Status of Aquatic Mollusks of New Mexico

COMPLETION REPORT

Submitted to:

United States Fish and Wildlife Service
Division of Federal Aid
Albuquerque, New Mexico 87103

Submitted by:

Brian K. Lang
Conservation Services Division
New Mexico Department of Game and Fish
P. O. Box 25112
Santa Fe, New Mexico 87504

February 2002

COMPLETION REPORT

State: New Mexico **Project Number:** E-20 (5-9)

Project Title: Status and Distribution of Aquatic Mollusks of New Mexico

Study Title: Endangered Species

Contract Period: 15 July 1996 **To:** 31 August 2001

I. Program Narrative Objectives

1. Document the status and distribution of aquatic mollusks of New Mexico with special emphasis on federal candidate species and species of concern and state-listed species.

2. Quantify habitat and record life history observations of aquatic mollusks.

3. Establish long-term population and habitat monitoring protocols for federal candidate species and species of concern and state-listed aquatic mollusks.

4. Provide management recommendations based on assessment of factors posing imminent threats to aquatic mollusk populations, habitats and ecosystems of New Mexico.

A. Justification

1. Problem and Need

Geologic events (rifting, blockfaulting, uplift; Chapin and Seager 1975, Seagar and Morgan 1979, Gable and Ration 1983) and changing post-Pleistocene climatic conditions have resulted in the isolation of aquatic mollusk populations that now occur as geographically disparate species inhabiting insular aquatic habitats in New Mexico. Speciation by isolation is likely responsible for the high degree of endemicity of hydrobiid spring snails in New Mexico—all 8 species that Taylor (1987) described from New Mexico (see Table 1 which excludes two federally listed snails) are state endemics.

Many of these insular aquatic mollusk populations are characterized by unique gene pools and species assemblages that are geographically restricted to point-habitats critical to species' survival. Anthropogenic factors, such as direct habitat alteration and loss, water contamination, poor watershed management, and ground water depletion, have resulted in the extirpation of many once common and rare aquatic mollusks throughout New Mexico (Metcalf 1982, Taylor 1987, Mehlhop 1996). Habitat fragmentation can increase the distance between once continuous mollusk populations and may have major consequences on the metapopulation structure of unionid bivalves and narrow endemic gastropods of restricted geographic distribution (Harrison 1991). As aquatic mollusk

populations are eliminated and dispersal distances are increased, demographic and genetic constraints may diminish the ability of local populations to respond to natural environmental disturbance and anthropogenic habitat changes (Mehlhop and Vaughn 1993).

The systematics, distribution and abundance, habitat requirements, and habitat-area relationships of New Mexico aquatic mollusks are not well understood amongst resource managers nor malacologists. Resource agencies have limited baseline data from which to characterize historic aquatic mollusk populations, recognize losses, or anticipate threats associated with the degradation of aquatic ecosystems. Identification of threats to aquatic mollusk populations is essential for public and private land managers and decision makers in New Mexico.

As a result of their trophic specializations (i.e., grazers, decomposers, filter feeders), aquatic mollusks (bivalves and gastropods) can concentrate toxic chemicals in soft body parts, and may function as sensitive "bioindicator" organisms facilitating ecological assessment of aquatic ecosystem health and integrity in relation to current environmental conditions. As such, population monitoring of aquatic mollusks is timely and may contribute to the establishment of an ecological baseline for evaluating broad-scale environmental trends and assessment of potential impacts at all levels of biodiversity (species, genetic, and ecosystem) due to degradation of ground and surface water resources in New Mexico. This concern is particularly germane considering that documented trends of progressive habitat loss have resulted in extirpations of endemic amphipod crustacean and mollusk populations in New Mexico (Cole 1981, 1985; Metcalf 1982; Taylor 1987; Mehlhop 1996).

2. Results and Benefits

This study will generate information on population status (distribution and abundance), aspects of life history, and habitat requirements of state-listed and federal species of concern and candidate aquatic mollusks of New Mexico. These data coupled with population and habitat threat assessments can facilitate the prescription of conservation and management options, including the formulation of long-term monitoring protocols.

Exploratory field inventory of aquatic systems in proximity to habitats of known populations are needed to assess the distribution of endemic aquatic mollusk species. Such a systematic survey protocol can also provide inventory data for state-listed aquatic mollusks that are known from only one or a few collecting localities in New Mexico.

A comprehensive monthly macroinvertebrate population monitoring program was initiated under a previous Section 6 grant (i.e., E-20 [1-4]; 1991-1995) at Bitter Lake National Wildlife Refuge (BLNWR), Roswell, New Mexico, and will continue under this project. The sampling protocol developed and implemented during E-20-4 generates quantitative ecological data (abundance, habitat affinities, and water quality) on a monthly basis for a suite of three federal candidate prosobranch snails (*Assiminea pecos, Pyrgulopsis roswellensis, Tryonia kosteri*) and Noel's amphipod (*Gammarus desperatus*, federal species of concern).

3. Status

An annotated checklist of mollusks of New Mexico lists 11 families and approximately 51 species of aquatic mollusks (NMDGF 1987). Of the 17 state-listed (threatened and endangered) aquatic mollusks (NMDGF 2000), six prosobranch snails are federal candidates species (Federal Register 2001). Three of these species (*A. pecos*, *P. roswellensis*, *T. kosteri*) are currently under a proposed rule to list as threatened or endangered under the federal Endangered Species Act (Federal Register 2001). Numerous populations of amphipod crustaceans and aquatic mollusks in New Mexico documented during the past 20 years require reinventory and threat assessment.

II. Procedures/Objectives

A. Sites of known occurrence of target species (Table 1) will be inventoried by the Project Leader and Contractors.

1. Inventory target aquatic mollusk species at sites of known or potential occurrence to assess population status.

Appendix A details results of surveys and monthly inventories for federal candidate and species of concern mollusks, including population status, threat assessments and management recommendations.

a. Population estimates will be obtained by benthic grabs, sweep nets, line-transect sampling techniques, and/or artificial substrates, where required.

All spring snail (prosobranch) taxa listed in Table 1, except *Pyrgulopsis gilae* and *Pyrgulopsis thermalis*, were monitored monthly for a minimum of 16 months. Sampling methods varied according to physical attributes of the aquatic system and habitat affinities of target taxa. See Appendix A for specific details.

b. All specimens collected will be identified to lowest taxonomic level possible and enumerated by taxa. Voucher material will be deposited into the Invertebrate Collection, New Mexico Museum of Natural History and Science (NMMNHS).

Processing of monthly collections is ongoing. Ultimately, voucher material will be deposited in the NMMNHS. The NMMNHS is seeking funds for museum equipment, facility improvements, and administrative infra-structure to establish a regionally based research institution focusing on Desert Southwest vertebrate and invertebrate studies (D. Haffner, Chair Science Division, *pers. com.*). Currently, the NMMNH is neither adequately funded nor staffed to process invertebrate collections. All voucher material collected during this grant is currently housed at the New Mexico Department of Game and Fish.

c. Collect soft tissue voucher from select aquatic mollusk populations. Soft

tissues will be frozen in liquid nitrogen and deposited into the frozen tissue collection at the Museum of Southwestern Biology, University of New Mexico.

Voucher material was collected for ongoing genetic studies of Desert Southwest prosobranch snails (Dr. Robert Hershler, Smithsonian Institution) and gammarid amphipods (Dr. David Berg, Miami University, Oxford, OH). Specimens were sent directly to these research institutions.

d. Habitat variables measured will include, but may not be necessarily limited to standard physicochemical water quality parameters (e.g., water depth and velocity, temperature, pH, salinity, specific conductance, TDS, dissolved oxygen).

The above-listed habitat variables were measured at each sample site during monthly inventories of hydrobiid spring snails and gammarid amphipods. Studies exploring the relationships between these aquatic habitat parameters and monthly demographic data of target taxa is contingent on the processing of field collections which is ongoing under Section 6 grant E-56. The results of water quality monitoring studies at Bitter Lake National Wildlife Refuge are presented in Appendix B.

e. Species distributions will be mapped using GPS modules for incorporation into a GIS database. Data layers may include population, geographic and habitat parameters.

Field survey sites were documented with a GPS module. These data exist as raw data files (Trimble GEO-PC 2.01-00 software) that are compatible with conventional GIS databases.

f. Data analysis will follow parametric and non-parametric statistical procedures.

Population monitoring results and abundance indices of target taxa are presented in Appendix A. Data analysis for monthly population studies of target taxa will be possible once macroinvertebrate density estimates are available from curated field collections.

2. Exploratory field surveys for select species will be conducted in close proximity to known site occurrences and in potential habitats of nearby aquatic systems.

Appendix A details the extent of exploratory field surveys to determine the distribution of target taxa.

3. Employ genetic analyses, where necessary, to assess genetic/taxonomic affinities of select aquatic mollusk populations

See A.1.c above.

B. Continue monthly spring snail population monitoring at BLNWR.

Monthly inventory of macroinvertebrates at BLNWR continued under E-20 grant Segments 5 and 6, and were reinstated for two years (Segments 8 and 9) following the March 2000 Sandhill Fire. See Appendix B for preliminary results of post-fire studies.

C. Formulate long-term population/habitat monitoring protocols for sensitive aquatic mollusk species based upon field inventory results.

See appendicies A and B.

D. Submit annual reports summarizing activities during the reporting period, including preliminary analysis of results, suggested changes (if necessary) of sampling protocol, identification of immediate threats, and management recommendations.

Annual performance reports were submitted under previous grant segments.

E. Prepare completion report summarizing the results of work accomplished under Procedures A-D, which includes management recommendations based on assessment of factors posing threats to aquatic mollusk species, populations, and ecosystems.

Activities completed under all grant segments (5-9) are summarized herein. Appendices A and B provide information regarding the (status) distribution and abundance, threats, and management recommendations for macroinvertebrate taxa that were the focus of this project.

III. Geographic Location

Project headquarters will be at the New Mexico Department of Game and Fish Laboratory, Santa Fe, NM. Field work will occur state-wide. Analysis of data will be conducted at the NMDGF headquarters and at facilities of contracting consultants.

