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MADISON CAVE ISOPOD

(Antrolana lira)

RECOVERY PLAN

U.S. Fish and Wildlife Service
Hadley, Massachusetts

MADISON CAVE ISOPOD *(Antrolana lira)*

RECOVERY PLAN

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EXECUTIVE SUMMARY

Madison Cave Isopod ~~Draft~~ Recovery Plan

Final

CURRENT STATUS: The Madison Cave isopod, *Antrolana lira*, is a subterranean freshwater crustacean endemic to the Shenandoah Valley in Virginia. This monotypic genus is the only member of the family Cirolanidae found north of Texas. Until 1990, *A. lira* was known only from two sites, Madison Saltpetre Cave and a fissure near the cave; since June 1990, the isopod has been collected from five additional sites. Although specimens from all seven sites are morphologically identical, they probably represent more than one but less than seven genetic populations. Population size appears to be extremely small at five of the species' seven occurrence sites. The Madison Cave isopod was listed as a threatened species in November 1982. Urban and agricultural development threatens the quality of its groundwater habitat and thus its survival; in addition, lack of knowledge of the basic ecology of this isopod hinders the development of plans for its management and protection.

LIMITING FACTORS AND HABITAT REQUIREMENTS: The Madison Cave isopod appears to have low reproductive potential, and the small population size at most of its sites indicates that it is highly sensitive to disturbance. The species, which is difficult to study and collect, is known only from areas where fissures descend to the groundwater table, thus allowing access to the surface of underground lakes, or deep karst aquifers. Little is known about the physical and chemical conditions of *A. lira* habitat. The temperature of the water ranges from 11-14°C, as is typical of groundwater for the latitude, and the water is saturated with calcium carbonates, a condition also typical of groundwater in areas of limestone. The level of the karst aquifers can fluctuate for tens of meters at some sites. The extent of the recharge zone of the aquifer at any site is unknown.

RECOVERY OBJECTIVE: The objective of this recovery plan is to protect populations of *Antrolana lira* from potential threats to the quality of their deep karst aquifer habitat, thereby enabling the removal of this threatened species from the Federal list of endangered and threatened wildlife and plants.

RECOVERY CRITERIA: **Delisting** may be considered when: (1) populations of *Antrolana lira* and groundwater quality at Front Royal Caverns, Linville Quarry Cave No. 3, and Madison Saltpetre Cave/Steger's Fissure are shown to be stable over a ten-year monitoring period; (2) the recharge zone of the deep karst aquifer at each of the population sites identified in criterion 1 is protected from all significant contamination sources; and (3) sufficient population sites are protected to maintain the genetic diversity of the species.

ACTIONS NEEDED:

1. Determine the number of genetic populations of *A. lira*.
2. Search for additional populations.
3. Identify potential sources and entry points of contamination of their deep karst aquifer habitat.
4. Protect known populations and habitats, taking a watershed perspective.
5. Collect baseline ecological data relevant to management and recovery.
6. Implement a program to monitor progress of the recovery plan.

PROJECTED COSTS ($000):

	Need 1	Need 2	Need 3	Need 4	Need 5	Need 6	Total
FY1	15	5	40	11	10.5	1.5	83
FY2	20	5	35	16	8.5	1.5	86
FY3	--	5	35	16	6.5	1.5	64
FY7-10	--	10	120	7	38.5	10.5	196
TOTAL	35	25	230	50*	64	15	419

* Additional funds may be required.

TIME FRAME: If recovery tasks are implemented on schedule, the projected date for delisting the Madison Cave isopod is the year 2007.

* * *

The following recovery plan delineates reasonable actions to recover and/or protect the threatened Madison Cave isopod *(Antrolana lira)*. Comments received on the technical/agency draft plan, which was prepared through the contract services of Daniel W. Fong, have been incorporated by the U.S. Fish and Wildlife Service into this final plan. Attainment of recovery objectives and availability of funds for implementing recovery actions will be subject to budgetary and other constraints affecting the parties involved, as well as the need to address other priorities.

This recovery plan does not necessarily represent the views or official position of any individual or agency involved in its formulation, other than the U.S. Fish and Wildlife Service. Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and implementation of recovery tasks.

Literature citations should read as follows:

U.S. Fish and Wildlife Service. 1996. Madison Cave Isopod *(Antrolana lira)* Recovery Plan. Hadley, Massachusetts. 36 pp.

Additional copies of this plan can be obtained from:

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PART I: INTRODUCTION

The Madison Cave isopod, *Antrolana lira*, is a subterranean freshwater crustacean. It belongs to the family Cirolanidae, which consists of mostly marine and a small number of freshwater species. In common with other freshwater cirolanids, *A. lira* is restricted to groundwater habitats (Botosaneanu *et al.* 1986). It is the only freshwater cirolanid found in North America north of Texas. This isopod is endemic to Virginia and has been collected from seven sites where the groundwater table is accessible occasionally during the year through vertical fissures in caves.

