the water resources necessary to support resilient populations of these species and the ecosystems on which they depend. More specifically, the strategy is to:

- Maintain and manage populations and sites throughout each species' range,
  - Ensure adequate water quantity and water quality,
  - Protect and restore habitats,
  - Control invasive species,
- Collaborate with partners to achieve conservation goals in balance with community water needs, and
- Engage in community outreach to promote the importance and value of Bitter Lake NWR and its diverse array of wildlife, including sensitive, rare aquatic invertebrates, worthy of preserving.

Employment of this strategy will lead to preservation of the array of habitat types used by the invertebrates, and provides increased habitat connectivity, helping to conserve genetic diversity (representation) of each of the four species.

2.2 Management Units

We define a management unit as a division of the listed entity that is identifiable based on risks of drying from groundwater declines, loss of water quality, and/or loss of habitat. Drying would occur due to lost spring flows, or lost connection between ground water and surface water. Sites within each MU have a similar risk of drying, decrease in water quality, and/or loss of habitats. Management units are a management tool and although they could align with biological population groupings, we are not certain to what degree these units capture actual biologically functioning populations. For recovery planning purposes, we divided the ranges of the four species of invertebrates into five MUs on BLNWR with one MU including City of Roswell property, and two additional MUs in Texas for Pecos assiminea (Tables 6 and 7). A site is a geographic unit that is typically composed of a distinct spring, spring-run, sinkhole, or spring-system within a MU. Although sites could align with biological population groupings, we are not certain to what degree these units capture actual biologically functioning populations.
The majority of MUs where the invertebrates are present are within BLNWR (Figure 1). Springs, spring-runs, and sinkholes on BLNWR may be connected by underground water sources, but are not connected on the surface. Establishment of MUs gives the Refuge a tool to implement management and monitoring activities in a manner that is consistent with the major threat, risk of drying due to declining ground water levels. Unit-based recovery actions are important because they provide for a representation of habitats that are grouped by risk of loss (drying). The maps of each species range on BLNWR are found in Figures 1 – 5. Because Pecos assiminea occurs in both BLNWR in New Mexico and at springs in Texas, it will have two additional MUs that will be addressed in the West Texas Invertebrate Recovery Plan, Diamond Y Spring (MU 7), and East Sandia Spring (MU 8) (Table 7; Figures 6 and 7). Management actions for the Diamond Y Spring system and East Sandia Spring will be developed in the West Texas Invertebrates Recovery Plan (in preparation).

Management unit conservation provides redundancy to the species by providing a sufficient number of occupied sites to provide a margin of safety for these species. Redundancy is important for these species since they cannot easily move long distances to other areas to reestablish themselves, and having adequate representation will provide the species with more flexibility and resiliency in coping with loss of habitat and/or catastrophic events.

Five sites are known to be occupied by the Roswell springsnail: Sago Springs (includes Sinkhole 31), Bitter Creek, Spring Ditch (Unit 6), City of Roswell, and Sinkhole 38. Ten sites are known to be occupied by the Koster's springsnail: Sago Springs, Bitter Creek, Spring Ditch (Unit 6, Unit 5), Unit 15, Hunter Marsh, Lake St. Francis, City of Roswell, and Sinkhole 38. Five sites are known to be occupied by the Noel's amphipod: Sago Springs, Bitter Creek, Spring Ditch (Unit 6), Hunter Marsh, and Rio Hondo. Three sites are known to be occupied by the Pecos assiminea at BLNWR: Sago Springs (from sinkhole 31 downstream to Bitter Lake), Bitter Creek (from Dragonfly Springs sporadically to the outflow at Bitter Lake), and Snail Unit. Additionally, they are found at two sites in Texas, East Sandia Spring and Diamond Y Spring. Table 8 lists the known occupied sites at BLNWR.

Table 6. Management Units, and associated sites, on and adjacent to BLNWR for Koster's Springsnail, Roswell Springsnail, and Noel's amphipod. Note that all species may not be found at every site (see Table 8).

Management Unit 1	Management Unit 2	Management Unit 3	Management Unit 4	Management Unit 5 (amphipod only)	Management Unit 6 (Koster's only)
Sago Springs	Spring Ditch Unit 5	Snail Unit	Hunter Marsh/ City of Roswell	Rio Hondo	Sinkhole 59
Bitter Creek	Spring Ditch Unit 6	Spring Ditch Unit 7			Lake St. Francis
Sinkhole 38	Spring Ditch Unit 3	Unit 15			

Table 7. Management Units for Pecos assiminea (Includes two units in Texas).

Management Unit 1	Management Unit 2	Management Unit 3	Management Unit 7	Management Unit 8
Sago Springs	Spring Ditch Unit 3	Snail Unit	Diamond Y Spring (Texas)	East Sandia Spring (Texas)
Bitter Creek	Spring Ditch Unit 5	Spring Ditch Unit 7		
	Spring Ditch Unit 6			

Table 8. Known occupied sites for the four invertebrate species on BLNWR. Empty boxes represent the species not known to ever be present. Bold borders depict Management Units.

Management Unit	Site Name	Koster's Springsnail	Noel's Amphipod	Pecos Assiminea	Roswell Springsnail
1	Sago Springs /Sinkhole 31 (32)	Occupied	Occupied	Occupied	Occupied
	Bitter Creek	Occupied	Occupied	Occupied	Occupied
	Sinkhole 38	Occupied			
2	Unit 3 Spring Ditch	Occupied			Occupied
	Unit 5 Spring Ditch	Occupied			
	Unit 6 Spring Ditch	Occupied	Occupied		Occupied
3	Snail Unit	Occupied	Occupied	Occupied	Occupied
	Unit 7 Spring Ditch		Occupied	Occupied	
	Unit 15	Occupied			
4	Hunter Marsh/City of Roswell	Occupied	Occupied		Occupied
5	Rio Hondo		Occupied		
6	Sinkhole 59	Occupied			
	Lake St. Francis	Occupied			
7	Diamond Y Spring, Texas			Occupied	
8	East Sandia Spring, Texas			Occupied	

2.3 Recovery Objectives

In addition to habitat protection (particularly the water resources), an increased understanding of the relationship of the four species to their physical and ecological environments is crucial to improve science-based management decisions and conservation actions. Implementation of the recovery plan requires that adaptive management be utilized so that the species' recovery strategy is following the most up-to-date information as it becomes available.

Though the vast majority of habitat for these invertebrates is located on BLNWR, their recovery will require concerted cooperation among Federal, State, and local government (City of Roswell), private landowners (The Nature Conservancy), and other stakeholders. Therefore, the success of the recovery strategy will rely heavily on the implementation of recovery activities by BLNWR that may be conducted by the Refuge or other conservation partners.

Objectives:

1) Secure and maintain the long-term survival of each species with the appropriate number, size, and distribution of resilient sites;
2) Preserve and manage sites that contain the necessary elements for each species' persistence, such as adequate water quantity and quality, above and below ground;
3) Address other threats, such as exposure to catastrophic spills and invasive and predatory species, within MUs so that the four invertebrate species' are capable of enduring stressors;
4) Work with partners to develop and implement management strategies and plans to benefit each of the four invertebrates;
5) Conduct monitoring and research to understand biological populations, population viability, identify new sites for species, and determine the effectiveness of conservation management actions;
6) Work with the community and partners to create and implement outreach and educational approaches that will inform the community about the value of diverse and functional ecosystems.

We describe our recommendations for increasing the resiliency, redundancy, and representation of the invertebrates in MUs below. Resiliency describes the ability of a species to withstand stochastic disturbance by ensuring replication of sites with high habitat quality and numbers of individuals, redundancy describes the ability of a species to withstand catastrophic events by spreading risk across large geographic areas or among multiple MUs, and representation describes the ability of a species to adapt to changing environmental conditions over time as characterized by the breadth of genetic and environmental diversity within and among MUs. The recommendations are grouped by actions to support the strategy.

2.3.1 Management Units throughout the Ranges

A minimal level of redundancy is essential for long-term viability of a species (Shaffer and Stein 2000: 307, 309-310; Groves et al. 2002: 506). Each invertebrate species needs to persist within multiple MUs throughout its range for adequate redundancy. In addition, these MUs, should be distributed such that the impacts from any single catastrophic event are minimized. The strategy of ensuring the persistence of multiple MUs for each species across its range creates a margin of safety for these species to withstand catastrophic events (Service and NOAA 2014: 37,578) by decreasing the chance of any one event affecting the entire species. To manage risk, at least five of the six MUs on BLNWR should be maintained at all times. The species should be distributed across multiple sites throughout the species' ranges. For Pecos assiminea, at least three MUs on and all MUs off BLNWR should contain occupied sites.

Exactly how many populations each species needs to be adequately viable depends upon the individual probability of persistence of each population. By "persistence", we mean being self-sustaining in the wild. Because of the extremely limited range of the four invertebrate species, and the inability to expand the species' range except for surveying new sites on and adjacent to the refuge, the probability of persistence will greatly depend on the ability to maintain and increase existing habitat and water resources on BLNWR. For the Pecos assiminea, the two MUs in Texas (Diamond Y Springs and East Sandia Spring) increase the redundancy and probability of persistence.

As MUs' probabilities of persistence decrease, more occupied MUs are needed to meet the overall goal. In cases where not enough MUs have a high enough probability of persistence to meet the criterion, two alternatives for recovery are to either increase the persistence probability of existing MU(s) (by improving habitat using the strategies described above) or conduct additional presence/absence surveys and find enough individuals or sites within a MU to raise the probability that one MU will persist in the long term (i.e., 20 years). The latter alternative is based on the fact that the more MUs that exist, the less likely that they all will be extirpated.

Maintaining persistence in existing MUs strengthens the possibility that the representation and, thus, the adaptive capabilities (Service and NOAA 2014: 37,578) of the four invertebrate species are conserved. Protecting multiple MUs across a species range may also contribute to its resiliency, especially if some populations MUs or habitats are more susceptible to certain threats than others (Service and NOAA 2014: 37,578).

The four invertebrate species on BLNWR occur together in several MUs on the Refuge, though they utilize various resources and microhabitats within those units. All four species are known to occur in Bitter Creek, Sago Springs and the Snail Unit. Other MUs on BLNWR contain various combinations of the four invertebrate species. Because a species' genetic makeup is shaped through natural selection by the environments it has experienced (Shaffer and Stein 2000: 308), all environments (springs, creeks, sinkholes and ditches) that the species occur in will be protected to ensure conservation of the species. Most of the occupied locations are located on BLNWR; however, several potential locations are off Refuge on private lands. If off refuge locations are discovered, efforts should be made to protect sites through the use of permanent conservation easements, and management agreements.

2.3.2 Ensuring Adequate Water Quantity

Water quantity decreases and associated spring flow declines are a primary threat to the four invertebrate species. Therefore, efforts are needed to ensure adequate quantities of water, in terms of base flow and recharge, on BLNWR and at other sites within the ranges of these species. Analyses of the effects of all groundwater activities on the four invertebrate species and their surface (the visible, wetted top layer of substrate) and subsurface (other underground areas of the underlying groundwater source) habitats should be conducted prior to initiation of these activities. Groundwater measurements will be used to define drought conditions, which will trigger enhanced monitoring protocols for the invertebrate species. Precautionary measures for recovery activities should be outlined in a comprehensive plan and implemented to prevent the following:

- Interruption and drawdown within groundwater flow paths;
- Alteration or disruption of the recharge or transmissive properties of the aquifer;
- Dewatering of underground aquifer reserves; and
- Loss of spring flow into invertebrate habitat.

Destruction, plugging, or filling of recharge features and the loss of natural drainage features may have long-term effects on water quantity and should be avoided. Recharge enhancement methods that contribute to or cause infiltration of high quality runoff without causing habitat alteration or destruction should be considered to protect water quantity within the range of the four species of invertebrates. Ideas from the Pecos Valley Artesian Conservancy District Plan will be considered and incorporated into decisions regarding the four invertebrate species.

Data suggest aquifer levels are critical to maintain adequate habitat on BLNWR, though further monitoring would be needed to determine what threshold of groundwater elevation would result in significant loss of the invertebrate populations (Butler and Tashjian 2016: 11). The four invertebrate species have persisted in droughts between 2009 and 2013, though it is not known as to how this drought impacted invertebrate population levels. Climate change models predict more frequent and longer lasting droughts in the future (Cayan et al. 2010: 21271, Butler and Tashjian 2016: 10). Future research should be focused on delineating surface and subsurface areas, flow and discharge for each MU and for the entire Refuge. Once delineated, measures to control water quality, avoid hazardous material spills, and protect water quantity can be implemented or refined. Additional information should be gathered to ensure adequate spring flow at levels that protect the four invertebrate species and their habitats. Predictive models should be developed to evaluate the potential for climate change, drought, and flooding to affect invertebrate habitat. In addition, aquifer characteristics, underground flow paths, and recharge patterns should be studied further so that this recovery strategy can be adaptively modified as new information becomes available. Also, various sinkholes on and off BLNWR have been identified as potential habitat for the four invertebrate species, but have not yet been surveyed for the species. If these sites are determined to be occupied in the future, they may be incorporated into existing MUs or designated as new MUs to be considered in the recovery of the four invertebrate species.