Prepared by: Brian K. Lang
Brian K. Lang
Project Biologist

Approved by:
Charles L. Hayes, Assistant Chief
Conservation Services Division

Approved by: Lisa B. Evans
Lisa Evans
Federal Aid Coordinator

Approved by: Tod W. Stevenson
Tod Stevenson, Chief
Conservation Services Division

Literature Cited

Chapin, C. E. and W. R. Seager. 1975. Evolution of the Rio Grande rift in the Socorro and Las Cruces areas. New Mexico Geol. Soc. Guidebook 26:297-321.

Cole, G. A. 1981. *Gammarus desperatus*, a new species from New Mexico (Crustacea: Amphipoda). Hydrobiologia 76:27-32.

Cole, G. A. 1985. Analysis of the *Gammarus-pecos* complex (Crustacea: Amphipoda) in Texas and New Mexico, USA. Journal of the Arizona-Nevada Academy of Science 20:93-103.

Federal Register. 2001. Endangered and Threatened Wildlife and Plants; Review of Plant and Animal Species that are Candidates or Proposed for listing as Endangered or Threatened, Annual Notice of Findings on Recycled Petitions; and Annual Description of Progress on Listing Actions; Proposed Rule. 50 CFR Part 17. 66(210):54808-54832.

Gable D. J. and T. Hatton. 1983. Maps of vertical crustal movements in the conterminous United States over the last 10 million years. United States Geologic Survey, Misc. Ser. Map No. 1-1315, 2 sheets, scale 1:5,000,000-1:10,000,000.

Harrison, S. 1991. Local extinction in a metapopulation context: an empirical evaluation. *In* Metapopulation Dynamics: empirical and theoretical investigations. Eds. M. Gilpin and E. Hanski. Cambridge University Press.

Hershler, R. and F. C. Thompson. 1987. North American Hydrobiidae (Gastropoda: Rissoacea): Redescription and systematic relationships of Tryonia Stimpson, 1865 and Pyrgulopsis Call and Pilsbry, 1896. The Nautilus 101(1):25-32.

Mehlhop, P. 1996. Ecology and conservation needs of hydrobiid snails. The Nature Conservancy, Biodiversity Network News 9(1):6- 7.

Mehlhop, P., and C. C. Vaughn. 1993. Threats to and sustainability of ecosystems for freshwater mollusks. Pp. 68-77, *in* Sustainable Ecological Systems: Implementing an Ecological Approach to Land Management (W. W. Covington and L. F. DeBano, technical coordinators). U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-247.

Metcalf, A. L. 1982. Fossil unionacean bivalves from three tributaries of the Rio Grande. Pp. 43-59 *In* Proceedings of the Symposium on Recent Benthological Investigations in Texas and Adjacent States, ed. J. R. Davis. Aquatic Sciences Section, Texas Academy of Science, Austin, Texas.

New Mexico Department of Game and Fish. 1987. A preliminary checklist of the mollusks of

New Mexico.

New Mexico Department of Game and Fish. 1988. Handbook of species endangered in New Mexico.

New Mexico Department of Game and Fish. 2000. Threatened and endangered species of New Mexico: biennial review and recommendations. 116 pp.

Seagar, W. R. and P. Morgan. 1979. Rio Grande rift in southern New Mexico, west Texas, and northern Chihuahua. Pp. 87-196 In Rio Grande Rift: Tectonics and Magnetism. (Ed. R. E. Rieker). American Geophysical Union, Washington, D.C.

Taylor, D. W. 1987. Fresh-water molluscs from New Mexico and vicinity. New Mexico Bureau of Mines & Mineral Resources. Bulletin 116.

Turgeon, D. D., A. E. Bogan, E.V. Coan, W.K. Emerson, W. G. Lyons, W. L. Pratt, C. F. E. Roper, A. Scheltema, F. G. Thompson, and J. D. Williams. 1988. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. American Fisheries Society Special Publication 16.

Table 1. State listed and federal candidate and species of concern aquatic mollusks and crustaceans of New Mexico. Species are categorized by ecological specialization, geographic region, and conservation status.

Taxa[1]	Species	County	2002 Status[2] State	Federal	Occurrence[3]
Spring Snails					
Pecos assiminea	*Assiminea pecos*	Chaves	E	C	BLNWR
Koster's tryonia*	*Tryonia kosteri*	Chaves	E	C	BLNWR, RCC†
Roswell springsnail*	*Pyrgulopsis roswellensis*	Chaves	E	C	BLNWR, RCC†
Pecos springsnail*	*Pyrgulopsis pecosesis*	Eddy	T	SC	Blue Spring
Chupadera springsnail*	*Pyrgulopsis chupaderae*	Socorro	E	C	Chupadera Mts.
Gila springsnail*	*Pyrgulopsis gilae*	Grant	T	C	Gila River
NM hot springsnail*	*Pyrgulopsis thermalis*	Grant	T	C	Gila River
Aquatic Snails & Bivalves					
wrinkled marshsnail	*Stagnicola caperatus*	Sandoval	E	-	Jemez Mts.
star gyro	*Gyraulus crista*	Colfax	T	-	Black Lake
lake fingernailclam	*Musculium lacustre*	Colfax	T	-	Cieneguilla Creek
paper pondshell mussel	*Utterbackia imbecillis*	San Miguel	E	-	Canadian River
swamp fingernailclam	*Musculium partumeium*	Union	T	-	Arkansas River Basin
long fingernailclam	*Musculium transversum*	Union	T	-	Arkansas River Basin
Texas hornshell mussel	*Popenaias popeii*	Eddy	E	C	Pecos River
Lilljeborg's peaclam	*Pisidium lilljeborgi*	Santa Fe	T	-	Sangre de Cristo Mts.
Sangre de Cristo peaclam*	*Pisidium sanguinichristi*	Taos	T	SC	Sangre de Cristo Mts.
Crustaceans					
Noel's amphipod*	*Gammarus desperatus*	Chaves	E	SC	BLNWR

[1] Taxonomic authorities: (a) Turgeon et al. (1988); (b) Hershler, R. and F. C. Thompson (1987).
[2] 2002 Status: (State) E = Endangered, T = Threatened; (Federal) C = Candidate, SC = Species of Concern; Federal Register (2001).
[3] Acronyms: BLNWR - Bitter Lake National Wildlife Refuge; RCC - Roswell Country Club.
* = endemic species; † = Chaves County

Appendix A. Results of surveys and monthly inventories for federal candidate and species of concern aquatic macroinvertebrates of New Mexico: monitoring, population status, and management recommendations.

Results of Surveys and Monthly Inventories for Federal Candidate and Species of Concern Aquatic Macroinvertebrates of New Mexico: Monitoring, Population Status, and Management Recommendations

Noel's Amphipod (*Gammarus desperatus*)

Monitoring: Cole (1981) described *Gammarus desperatus* as an endemic amphipod from North Spring, Roswell Country Club, Roswell, Chaves County, New Mexico. Similar amphipods once occurred in Landerspring Brook located about three miles northeast of this type locality, where Noel (1954) errantly identified the once extant gammarid amphipod population as *Gammarus fasciatus* (Cole 1981, 1985, 1988a, 1988b). A comparison of specimens from Landerspring Brook with specimens from the type locality (North Spring) led Cole (1981) to consider them the same species. The Landerspring Brook population went extinct some time during the period from 1951 to 1957 due to habitat dessication (Cole 1981, 1988a). By early May 1988, North Spring had been capped and walled; no *G. desperatus* have been observed at this site in subsequent collections (Cole 1988b; Mehlhop 1992, 1993). Noel's amphipod is considered extirpated from its type locality. Based on the similarity of structural features, Cole (1988a, 1988b) allied *Gammarus* specimens from "Lost River" (Bitter Creek) at Bitter Lake National Wildlife Refuge (BLNWR), Chaves County, with the nominal species from North Spring (NMDGF 1988a).

Monthly (1995-1998) monitoring of macroinvertebrates at BLNWR documented a second population of *G. desperatus* in Sago Spring complex. From June 1995 to May 1996, the relative abundance of *G. desperatus* in Bitter Creek was 64-8768 amphipods/m^2 compared to lower densities (26-575 amphipods/m^2) in Sago Spring complex (NMDGF 1998). A third population of *G. desperatus* was found recently (ca. 1999) in a ditch along the western shore line of refuge Unit 6 where densities were estimated at 344 amphipods/m^2 (Lang et al., *In Press*).

From 1996 to 2001 several new populations of gammarid amphipod were located in southeastern New Mexico and West Texas: an isolated population from Sitting Bull Spring, Gaudalupe National Forest, Eddy County New Mexico, and two populations from Giffin and East Sandia springs in Reeves County, Texas (Lang et al. *In Press*). Preliminary inspection of voucher material revealed that gammarid amphipods from these populations possess morphological characteristics referable to traits that Cole (1985) considered diagnostic of the *G. pecos* complex (i.e., non-calceolate antennae; setaceous mandibular palps; setiferous coxal plates I-IV; and narrow oöstegites [brood plates]).

Comparative morphological and genetic studies are ongoing to assess the taxonomic affinities of these new gammarid populations in relation to all other known members of the *G. pecos* complex in the Pecos River Valley of New Mexico and Texas. A cursory examination of specimens from Sitting Bull Spring indicates that this *Gammarus* population appears morphologically distinct when compared with *G. desperatus* from BLNWR (Lang et al. *In Press*). Preliminary results of

genetic studies comparing the nine known populations of this complex revealed significant within-population variation. Several populations exhibited heterozygosity deficits with high percentages of polymorphic loci, which may indicate the presence of cryptic species. A phenogram estimating the genetic distances among all populations showed two distinct groups: a BLNWR clade and a West Texas clade. Ironically, the geographically more distant population of *Gammarus pecos* from Diamond Y Preserve, Pecos County, Texas, was genetically most similar to the BLNWR group, whereas the Sitting Bull Spring *Gammarus* population grouped with the West Texas clade (Viviana Gervasio and Dr. David Berg, University of Miami [OH], *pers. com.*; Gervasio et al. *In Preparation*).