Antrolana lira was listed as a threatened species in November of 1982 (47 FR 43701: October 4, 1982). The species appears to have low reproductive potential, and its population size seems extremely small at five of its seven occurrence sites, indicating that it is highly sensitive to disturbance. Rapid expansion of urban and agricultural development threatens the quality of its groundwater habitat and thus the survival of *A. lira*. Lack of data about the basic ecology of *A. lira* impedes the development of plans for its management and protection.

Following its listing, the Madison Cave isopod was assigned a recovery priority number[1] of 7, based on (1) a moderate degree of threat to the species' survival, (2) a high potential for recovery, and (3) its taxonomic standing as a monotypic genus. For several years, the species' highly limited distribution and lack of data proscribed development of a recovery plan; however, the recent discovery of additional *A. lira* occurrences coupled with heightened concerns about effects of groundwater disturbances have led to consideration of a recovery program for this isopod.

1 Recovery priority numbers ranging from a high of 1C to a low of 18 are determined for all species listed pursuant to the Endangered Species Act of 1973, as amended. These numbers are based on criteria defined in the Federal Register (Vol. 48, No. 184). A listed taxon with a ranking of 1C receives the highest priority for the development and implementation of recovery plans.

DESCRIPTION AND DISTRIBUTION

Thomas C. Barr, Jr. discovered the Madison Cave isopod in 1958 in a deep lake at the bottom of a fissure in Madison Saltpetre Cave in Augusta County, Virginia. It was described by Bowman (1964) as *Antrolana lira*, a new genus as well as a new species. *Antrolana* remains a monotypic genus to date, and is closely related to the genera *Cirolanides*, found in Texas, and *Mexilana* and *Speocirolana*, both found in Mexico (Holsinger *et al.* 1994).

As is typical of isopods, *A. lira* has a dorso-ventrally flattened, compact body plan, a pair of short first antennae and a pair of long second antennae. It has seven pairs of pereopods. The first, anterior-most pair is modified as prehensile grasping structures. The second through seventh pairs, which get progressively longer toward the posterior, are ambulatory. Unlike most freshwater isopods, which can only walk along the substrate, *A. lira* is also an excellent swimmer in the water column. Like most subterranean organisms, *A. lira* is eyeless and depigmented. It has a translucent cuticle through which some of its internal organs, such as the hepatopancreas, are visible. Males reach about 15 mm in length and 5 mm in width, females about 18 mm in length and 6 mm in width, making this species among the longer, and the most massive, of subterranean isopods in the eastern United States.

Before 1990, *A. lira* was thought to exist only in Madison Saltpetre Cave and in Steger's Fissure about 100 meters north-northeast relative to the cave. Both sites are located on the northeastern end of Cave Hill in Augusta County. The isopod has been collected from five additional sites since June 1990 (Figure 1; Holsinger *et al.* 1994). The northernmost of the seven sites where *A. lira* occurs is Front Royal Caverns in Warren County, Virginia. It is also the most isolated site, being more than 70 km north-northeast from the nearest of the other six sites. The other sites are clustered within an area defined by a radius of 20 km. Ranging from north to south, these are 3-D Maze Cave, Devils Hole Cave, Linville Quarry Cave No. 3 and Massanutten Caverns in Rockingham County, and the Cave Hill sites, Steger's Fissure and Madison Saltpetre Cave, in Augusta County. All seven sites are located within the Shenandoah