The effects of droughts on the aquifer may be worsened by climate change, development, and other human activities on the watershed. Continued monitoring of groundwater levels in the aquifer, and discharge at the Bitter Creek Flume should be integrated into an adaptive management strategy for the species. An overall Aquifer Management Plan should be developed by stakeholders and implemented to conserve the four species of invertebrates and maintain sufficient spring flows during periods of drought. An aquifer management plan should be developed to address short-term and long-term approaches that can be used for managing water quantity and groundwater use from the aquifer under various scenarios of climate change anticipated. Reduction of groundwater pumping during periods of drought is particularly critical. More studies may be necessary to determine how much pumping can be sustained while still maintaining the invertebrates and their ecosystems during drought conditions.

2.3.3 Protection and Improvement of Water Quality

The four species of invertebrates depend on sufficient water quantity and quality to meet requirements for survival, growth, and reproduction. Habitat modification in the form of degraded water constituents (or contaminants) and sediment quality is a primary threat to the four species of invertebrates and their food sources. We consider threats to water quality and to be important due to the species' extremely limited range that could be impacted by spills of high magnitude (degree to which the threats are affecting or can affect the species) or scope (how much of the species' range the threats are affecting or can affect). Sources of threats to water quality degradation include, but are not limited to, the following: 1) contamination of groundwater, 2) urbanization (specifically septic leach fields and stormwater runoff) 3) oil and gas activities, 4) hazardous materials spills from train derailments or other causes, risks from all of which are expected to increase in the future.

Water quality measures that may help protect invertebrate habitat from the threat of water and sediment quality degradation need to be defined and implemented. In general, water quality protection measures should either improve or prevent further reduction of surface and underlying aquifer water quality.

2.3.4 Protection and Restoration of Habitat

The aquatic and semiaquatic habitat that the four invertebrates use can become degraded through invasive aquatic plant overgrowth (such as common reed), species disturbances, and siltation. High nutrients loads from surface runoff can lead to elevated algal growth that can depress dissolved oxygen conditions. Species impacts could include space occupation by invasive snails excluding the four invertebrates and increased turbidity through bottom disturbance by carp. Runoff with fine sediment materials can lead to siltation, burying or rendering habitat unsuitable. The terrestrial habitat component is also important in maintaining four invertebrates' aquatic habitat. Terrestrial vegetation provides shelter and shading for aquatic species. In addition, upland and wetland vegetation provide a buffer from eroding soils sedimentation as well as contamination from surface runoff and spills. Overgrown conditions at springs can degrade water quality or impede flows leading to poor water quality. Terrestrial plants provide a carbon source for foraging invertebrates and aquatic plants. Changes to terrestrial habitat condition through excess runoff, increased oxygen demand and altered nutrient loads can also influence water quality. Maintaining and enhancing aquatic and terrestrial habitat will help protect the four invertebrates.

BLNWR has completed several restoration projects that were focused on increasing habitat for the four invertebrates including a comprehensive habitat restoration project along the Rio Hondo and common reed removal on BLNWR. These efforts should continue to be monitored for effectiveness and occupancy by the four invertebrates. It is currently unknown the extent to which restoration efforts improve habitat quality for these species. Habitat restoration methods should be evaluated and species monitoring conducted to determine success. Successful restoration projects should enhance the abundance of the four invertebrates within the MUs or at least maintain them.

The protection and restoration of habitat is important to maintain suitable habitat for the four invertebrates and adequate water quantity and quality. Not all of the MUs or sites within each MU will require restoration or active management, though all sites should be evaluated on a regular basis to determine if habitat restoration is required. This habitat evaluation should be incorporated into a habitat management plan.

2.3.5 Monitoring and Research

Long-term monitoring programs should be put into place for each of the four invertebrate species. BLNWR has evaluated statistical precision and power related to density estimates from a trial survey with a randomized design. Past surveys at BLNWR have largely been opportunistic (not design based), which limits inferences that can be made concerning changes in density and abundance (trends), and have also lacked information on precision and power, which is necessary to understand limitations of data. Information on statistical precision and power are being incorporated into a protocol that will guide future monitoring efforts on the Refuge. Density estimates will be collected from 3 sites, two of which have a high and low risk of going dry, but it will not be possible to obtain density estimates for all sites and MUs due to logistical constraints. However, presence/absence surveys will be developed for all sites. Monitoring efforts are tied to recovery criteria.

Monitoring schemes that fail to offer thresholds for conservation actions are of little utility. Thus, effort is also being made to insure long-term monitoring strategies will elucidate the relation between invertebrate abundance and declining water levels, and that evaluate recovery and restoration actions. Understanding invertebrate response to water-levels will allow thresholds, both in terms of density and water levels, to be developed that guide adaptive management actions. Additionally, data collected from monitoring programs can be fed into models that predict the probability of persistence.

In addition to monitoring programs, biological research should be conducted to answer currently unknown life history characteristics that would inform management decisions or address population viability/sustainability. This information is important for conducting population viability analyses and understanding the species' response to stressors (for example, contaminants or low flow conditions). Thorough surveys should be completed in potential habitat within the historic range to determine if additional sinkholes are occupied.

2.3.6 Planning for Emergency Captive Rearing

Because of the small and isolated nature of these invertebrates, sudden extirpation from certain sites could occur. Captive propagation (in a hatchery or zoo setting) can be used to minimize the loss of genetic diversity. Maintaining natural genetic diversity is important given there is significant genetic variation for three of the species (Walters and Berg 2016, 2017). An emergency captive rearing plan should develop techniques necessary to preserve the species from extinction in the event of a catastrophic event, Planning should identify and prioritize which sites or MUs need to be represented in captivity, with the overall goal of maintaining natural genetic diversity among and within the different MUs. These captive populations will provide a representation of the genetic characteristics of at-risk wild populations should reintroduction be necessary if MUs are lost or densities significantly reduced. Other benefits of captive rearing include educating and engaging the public on conservation issues and providing opportunities for research of the species, yielding knowledge that can be applied to conservation in the wild. Captive propagation should be maintained until species' threats are sufficiently reduced to a point where the loss of adequate redundancy or representation in the wild is no longer likely. Rogowski and Funkhouser (2012: 12) investigated establishing a reproducing self-sustaining population of both springsnails; unfortunately none of the offspring survived to adulthood to reproduce. Currently, there are no successful captive breeding programs for any of these four invertebrate species. Thus, if captive rearing becomes necessary, research will have to be done for a successful protocol to be developed. Prior to breeding, holding sites should be developed in case of catastrophic events that could decimate sites or entire MUs.

2.4 Recovery Criteria

Recovery criteria are the values by which it is determined that an objective has been reached (National Marine Fisheries Service 2010: 5.1-14). Recovery criteria must be objective and measurable. They provide a basis for determining whether a species can be considered for downlisting to threatened status, or removed from the list of threatened and endangered species. Because the same five statutory factors must be considered in delisting as in listing (16 USC 1533 (a), (b), (c)), the objective, measurable criteria in this recovery plan address each of the five statutory delisting factors and provide a way to measure threats.

The recovery criteria in this plan are not binding, and it is important to note that meeting the recovery criteria provided below does not automatically result in downlisting or delisting the species. Downlisting and delisting decisions are under the authority of the FWS Director and must undergo the rulemaking process and analyses. Both anthropogenic and non-anthropogenic threats to the four invertebrates must be acceptable in a five-factor analysis and adequate regulatory mechanisms must be in place to ensure that the species will persist into the foreseeable future. The management recommendations in this plan are believed to be necessary and advisable to achieve this goal, but the best scientific information derived from research, management experiments, and monitoring conducted at the appropriate scale and intensity should be used to test this assumption. Even if these criteria are achieved, continued management of the four invertebrates may be necessary to control the threats that otherwise might create a need to relist. Each species should be considered, separately, for downlisting or delisting when the following objectives and criteria have been met.

Objective 1 – Secure and maintain the long-term survival of each species with the appropriate number, size, and distribution of resilient management units.

Downlisting Criterion 1: Maintain the presence of each species in the occupied management units as of the start of this plan, with a stable or increasing average trend in density over 10 years at currently monitored management units (1 and 3).

Delisting Criterion 1: Maintain the presence of each species in the occupied management units as of the start of this plan, with a stable or increasing average trend in density over 20 years in management units (1 and 3).

Justification for Criteria 1: Current monitoring in management units 1 and 3 (Figure 1) is designed to cover the range of elevational gradients and habitats across the spring systems at BLNWR and indicate trends across the entire system (all management units). Given a reasonable expectation of available staff and resources, future monitoring will remain focused on the most "at risk" management units (1 and 3). Management unit 1 (Figure 8) contains Bitter Creek and Sago Springs which occur at the top of the watershed and have the greatest risk of drying. Management unit 3 (Figure 12) contains the Snail Unit which is near the lower end of the watershed and has the least risk of drying. Within the spring system at BLNWR, higher elevations are more likely to become dry and have a weaker connection to groundwater than lower elevations. To accommodate high temporal and spatial variation in invertebrate presence and density across small scales, this criterion focuses on maintaining invertebrate presence in all currently occupied management units and average densities within two representative management units. Density of each species within monitored management units will be measured, with sufficient sample size, using a peer reviewed protocol which is currently under development. A trend in density is defined as the average change in density over a period of time. For downlisting purposes, a stable to increasing trend over a 10-year period is considered sufficient to observe most periodic threats like drought. For delisting purposes, a 20-year period is considered sufficient to monitor the effect of threats like major drought (Butler and Tashjian 2016). We define persistence as a stable to increasing population over 10- and 20-year time frames as surrogates for measures of the populations resiliency. For example, if the population persists for 10 years, then we know it is resilient enough to withstand typical drought conditions. If the population persists for 20 years, then we know it is resilient enough to withstand major drought conditions. Monitoring will also address relationships between water flow, water quality, and substrate characteristics to inform thresholds for management action. There are several sink holes in the BLNWR wilderness that could potentially serve as habitat for any or all of the four invertebrates. If species are located, the new sites could be incorporated into existing or identified as additional management units, potentially increasing the documented species redundancy.

Objective 2 – Protect water quantity

Downlisting Criterion 2: Develop, implement, and fulfill a water management plan or equivalent conservation agreement, supported by the local irrigation district and other partners, that ensures adequate surface and groundwater levels to 1) sustain downlisting criteria measured by Criterion 1 above, and 2) meet or exceed BLNWR's minimum federally reserved water right flow (0.0042 m^3/s (0.15 cfs) for 10 years.

Delisting Criterion 2: Develop, implement, and fulfill a water management plan or equivalent conservation agreement, supported by the local irrigation district and other partners, that ensures adequate surface and groundwater levels to 1) sustain delisting criteria measured by Criterion 1 above, and 2) ensure that the flows in Bitter Creek as measured at the Bitter Creek Flume are greater than 0.007 m^3/s (0.25 cfs) for 20 years.

Justification for Criteria 2: Natural spring and subsurface flows capable of supporting resilient invertebrate populations (those populations identified in Objective 1) should be ensured over at least 20 years, because sufficient, long-term water quantity is critical to the survival of these aquatic invertebrates. The most critical period of time for the invertebrate populations is the growing season (May through August) when flows in Bitter Creek are at a minimum. Federal water rights exist for BLNWR which provide assurances of minimal flows in the spring system within the bounds of priority administration by the New Mexico Office of the State Engineer (as measured at the Bitter Creek Flume site). During the period April 1995–July 2015, discharge at the Bitter Creek Flume was at or above the summer minimal flow of 0.0042 m^3/s (0.15 cfs) as indicated by the federally reserved water right during 97.5 percent of the time. During this same period, the growing season's mean monthly discharge for the Flume was 0.007 m^3/s (0.25 cfs). By working with the local irrigation district and other partners to establish a management plan for this water right, a mechanism can be established that will benefit the invertebrates and other valued resources. During drought, measures are established to ensure that flows do not drop below critical levels resulting in no negative impact on invertebrate populations. Maintaining criteria 2 will be measured using 1) monitoring results and trends as indicated by Criterion 1, as this provides an objective and measureable benchmark by which we can gauge progress in attaining these criteria, and 2) hydrologic and habitat data from each management unit.

Objective 3 – Protect water quality

Downlisting Criterion 3a: Long-term commitments (Conservation Agreements etc) are in place and will continue to maintain sufficient water quality protections for 10 years, and water quality sustains each species as measured by Criterion 1 above.

Delisting Criterion 3a: Long-term commitments (Conservation Agreements etc) are in place and will continue to maintain sufficient water quality protections for 20 years, and water quality sustains each species as measured by Criterion 1 above.

Justification for Criteria 3a: Water quality constituents need to be permanently maintained below exposure levels (that is, concentrations, durations, and combinations of these) that could have a negative impact on invertebrate populations and sites identified in Objective 1. Negative impacts include direct lethal or sublethal effects, such as effects on reproduction, growth, development, or metabolic processes as demonstrated on individuals or developmental life stages. Specific exposure levels (e.g., salinity levels, temperature ranges, and water contamination level thresholds) will be identified as part of the recovery actions section. Monitoring water quality will be achieved using monitoring protocol outlined in Criterion 1.

Downlisting Criterion 3b: Long-term commitments (Conservation Agreements etc) are in place that would specifically address the four invertebrates and reduce the risk of a catastrophic spill occurring within a drainage or recharge area occupied by any of the four invertebrates for 10 years.