Gammarus desperatus populations at BLNWR appear sensitive to changes in lotic habitat conditions. Over the course of this study, the progressive spread of the monocot, *Phragmites australis,* along the upper reach of Bitter Creek resulting from phreatophyte control and post-fire release following the March 2000 Sandhill Fire has effectively altered the physicochemical and flow patterns of Bitter Creek (NMDG 2001). The dense growth form of this native grass effectively shades the stream corridor and alters flow patterns of Bitter Creek by clogging the stream channel. In several instances, these conditions have favored the growth of filamentous blue-green algae, which impedes the movement of geotictic pericarida crustaceans (e.g., aquatic isopods and amphipods), while apparently disfavoring the persistence of aquatic macrophytes (i.e., widgeon grass [*Ruppia maritima*] and the marine algae [*Enteromorpha* sp.]) that are typically colonized by *G. desperatus*. For example, Noels' amphipod was once abundant in monthly collections at Dragonfly Spring run from 1995-1997 where these submergents were common. Under post-fire riparian and aquatic conditions at Dragonfly Spring run, cover once afforded by these macrophytes has been replaced by a dense mass of emergent *P. australis* stems – only four *G. desperatus* occurred in monthly post-fire samples (n = 3 per month) from April 2000 to March 2001 at Dragonfly Spring run. Aeolian deposition of post-fire ash laden with polycyclic aromatic hydrocarbons at Dragonfly Spring may account for the overall dramatic decline of macroinvertebrate populations observed in this portion of the study area (see NMDGF [2001] and Appendix B [this report]).

Interestingly, the addition of stones has created a flow gradient in a drainage ditch along the western limit of Unit 6. This habitat manipulation by has resulted in conditions favorable to Noel's amphipod (Gordon Warrick, Biologist, BLNWR, and Brian Lang, Biologist, NMDGF; *pers. obs.*).

Status: The specific epithet, *desperatus*, refers to what Cole (1981) considered an imperiled situation for the species: the progressive extirpation of isolated gammarid amphipod populations in Chaves County, New Mexico, between 1951-1988 (Cole 1985, 1988a, 1988b). Cole attributed these extirpations to regional ground water depletion and habitat alterations (e.g., artesian spring source diversion, dewatering, capping). Similar factors likely affected localized gammarid populations of the *G. pecos* complex in West Texas (Lang et al. *In Press*). In 1990 *G. desperatus* was uplisted from state threatened to endangered under NMDGF Regulation (682).

While populations of *G. desperatus* are stable under current refuge management plans (Research

Management Consultants, Inc. 1998), off-refuge land use practices within areas of the Roswell Basin pose threats to the long-term viability of *G. desperatus* populations at BLNWR. Regional ground water pumping for agriculture and oil and gas industry operations (exploration, storage, transfer and refining) continue in the Pecos River Valley (BLM 1994, USFWS 1997). Oil and gas exploration is ongoing within areas that Balleau Groundwater, Inc. (1996, 1999) identified as primary ground water sources (i.e., "source-water protection zones") for surface waters at BLNWR. Such extractive processes and industry operations are known to deplete ground water aquifers and to contaminate ground and surface waters in New Mexico (Hennighausen 1969; Jercinovic 1982, 1984; Longmire 1983; Quarles 1983; Boyer 1986; Richard 1988a, 1988b; Rail 1989; Richard and Boehm 1989a, 1989b; Balleau Groundwater, Inc. 1996; Martinez et al. 1998). Amphipod crustaceans are acutely sensitive to ground and surface water contaminants (Eisler 1987, Green and Trett 1989, Pennak 1989, Covich and Thorpe 1991). There is increased risk of potential degradation of ground and surface water quality posed by domestic sewage contamination (i.e., septic discharge) from urban encroachment in aquifer recharge-discharge areas along the western bounds of BLNWR. Illicit dumping of domestic contaminants (e.g., pesticides, herbicides, waste oil, etc.) and septic leachate are known to contaminate ground water resources in karst areas of the United States (White et al. 1995, Zokaites 1997) and in New Mexico (Bitner and Graves 1992, McQuillan et al. 1989).

Natural stochastic events, such as fire or drought, could adversely impact extant *G. desperatus* populations at BLNWR. In the short-term, Noel's amphipod is threatened by impoverished aquatic conditions following the March 20000 Sandhill Fire which severely burned reaches of Bitter Creek formerly inhabited by *G. desperatus* (NMDG 2001). The long-term impact of these effects, whether beneficial or adverse, on the aquatic biota and riparian corridor of Bitter Creek remain undetermined (see Appendix B). Prolonged drought may affect hydrologic conditions on BLNWR by reducing discharge through refuge surface waters while concomitantly increasing salinity and concentrating potential contaminants.

Long-term population viability of *G. desperatus* at BLNWR will be contingent upon protection of ground and surface water quality and quantity. Federal water-rights for BLNWR were acquired in 1996 (USDJ 1996, Balleau Groundwater, Inc. 1997). In compliance with Section 17-2-40.1.A-G of the amended Wildlife Conservation Act (1995), the NMDGF in 1995 initiated conservation planning for 4 state-listed invertebrate species of Chaves County, including *G. desperatus*. Development of a state recovery plan for these macroinvertebrates is currently ongoing.

Management Recommendations:

(1) Recommend biannual monitoring of *G. desperatus* at BLNWR.

(2) Continued Section 6 funding will facilitate the Project Biologist's efforts to process voucher material collected during monthly pre- and post-fire samples (June 1995 to July 1998), compile macro- and microhabitat data, analyze ecological data, and synthesize reports.

(3) Through formal Section 7 Consultation on threatened and endangered species of the Bureau of Land Management's Roswell Resource Area Draft Resource Management Plan/Environmental Impact Statement (Roswell DRMP/EIS) (BLM 1994) , the U.S. Fish and Wildlife Service (1997a) rendered jeopardy opinion that potential oil and gas activities along the Pecos River may adversely impact the Pecos bluntnose shiner and Pecos gambusia.

Since all macroinvertebrate species of BLNWR that possess state and federal status are sympatric with the federally endangered Pecos gambusia in Bitter Creek and Sago Spring complex, adherence with Section 7 Consultation Reasonable and Prudent Alternative No. 1 (RPA-1) for Pecos Gambusia (USFWS 1997) is recommended. The RPA-1 states:

> "Use the best available hydrologic information to map the source and movement of water that supplies springs occupied by Pecos Gambusia on the Bitter Lake National Wildlife Refuge and Salt Creek Wilderness. Close the lands within the mapped area to oil and gas leasing unless or until the BLM can demonstrate that mandatory protective measures will ensure no aquifer contamination."

This abeyance for exploratory oil and gas well permits on lands referred to in RPA-1 is equally justified for *G. desperatus* since these two species occur sympatrically, although *G. desperatus* is even more narrowly distributed than Pecos gambusia.

(4) In the event that oil and gas activities proceed within off-refuge source-water protection zones, as identified by Balleau Associates, Inc. (1999), without demonstrating that mandatory protective measures will ensure no aquifer contamination within the area referenced by RPA-1, then there would be a threatened curtailment and possible destruction of the limited habitat of *G. desperatus*, thus demonstrating that regulatory mechanisms are inadequate. The species would be in danger of extinction throughout all of its range.

The New Mexico Department of Game and Fish (NMDGF) should commit resources necessary to assess whether or not the current implementation of RPA-1 is sufficient to conserve *G. desperatus* in its native habitats on BLNWR. If this assessment concludes that current regulatory activities proposed under RPA-1 do not sufficiently protect this species, then further conservation measures, as identified by the NMDGF in the development of a state recovery plan (New Mexico Wildlife Conservation Act, 17-2-37 to 17-2-46 NMSA 1978), will be required to ensure the survival of *G. desperatus*.In compliance with Section 17-2-40.1.A-G of the amended Wildlife Conservation Act (1995), the NMDGF in 1995 initiated conservation planning for 4 state-listed invertebrate species of Chaves County, including *G. desperatus*. Development of a state recovery plan is currently ongoing.

(5) Management practices at BLNWR might include rehabilitation of vestigial habitat of *G.*

desperatus along the western ditch of refuge Unit 6, and in other ditches with freshwater spring sources, providing that such practices do not adversely impact habitats, populations, or management plans (Research Management Consultants, Inc. 1998) for other taxa on the Refuge.

Pecos assiminea (*Assiminea pecos*)

Monitoring: *Assiminea pecos* occupies a niche very similar to marsh-inhabiting land snails–it occurs more often on land (i.e., on moist soils beneath marsh emergents) than in the water. Due to its peludal riparian habits, standard benthic sampling techniques are inappropriate to determine its abundance in aquatic systems. While a few live *A. pecos* have been collected live from benthic substrata (NMDGF 1998), survey effort during this study focused on qualitative hand search methods (i.e., presence/absence) without attempting more rigorous quantitative methods.

In New Mexico, extensive survey effort (1995-2001) statewide confirmed that *A. pecos* sensu stricto is restricted to riparian corridors along the upper reaches of Bitter Creek near Dragonfly Spring and in the lower reaches Sago Spring wetland complex near Sinkhole #32 on BLNWR. An extant but very localized population of *A. pecos* occurs at the type locality along the western perimeter of refuge Unit 7 where Taylor (1987) reported extirpation of this isolated population. In Summer 2001 a small population of *A. pecos* was located near a spring source in the extreme southwestern corner of refuge Unit 15 (Dr. Mark Gordon, New Mexico Museum of Natural History and Science, *pers. com.*). No live specimens or dead shells were found in suitable habitat at Bottomless Lakes State Park, Chaves County, despite extensive search effort.

Surveys in West Texas from 2000 to 2001 documented the persistence of *Assiminea pecos* sensu lato throughout Diamond Y Preserve, Pecos County, and a new population from East Sandia Spring in Reeves County (Lang et al. *In Press*). The NMDGF, working in collaboration with Dr. Robert Hershler (U. S. National Museum, Smithsonian Institution), collected representative voucher material from populations of *A. pecos* in New Mexico and Texas for ongoing phylogenetic studies of the *Assiminea pecos* complex in North America.

Field observations imply that *A. pecos* is closely associated with marsh communities dominated by *Scirpus americanus* and *Elocharis* spp. Numerous empty shells have been located in the riparian corridor of Bitter Creek, especially in contiguous marsh habitat of the lower reach near Bitter Lake. Although this habitat appears very similar to marsh conditions of Sinkhole #32, where *A. pecos* is most abundant, the site is seasonally inundated by Bitter Creek with standing water that is subject to freezing. Frost was observed on soils and dead stems of reeds overlain by annual growth of *Juncus* sp., *Scirpus americanus*, and *Distichlis spicata* var. *stricta*. Such seasonally variable and unstable edaphic conditions appear to limit successful colonization by *A. pecos*. Similar marginal edaphic conditions were observed at the species' type locality in the southwestern corner of impoundment Unit 7 (type locality) where Taylor (1987) reported the species extirpated. Site conditions have likely changed since Taylor collected there in 1981. This habitat is currently subject to a seasonally fluctuating hydrologic regime for waterfowl

management practices.