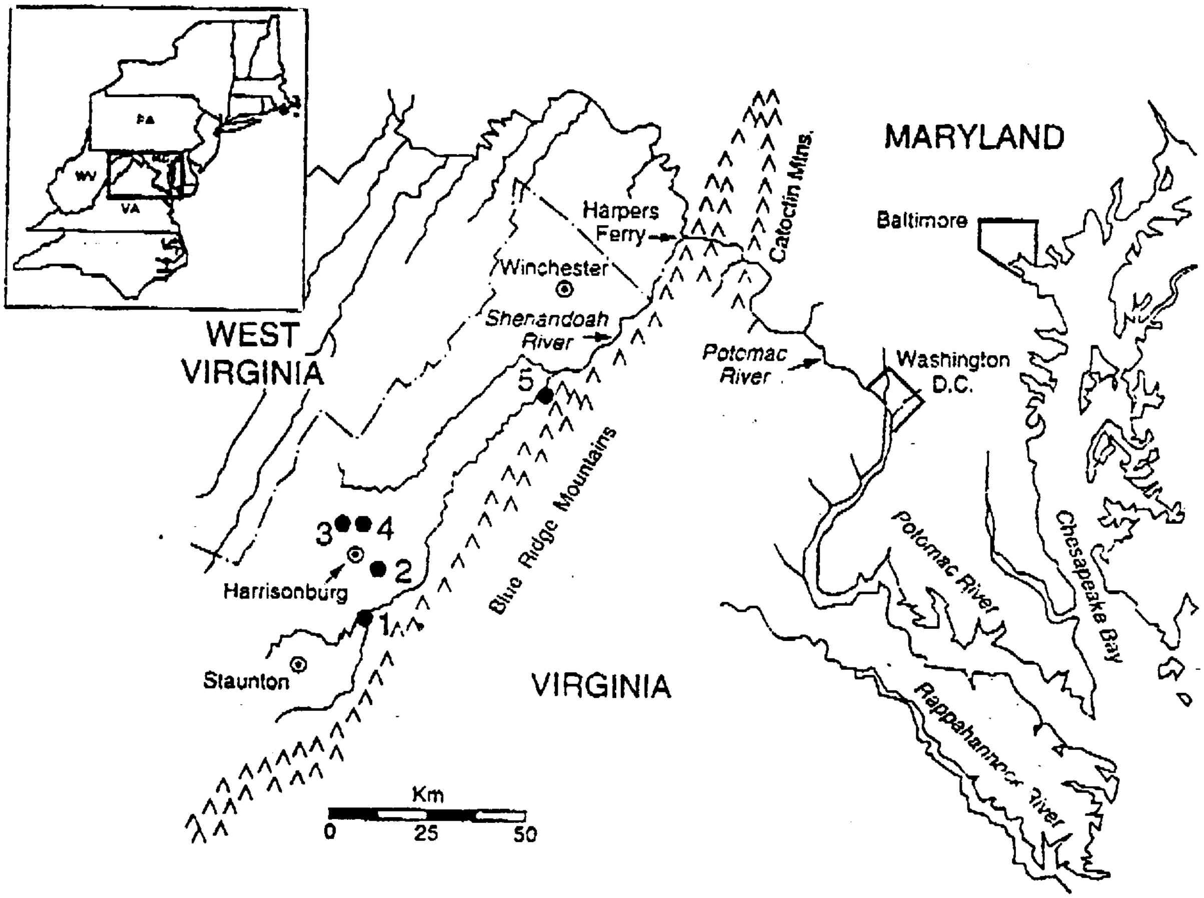

Figure 1. Distribution of *Antrolana lira* in the Potomac River drainage basin. Occurrence sites are: (1) Madison Saltpetre Cave and Steger's Fissure; (2) Massanutten Caverns; (3) Devils Hole and 3-D Maze Cave; (4) Linville Quarry Cave No. 3; and (5) Front Royal Caverns. From Holsinger *et al.* (1994)

Valley, a part of which in the vicinity of Harpers Ferry is hypothesized to have been in contact with shallow sea water during Cretaceous or Tertiary marine embayment (Holsinger *et al.* 1994; J.R. Holsinger, Old Dominion University, *in litt.* 1996). Populations of *A. lira* at these sites are thought to have derived from marine ancestors that were left stranded from regressions of the marine embayments and became adapted to the subterranean groundwater ecosystem (Holsinger *et al.* 1994).

HABITAT

All seven sites where *Antrolana lira* occurs contain vertical fissures that descend to the groundwater table, thus allowing access to the surface of underground lakes, or deep karst aquifers (phreatic waters). Figure 2 shows the conjectured configuration of deep karst aquifer habitat near Madison Saltpetre Cave. Although some of these aquifers extend to great depths, sampling of *A. lira* has been restricted to their surface, which is relatively shallow in many places (D.A. Hubbard, Virginia Department of Mines, Minerals and Energy, *in litt.* 1996). The surface of these deep karst aquifers fluctuates with the local groundwater table and may disappear entirely from accessible cave passages in most sites during dry periods. All specimens of *A. lira* were collected either by shrimp-baited traps placed in these underground lakes or directly from temporary pools in shallow depressions on the floor of low-level cave passages or low-gradient streams previously flooded by rising groundwater, indicating that deep karst aquifers, i.e., phreatic waters, are the species' primary habitat.

Only two other macroinvertebrates occupy this deep karst aquifer habitat with *A. lira*. In the two Cave Hill sites, *A. lira* is found along with the Madison Cave amphipod, *Stygobromus stegerorum*, a rare crustacean endemic to the Cave Hill aquifer. A relatively more common and widespread subterranean amphipod, *S. gracilipes*, was collected with *A. lira* in Front Royal Caverns, 3-D Maze Cave and Devils Hole; however, this amphipod is not restricted to the deep aquifer habitat and has been collected from streams and drip pools in many caves in the upper Shenandoah Valley (Holsinger 1978). How and whether *A. lira* interacts with these