Delisting Criterion 3b: Long-term commitments (Conservation Agreements etc) are in place that would specifically address the four invertebrates and reduce the risk of a catastrophic spill occurring within a drainage or recharge area occupied by any of the four invertebrates for 20 years.

Justification for Criteria 3b: Because the four invertebrates tend to occur in clusters or discrete locations and are relatively immobile, any natural or human created catastrophic exposure event to their immediate environment could extirpate populations, depending on the scope of the exposure. To reduce the possibility of this occurring, long-term commitments need to be developed and implemented when necessary to ensure protection of the invertebrates if a spill occurs at or near management units. On BLNWR, strategies for addressing catastrophic spills will follow guidelines based on those that are in place for the Pecos gambusia (Service 1983).

Objective 4 – Protect and restore habitat that supports invertebrate populations

Downlisting Criterion 4: A habitat management plan is developed and implemented that ensures that the environment remains as suitable habitat that sustains each species for 10 years.

Delisting Criterion 4: A habitat management plan is developed and implemented that ensures that the environment remains as suitable habitat that sustains each species for 20 years.

Justification for Criterion 4: Because the four invertebrates are limited in their range and habitat requirements, protecting habitat in areas surrounding occupied sites from erosion, development, and invasive species is necessary to maintain resilient invertebrate populations. Invasive plants, principally saltcedar, common reed, kochia, and Russian thistle (tumbleweeds), can alter stream flows degrading water quality, and change soil and water chemistry making habitat less suitable. These plants outcompete native plants that are often plants preferred by the four invertebrates. Aquatic habitat can become compromised by invasive invertebrate colonization, algal blooms, and siltation. Additionally, urban and oil and gas development in areas upstream of occupied management units has the potential to negatively impact the invertebrates by decreasing both water quantity and water quality. Therefore, a habitat management plan should be implemented to protect the invertebrates from habitat alterations and achieve Criterion 1. This plan should include working with adjacent landowners to help minimize threats to the four invertebrate's habitat.

3.0 RECOVERY ACTIONS

This section provides a broad framework of activities that are necessary to achieve recovery. The actual on-the-ground activities or specific tasks will be included in separate Recovery Implementation Action Plans. These action plans are intended to be adaptable operational plans stepped-down from recovery plan actions. We intend to develop these action plans and specific activities with our conservation partners to design tasks that are feasible, effective, and take our partners' interests and abilities into consideration.

The actions described below apply to all four invertebrate species, unless otherwise specified. Implementation of this recovery plan is strictly voluntary and dependent on the cooperation and commitment of numerous partners in conservation.

The actions needed to meet recovery criteria are organized below into six categories that are ranked in order of urgency: 1) ensure adequate water quantity, 2) protect and improve water quality, 3) protect and restore habitat, 4) design a long term monitoring strategy that will inform the post delisting monitoring plan, 5) establish emergency captive rearing programs, and 6) develop a post de-listing monitoring plan. These rankings are primarily based on our assessment of the scope, magnitude, and imminence of the threats impacting the four invertebrate species. Actions that address threats of higher magnitude and scope are considered more urgent compared to other actions. While this ranking will guide where we proactively focus our attention in the recovery process, it does not imply that these actions are restricted to being completed in this particular order. For example, opportunities to address lower priority tasks will be considered if they arise before higher priority actions are completed. Although other threats, such as predatory invasive species do not have the same level of urgency they will continue to be addressed

3.1 Ensure Adequate Water Quantity

3.1.1 Gather information necessary to ensure adequate water quantity

Additional information needs to be gathered and evaluated to ensure adequate water quantity in MUs at levels that protect the four invertebrate species and their habitat. This will involve determining recharge areas and patterns; developing watershed models; continued monitoring of aquifer levels and spring flow under normal and drought conditions; modeling the impact of climate change on aquifer levels and spring flows; and determining water quantity requirements for each species.

3.1.2 Implement measures to provide adequate water quantity

To protect habitat, a comprehensive approach to watershed management would be beneficial in protecting water quantity. This should include a regional aquifer management plan and the protection of aquifer recharge features. Long-term commitments need to be in place to ensure that these protections will continue over at least 25 years.

3.1.3 Evaluate the effectiveness of measures to provide adequate water quantity

Long-term water quantity monitoring should be in place to evaluate how well the implemented measures are protecting water quantity. This monitoring campaign will include utilizing the aquifer level data being collected by the Pecos Valley Artesian Conservancy District and measurement at the Bitter Creek Flume by the U.S. Fish and Wildlife Service. Additional data on the variability of flows in Bitter Creek and other spring features at BLNWR will be collected. These data will be placed into a management framework that identifies critical aquifer levels and associated on-the-ground habitat conditions.

Combined, these actions will ameliorate the impacts of threats associated with loss of water quantity (i.e. drought, ground water pumping, climate change) by identifying water quantity needs, ensuring adequate water levels to protect the species and its habitat, and by monitoring the conservation measures to ensure they are effective.

3.2 Protect and Improve Water Quality

3.2.1 Develop plans to minimize catastrophic water quality threats

Information should be gathered and evaluated to design measures that minimize the risk of catastrophic water quality degradation. Plans should be developed to reduce the risk of spill, in addition to reducing the impacts of spills through containment within the watersheds occupied by the four species of invertebrates. Recovery Action 3.5.1 addresses planned rescues of invertebrates during times of high risk.

3.2.2 Determine potential effects of different levels of water quality constituents and contaminants on the four invertebrates, their food sources, and habitats

Water quality constituent levels (including the durations, concentrations, and the combinations of these) that could negatively affect the four invertebrate species should be identified. Target or threshold levels of water quality constituents needed to ensure long-term protection of the species should also be identified. The information collected through the implementation of this recovery action should be used in comparison to water quality monitoring data to help determine when water quality degradation has occurred or if the water quality of occupied sites is adequate to sustain the populations of four invertebrate species in their natural environments.

3.2.3 Implement effective measures in place to avoid chronic water quality degradation

Measures to avoid or limit chronic water quality degradation should be developed, implemented, and when needed, modified to ensure their effectiveness. These measures could involve land acquisition, conservation easements, best management practices, buffer zones, outreach programs, and numerous other tools.

3.2.4 Monitor the physical and chemical constituents (sediment, salt, nutrients, and contaminants) present during baseflow and stormflow conditions

Information should be collected on the physical and chemical constituents of greatest concern during baseflow and stormflow conditions. This research should also be designed to evaluate the effectiveness and modify (if necessary) the measures that avoid or minimize water quality degradation.

3.2.5 Develop a tool for assessing the risk of surface water and groundwater contaminant spills

Information should be collected about potential activities that could lead to a contaminant spill within the surface water drainage and the ground water source area for the MUs. This information should be integrated into a decision tool that would define measures to minimize this risk and define when enough of these measures are in place to determine that the risk of contamination is negligible.

The threats addressed by developing and implementing water quality measures are: impacts from oil and gas development and activities, impacts from urbanization, impacts from invasive species such as golden algae, and impacts from other contamination sources. Understanding how such threats impact these species and their habitat and having plans to reduce the potential for occurrence and the severity of their impacts will allow us to better buffer these invertebrate species from degradation of water quality. Monitoring for changes in water quality may provide the opportunity to address declining water quality prior to reaching harmful levels or to rescue species before they are impacted.

3.3 Protect and Restore Habitat

3.3.1 Protect sensitive habitat areas

Invertebrate MUs should be protected from surface disturbing activities that would increase erosion and decrease habitat suitability. It is recommended that areas that are accessible by the public or livestock be fenced to avoid surface disturbance at occupied sites. Invertebrate MUs should be monitored to evaluate effectiveness of protective measures and modify them if necessary.

3.3.2 Restore degraded surface sites

Sites that have been degraded by surface disturbance should be restored. This may include such activities as restoring substrate, restoring riparian or bank vegetation to limit erosion, and removing nonnative, invasive vegetation such as saltcedar, common reed, kochia, and Russian thistle (tumbleweeds). Completed restoration efforts should be monitored to determine the effectiveness for the four invertebrates so as to build on successful restoration actions.

The threats addressed by developing and implementing habitat restoration are: habitat fragmentation, fire, climate change and drought, invasive species, and limited habitat availability. These actions will reduce the likelihood that habitat is disturbed or damaged rendering it unsuitable and restore habitat that is currently or may become unsuitable in the future.

3.4 Conduct Research and Monitoring to Acquire Demographic, Life History, and Threat Response Information to Improve Management and Recovery

3.4.1 Develop and implement monitoring protocols to capture presence/absence and density measurements to determine whether recovery criterion 1 is achieved.

One of the goals of the monitoring effort will be to develop thresholds for adaptive management actions; however, it will take several years of monitoring to accumulate the data necessary to develop thresholds.

3.4.2 Establish long-term monitoring programs to track population trends and habitat trends over time

Information on the density or presence/absence (depending on how MUs are prioritized for monitoring in protocols) found at each MU should be collected during annual surveys, along with associated habitat data. It is imperative to monitor population responses to habitat restoration, water levels, and other habitat changes, along with surveying new sites for occupancy. The protocol will address timely data entry, data management, and reporting. Data will be maintained by the refuge and on the FWS data repository (FWS Service Catalog: U.S.

Fish and Wildlife ECOS website) where it can be accessed by BLNWR, National Wildlife Refuge System-Biological Services, and the New Mexico Ecological Services Field Office.

3.4.3 Implement research and monitoring to evaluate habitat preference, particularly with regard to spring source proximity and influence

The four invertebrates may have different requirements with respect to habitat, including spring influence, hydrology, substrate, and vegetation. These data may guide future restoration efforts and conservation actions, such as translocations to potential sites or MUs.

3.4.4 Evaluate population viability to determine life history characteristics that address population dynamics (such as intrinsic rate of increase/decrease and population viability) of the four invertebrate species

Information such as effective population size, extinction probability, longevity, reproduction rates, survival rates, mortality rates, and density-dependence would inform species specific risk assessments. This information will be useful in estimating the probability of persistence of invertebrate populations.

Additionally, species specific habitat requirements should be refined. Much of the existing information on the environmental parameter requirements (water temperature, pH, substrate, etc.) for each species was collected during opportunistic sampling efforts. Improved knowledge pertaining to habitat and environmental parameters associated with each species would improve the ability to make informed conservation decisions.

The utility of using environmental DNA to evaluate springsnail species composition (ratio of Roswell to Koster's), site occupancy (presence/absence), habitat requirements, and density estimates should be assessed. Environmental DNA may prove to be a nondestructive method of monitoring.

3.4.5 Estimate the probability of persistence for populations

The probability of persistence over 20 years for all four invertebrate species should be evaluated with peer-reviewed analyses. These analyses will help determine if Recovery Objective 1 has been met.

3.4.6 Implement research programs to determine the effects of invasive species (plants and animals) on the four invertebrate species

Determine if invasive species pose significant risk to species recovery. If it is determined that invasive species would impact the probability of persistence for any of the MUs, measures should be developed to mitigate these threats.

3.4.7 Survey unoccupied habitat for additional populations

An initial assessment of available aquatic habitats (specifically sinkholes) on and adjacent to BLNWR can be completed using aerial images. Areas identified as potential habitat should be surveyed to determine suitability (e.g. water quality) and occupancy. Discovery of additional suitable habitat, whether occupied or unoccupied, could result in 1) identification of sites for release of captive reared individuals, 2) incorporation of occupied sites into existing MUs, or 3) designation of new MUs. Such results may increase the species probability of persistence.

Monitoring is meant to capture the status of the species and habitat, in order to know if any threats are continuing to impact any or all of the species. Continued monitoring will provide managers with the information necessary for determining if further actions should be taken to alleviate specific threats.

3.5 Establish an Emergency Propagation and Contingency Plan

3.5.1 Develop a comprehensive captive propagation and contingency plan (CPCP) for the four species consistent with the Service's "Policy Regarding Controlled Propagation of Species Listed Under the Endangered Species Act" (Service and NOAA 2000: entire)

A comprehensive CPCP should be developed to guide captive maintenance and breeding programs and a reintroduction strategy for all four species of invertebrates. The goal of the captive propagation portion of the CPCP will be to outline the steps necessary to provide representation of the genetic characteristics of the wild populations should reintroduction be necessary.

The contingency portion of the CPCP also will establish the collection targets and protocols needed to respond to crisis situations. Contingency planning should not be delayed until the completion of genetic, breeding, and reintroduction studies, but should be updated as these studies are completed. The CPCP should be developed in coordination with agencies that would likely be involved with the collection efforts, including BLNWR, City of Roswell, New Mexico Department of Game and Fish, Texas Parks and Wildlife Department (TPWD), and experts from academic institutions with expertise in determining collection levels that will represent enough genetic diversity to keep the population viable.

The CPCP needs to address four situations: 1) captive rearing during non-crisis times in the event of a rapidly developing crisis when there is no time to collect wild animals; 2) collection and captive rearing of animals as a response to a rapidly developing crisis in which there is time to collect additional wild animals; 3) collection and captive rearing of animals in response to a slowly developing crisis; and 4) captive rearing of animals during non-crisis times without a developing crisis (standard operating procedures).