The persistence of *A. pecos* at Sinkhole #32 on BLNWR is noteworthy as the habitat burned in Spring 1997. Following the March 2000 Sandhill Fire, live *A. pecos* were also found beneath moist leaf litter of *Phragmites australis* near Dragonfly Spring in August and November 2001. Interestingly, Taylor (1987) attributed extirpation *A. pecos* to annual burning of marsh emergents in the Bolsón de Cuatro Cíengas, México. It appears that *A. pecos* is tolerant of fire, and that intensity, duration, and frequency of fire are principal factors that likely determine the species' ability to recover in response to variable fire regimes.

Status: In New Mexico, *A. pecos* sensu stricto appears restricted to isolated populations in the upper reaches of Bitter Creek, the lower reaches of Sago Spring wetland complex near Sinkhole #32, and in low abundance in the southwest corners of Unit 7 and 15 at BLNWR. Populations of *A. pecos* sensu lato in Texas occur on private lands under stewardship of The Nature Conservancy.

While BLNWR populations of *A. pecos* are stable under current refuge management plans (Research Management Consultants, Inc. 1998), off-refuge land use practices within areas of the Roswell Basin pose threats to the long-term viability of *A. pecos* populations on BLNWR. Regional ground water pumping for agriculture and oil and gas industry operations (exploration, storage, transfer and refining) continue in the Pecos River Valley (BLM 1994, USFWS 1997). Oil and gas exploration is ongoing within areas that Balleau Groundwater, Inc. (1996, 1999) identified as primary ground water sources (i.e., "source-water protection zones") for surface waters at BLNWR. Such extractive processes and industry operations are known to deplete ground water aquifers and to contaminate ground and surface waters in New Mexico (Hennighausen 1969; Jercinovic 1982, 1984; Longmire 1983; Quarles 1983; Boyer 1986; Richard 1988a, 1988b; Rail 1989; Richard and Boehm 1989a, 1989b; Jones and Balleau 1996; Martinez et al. 1998). Aquatic mollusks are acutely sensitive to ground and surface water contaminants (Havlik and Marking 1987, Eisler 1987, Green and Trett 1989, Pennak 1989, Covich and Thorpe 1991). There is increased risk of potential degradation of ground and surface water quality posed by domestic sewage contamination (i.e., septic discharge) from urban encroachment in aquifer recharge-discharge areas along the western bounds of BLNWR. Illicit dumping of domestic contaminants (e.g., pesticides, herbicides, waste oil, etc.) and septic leachate are known to contaminate ground water resources in karst areas of the United States (White et al. 1995, Zokaites 1997) and in New Mexico (Bitner and Graves 1992, McQuillan et al. 1989).

Natural stochastic events, such as frequent fires or drought, could adversely impact extant *A. pecos* populations at BLNWR. Prolonged drought may affect hydrologic conditions on BLNWR by reducing discharge through refuge surface waters which could result in dessication of marsh and riparian habitats occupied by this species.

The long-term viability of *A. pecos* populations at BLNWR will be contingent upon protection of ground and surface water quality and quantity. Federal water-rights for BLNWR were acquired

in 1996 (USDJ 1996, Balleau Groundwater, Inc. 1997). In compliance with Section 17-2-40.1.A-G of the amended Wildlife Conservation Act (1995), the NMDGF in 1995 initiated conservation planning ("recovery plan") for 4 state-listed invertebrate species of Chaves County, including *A. pecos*. Development of a state recovery plan for these macroinvertebrates is currently ongoing.

Management Recommendations:

(1) Conduct biannual surveys employing stream-side searches in areas of recorded occurrences to document the persistence of *A. pecos* at BLNWR.

(2) Continued Section 6 funding will facilitate the Project Biologist's ongoing efforts to process field voucher material, compile macro- and microhabitat data, analyze ecological data, and synthesize reports.

(3) Through formal Section 7 Consultation on threatened and endangered species of the Bureau of Land Management's Roswell Resource Area Draft Resource Management Plan/Environmental Impact Statement (Roswell DRMP/EIS) (BLM 1994), the U. S. Fish and Wildlife Service (1997a) rendered jeopardy opinion that potential oil and gas activities along the Pecos River may adversely impact the Pecos bluntnose shiner and Pecos gambusia.

Since all macroinvertebrate species of the BLNWR that possess state and federal status are sympatric with the federal endangered Pecos gambusia in Bitter Creek and Sago Spring complex, adherence to Section 7 Consultation Reasonable and Prudent Alternative No. 1 (RPA-1) for Pecos Gambusia (USFWS 1997) is recommended. The RPA-1 states:

> "Use the best available hydrologic information to map the source and movement of water that supplies springs occupied by Pecos Gambusia on the Bitter Lake National Wildlife Refuge and Salt Creek Wilderness. Close the lands within the mapped area to oil and gas leasing unless or until the BLM can demonstrate that mandatory protective measures will ensure no aquifer contamination."

This abeyance for exploratory oil and gas well permits on lands referred to in RPA-1 is equally justified for *A. pecos* since it occurs sympatrically with Pecos gambusia.

(4) In the event that oil and gas activities proceed within off-refuge source-water protection zones, as identified by Balleau Groundwater, Inc. (1999), without demonstrating that mandatory protective measures will ensure no aquifer contamination within the area referenced by RPA-1, then there would be a threatened curtailment and possible destruction of the limited habitat of *A. pecos*, thus demonstrating that regulatory mechanisms are inadequate. The species would be in danger of extinction throughout all of its range in New Mexico.

The NMDGF should commit resources necessary to assess whether or not the current implementation of RPA-1 is sufficient to conserve *A. pecos* in its native habitats on BLNWR. If this assessment concludes that current regulatory activities proposed under RPA-1 do not sufficiently protect this species, then further conservation measures, as identified by the NMDGF in the development of a state recovery plan (New Mexico Wildlife Conservation Act, 17-2-37 to 17-2-46 NMSA 1978), will be required to ensure the survival of *A. pecos*.

Chupadera springsnail (*Pyrgulopsis chupaderae*)

Monitoring: *Pyrgulopsis chupaderae* is known from Willow Spring (Taylor 1987) and a nearby unnamed spring, both situated along the southwest flank of the Chupadera Mountains, Socorro County, New Mexico. Monthly monitoring of the *P. chupaderae* at Willow Spring spanned the period May 1997 to July 1998, and ceased in September 1999 since a change in land ownership precluded access. This species was uplisted from state Threatened to Endangered due to over-grazing of habitat at the northernmost unnamed spring which decimated the population (NMDGF 1996a).

During monthly population monitoring, cattle grazing throughout the riparian corridor of Willow Spring was minimal. The riparian corridor was intact under this level of grazing pressure. While no efforts were observed to improve surface water catchment, water was diverted from an artesian springhead adjacent (i.e., within 4 m) to the spring source. Diverted water was returned to the pond down-gradient of natural spring run. This diversion did not appear to affect adversely the habitat or population of *P. chupaderae* at Willow Spring.

Willow Spring was visited on 4 occasions under grant Segment 7. In November 1998, the springrun and wetted riparian corridor was reduced notably to approximately ⅓ to ½ the width observed during previous monthly visits. Whether this reduced spring discharge was attributed to ground water withdrawals up-gradient, seasonally diminished flows, or a combination of these factors remains undetermined. Notwithstanding, this reduction in spring discharge did not appear to affect adversely *P. chupaderae*.

Routine population and habitat monitoring in August 1999 revealed removal of woody debris from the riparian corridor of the natural spring. These alterations did not affect habitat of the spring or the *P. chupaderae* population. Sampling tiles were removed from the springrun, and a water temperature data logger could not be relocated for data retrieval. Consequently, minimal population and habitat data was recorded.

In 1999, the Cienega Ranch (ca. 30,000 acres) was sold and renamed. Small parcels were placed under land auction in September 1999. The Project Biologist contacted the current owner, in person and with correspondence, to inform the land steward of agency efforts to conserve *P. chupaderae* and native habitats. Requests for access from 1999 to 2002 have been denied repeatedly.

Status: The present status of the Chupadera springsnail is unknown. Ground water depletion and an increase in surface water diversion, above and beyond historic spring water withdrawals, represent the primary threats to *P. chupaderae*. If grazing was controlled for a sufficient period of time, the northernmost unnamed spring might support reintroduction of *P. chupaderae* once a contiguous riparian plant community has developed.

Management Recommendations:

(1) Renegotiate access to continue monitoring populations of *P. chupaderae* in its native habitat.

(2) Continue state and federal funding to process monthly voucher collections and ecological data.

(3) Recommend development of a habitat management plan in cooperation with the land owner under the "candidate conservation agreement" (Federal Register 1997), or similar agreement, that perpetuates the aquatic habitat of Willow Spring. This conservation plan must consider balancing water stewardship wisely to meet the needs of historic land use practices, which, heretofore, have allowed for persistence of native habitat critical to the survival of *P. chupaderae*.

(4) Establish a refuge population of *P. chupaderae* in an artificial stream system at the Albuquerque Biological Park.

Gila springsnail *(Pyrgulopsis gilae)*

Monitoring: Based on collections by Taylor (1987) and Mehlhop (1992, 1993), the New Mexico Natural Heritage Program database provides the most complete listing of *Pyrgulopsis gilae* populations from the Gila River Basin in New Mexico. This species is currently known from ten geographically isolated populations throughout the Basin: Alum Hot Spring, Gila River mainstem; a single population from an unnamed spring in the Middle Fork Gila River; three populations from the East Fork Gila River; and five populations from headwater tributaries (i.e., Taylor Creek, 3 sites; Beaver Creek, 2 sites) of the East Fork Gila River.