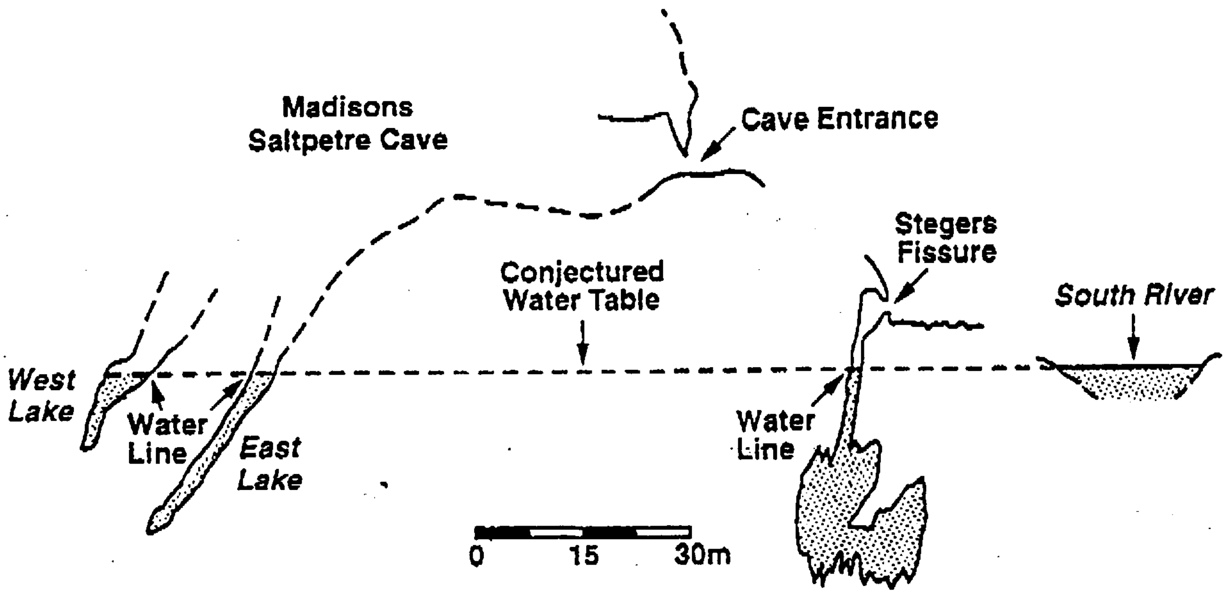

Figure 2. Profile of section through the Cave Hill sites showing conjectured configuration of the deep karst aquifer habitat. From Collins and Holsinger (1981)

other species is unknown. Other than the fact that *A. lira* is attracted to and will readily consume the shrimp used as bait, and that insect parts were detected in the gut content of some individuals from Steger's Fissure (J.R. Holsinger pers. comm. 1995), its feeding habit is also unknown.

Little is known about the physical and chemical conditions of the habitat of *A. lira*. The temperature of the water ranges from 11-14°C, as is typical of groundwater for the latitude. Rafts of calcite plates are usually present on the surface of the aquifers, indicating that the water is supersaturated with calcium carbonates, a condition also typical of groundwater in areas of limestone. The level of the karst aquifers can fluctuate for tens of meters at some sites. The extent of the recharge zone of the aquifer at any site is unknown.

NUMBER OF POPULATIONS

The number of genetic populations of *A. lira* sampled from the seven sites is unclear. The number of populations is determined by the extent of physical connection among deep karst aquifers through which the isopod can migrate. The strongly folded and faulted nature of the sedimentary rocks in the Shenandoah Valley (Hubbard 1983) indicates limited connectivity among aquifers. Thus, although specimens from all seven sites are morphologically identical, they probably represent more than one, but less than seven, genetic populations. For example, it is probable that isopods from Front Royal Caverns in Warren County represent a distinct population completely isolated from the rest of the species' range, and thus is represented by unique genotypes. It is also probable that isopods from Madison Saltpetre Cave and Steger's Fissure are a single genetic population, because these two sites essentially allow access to the same aquifer.

ABUNDANCE AND LIFE HISTORY

The population size of *A. lira* is unknown at most sites; rough estimates of population size are, however, available for Madison Cave and Steger's Fissure. To date, a documented total of 33 specimens has been collected from the five sites discovered since 1990 (28 listed in Holsinger *et al.* 1994, plus five collected by the author at Linville Quarry Cave No. 3). *A. lira* appears to be extremely rare at some sites; for example, only one and two specimens have ever been documented from Massanutten Caverns and Devils Hole Cave, respectively. Although the population size at these five sites may truly be small, it may also be that the small number of specimens is a result of inadequate sampling, because the surface of the deep aquifers at these sites is not accessible most of the year for sampling isopods.

Mark-recapture estimates of population sizes at Madison Saltpetre Cave and Steger's Fissure were, respectively, 1972 ($\pm$ 851) and 6678 ($\pm$ 3782) isopods per two-hour baiting effort, with a 24-hour dispersal interval between marking and recapturing, in June 1995 (Fong *in prep.*). The large standard errors of these estimates result from low recapture rates. Nonetheless, these estimates indicate that the Cave Hill sites potentially harbor large populations of *A. lira*, especially compared with estimated population sizes of other subterranean organisms (see Culver 1982 and Culver *et al.* 1995). A total of 190 and 303 different individuals were actually observed at Madison Saltpetre Cave and Steger's Fissure, respectively, during the mark-recapture study. It is interesting to speculate that the large size of the population at Steger's Fissure may be the result of organic matter entering directly on the surface, making it a hot spot for this species (D.C. Culver, The American University, *in litt.* 1996).