Identifying facilities interested in participating in both the captive propagation and contingency portions of the CPCP is necessary for its success. Institutions involved in collection efforts would need to hold appropriate state and Federal permits. For each facility, a Participation Plan should be developed in coordination with the Service that outlines the level of commitment to cooperate (long-term versus short-term holding facilities), personnel willing to collect and transport animals, research to be conducted, and level of information to be collected. The CPCP and Participation Plans should be periodically reassessed (for example, annually) and altered as necessary.

The establishment of an emergency propagation and contingency plan will address the threat of losing entire management units to catastrophic events. This will address the emergency threat of water quantity (springs drying or limited flow), water quality (contaminant events such as oil spills), habitat fragmentation or isolation, or habitat loss.

3.6 Design Post-Delisting Monitoring

3.6.1 Develop a post-delisting monitoring plan

Section 4 (g) (1) of the ESA requires that the Service monitor the status of all recovered species for at least 5 years following delisting to ensure the recovery of the species. A post-delisting monitoring plan should be developed by the Service in cooperation with NMDGF, TPWD, and other appropriate entities. This plan should outline the indicators that will be used to assess the status of the four invertebrate species (considering population numbers and threats monitoring), develop monitoring protocols for those indicators, and evaluate factors that may trigger consideration for relisting.

4.0 RECOVERY IMPLEMENTATION SCHEDULE

The following implementation schedule outlines priorities, potential or responsible parties, and estimated costs for the specific actions for recovering Pecos assiminea, Roswell springsnail, Noel's amphipod, and Koster's springsnail. It is a guide to meeting the goals, objectives, and criteria from Part II of this recovery plan. The schedule 1) lists the specific recovery actions, corresponding outline numbers, the action priorities, and the expected duration of actions; 2) recommends agencies or groups for carrying out these actions; and 3) estimates the financial costs for implementing the actions. These actions, when complete, should accomplish the goal of this plan—recovery of Pecos assiminea, Roswell springsnail, Noel's amphipod, and Koster's springsnail.

We estimate the time required to accomplish recovery of Pecos assiminea, Roswell springsnail, Noel's amphipod, and Koster's springsnail is 20 years to achieve all of the actions and meet the recovery criteria included in this recovery plan, and the cost to recovery (delisting) is estimated to be $880,000. The time estimated to downlist the four invertebrates is 10 years, with an estimated cost of $830,000, because the majority of the expenses occur during the first 5 years of recovery implementation, as illustrated in the Implementation Schedule below. We made efforts to the maximum extent practicable to estimate costs for recovery of Pecos assiminea, Roswell springsnail, Noel's amphipod, and Koster's springsnail. The amount in the Total Cost column for each action is calculated based on the duration of that action until recovery.

The value of this plan depends on the extent to which it is implemented. The recovery of the Pecos assiminea, Roswell springsnail, Noel's amphipod, and Koster's springsnail is dependent upon the voluntary cooperation of other organizations and individuals who are willing to implement the recovery actions. The implementation schedule identifies agencies and other potential "responsible parties" (private and public) to help implement the recovery of these species. This plan does not commit any "responsible party" to carry out a particular recovery action or to expend the estimated funds. It is only recognition that particular groups may possess the expertise, resources, and opportunity to assist in the implementation of recovery actions. Although collaboration with private landowners and others is preferred in the recovery plan, no one is obligated by this plan to any recovery action or expenditure of funds. Likewise, this schedule is not intended to preclude or limit others from participating in this recovery program.

The cost estimates provided are not intended to be a specific budget but are provided solely to assist in planning. The total estimated cost of recovery, by priority, is provided in the Executive Summary. The schedule provides cost estimates for each action on an annual or biannual basis. Estimated funds for agencies included only project-specific contract, staff, or operations costs in excess of base budgets. They do not include ordinary operating costs (such as staff) for existing responsibilities.

Priorities in column 1 of the following implementation schedule are assigned using the following guidelines (Table 9):

Priority 1 – An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.

Priority 2 – An action that must be taken to prevent a substantial decline in species population/habitat quality or some other substantial negative effect short of extinction.

Priority 3 – All other actions necessary to meet the recovery objectives.

The assignment of these priorities does not imply that some recovery actions are of low importance, but instead implies that lower priority items may be deferred while higher priority items are being implemented.

Table 9. Implementation schedule for four New Mexico invertebrate species: Roswell springsnail, Koster's springsnail, Pecos assiminea, and Noel's amphipod.

Priority Number	Action Number	Action Description	Species Benefitting	Action Duration (Years)	Responsibility			Cost Estimate by FY (by $1,000s)					
					Parties	Lead Agency	Total Cost ($1,000s)	2019	2020	2021	2022	2023	Comments
1	1.1	Develop habitat and water manageme nt plan	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	2	Service	Service	10	5	5	0	0	0	This action relates to Recovery Criteria 4
1	1.1	Gather information necessary to ensure adequate water quantity	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos	3	Service , Externa l Researc hers	Service	50	10	40	0	0	0	This action relates to Recovery Criteria 2

			Wherever found										
1	1.2	Implement measures to provide adequate water quantity	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	10	Service, TNC, State	Service	300	0	0	100	100	100	This action relates to Recovery Criteria 2
2	1.3	Evaluate the effectiveness of measures to provide adequate water quantity	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	10	Service, External Researchers	Service	20	0	0	0	10	10	This action relates to Recovery Criteria 2

1	2.1	Develop plans to minimize catastrophic water quality threats	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	3	Service	Service	10	5	5	0	0	0	This action relates to Recovery Criteria 2, 3a, 3b
3	2.2	Conduct research to expand understanding of potential effects of different levels of water quality constituents, pollutants, and contaminants can have on the four species of invertebrates, their	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	3	Service, External Researchers	Service	80	0	40	40	0	0	This action relates to Recovery Criteria 3a, 3b

		food sources, and their habitats										
1	2.3	Put effective measures in place to avoid chronic water quality degradation	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	5	Service, TNC	Service	10	0	10	0	0	0	This action relates to Recovery Criteria 3a, 3b, 4
3	2.4	Monitor the physical and chemical constituents present during baseflow and stormflow conditions	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found,	10	Service, TNC, State	Service	10	0	0	0	10	0	This action relates to Recovery Criteria 4

			Assiminea pecos Wherever found										
3	2.5	Develop a tool for assessing the risk of surface water and groundwater contaminant spills	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	5	Service, TNC, State	Service	20	10		10	0	0	This action relates to Recovery Criteria 4
3	3.1	Manage habitat	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	10	Service, TNC, State	Service	95	55	10	10	10	10	This action relates to Recovery Criteria 4

2	3.2	Restore degraded surface sites	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	5	Service , TNC, State	Service	75	25	25	0	25	0	This action relates to Recovery Criteria 4
1	3.3	Maintain habitat protections	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	10	Service , TNC, State	Service	0	0	0	0	0	0	This action relates to Recovery Criteria 4
3	4.1	Implement research programs to determine	Gammarus desperatus Wherever found, Juturnia	10	Service , External	Service	120	80	40	0	0	0	This action relates to Recovery Criteria 1a

		patterns of genetic variation and life history characteristics that accurately predict population dynamics	kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found		Researchers								
3	4.2	Estimate the probability of persistence for populations	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	3	Service, External Researchers	Service	120	60	0	60	0	0	This action relates to Recovery Criteria 1a
1	4.3	Survey unoccupied habitat for additional populations	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis	3	Service	Service	20	10	10	0	0	0	This action relates to Recovery Criteria 1a, 1b

			Wherever found, Assiminea pecos Wherever found										
2	4.4	Establish long-term monitoring programs to track population trends and habitat trends over time	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	5	Service	Service	54	30	6	6	6	6	This action relates to Recovery Criteria 1a, 1b
1	5.1	Develop a comprehen sive captive propagatio n and contingenc y plan for the four invertebrat es	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos	5	Service	Service	75	50	25	0	0	0	This action relates to Recovery Criteria 1a, 1b

			Wherever found										
2	5.2	Establish and maintain captive breeding programs for each of the invertebrates	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	10	Service	Service	90	50	10	10	10	10	This action relates to Recovery Criteria 1a, 1b
3	6.1	Develop a post-delisting monitoring plan	Gammarus desperatus Wherever found, Juturnia kosteri Wherever found, Pyrgulopsis roswellensis Wherever found, Assiminea pecos Wherever found	3	Service	Service	10	0	0	0	0	10	This action relates to all Recovery Criteria

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6.0 APPENDIX

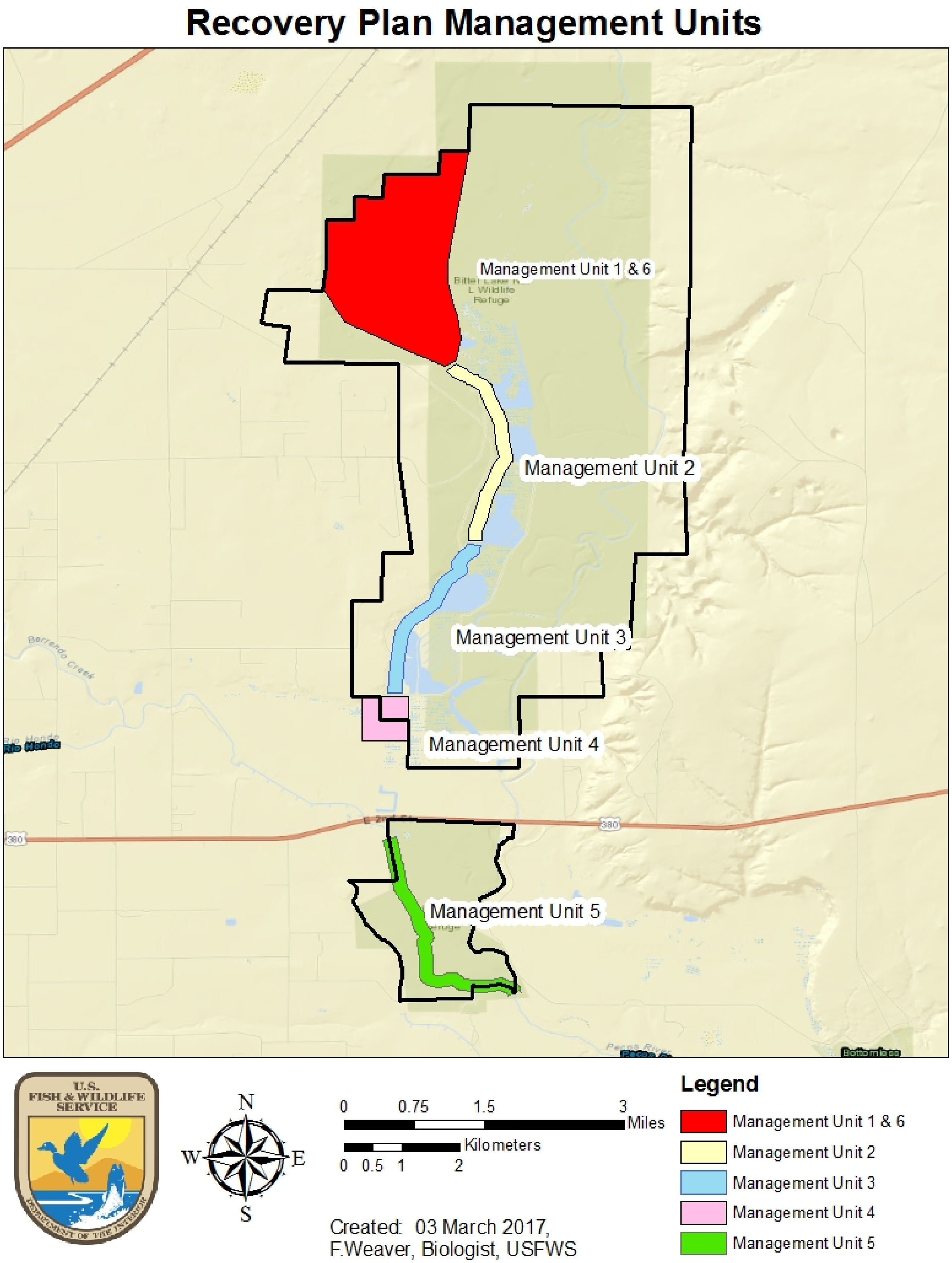

Figure 1. Recovery Plan Management Units on Bitter Lake National Wildlife Refuge.