Under grant Segment 6, approximately 20 miles of riparian corridor along the West Fork Gila River were surveyed for suitable spring habitats that might support populations of *P. gilae*. Only pulmonate physid snails were collected from spring-fed backwater habitats of the West Fork Gila River. This sub-basin lacks the abundance of artesian springheads characteristic of the East Fork and Middle Fork sub-basins, and the Gila River mainstem. A single thermal spring on the Middle Fork Gila River, located approximately 0.7 river miles upstream of the Gila Visitor Center, was not conducive to successful colonization by *Pyrgulopsis* species, as the water temperature exceeded 55°C, and the thermal pools were located in the riverine floodway. Segment 9 field surveys (October 2001) documented the persistence of this species at the type

locality (East Fork Gila River). However, only dead specimens were recovered from Alum Hot Spring (Gila River mainstem) in October 2001 where Taylor (1987) reported *P. gilae* from a few live snails in the lower reaches of the spring run.

Status: The genetic affinities of such geographically disparate populations are poorly understood and seldom studied, and must be adequately explored prior to planning effective conservation measures (Weins 1996). Population threat assessment relative to land-use practices is inherent to this process.

The Gila River mainstem and Middle Fork Gila River populations of *P. gilae* occur on U. S. Forest Service (USFS) lands. The East Fork Gila River sub-basin harbors eight populations: two each on private and dual stewardship (private-USFS) lands, and four populations on USFS managed lands.

Management Recommendations:

(1) Expand inventory to unexplored reaches within the Gila River Basin.

(2) Recommend allocation of Section 6 funding to assess genetic divergence of *P. gilae* within and among geographically isolated populations throughout the Gila River Basin. Genetic divergence between disjunct populations may warrant taxonomic reevaluation of the species, which in turn could confer specific management recommendations particular to genetically distinct populations relative to current ownership and land-use practices.

Pecos springsnail (*Pyrgulopsis pecosensis*)

Monitoring: Taylor (1987) reported two populations of *Pyrgulopsis pecosensis* from perennial tributaries of the Black River, Eddy County, New Mexico: Blue Spring (type locality) and Castle Spring. During the period 1968-1980, Landye (1981) reported densities of *P. pecosensis* as 2.0 snails/cm^2 in "optimum habitat" (i.e., Blue Spring) with less dense and more variable populations from Castle Spring. This species was extirpated from Castle Spring sometime from 1980 to 1992 Mehlhop (1992). Under grant segments 5 and 6, the habitat and population of *P. pecosensis* in Blue Spring was monitored monthly at two localities from July 1997 to September 1998. Blue Spring was visited twice under project segments 7 and 8.

Status: Extirpation of the Castle Spring population was attributed to a number of factors including flood scour, ground water depletion, and possible contamination from an upstream livestock tank (Landye 1981, NMDGF 1988b, Mehlhop 1992). The habitat and population of *P. pecosensis* of Blue Spring were stable under grazing pressure and irrigation withdrawals observed during project segments 5-8.

Acquisition of Blue Spring surface water rights (NMSA 1995) and the "...lack of oil and gas reserves in the area..." prompted reclassification of *P. pecosensis* from a federal Candidate for

listing under the ESA to a Species of Concern (Federal Register 1996). Contrary to conclusions possibly drawn from this reclassification, the Black River Valley has experienced repeated problems of ground water depletion and contamination. Water levels of domestic and agricultural/range wells in the Black River Valley have lowered and even dried-up (residents of Black River Village and environs, *pers. com.*). The acquisition of surface water rights from Blue Spring was a temporary state lease (NMSA 1995).

Taylor (1985) identified ground water depletion as the primary threat to extant populations of *P. pecosensis*. Regional ground water withdrawals for agriculture and oil and gas industry operations (exploration, storage, transfer and refining) are ongoing in the Black River Valley and adjacent aquifers in Eddy County (BLM 1994, 1997). Such extractive processes and industry operations are known to deplete ground water aquifers and to contaminate ground and surface waters in New Mexico (Hennighausen 1969; Jercinovic 1982, 1984; Longmire 1983; Quarles 1983; Boyer 1986; Richard 1988a, 1988b; Rail 1989; Richard and Boehm 1989a, 1989b; Balleau Groundwater, Inc. 1996; Martinez et al. 1998). Aquatic mollusks are acutely sensitive to ground and surface water contaminants (Havlik and Marking 1987, Eisler 1987, Green and Trett 1989, Pennak 1989, Covich and Thorpe 1991).

Richard (1988a, 1988b) and Richard and Boehm (1989a, 1989b) documented ground water contamination of domestic and agricultural/range wells in the upper Black River Valley (i.e., Washington Ranch, Ballard Wells) by petroleum-derived hydrocarbons and sulfides. Richard and Boehm (1989b) reported "severe" sulfide contamination of Blue Spring in 1988, the most down-gradient surface discharge point for ground water in the upper Black River Valley. These authors indicated that gas contamination originating up-gradient was likely transported about 20 miles down-gradient to Blue Spring. Such long distance transport of ground water is common in karst, evaporite rock (White 1995, Martinez et al. 1998), which raises concerns for surface water quality of the Blue Spring wetland complex and the Black River in the long-term, especially considering the concentration of petroleum industry operations in the Black River Valley. Oil and gas industry operations within the immediate watershed of Blue Spring are ongoing.

Management Recommendations:

(1) Recommend exploring options for a "candidate conservation agreement" (Federal Register 1997), or similar agreement, that provides a mechanism for species and habitat conservation compatible with past and present land-use practices.

(2) Financial support under Section 6 will facilitate the Project Biologist's efforts to process monthly voucher collections, compile a database, analyze data, and synthesize reports.

(3) Continue annual habitat and population inventory of *P. pecosensis* at monitoring sites in the Blue Spring wetland complex.

Roswell springsnail (*Pyrgulopsis roswellensis*)

Monitoring: Taylor (1987) described *P. roswellensis* from a spring seep along the west side of refuge Unit 7 on Bitter Lake National Wildlife Refuge (BLNWR), while also reporting extant populations from refuge Unit 6 and Sago Spring (BLNWR), and from North Spring at the Roswell County Club, Roswell. Mehlhop (1992, 1993) documented persistence of the species on BLNWR and at North Spring, where a relict population still occurred in March 1995 (P. Mehlhop, *pers. com.*). Monthly (June 1995-July 1998) population monitoring of macroinvertebrates documented a second population of *P. roswellensis* in Bitter Creek at the Lost River confluence on BLNWR (NMDGF 1998). From June 1995 to May 1996, the abundance of *P. roswellensis* in Bitter Creek was 64-512 snails/m^2 compared to higher densities in Sago Spring complex (1125-27,924 snails/m^2). A small population of *P. roswellensis* exists near a beaver dam along the western drainage ditch of refuge Unit 6.

Status: Habitat loss and alteration (e.g., artesian spring source diversion, dewatering, capping), and diminution of spring flows from ground water mining are considered principal causes of decline in isolated populations of hydrobiid spring snails in New Mexico and Texas (Cole 1981, Taylor 1987, Lang et al. *In Press*).

The status of *P. roswellensis* at North Spring is unknown. The species is currently known from four populations at BLNWR. While these populations are stable under current refuge management plans (Research Management Consultants, Inc. 1998), off-refuge land use practices within areas of the Roswell Basin pose threats to the long-term viability of *P. roswellensis* at BLNWR.

Regional ground water pumping for agriculture and oil and gas industry operations (exploration, storage, transfer and refining) continue in the Pecos River Valley (BLM 1994, USFWS 1997). Oil and gas exploration is ongoing within areas that Balleau Groundwater, Inc. (1996, 1999) identified as primary ground water sources (i.e., "source-water protection zones") for surface waters at BLNWR. Such extractive processes and industry operations are known to deplete ground water aquifers and to contaminate ground and surface waters in New Mexico (Hennighausen 1969; Jercinovic 1982, 1984; Longmire 1983; Quarles 1983; Boyer 1986; Richard 1988a, 1988b; Rail 1989; Richard and Boehm 1989a, 1989b; Balleau Groundwater, Inc. 1996; Martinez et al. 1998). Aquatic mollusks are acutely sensitive to ground and surface water contaminants (Havlik and Marking 1987, Eisler 1987, Green and Trett 1989, Pennak 1989, Covich and Thorpe 1991). There is increased risk of potential degradation of ground and surface water quality posed by domestic sewage contamination (i.e., septic discharge) from urban encroachment in aquifer recharge-discharge areas along the western bounds of BLNWR. Illicit dumping of domestic contaminants (e.g., pesticides, herbicides, waste oil, etc.) and septic leachate are known to contaminate ground water resources in karst areas of the United States (White et al. 1995, Zokaites 1997) and in New Mexico (Bitner and Graves 1992, McQuillan et al. 1989).

Natural stochastic events, such as fire or drought, could adversely impact extant *P. roswellensis*

populations at BLNWR. Although the NMDGF (2001) demonstrated short-term fire effects on the physicochemical conditions in Bitter Creek following the March 20000 Sandhill Fire, the long-term impact of these effects, whether beneficial or adverse, on the aquatic biota and riparian corridor remain undetermined (see Appendix B). Prolonged drought may affect hydrologic conditions on BLNWR by reducing discharge through refuge surface waters while concomitantly affecting the aquatic physicochemical conditions and concentrating potential contaminants.

Long-term population viability of *P. roswellensis* at BLNWR will be contingent upon protection of ground and water quality and quantity. Federal water-rights for BLNWR were acquired in 1996 (USDJ 1996, Balleau Groundwater, Inc. 1997). In compliance with Section 17-2-40.1.A-G of the amended Wildlife Conservation Act (1995), the NMDGF in 1995 initiated conservation planning for 4 state-listed invertebrate species of Chaves County, including *P. roswellensis*. Development of a state recovery plan for these macroinvertebrates is currently ongoing.

Management Recommendations:

(1) Monitor populations of *P. roswellensis* biannually.

(2) Financial support under Section 6 will facilitate the Project Biologist's efforts to process monthly pre- and post-fire voucher collections, compile a database, analyze data, and synthesize reports.

(3) Through formal Section 7 Consultation on Threatened and Endangered species of the Bureau of Land Management's Roswell Resource Area Draft Resource Management Plan/Environmental Impact Statement (Roswell DRMP/EIS) (BLM 1994), the U.S. Fish and Wildlife Service (1997a) rendered jeopardy opinion that potential oil and gas activities along the Pecos River may adversely impact the Pecos bluntnose shiner and Pecos gambusia.