These numbers are similar to the numbers reported from a year-long study of the life-history of *A. lira* conducted by Collins and Holsinger (1981) at Madison Saltpetre Cave and Steger's Fissure from September 1979 to September 1980. Their numbers, per 30-minute baiting effort, varied among monthly samples, ranging from 3 to 285 in Madison Saltpetre Cave and from zero to 593 in Steger's Fissure. Their data showed an apparent difference in temporal trends in abundance between the two sites. Of the cumulative 13-month total of 656 isopods trapped in Madison Saltpetre Cave, 285 (43.4%) were obtained in the first September sample, while the numbers for the rest of the study period showed no obvious pattern of variation. In contrast, of the total of 1309 isopods trapped in Steger's Fissure, 1001 (76.5%) were obtained in the three-month interval from December to February. These results suggest a seasonal peak of isopod abundance in Steger's Fissure that was not evident in Madison Saltpetre Cave, although a much longer study period is required to check the validity of this pattern. The mean body size of isopods showed no significant variation among monthly samples in both sites, but specimens from Steger's Fissure were generally slightly larger than ones from Madison Saltpetre Cave.

Samples of *A. lira* typically consisted of none or very few juveniles and a female-biased sex ratio (see Collins and Holsinger 1981, Holsinger *et al.* 1994). Juveniles accounted for 13% of individuals sampled from Madison Saltpetre Cave, 4% from Steger's Fissure, and have not been found at other sites. The female-biased sex ratios were 2.2 females to male at Madison Saltpetre Cave, 3.5 at Steger's Fissure, and 3.7 at all other sites combined. Differential intensity of response to the shrimp bait may partially account for the female-biased sex ratio in the samples: females may be more responsive than are males to the protein-rich bait because of the high energetic cost of egg-production. The apparently adult-dominated population structure of *A. lira* suggests that it has a lengthy life span with a low rate of reproduction.

How *A. lira* reproduces is unknown. Among freshwater isopods in general as well as most marine cirolanids, females incubate fertilized eggs in a ventral marsupium after mating (Pennak 1989, Schultz 1969). Such ovigerous females of *A. lira* have never been observed. Dissection of large females by Collins and Holsinger (1981) revealed no internal brooding of fertilized eggs, but did show spherical structures that appear to be oocytes. Assuming that *A. lira* females do carry fertilized eggs in a marsupium, the lack of ovigerous females in the samples also points to a low rate of reproduction. Alternatively, ovigerous females may occupy a different, inaccessible microhabitat deep in the aquifer, or are simply not responsive to the bait, or both.

THREATS

General

The potentially large populations of *A. lira* at the Cave Hill sites showed no decline since 1979, when Collins and Holsinger (1981) first collected quantifiable population data. There is no baseline information, however, on populations at other sites. Evidence indicates that population sizes at these sites are small, and that *A. lira* individuals are long-lived with low reproductive potential, suggesting that all populations are highly sensitive to disturbance. That the species is found at only seven sites and likely consists of fewer genetic populations underscores its vulnerability to perturbation. Plans for the management and protection of *A. lira* will require data on such basic ecological parameters as the number and the sizes of its populations.

Because the recharge zone of the aquifer at any of the *A. lira* sites is unknown, the zone of potential sources of contamination is also unknown. Expanding urban development, especially in the northern part of the range of *A. lira*, has increased the probability of pollutants entering the groundwater. Pollution from agricultural runoff is a real threat because of extensive agriculture in the Shenandoah Valley. Of special concern is the rapid expansion of intensive poultry farming practices in karst regions (Berryhill 1994). Work on determining the zones of recharge and the boundaries of the aquifers, in concert with monitoring land-use practices within the potential zones of recharge, needs to be initiated soon.

Human disturbance at these sites, with the exception of Madison Saltpetre Cave, is likely to be minor because of the low intensity of visits. All seven sites are located on privately owned property, and the owners discourage casual visits to the caves. The technically difficult nature of the entrances and passages in these caves also filters out many potential cave visitors, and the deep aquifer habitat of *A. lira* is inaccessible to most cave visitors. Madison Saltpetre Cave, however, presents no technical challenge and, indeed, was open in the past for commercial tours and experienced extensive damage from vandalism. Whether the past commercial operation and intensive use affected the isopod population in this cave is unknown. The cave is now protected by a gate and is being managed by its owner along with the Cave Conservancy of the Virginias for conservation purposes (see Conservation Measures).

Site-Specific Threats

In addition to the general issues discussed above, unique site-specific threats to *Antrolana lira* populations exist at Front Royal Caverns and at Linville Quarry Cave No. 3.