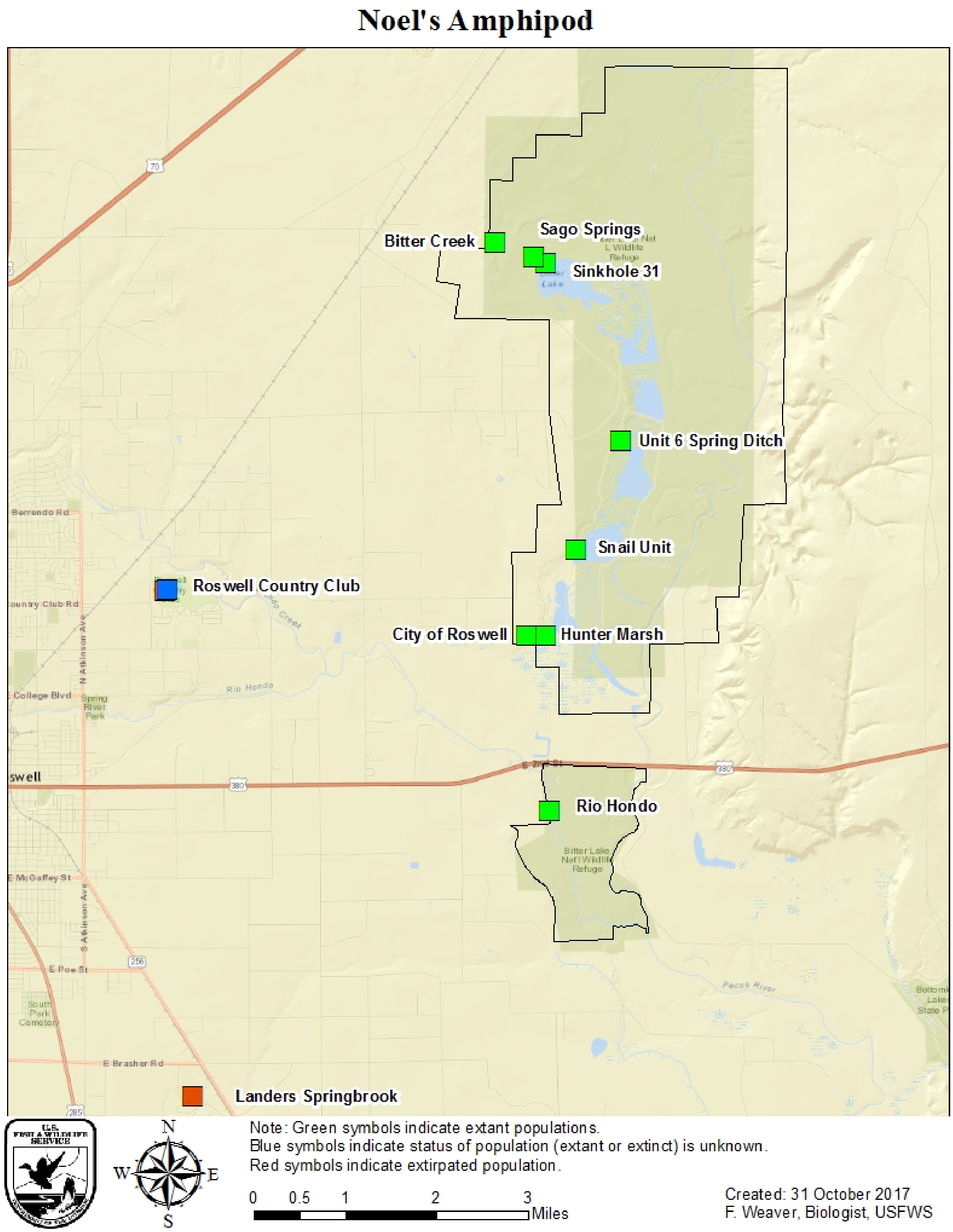

Figure 2. Noel's amphipod current and historical locations.

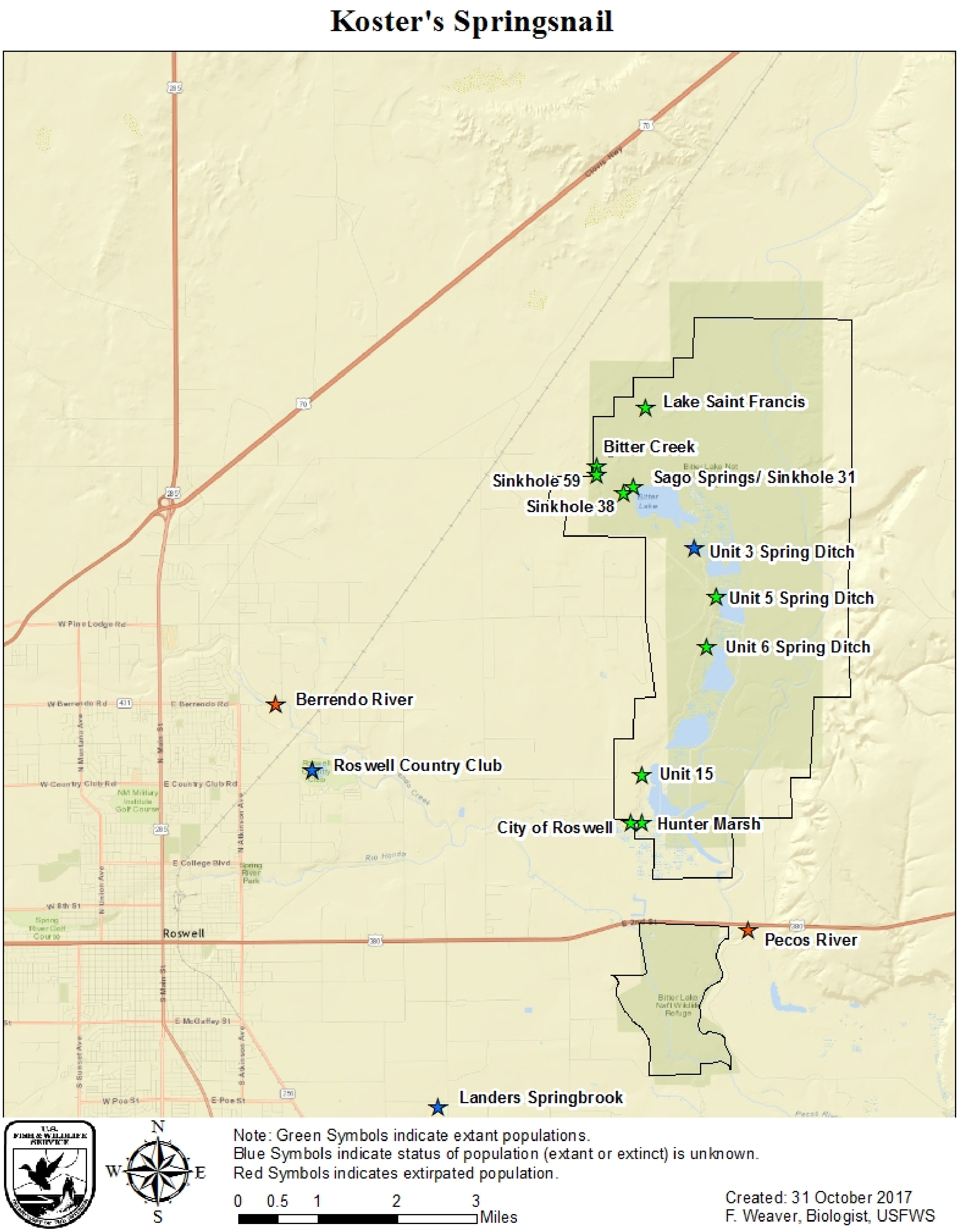

Figure 3. Koster's springsnail current and historical locations.

Roswell Springsnail

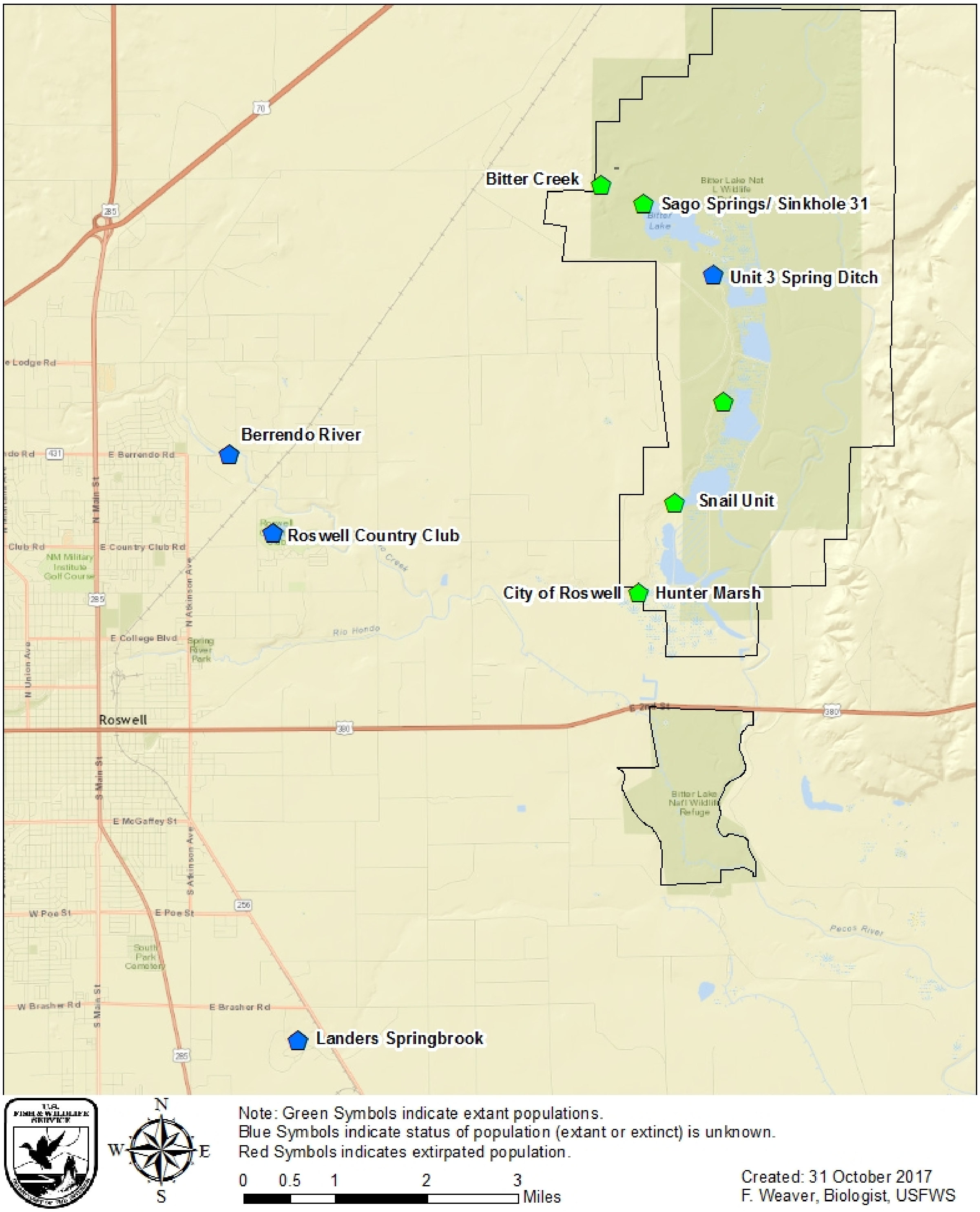

Figure 4. Roswell springsnail current and historical locations.

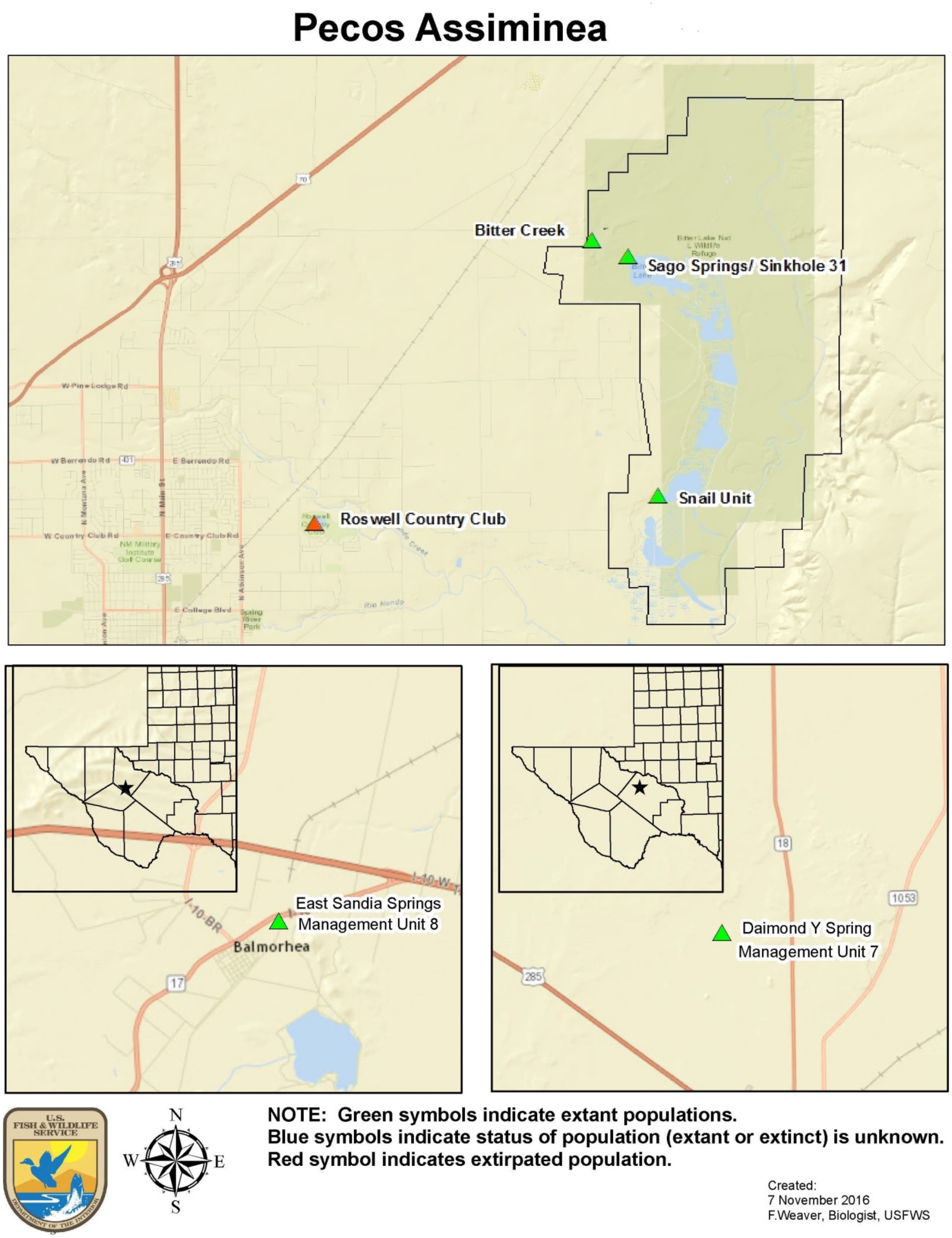

Figure 5. Pecos assiminea current and historical locations in New Mexico and Texas.