Since all macroinvertebrate species of BLNWR that possess state and federal status are sympatric with the federal endangered Pecos gambusia in Bitter Creek and Sago Spring, adherence with Section 7 Consultation Reasonable and Prudent Alternative No. 1 (RPA-1) for the Pecos Gambusia (USFWS 1997) is recommended. The RPA-1 states:

> "Use the best available hydrologic information to map the source and movement of water that supplies springs occupied by Pecos Gambusia on the Bitter Lake National Wildlife Refuge and Salt Creek Wilderness. Close the lands within the mapped area to oil and gas leasing unless or until the BLM can demonstrate that mandatory protective measures will ensure no aquifer contamination."

This abeyance for exploratory oil and gas well permits on lands referred to in RPA-1 is equally justified for *P. roswellensis* since these two species occur sympatrically, although

P. roswellensis is even more narrowly distributed than Pecos gambusia.

(4) In the event that oil and gas activities proceed without demonstrating that mandatory protective measures will ensure no aquifer contamination within the area referenced by RPA-1, then there would be a threatened curtailment and possible destruction of the limited habitat of *P. roswellensis*, thus demonstrating that regulatory mechanisms are inadequate. The species would be in danger of extinction throughout all of its range.

The New Mexico Department of Game and Fish (NMDGF) should commit resources necessary to assess whether or not the current implementation of RPA-1 is sufficient to conserve *P. roswellensis* in its native habitats on BLNWR. If this assessment concludes that current regulatory activities proposed under RPA-1 do not sufficiently protect this species, then further conservation measures, as identified by the NMDGF in the development of a state conservation and recovery plan (New Mexico Wildlife Conservation Act, 17-2-37 to 17-2-46 NMSA 1978), will be required to ensure the survival of *P. roswellensis*.

(5) Management practices at the BLNWR might include rehabilitation of vestigial habitat along the western ditch of refuge Unit 6, and in other spring-fed impoundment ditches, providing that such practices do not adversely impact habitats, populations, or management plans (Research Management Consultants, Inc. 1998) for other taxa on the Refuge.

New Mexico Hot Springsnail (*Pyrgulopsis thermalis*)

Monitoring: Mehlhop (1993) last reported on the status of hydrobiid spring snails of the Gila River Basin, and documented the persistence of *P. thermalis* at historic site occurrences (see Taylor 1987) in the East Fork Gila River, and from Alum Hot Spring (type locality), Gila River mainstem, Grant County.

In August 1998, approximately 20 miles of riparian corridor along the West Fork Gila River were surveyed for suitable spring habitats that might support populations of *P. thermalis*. No hydrobiid snail populations were located, as only pulmonate physid snails were collected from spring-fed backwater habitats of the West Fork Gila River. This sub-basin lacks the abundance of artesian springheads characteristic of the East Fork and Middle Fork sub-basins, and the Gila River mainstem. A single thermal spring on the Middle Fork Gila River, located approximately 0.7 river mile upstream of the Gila Visitor Center, was not conducive to successful colonization by any *Pyrgulopsis* species, as the water temperature exceeded 55°C, and the thermal pools were in located in the riverine floodway. Segment 9 field surveys (2001) documented the persistence of this species at the type locality (Alum Hot Spring) and at Taylor's (1987) East Fork Gila River site.

Status: Extant populations of *P. thermalis* are widely dispersed. The genetic affinities of such

geographically disparate populations are poorly understood and seldom studied, and must be adequately explored prior to planning effective conservation measures (Weins 1996). Population threat assessment relative to land-use practices is inherent to this process.

The East Fork Gila River population (type locality) occurs on lands at the limit of private and U. S. Forest Service lands. This site is most easily accessed by a two-track road that ends at "Lyon's Lodge". Any form of construction disturbance to extend this road for access to private lands located up-canyon from its current terminus could potentially impact the East Fork Gila River population of *P. thermalis*. While soil disturbance for road grading per se would likely not affect this population, deposition of overburden materials, excavation of aggregates/soils materials to establish road grade, or removal of overstory trees would be factors to consider as potential impacts.

The Gila River mainstem population (Alum Hot Spring) occurs in the Gila Wilderness where this species is most abundant in a thin film of water flowing over vertical rhyolitic cliff facies. During Segment 9, intensive sampling in the Alum Hot Spring rheocrene, where recreational bathers had created pools with rock dams, and in the densely vegetated springrun downstream of these pools, yielded only empty shells of *P. gilae, P. thermalis*, the pulmonate snail, *Physa* sp. Although Taylor (1987) reported *P. thermalis* in lower numbers within this portion of the Alum Hot Spring system, such physical disturbance and potential for water contamination from personal hygiene cleansers, may limit the species' ability to recolonize the spring run from upgradient source populations, where *P. thermalis* is abundant.

Annual flood events likely represent a natural form of mortality for the stream-dwelling population of *P. thermalis* at Alum Hot Spring (Taylor 1987).

Management Recommendations:

(1) Expand area of survey to malacologically unexplored reaches within the Gila River Basin.

(2) Efforts to control the use of personal hygiene detergents (e.g., soaps, shampoo, etc.) by bathers could protect habitat for *P. thermalis* in the downstream reaches of Alum Hot Spring. Signage that prohibits use of cleansing agents would still allow for recreational use of the spring.

(3) Recommend allocation of Section 6 funding to assess genetic divergence of *P. thermalis* within and among geographically isolated populations throughout the Gila River Basin. Genetic divergence between disjunct population may warrant taxonomic reevaluation of the species, which may in turn confer specific management recommendations particular to genetically distinct populations relative to current ownership and land-use practices.

Koster's springsnail (*Tryonia kosteri*)

Monitoring: Taylor (1987) described *Tryonia kosteri* from Sago Spring, BLNWR, and reported additional populations in Bitter Creek (Lost River), in the marsh of Sago Spring wetland complex downstream of Sinkhole #32, and along the western perimeter of refuge units 3 and 6. The westernmost limits of this species range was from North Spring, Roswell Country Club, Roswell (Taylor 1987). Mehlhop (1992, 1993) documented the persistence of BLNWR populations, and spot-checked the species' status in North Spring, where *T. kosteri* was last collected live in March 1995 (Pat Mehlhop, *pers. com.*). Under project segments 4-6, macroinvertebrate populations at BLNWR were monitored monthly from June 1995 to June 1998. During Year I monitoring (June 1995- May 1996), the abundance of *T. kosteri* in Bitter Creek was 704-89,472 snails/m^2 compared to lower densities in Sago Spring complex (75-512 snails/m^2) (NMDGF 1998).

In 1999 the persistence of relict *T. kosteri* populations along refuge units 3, 6, and 7 were verified by Dr. Mark E. Gordon (NM Museum of Natural History and Science, *pers. com.*), who also found isolated populations of this species in the southwestern corner of Unit 15 and the northwestern border of Hunter Marsh. These relict populations seem to occupy vestigial habitats where freshwater springs and seeps discharge less saline, more thermally stable waters compared to impounded waters (B. Lang, *pers. obs.*).

A survey of Lake St. Francis on BLNWR documented an extant population of *T. kosteri* in May 2002.

Status: Habitat loss and alteration (e.g., artesian spring source diversion, dewatering, capping) and diminution of spring flows from ground water mining are considered principal causes of decline in isolated populations of hydrobiid spring snails in New Mexico and Texas (Cole 1981, Taylor 1987, Lang et al. *In Press*).

The status of *T. kosteri* at North Spring is unknown. The species' primary populations at BLNWR occur in Bitter Creek and Sago Spring wetland complex, with isolated populations persisting in relict habitats along the western limits of all refuge impoundments except Unit 3. While these populations are stable under current refuge management plans (Research Management Consultants, Inc. 1998), off-refuge land use practices within areas of the Roswell Basin pose threats to the long-term viability of *T. kosteri* at BLNWR.

Regional ground water pumping for agriculture and oil and gas industry operations (exploration, storage, transfer and refining) continue in the Pecos River Valley (BLM 1994, USFWS 1997). Oil and gas exploration is ongoing within areas that Balleau Groundwater, Inc. (1996, 1999) identified as primary ground water sources (i.e., "source-water protection zones") for surface waters at BLNWR. Such extractive processes and industry operations are known to deplete ground water aquifers and to contaminate ground and surface waters in New Mexico (Hennighausen 1969; Jercinovic 1982, 1984; Longmire 1983; Quarles 1983; Boyer 1986; Richard 1988a, 1988b; Rail 1989; Richard and Boehm 1989a, 1989b; Balleau Groundwater, Inc.

1996; Martinez et al. 1998). Aquatic mollusks are acutely sensitive to ground and surface water contaminants (Havlik and Marking 1987, Eisler 1987, Green and Trett 1989, Pennak 1989, Covich and Thorpe 1991). There is increased risk of potential degradation of ground and surface water quality posed by domestic sewage contamination (i.e., septic discharge) from urban encroachment in aquifer recharge-discharge areas along the western bounds of BLNWR. Illicit dumping of domestic contaminants (e.g., pesticides, herbicides, waste oil, etc.) and septic leachate are known to contaminate ground water resources in karst areas of the United States (White et al. 1995, Zokaites 1997) and in New Mexico (Bitner and Graves 1992, McQuillan et al. 1989).

In March 2000, the Sandhill Fire burned approximately 1050 acres on BLNWR, including the riparian corridor of Bitter Creek. Post-fire studies are ongoing to assess the effects of fire on the resident population of *T. kosteri* in Bitter Creek. Based on threats posed by the Sandhill Fire, *T. kosteri* was uplisted from state threatened to endangered under the NMDGF's 2000 Biennial Review of New Mexico Threatened and Endangered Species.

Natural stochastic events, such as fire or drought, could adversely impact extant *T. kosteri* populations at BLNWR. Although NMDGF (2001) demonstrated short-term fire effects on the physicochemical conditions in Bitter Creek following the March 2000 Sandhill Fire, the long-term impact of these effects, whether beneficial or adverse, on the aquatic biota and riparian corridor remain undetermined (see Appendix B). Prolonged drought may affect hydrologic conditions on BLNWR by reducing discharge through refuge surface waters while concomitantly affecting the aquatic physicochemical conditions and concentrating potential contaminants.