Front Royal Caverns: Recent tracer testing in the Front Royal Caverns study area confirmed hydrologic connections between runoff and recharge from the Shenandoah National Park, the band of intensely karsted private land between the Park and the south fork of the Shenandoah River, the deep aquifer providing the Madison Cave isopod's habitat, and steady baseflow/fresh groundwater recharge to the river and public water supply (T. Brown, Virginia Department of Conservation and Recreation, Division of Natural Heritage, *in litt.* 1996). Several very vulnerable recharge areas in need of active protection have been identified. Despite the karst topography, this land is located in a developing area and is being marketed for residential and commercial tracts.

In fact, this site is the most vulnerable of all the sites to potential impacts from urban development. One entrance to Front Royal Caverns was destroyed by the widening of U.S. Highway 340; a second entrance is in a sinkhole less than 10 m west of Highway 340 just south of the city of Front Royal. On the east side of the highway opposite the cave entrance is a busy street that leads into a large housing development. Within the last decade, approximately 14 homes, the new entrance to Shenandoah National Park, and a large church have been constructed in the immediate recharge area of the Front Royal Caverns aquifer. One home was completed on top of a very deep sinkhole-fill last summer, and another key sinkhole was filled with construction debris from the demolition of an old service station – potentially introducing petroleum hydrocarbons, asbestos, metals, and other contaminants into the groundwater system (T. Brown *in litt.* 1996). The effects of expanding development on the recharge zone of this aquifer and the proximity of one entrance to a major highway generally increase the probability of contamination of this aquifer.

The Front Royal Caverns area is naturally prone to subsidence, which in some cases has been induced or magnified by construction activities. Further development in the vicinity could exceed the carrying capacity of the system by adversely affecting surface inputs to the Front Royal Caverns aquifer (T. Brown *in litt.* 1996). The impact of potential threats to this population of *A. lira* is compounded by the possibility of existence of unique genotypes and of small population size.

Linville Quarry Cave No. 3: The entrance to this cave is one of several openings in the northwest wall of a limestone quarry. Possible resumption of quarry operations in the future may adversely affect the *A. lira* population at this site. The extent of the potential impact is unknown because of the lack of baseline data, and it is not known whether past quarry operations had already affected the isopod population. The result of future quarry operations may also lead to the destruction of openings allowing access to this *A. lira* population, thus eliminating any possibility of monitoring this site.

CONSERVATION MEASURES

Madison Saltpetre Cave, the type locality of *Antrolana lira*, is protected through cooperation between the property owner and cave conservation organizations. Protection is geared not only toward *A. lira*, but also toward other rare species found in the cave, such as a rare amphipod, *Stygobromus stegerorum*, and several rare terrestrial species such as the harvestman, *Erebomaster acanthina* (Holsinger and Culver 1988). In addition, this cave is also of significant geological, historical, and esthetic value.

The cave entrance is protected by a heavy steel gate, installed in 1981 by members of the Cave Conservancy of the Virginias, Cave Conservation Institute and Virginia Region of the

National Speleological Society. All visits to the cave must be approved by a management subcommittee of three, and one member of the subcommittee must accompany all visitors to the cave to ensure that visits are limited to scientific studies or educational purposes. This management plan has undoubtedly reduced the extent of human impact on *A. lira* habitat at this site; however, the plan is insufficient in terms of protection of the aquatic habitat, because the zone of recharge of groundwater in the cave is unknown and unprotected.

In 1994, the federal Nonpoint Source Program funded a Virginia Department of Conservation and Recreation multi-year demonstration project to delineate groundwater basin boundaries with the deep aquifer habitat of *Antrolana lira* in Front Royal Caverns (T. Brown *in litt.* 1996). The data resulting from this project should help in setting protection priorities for the species.

RECOVERY STRATEGY

Recovery of the Madison Cave isopod will hinge on extending and augmenting protection efforts that have been underway for several years. Protection of known population sites coupled with searches for additional populations should lead to long-term stability for this isopod across its range. Collection of baseline population and ecological data will help to focus protection priorities and verify recovery needs. Of primary importance will be delineation of recharge zones for the Madison Cave isopod's deep karst aquifer habitat. When the extent of the recharge zones for the key sites is known, cooperative protection efforts can be initiated more effectively.

PART II: RECOVERY

RECOVERY OBJECTIVE

The objective of this recovery plan is to protect populations of *Antrolana lira* from potential threats to the quality of its deep karst aquifer habitat, thereby enabling the removal of this threatened species from the Federal list of endangered and threatened wildlife and plants. Delisting may be considered when the following criteria are met:

1. Populations of *Antrolana lira* at Front Royal Caverns, Linville Quarry Cave No. 3, and Madison Saltpetre Cave/Steger's Fissure are shown to be stable over a ten-year monitoring period, based on a monitoring protocol that ensures standardized and comparable population trend data.