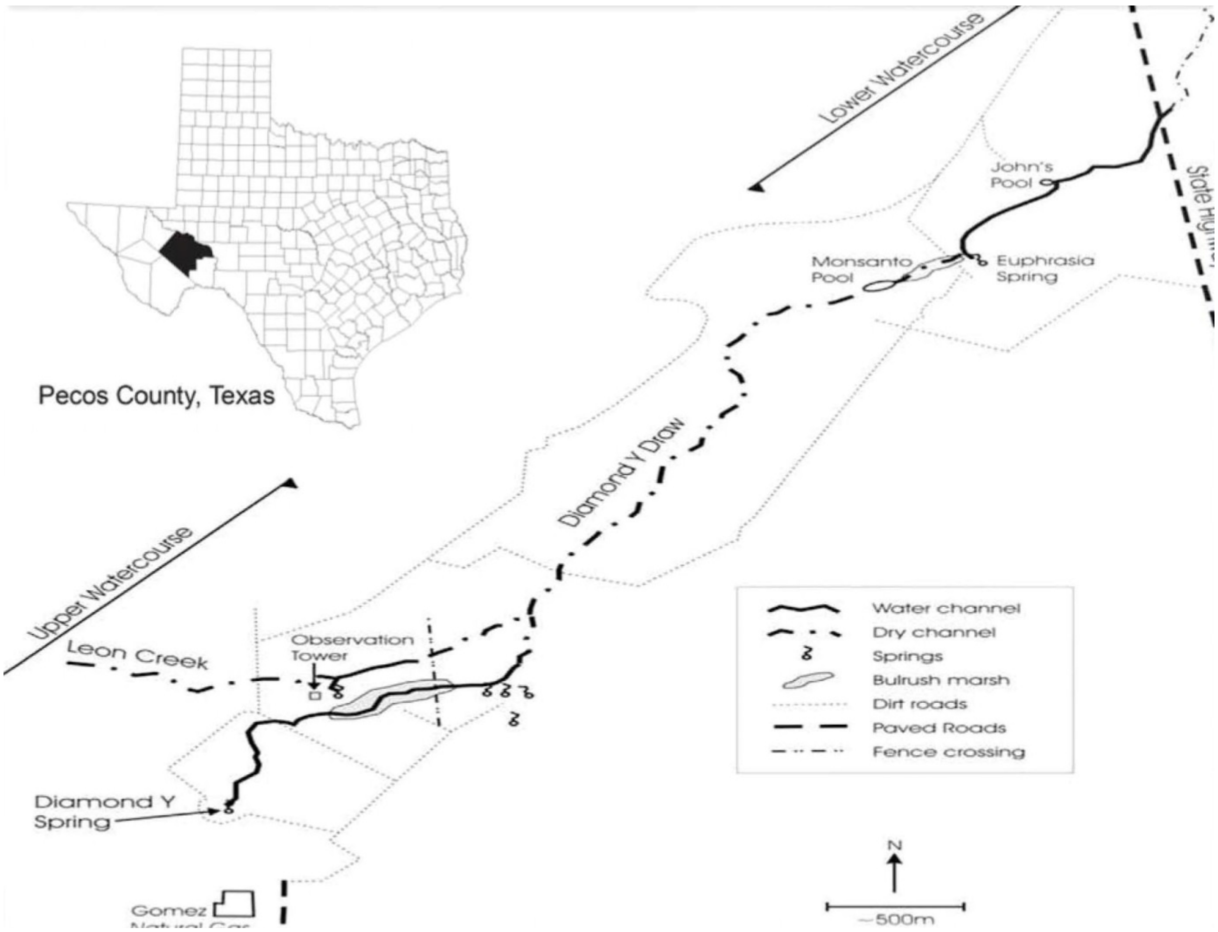

Figure 6. Pecos assiminea locations at Diamond Y Springs (after Service 2015b: 8) (Management Unit 7).

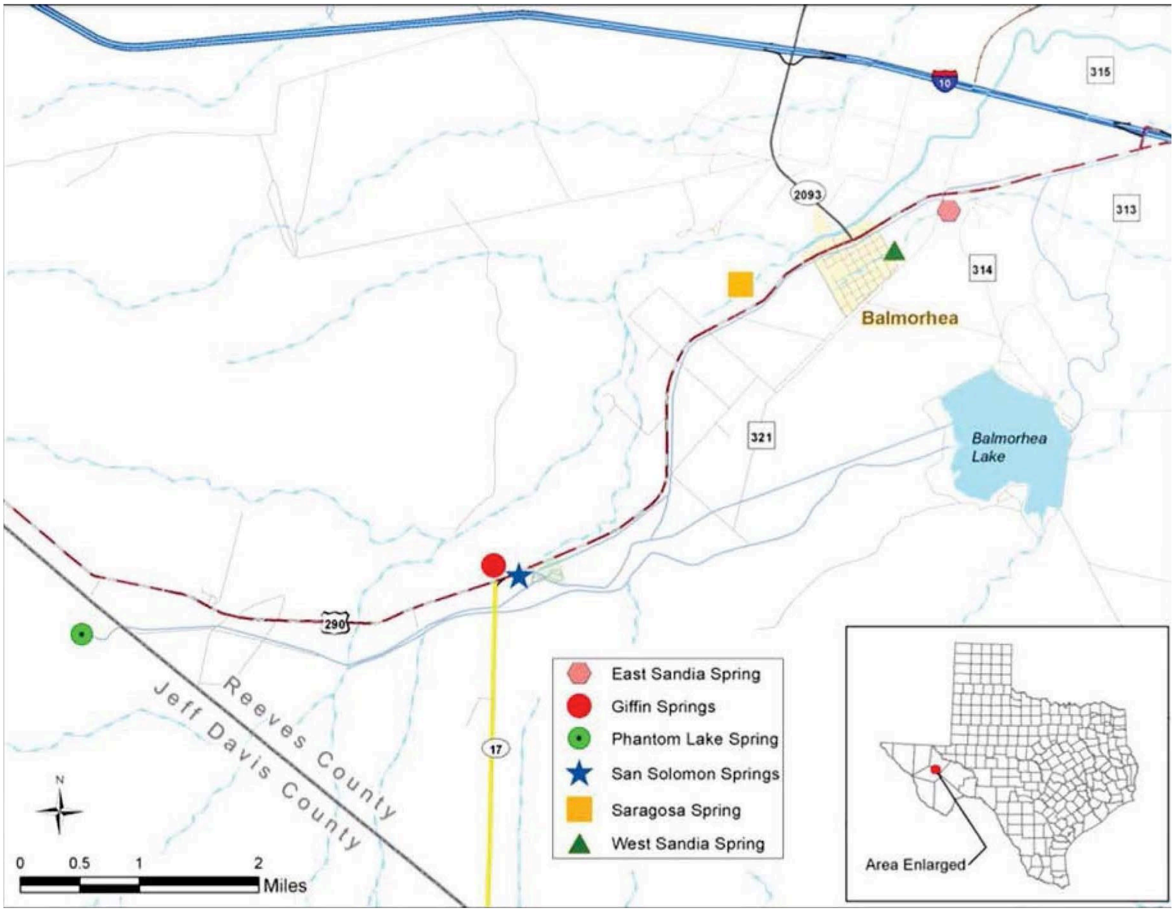

Figure 7. Pecos assiminea locations at East Sandia Spring part of the San Solomon Springs Complex, Texas (after Service 2015b: 6) (Management Unit 8).

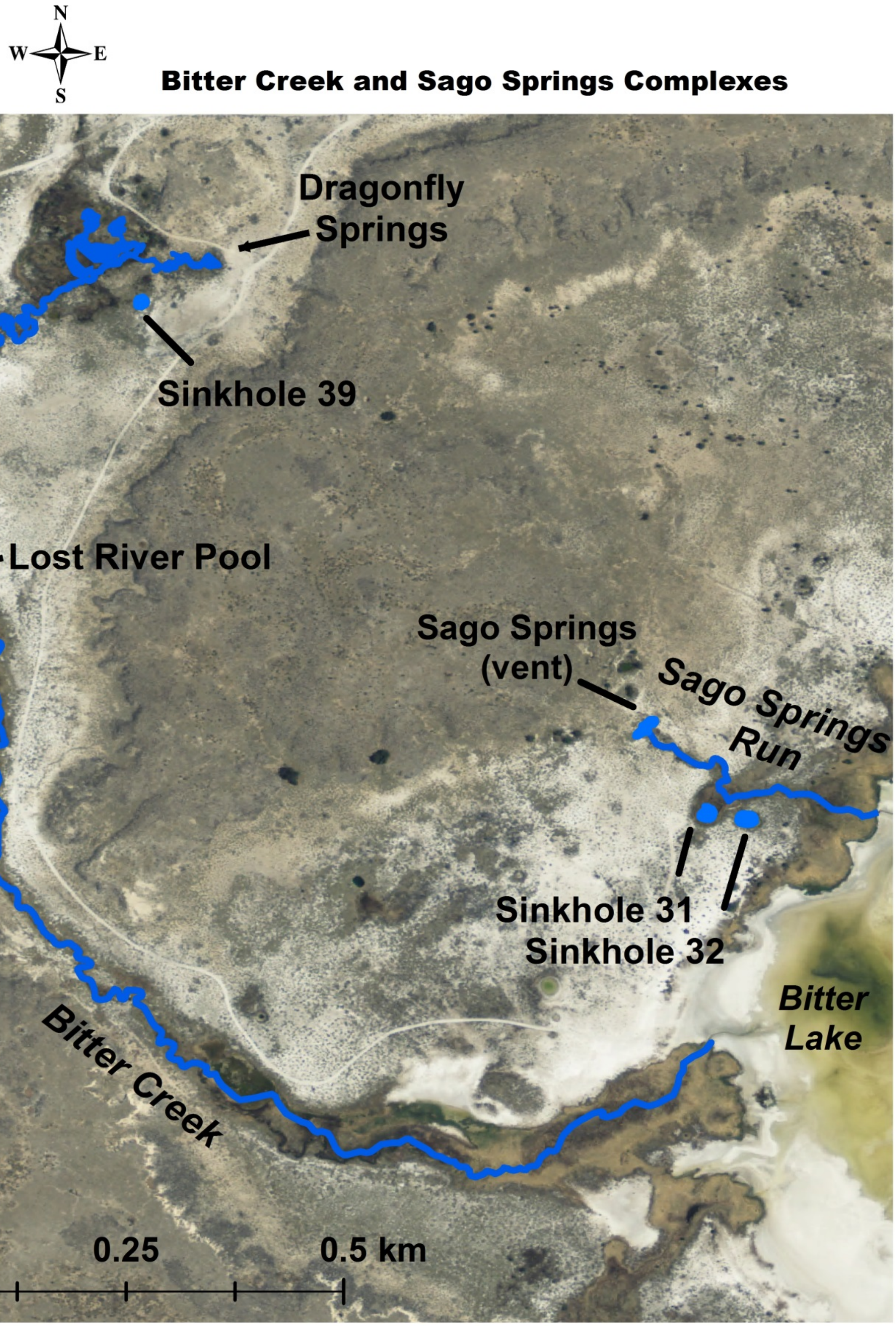

Figure 8. Bitter Creek and Sago Springs Complexes at Bitter Lake National Wildlife Refuge (Management Unit 1).