Long-term population viability of *T. kosteri* at BLNWR will be contingent upon protection of ground and surface water quality and quantity. Federal water-rights for BLNWR were acquired in 1996 (USDJ 1996, Balleau Groundwater, Inc. 1997). In compliance with Section 17-2-40.1. A-G of the amended Wildlife Conservation Act (1995), the NMDGF in 1995 initiated conservation planning for 4 state-listed invertebrate species of Chaves County, including *T, kosteri*. Development of a state recovery plan for these macroinvertebrates is currently ongoing.

Management Recommendations:

(1) Monitor populations of *T. kosteri* at BLNWR biannually.

(2) Financial support under Section 6 will facilitate the Project Biologist's efforts to process monthly pre- and post-fire voucher collections, compile a database, analyze data, and synthesize reports.

(3) Through formal Section 7 Consultation on threatened and endangered species of the Bureau of Land Management's Roswell Resource Area Draft Resource Management Plan/Environmental Impact Statement (BLM 1994), the U.S. Fish and Wildlife Service (1997a) rendered jeopardy opinion that potential oil and gas activities along the Pecos River may adversely impact the Pecos bluntnose shiner and Pecos gambusia.

Since all macroinvertebrate species of BLNWR that possess state and federal status are sympatric with the federal endangered Pecos gambusia in Bitter Creek and Sago Spring complex, adherence with Section 7 Consultation Reasonable and Prudent Alternative No. 1 (RPA-1) for Pecos Gambusia (USFWS 1997) is recommended. The RPA-1 states:

> "Use the best available hydrologic information to map the source and movement of water that supplies springs occupied by Pecos Gambusia on the Bitter Lake National Wildlife Refuge and Salt Creek Wilderness. Close the lands within the mapped area to oil and gas leasing unless or until the BLM can demonstrate that mandatory protective measures will ensure no aquifer contamination."

This abeyance for exploratory oil and gas well permits on lands referred to in RPA-1 is equally justified for *T. kosteri* since these two species occur sympatrically, although *T. kosteri* is even more narrowly distributed than Pecos gambusia.

(4) In the event that oil and gas activities proceed without demonstrating that mandatory protective measures will ensure no aquifer contamination within the area referenced by RPA-1, then there would be a threatened curtailment and possible destruction of the limited habitat of *T. kosteri*, thus demonstrating that regulatory mechanisms are inadequate. The species would be in danger of extinction throughout all of its range.

The New Mexico Department of Game and Fish (NMDGF) should commit resources necessary to assess whether or not the current implementation of RPA-1 is sufficient to conserve *T. kosteri* in its native habitats on BLNWR. If this assessment concludes that current regulatory activities proposed under RPA-1 do not sufficiently protect this species, then further conservation measures, as identified by the NMDGF in the development of a state conservation and recovery plan (New Mexico Wildlife Conservation Act, 17-2-37 to 17-2-46 NMSA 1978), will be required to ensure the survival of *T. kosteri*.

(5) Management practices at BLNWR might include rehabilitation of vestigial habitat of *T. kosteri* along the western shore line of refuge impoundments, providing that such practices do not adversely impact habitats, populations, or management plans (Research Management Consultants, Inc. 1998) for other taxa on the Refuge.

Sangre de Cristo peaclam, *Pisidium sanguinichristi*

Monitoring: Taylor (1987) described *Pisidium sanguinichristi* from a single collection in a high-elevation glacial cirque, Middle Fork Lake, Questa Ranger District, Carson National Forest (CNF), Taos County, New Mexico. This endemic peaclam can be considered the most narrowly restricted of all known North American pisidia and perhaps worldwide.

The NMDGF initiated annual population monitoring of *P. sanguinichristi* in July 1995 under a multi-agency conservation effort initiated by the U. S. Forest Service (1996). A total of 42 sites was surveyed from 1996-1999 in the northern Sangre de Cristo Mountains to determine the species' range. Only six valves out of an abundance (i.e., exceeding ca. 750 specimens) of *Pisidium* voucher material collected from Middle Fork Lake (1995-1999) remotely resembled paratype *P. sanguinchristi* specimens (Brian Lang, Biologist, NMDGF, and Dr. Gerry L. Mackie, University of Guelph, Canada; *pers. obs.*). No pisidia collected from any other survey sites were referable to *P. sanguinichristi.*

Based on the absence of *P. sanguinichristi* from the 1995 and 1996 surveys at Middle Fork Lake, and the lack of discernable differences in shell shape and hinge dentition between paratype *P. sanguinichristi* and the conchologically similar and co-occurring congener, *Pisidium milium*, the NMDGF requested taxonomic assessment of the putative *P. sanguinichristi* as a valid taxon (NMDGF 1996b). A mitochondrial DNA study comparing the nominal species with *P. milium* yielded inconclusive results since the biochemical analysis was restricted to a comparison of shell proteins, as proteins from soft tissues of *P. sanguinichristi* specimens were not readily extracted (Wilson et al. 1998). However, protocols for amplification of *Pisidium* DNA are now established that will facilitate genetic analysis in the event future field surveys may yield live *P. sanguinichristi.*

Status: Although numerous Sphaeriacean clams have cosmopolitan distributions (Herrington 1962, Burch 1975), geographically dispersed and localized sphaeriid bivalve populations are common (Wu 1978), and largely the result of natural introductions by migratory shorebirds and waterfowl (Bequaert and Miller 1973). Avifauna, that frequent margins of wetlands or forage on benthic substrata by wading, dabbling or diving, commonly transport young clams from one body of water to another in mud that clings to their feet and/or feathers (Pennak 1989, MacMahon 1991). Founding populations of highly adaptable species, such as sphaeriid clams, commonly demonstrate short-term, rapid population success followed by decrease to some lower sustainable number, or extinction within a relatively short period (MacArthur 1972). Although local environmental factors may play a significant role influencing the success of introductions by avian phoresy events, sphaeriid distribution patterns are also correlated with general climatic conditions. Habitat conditions (e.g., substrate type, physicochemical regime, permanency of water, flow) commonly affect development and growth of sphaeriid bivalves, and manifest marked ecophenotypic variation of shell characteristics in sphaeriid populations of geographically disparate conspecifics (Herrington 1962).

Consequently, endemicity of Sphaeriacean clams is uncommon, as only two taxa, *P. sanguinichristi* and *Pisidium ultramontanum* are considered endemic to North America (Taylor 1960, 1987). The latter species is known from only a few isolated populations in northern California and southwestern Oregon (Herrington 1962, Burch 1975), and appears to be a Pleistocene relict that once occupied an historically wider range eastward into southern Idaho (Taylor 1960). On a worldwide basis, endemic pisidia seem restricted to large, deep lakes in South America (Lago Titicaca) and in eastern Russia (Drs. Gerry L. Mackie and Mark E. Gordon, *pers. com.*). These bodies of water, like those presently colonized by *P. ultramontanum*,

were formed by mountain building events (e.g., block faulting, uplift), whereas the type locality of *P. sanguinichristi*, Middle Fork Lake, was formed by Pleistocene glaciation events.

That the common and widespread *P. milium* occurs sympatrically with the putative *P. sanguinichristi* in Middle Fork Lake, and in similar habitats in the northern Sangre de Cristo Mountains of New Mexico (Brian Lang, *pers. obs.*) and adjacent Colorado (Wu 1978), may simply reflect the presence of an ecophenotypic morphotype of *P. milium* errantly identified by Taylor (1987) as the undescribed nominal taxon. However, Taylor (1987) emphasized that specimens of these two species from Middle Fork Lake were easily distinguished. Taylor's (1987) description of *P. sanguinichristi* was not peer-reviewed by malacologists prior to publication, and it received limited post-publication distribution in a professional journal of non-malacological focus. Taylor (1987) commented on the uniqueness of this population, implying that such a geographic isolate is uncommon within the Sphaeriidae: "...as most species of the genus are widespread."

Whereas the remoteness and ownership of Middle Fork Lake (U. S. Forest Service) affords some measure of protection, the site experiences intense periods of active and passive recreational use. Population threats include shoreline destabilization (erosion and sedimentation due to foot/vehicular traffic), contamination from chemicals used in fish stocking and forest fire suppressants, placer mining runoff, and natural stochastic events (fire, drought) (Taylor 1985, McDonald and Hamilton 1995, USFS 1996).

Management Recommendations:

(1) Continue sphaeriid surveys in high-elevation wetland habitats throughout the Sangre de Cristo Mountains, and expand this effort to include the Jemez Mountains. In the event live peaclams referable to *P. sanguinichrisiti* are located, genetic studies comparing *P. sanguinichristi* with *P. milium* would be in order.

(2) Conduct a conchological morphometric study a comparing *P. sanguinichristi* and *P. milium*, if such an investigation merits the effort. While shell meristics may help resolve outstanding taxonomic questions, significant ecophenotypic variation in shell morphology and hinge dentition of sphaeriid clams manifested by local environmental influences could render such an effort futile (Herrington 1962).

Literature Cited

Balleau Groundwater, Inc. 1996. Interrelation of groundwater and surface water at Bitter Lake National Wildlife Refuge. A report prepared for the U.S. Department of Justice. 16 pp. (with addenda).

Balleau Groundwater, Inc. 1997. Annotated abstract of water-rights administration Bitter Lake National Wildlife Refuge. A report prepared for the U.S. Department of Justice. 22 pp. (with addenda).

Balleau Groundwater, Inc. 1999. Source-water protection zones for Bitter Lake National Wildlife Refuge. A report prepared for the U.S. Department of Justice. 42 pp.

Bequaert, J. C. and W. B. Miller. 1973. The mollusks of the Arid Southwest with an Arizona checklist. University of Arizona Press, Tucson. 271 pp.

Bitner, M. J. And T. Graves. 1992. Effect of lot sizes on potential ground-water contaminants from conventional septic-tank systems: numerical modeling. Policy Coordinating Committee. 47 pp.

Boyer, D. G. 1986. Differences in produced water contaminants from oil and gas operations in New Mexico - implications for regulatory action. Pp. 291-316, *In* Proceedings of the Conference on Southwestern Groundwater Issues (D. K. Kreamer, Moderator). National Well Water Association, Dublin, Ohio.

Burch, J. B. 1975. Freshwater sphaeriacean clams (Mollusca: Pelecypoda) of North America. U. S. Environmental Protection Agency. Biota of Freshwater Ecosystems, Identification Manual No. 3.