2. The recharge zone of the deep karst aquifer habitat at each of the population sites identified in Criterion 1 is protected from all significant groundwater contamination sources. This will involve delineating the recharge zone, identifying potential sources of groundwater contamination, and establishing a cooperative program with private and public landowners to maintain or enhance groundwater quality. A long-term groundwater monitoring program based on an approved protocol must also be established, with results demonstrating maintenance of groundwater quality over a ten-year period.

3. Sufficient population sites are protected to maintain the genetic diversity of the species. Upon completion of Recovery Tasks 1 and 2, below, additional sites to those in Criterion A may be identified as warranting permanent protection to meet this criterion. Protection of newly discovered populations, if any, will be incorporated into this criterion insofar as they contribute to maintenance of overall genetic diversity.

RECOVERY TASKS

1. **Determine the number of genetic populations.**

The number of populations of *Antrolana lira* can be estimated by examining the genetic distance among individuals from all seven sites, as well as from any additional sites that may be found through Task 2. Initial analysis of genetic distance can take advantage of the technique of RAPD (Random Amplification of Polymorphic DNA) (Williams *et al.* 1990). This technique is advantageous in the absence of prior knowledge of the molecular genetics of an organism, as is the case for *A. lira*, because a large set of polymorphism can be examined from a small amount of DNA and only a small number of specimens per site, i.e., five, are needed.

These data will be useful for generating hypotheses on the number of genetic populations of *A. lira*; the hypotheses can then be tested at a finer scale by sequence analyses of mitochondrial genes. Data from such a study are critical for understanding the metapopulation structure of *A. lira* and, in concert with data obtained from Recovery Task 2, for identifying populations most vulnerable to extinction and for clarifying the scope of the recovery effort.

2. **Search for additional populations.**

The hypothesis of a "stranding" evolutionary origin of *A. lira* suggests that additional populations may exist in karst aquifers as far north in the Shenandoah Valley as Harpers Ferry, West Virginia (Holsinger *et al.* 1994). The 70-km wide gap in the distribution of *A. lira* between Front Royal Caverns and other sites also indicates the possibility of additional populations. Well samples from this area should also be a focus of search efforts, together with a systematic search (during periods of high water table) of caves with the appropriate deep karst aquifer habitat. In particular, the presence or absence of additional populations near Front Royal Caverns, in conjunction with data obtained from

Recovery Task 1, should indicate whether isopods at the Front Royal Caverns site constitute a unique population highly vulnerable to extinction, or if it is part of an undiscovered metapopulation.

3. **Identify potential sources and entry points of contamination of the deep karst aquifer habitat.**

   3.1 **Delineate the recharge zone of deep karst aquifers.** Hydrological studies using dye-tracing or other techniques to identify the zone of recharge of aquifers at *A. lira* sites should be conducted. The expense and environmental effects of drilling wells specifically for the purpose of dye injection may be offset by coordinating tracer testing, water level monitoring, and groundwater sampling trips among sites, and by utilizing trained local cavers, students, and volunteers (T. Brown *in litt.* 1996). Developing this pool of expertise will require some effort, but will increase local involvement and the consistency of methodologies used at the different sites.

   Natural karst features should serve as better dye-injection points than drilled wells unless a specific site without such features is of concern. Wells can be used as dye receptor sites and pump points to enhance flow within the aquifer to facilitate dye transport within the aquifer. It should be noted that some areas within the aquifer may not be along existing flow paths unless existing or future wells are pumped, i.e., dye from a particular input within the aquifer might not show up at receptor sites, but a future pollutant entering at that input point could still affect parts of the aquifer habitat (D.A. Hubbard *in litt.* 1996).

   In considering delineation techniques, it should also be kept in mind that dye-tracing is of limited applicability in characterizing deep aquifer flow regimes where the number of spring resurgences and subsurface access points for monitoring are restricted. A cost-efficient means of obtaining the necessary data may involve matching U.S. Geological Survey funds for applying proven isotope tracing and dating techniques to assist in characterizing the flow regime and recharge areas of these deep karst aquifers. GPS (global positioning systems) mapping of sinkholes and related features, coordinated cave surveys, and nonintrusive geophysical investigative techniques are recommended tools for the further delineation of epikarst, vadose, and phreatic habitats (T. Brown *in litt.* 1996).

If this recovery task cannot be carried out concurrently at all sites by multiple teams, it should be conducted at Front Royal Caverns, Linville Quarry Cave No. 3, and the Cave Hill sites before the other sites.

3.2 **Monitor the effects of land use patterns on potential and identified recharge zones of deep karst aquifers.** This task is intended to identify potential sources of pollution of the aquifers, including underground storage tanks housing petroleum or other chemicals, manufacturing plants, concentration of septic fields in small areas, farm waste storage facilities, intensive poultry operations, among others. This task should be conducted in conjunction with Task 3.1 to increase efficiency.