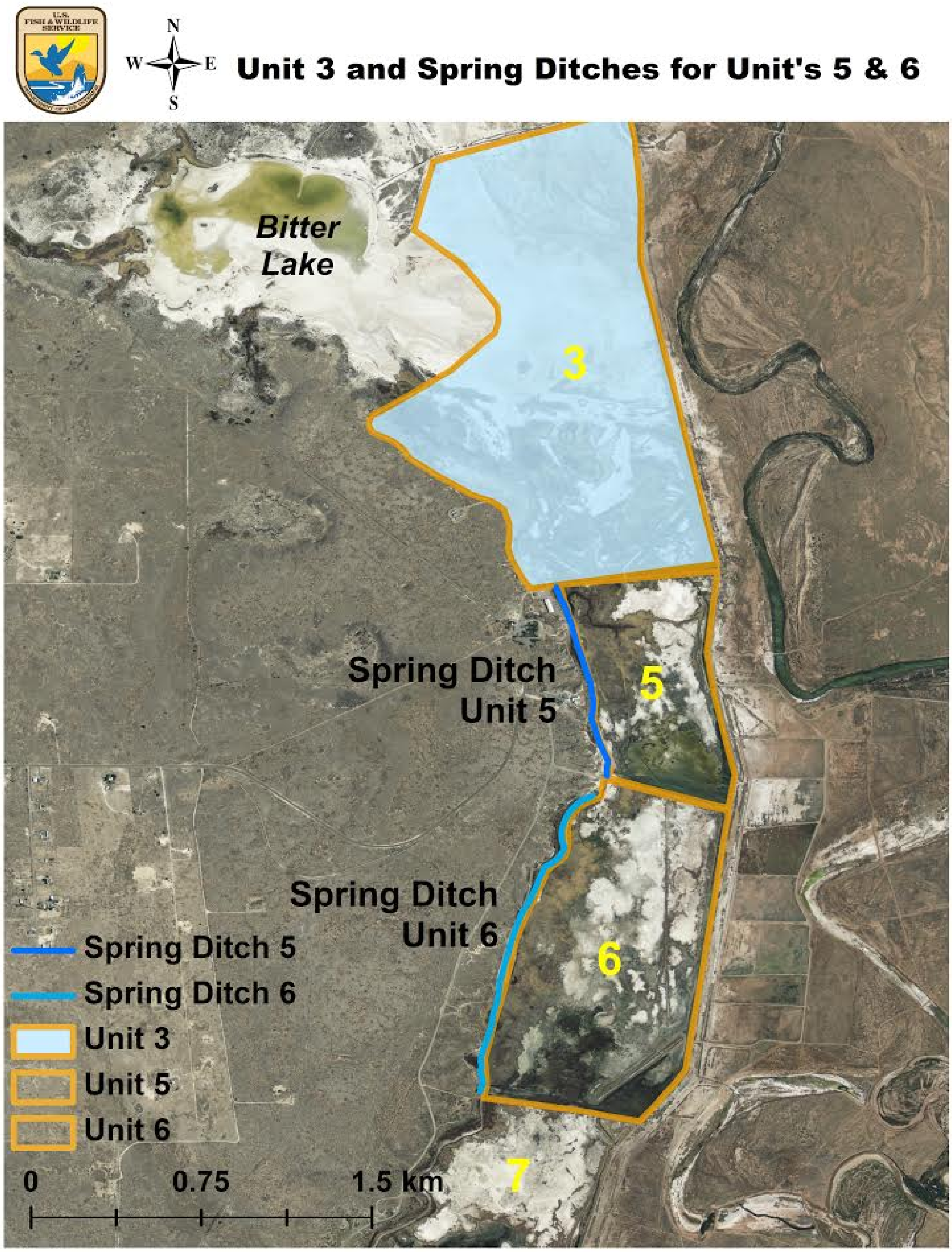

Figure 9. Unit 3, and Spring Ditches for Units 5, and 6 at Bitter Lake National Wildlife Refuge (Management Unit 2).

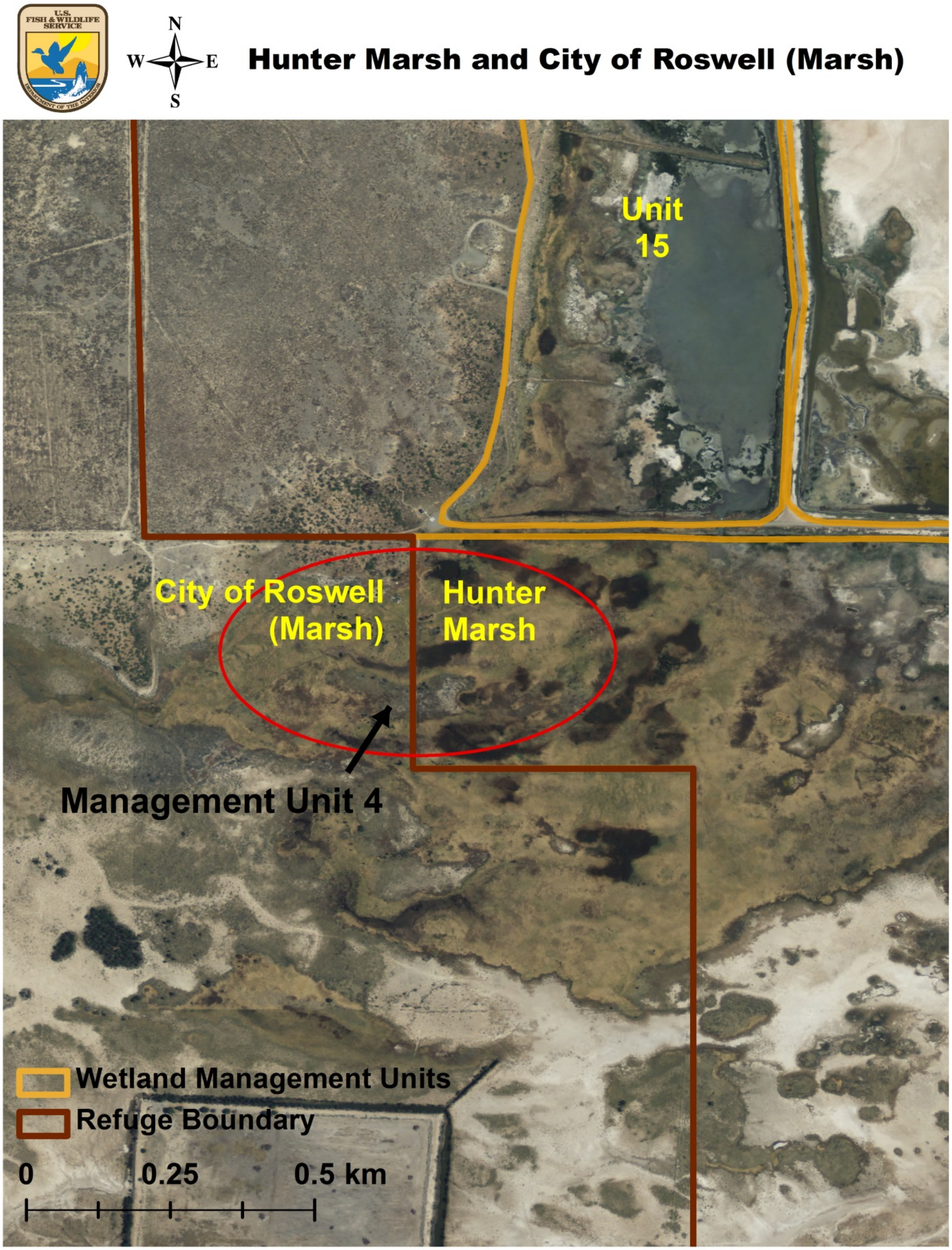

Figure 10. City of Roswell Property and Bitter Lake National Wildlife Refuge Hunter Marsh area (Management Unit 4).

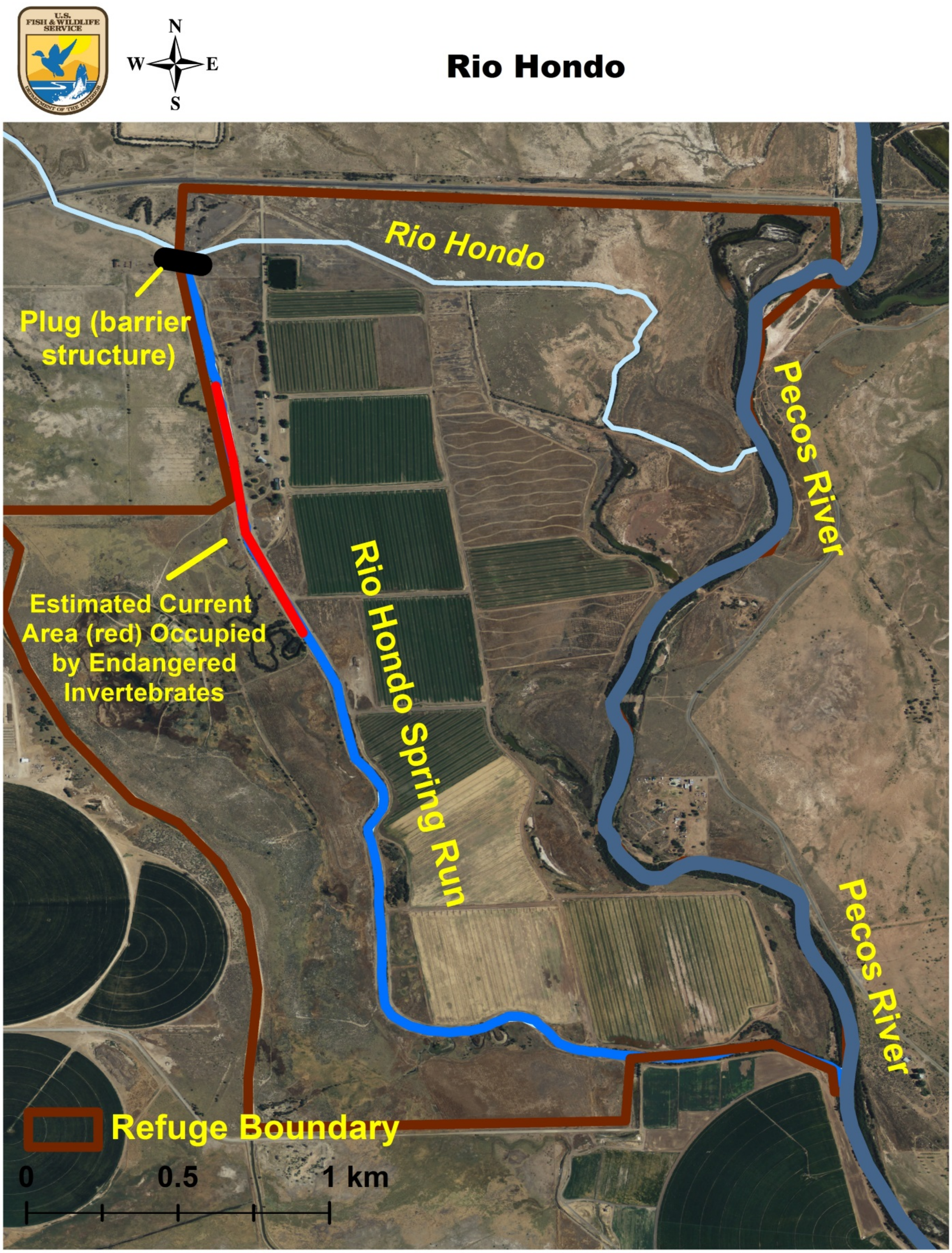

Figure 11. Bitter Lake National Wildlife Refuge Rio Hondo area (Management Unit 5).

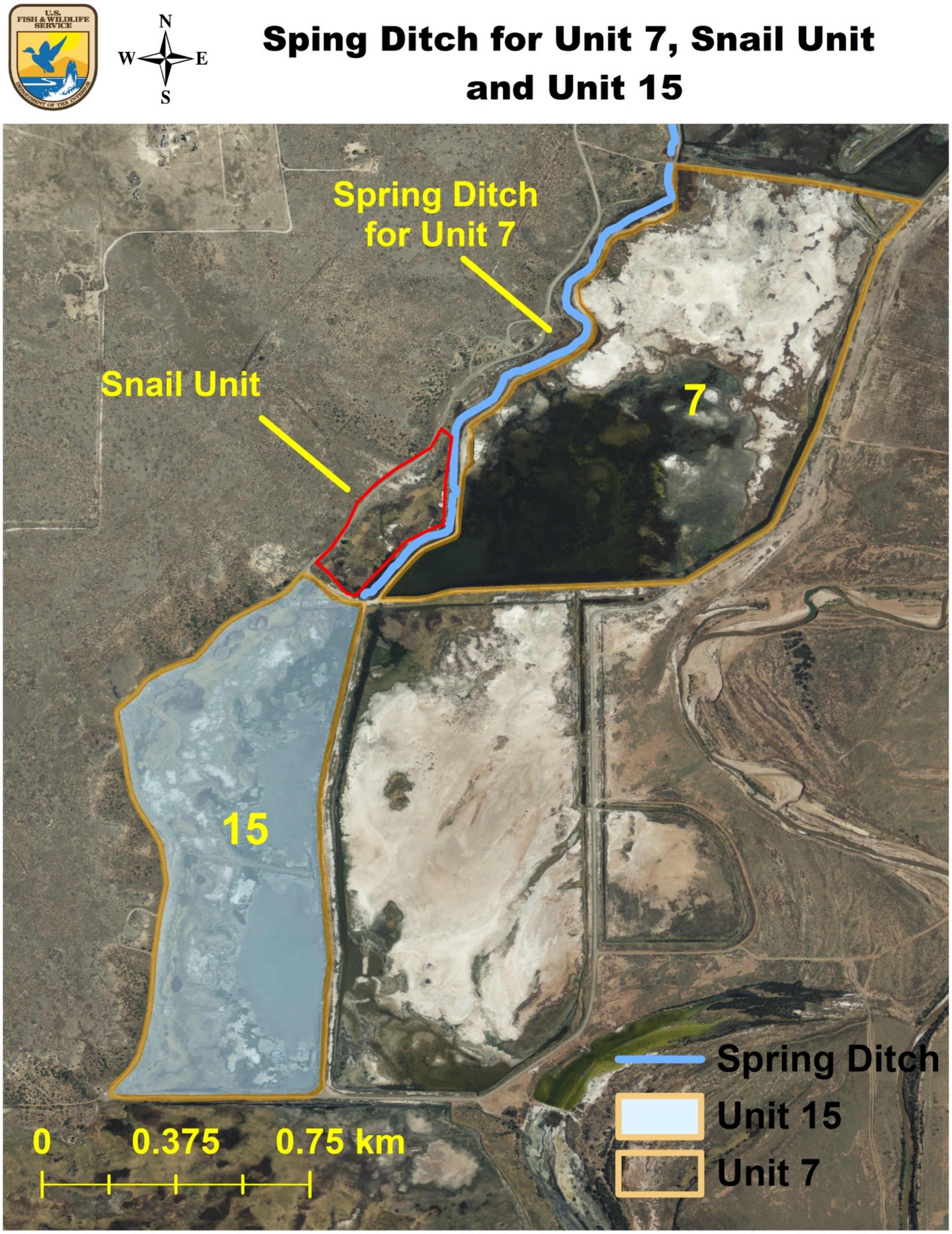

Figure 12. Spring Ditch for Unit 7, Snail Unit, and Unit 15 at Bitter Lake National Wildlife Refuge (Management Unit 3).