Bureau of Land Management. 1994. Draft resource management plan/environmental impact statement for the Roswell Resource Area, Roswell, New Mexico, and draft resource management plan amendment/environmental impact statement for the Carlsbad Resource Area, Carlsbad, New Mexico. Bureau of Land Management, Roswell, NM.

Bureau of Land Management. 1997. Carlsbad Approved Resource Management Plan, Amendment and Record of Decision, Carlsbad Resource Area, Roswell District, New Mexico. BLM-NM-PT-98-004-1610.

Cole, G. A. 1981. *Gammarus desperatus*, a new species from New Mexico (Crustacea: Amphipoda). Hydrobiologia 76:27-32.

Cole, G. A. 1985. Analysis of the *Gammarus*-pecos complex (Crustacea: Amphipoda) in Texas and New Mexico, USA. Journal of the Arizona-Nevada Academy of Science 20:93-103.

Cole, G. A. 1988a. Noel's amphipod *(Gammarus desperatus)*. Final Report submitted to the New Mexico Department of Game and Fish Endangered Species Program under Professional Service Contract 519-77-02. 6 pp.

Cole, G. A. 1988b. A report on the status of Amphipoda, including *Gammarus desperatus* in New Mexico. Submitted to the New Mexico Department of Game and Fish Endangered Species Program under Professional Service Contract 519-77-02. 15 pp.

Covich, A. P. and J. H. Thorp. 1991. Crustacea: introduction and Peracarida. Pp. 665-689, *In* Ecology and Classification of North American Freshwater Invertebrates (J. H. Thorp and A. P. Covich, Eds.). Academic Press, Inc.

Eisler, R. 1987. Polycyclic aromatic hydrocarbon hazards to fish, wildlife, and invertebrates: a syntopic review. U. S. Fish and Wildlife Service. Contaminant Hazard Reviews Report No. 11, Biological Report 85 (1.11).

Federal Register. 1996. Endangered and Threatened Wildlife and Plants; Review of Plant and Animal Taxa that are Candidates for Listing as Endangered or Threatened Species. 50 CFR 17. 61(40):7596-7613.

Federal Register. 1997. Announcement of Draft Policy for Candidate Conservation Agreements; Notice of Review. 50 CFR 17. Federal Register 62(113):32183-32188.

Gervasio, V., D. J. Berg, B. K. Lang, N. Allan, M. E. Gordon, G. Warrick, S. I Guttman. *In Preparation*. Genetic variability of the *Gammarus-pecos* species complex (Crustacea: Amphipoda) in Chihuahuan Desert springs.

Green, J. and M. W. Trett. 1989. The fate and effects of oil in freshwater. Elsevier Science Publishing Co., Inc., New York.

Havlik, M. E. and L. L. Marking. 1987. Effects of contaminants on naiad mollusks (Unionidae): a review. U. S. Fish and Wildlife Service, Resource Publication 164.

Hennighausen, F. H. 1969. Meters and their effects in the Roswell Artesian Basin in Chaves and Eddy counties, New Mexico. Pp. 29-33, *In* 14th Annual New Mexico Water Conference (Water Resources Institute).

Herrington, H. B. 1962. A revision of the Sphaeriidae of North America (Mollusca: Pelecypoda). University of Michigan Museum of Zoology. Miscellaneous Publications No. 18.

Jercinovic, D. E. 1982. Assessment of refined petroleum-product contamination problems in surface and ground waters of New Mexico. A Report to the Soil and Water Division, New Mexico Natural Resources Department. Water Pollution Control Bureau, New

Mexico Environmental Improvement Division, EID/WPC-82/5.

Jercinovic, D. E. 1984. Petroleum-product contamination of soil and water in New Mexico. A Report to the Soil and Water Division, New Mexico Natural Resources Department. New Mexico Environmental Improvement Division, EID/GWH-84/2.

Landye, J. J. 1981. Current status of endangered, threatened, and/or rare mollusks of New Mexico and Arizona. Endangered Species Office, U. S. Fish and Wildlife Service, Final Report 13.

Lang et al. *In Press*. Gammarid amphipods of Northern Chihuahuan Desert spring systems: an imperiled fauna. Proceedings of the 2001 Annual Desert Fishes Council Meeting.

Longmire, P. A. 1983. Petroleum-product contamination of ground and surface water: a literature review. Ground Water Section, Water Pollution Control Bureau, New Mexico Environmental Improvement Division. EID/WPC-83/7.

MacArthur, R. M. 1972. Geographical Ecology. Harper & Row, New York.

MacMahon, R. F. 1991. Mollusca: Bivalvia. Pp. 315-399, *In* Ecology and Classification of North American Freshwater Invertebrates (J. H. Thorp and A. P. Covich, Eds.). Academic Press, Inc.

Martinez, J. D., K. S. Johnson, and J. T. Neal. 1998. Sinkholes in evaporite rocks. American Scientist 86:38-51.

McDonald, S. F. and S. J. Hamilton. 1995. Fire retardant and foam suppressant chemicals may be toxic to aquatic invertebrates and algae. National Biological Service. NBS Information Bulletin 35.

McQuillan, D. M., M. J. Jasper and B. H. Swanson. 1989. Ground-water contamination by septic-tank use: a field study in the Albuquerque south Valley - West Mesa Region, Bernalillo County, New Mexico. New Mexico Health and Environment Department, Environmental Improvement Division, Ground Water Bureau.

Mehlhop, P. 1992. Establishment of a rare mollusc inventory and monitoring program for New Mexico. Progress Report. NMGF Professional Services Contract 80-519-52.

Mehlhop, P. 1993. Establishment of a rare mollusc inventory and monitoring program for New Mexico. Year II Progress Report. NMGF Professional Services Contract No. 80-519-52-Amendment 1.

New Mexico Department of Game and Fish. 1988a. Handbook of species endangered in New Mexico. Account: A-650.

New Mexico Department of Game and Fish. 1988b. Handbook of species endangered in New Mexico. Account: A-299.

New Mexico Department of Game and Fish. 1996a. Threatened and endangered species of New Mexico: Biennial Review and Recommendations. 122 pp.

New Mexico Department of Game and Fish. 1996b. Status of aquatic and terrestrial mollusks of New Mexico. Completion Report for E-20-(1-4) submitted to the Office of Federal Aid, U. S. Fish and Wildlife Service, Albuquerque, NM.

New Mexico Department of Game and Fish. 1998. Status of aquatic mollusks of New Mexico. Annual Performance Report (E-20-6) submitted to the Office of Federal Aid, U. S. Fish and Wildlife Service, Albuquerque, NM.

New Mexico Department of Game and Fish. 2001. Status of aquatic mollusks of New Mexico. Annual Performance Report (E-20-8) submitted to the Office of Federal Aid, U. S. Fish and Wildlife Service, Albuquerque, NM.

New Mexico Statutes Annotated. 1995. Interstate Stream Commission Water Conservation Program: Pecos River Portion. NMSA Supplement 72-5-28.

Noel, M. S. 1954. Animal ecology of a New Mexico springbrook. Hydrobiologia 6:120-135.

Pennak, R. W. 1989. Fresh-water invertebrates of the United States: Protozoa to Mollusca. John Wiley & Sons, Inc.

Quarles, J. 1983. Groundwater contamination in the United States. University of Pennsylvania Press, Philadelphia.

Rail, C. D. 1989. Groundwater contamination: sources, control, and preventative measures. Techonomic Publishing Company, Inc. Lancaster, PA.

Research Management Consultants, Inc. 1998. Final comprehensive conservation plan and Environmental Assessment: Bitter Lake National Wildlife Refuge.

Richard, M. 1988a. Natural gas contamination at Rattlesnake Springs, Carlsbad Caverns National Park: review of the geohydrology in the vicinity of Rattlesnake Springs and the contamination problem. Report 1. National Park Service Contract RFQ 7029-8-0025.

Richard, M. 1988b. Natural gas contamination at Rattlesnake Springs, Carlsbad Caverns National Park: report of the first field investigation, August 1988. Report 2. National Park Service Contract RFQ 7029-8-0025.

Richard, M. and A. Boehm. 1989a. Natural gas contamination at Rattlesnake Springs, Carlsbad

Caverns National Park: report of the second field investigation, March, 1988. Report 3. National Park Service Contract RFQ 7029-8-0025.

Richard, M. and A. Boehm. 1989b. Natural gas contamination at Rattlesnake Springs, Carlsbad Caverns National Park: final summary of the investigation. Report 4. National Park Service Contract RFQ 7029-8-0025.

Taylor, D. W. 1960. Distribution of the freshwater clam *Pisidium ultramontanum*: a zoogeographic inquiry. American Journal of Science 258-A:325-334.

Taylor, D. W. 1985. Endangered Species: Status investigation of mollusks of New Mexico. Professional Service Contract Nos. 519-69-01 and 519-69-01-A.

Taylor, D. W. 1987. Fresh-water mollusks from New Mexico and vicinity. New Mexico Bureau of Mines & Mineral Resources Bulletin 116.

United States Department of Justice. 1996. United States of America's statement of claim for reserved surface water and groundwater rights for Bitter Lake National Wildlife Refuge. Roswell Basin Section, RAB 923 and 1793, Denver.

United States Fish and Wildlife Service. 1997. Biological opinion on the Roswell Resource Area Resource Management Plans. Section 7 Consultation #2-22-96-102.

United States Forest Service. 1996. Habitat conservation assessment for the Sangre de Cristo peaclam (*Pisidium sanguinichristi*).

Weins, J. A. 1996. Wildlife in patchy environments: metapopulations, mosaics, and management. Pp 53-84, *In* Metapopulations and Wildlife Conservation (Ed. D. R. McCollough). Island Press.

White, W. W., D C. Culver, J. S. Herman, T. C. Kane, and J. E. Mylroie. 1995. Karst Lands. American Scientist 83:450-459.

Wu, S-K. 1978. The Bivalvia of Colorado. Part 1. The fingernail and pill clams (Family Sphaeriidae). University of Colorado Museum, Natural History Inventory of Colorado 2.

Zokaites, C. 1997. Living on karst: a reference guide for landowners in limestone regions. Cave Conservancy of the Virginias. 25 pp.

Appendix B. Preliminary findings of Sandhill Fire effects on the physicochemical conditions of Bitter Creek, Bitter Lake National Wildlife Refuge.