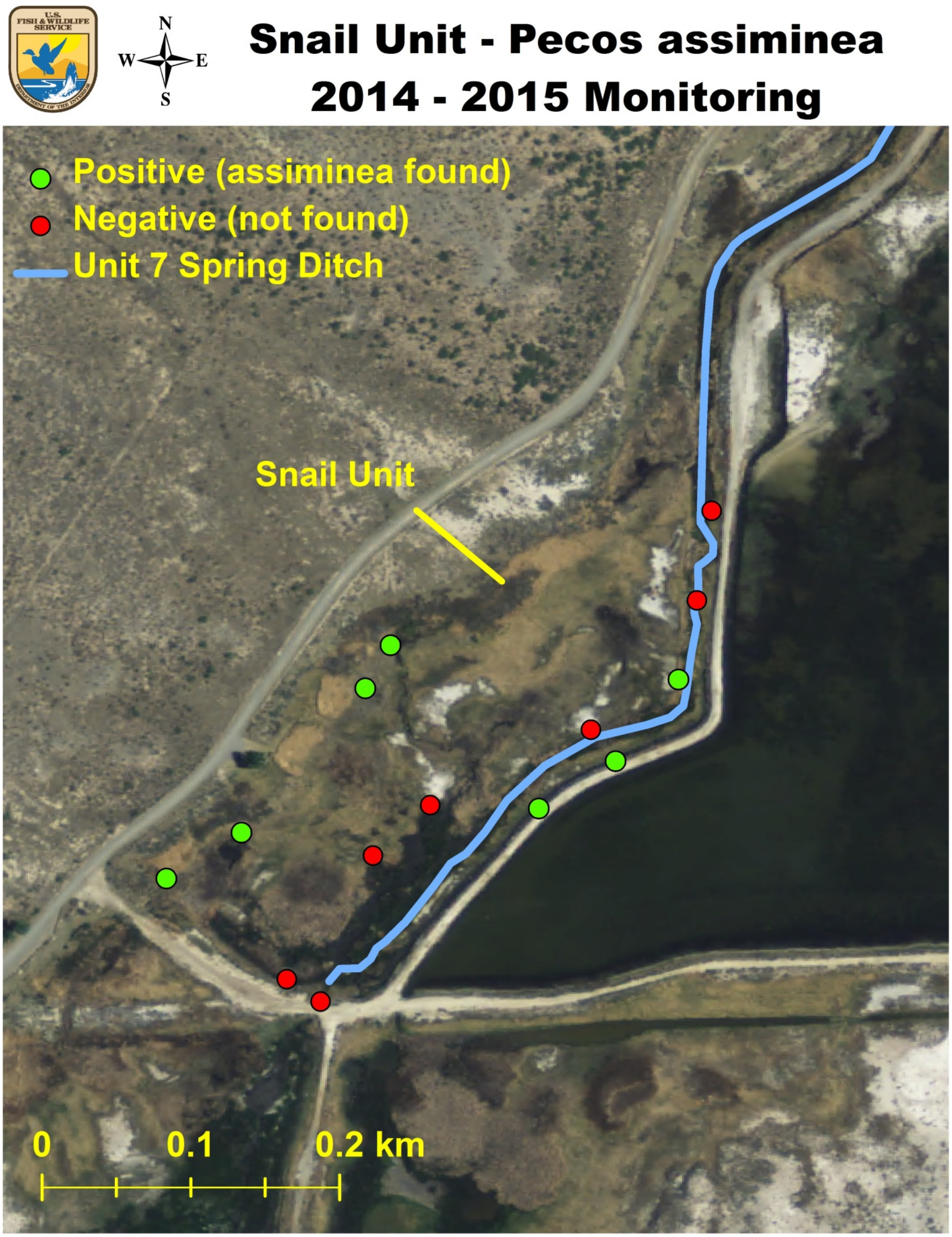

Figure 12a. Snail Unit, within Management Unit 3, at Bitter Lake National Wildlife Refuge depicting distribution of known Pecos assiminea sites from monitoring efforts in 2014 and 2015. Snails were found by monitoring wooden tiles (following Roesler, 2016).

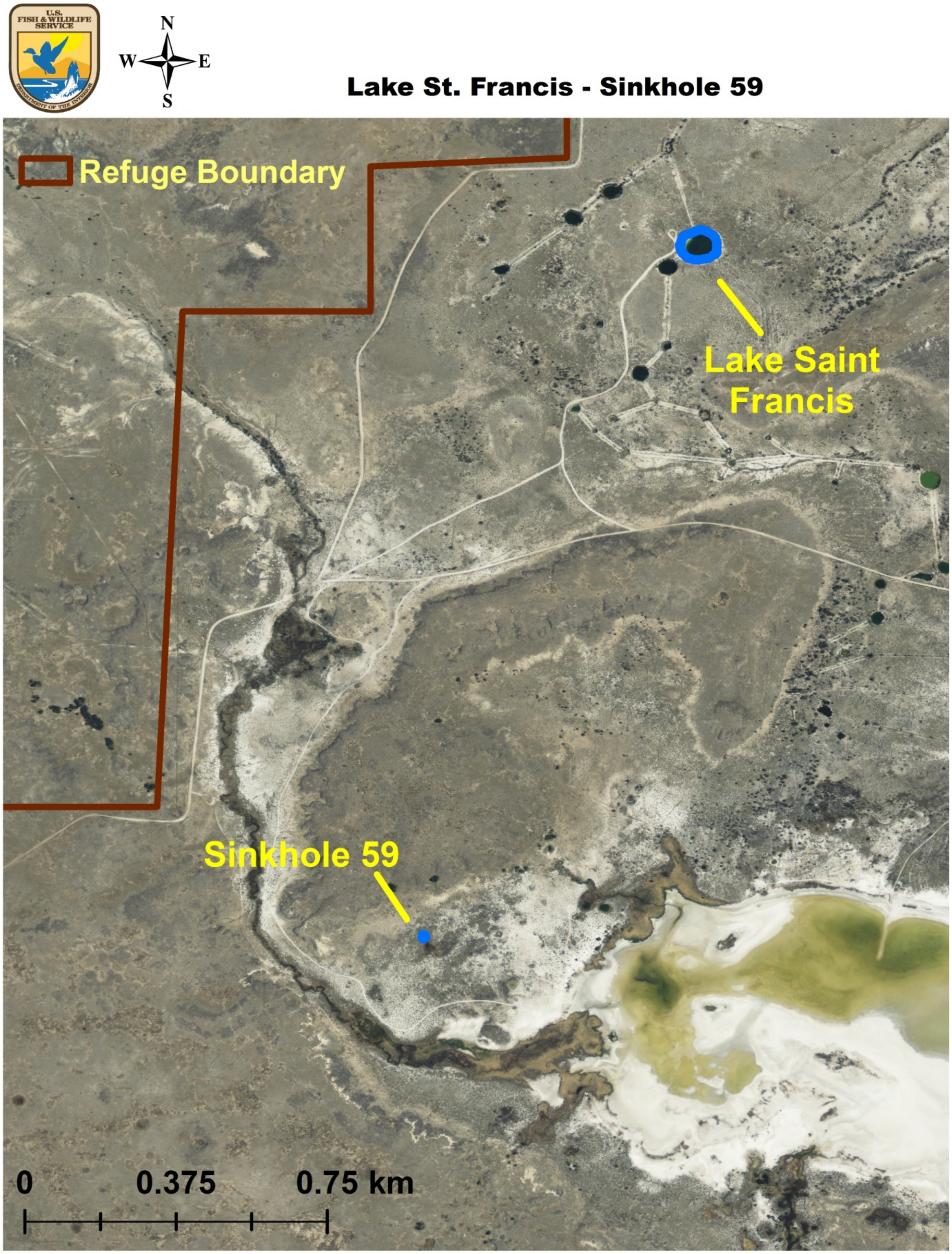

Figure 13. Lake Saint Francis at Bitter Lake National Wildlife Refuge (Management Unit 6).

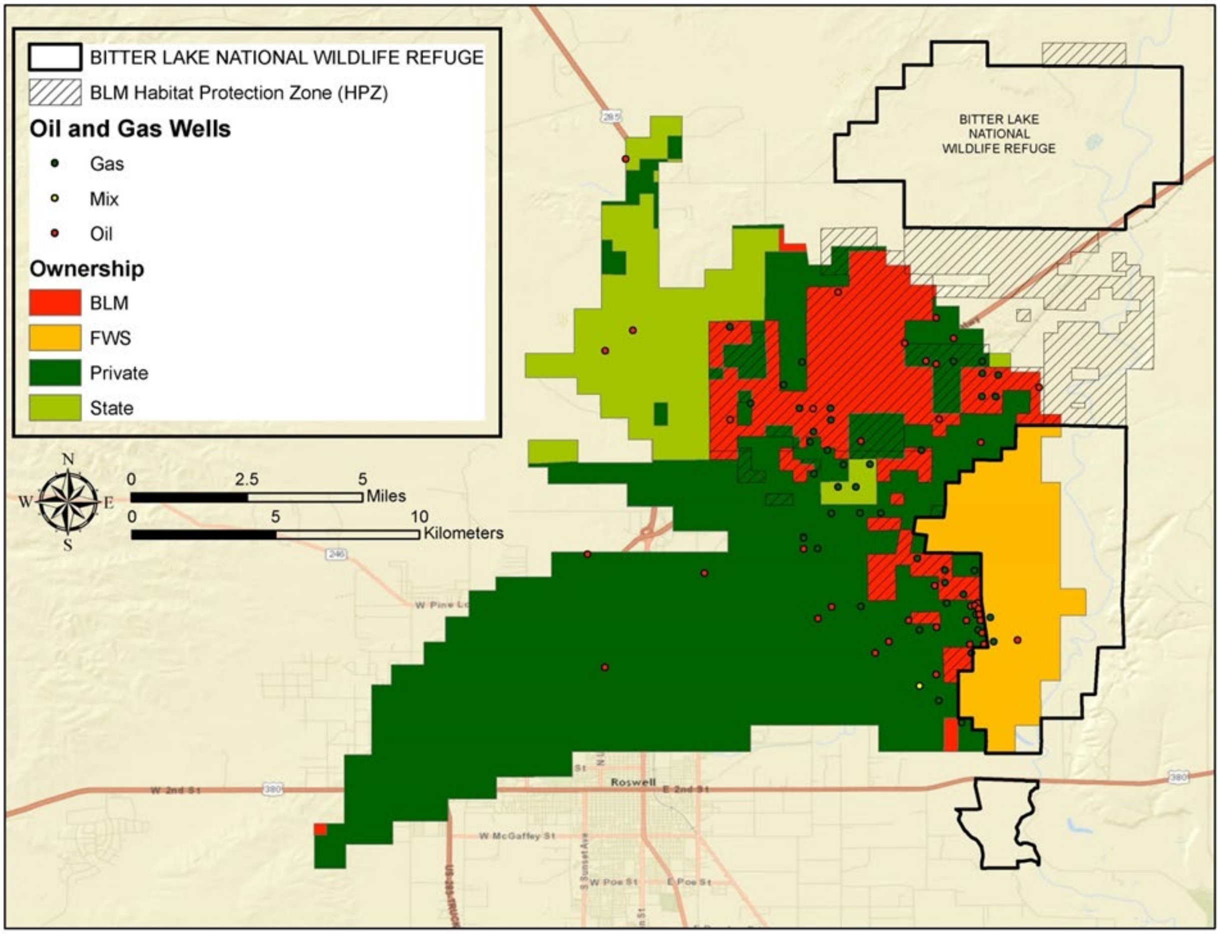

Figure 14. Source-water area for the Bitter Lake National Wildlife Refuge Middle Tract and BLM Habitat Protection Zone (after Balleau Groundwater, Inc. 1999: Figure 11 and BLM 2002: Map 2).