4. **Protect known populations and habitats, taking a watershed perspective.** Protection of *A. lira* must be approached from both the population level and the watershed level. The relatively inaccessible nature of the deep karst aquifer habitat and the rarity of *A. lira* specimens has already afforded some protection of the isopod populations; current regulations under the Endangered Species Act and the Virginia Cave Protection Act also help in protecting the isopod populations. The major threats to the habitat of *A. lira* are from contaminants entering through the recharge zones, which will be delineated in Task 3. Ultimately, protection of the isopod's aquifer habitat must be approached from the level of the entire watershed of the recharge zone of each deep karst aquifer.

4.1 Enforce existing regulations to protect *A. lira* and its deep aquifer habitat. Protection of the deep aquifer habitat from possible contamination can be aided by enforcement of regulations governing discharge from industries, businesses, housing developments and agricultural concerns, especially those within the zones of recharge delineated in Task 3. To this end, it is critical to enlist the help of local government officials, business and community leaders, and landowners, especially in promoting and formulating land use regulations that ensure long-term maintenance of water quality. Particular attention should be given to regulations geared toward (1) avoiding the use of pesticides in and around established habitats, (2) restricting/reducing the discharge of hazardous materials (from poultry farms and cropland) entering lakes, streams, rivers, etc., and (3) minimizing road construction within the species' habitat (A.F. Maciorowski and C.E. Laird, U.S. Environmental Protection Agency, *in litt.* 1996).

4.2 Encourage cooperation among landowners and governmental and nongovernmental agencies in achieving long-term protection of *A. lira* habitat. Because all *A. lira* sites are on private land, a landowner may own either part of or all of the recharge area of a particular deep aquifer. The cooperation of these landowners, not only of the immediate cave site, but also of other land parcels delineated within the zone of recharge through Recovery Task 3, is critical to both the near- and long-term protection of the isopod's habitat. This task should be given high priority, as it will ultimately dictate the practicality of recovery. Protection of sites can only be accomplished through cooperation with the landowner. Indeed, there is common ground between the landowner and the isopod, that is water quality, inasmuch as many rural landowners depend on groundwater as a source of drinking water (R. Reynolds *in litt.* 1996).

4.21 Develop a management profile for each site. This profile should include, but not be limited to, the following: (a) site name/number, (b) name, address, and telephone number of essential habitat owners (s), (c) a photograph of the site, (d) all available historic information on population levels, (e) results of annual surveys on populations and water quality, (f) a map delineating essential habitat, (g) measures taken or planned to protect the sites and essential habitat, (h) a habitat maintenance/enhancement schedule, (i) a copy of cooperative agreements with landowners, and (j) a record of any disturbance at the site. This profile should be maintained by at least the regulatory agencies involved.

4.22 **Establish landowner contacts, conservation agreements, and/or other means of protecting the isopod's habitat.** Landowner contact and, where necessary, conservation easements, will be needed to accomplish this task. Memoranda of understanding and direct acquisition should also be considered. The Madison Saltpetre Cave system can serve as a useful model, where the landowner serves on the cave management subcommittee along with members of the Cave Conservancy of the Virginias and the Virginia Cave Board. Development of similar cooperative management programs should be initiated for all other sites through the combined efforts of the following agencies: U.S. Fish and Wildlife Service, Virginia Department of Game and Inland Fisheries, Virginia Division of Natural Heritage, The Nature Conservancy, Cave Conservancy of the Virginias, and the Virginia Region of the National Speleological Society, among others.

Another resource that can be used to help recover this species is the Forest Stewardship Program. This program, implemented by the Virginia Department of Forestry, is designed to help landowners manage forested tracts on their property. Landowners select management priorities and the program develops a plan. Of interest to the landowner is the cost-share aspect of this program. This may be a cost-effective approach to implementing certain management actions for the protection of groundwater and the isopod.

4.23 Establish a public outreach and education program where needed. One focus should be on establishing an institutional framework to organize and orient surrounding landowners toward karst resource conservation. Local grottoes, planners, and environmental advocacy groups should be included in the process.

Efforts by the Virginia Division of Natural Heritage and others to educate local officials and landowners in the Front Royal Caverns area should continue. Emphasis should be placed on strengthening local appreciation and stewardship for karst resources to enhance long-term habitat preservation. The grassroots groups voluntarily carrying out these public awareness activities should receive encouragement and support. Funding should be obtained by the Virginia Department of Conservation and Recreation, Division of Natural Heritage, or other organizations to conduct karst resource recognition, hazard prevention, and protection workshops for developers, real estate agents, and land speculators. Concise, factual informational materials (maps, fact sheets, brochures) should be developed to facilitate public education on these issues.

5. Collect baseline ecological data for management and recovery.

5.1 Characterize the habitat requirements of *A. lira* and monitor habitat conditions. As discussed in Part I, little is known about the physical and chemical conditions of the deep aquifer habitat of *A. lira*, and baseline descriptive data on this habitat need to be collected and compiled. Long-term monitoring of baseline conditions, using a protocol for monitoring groundwater, will allow for early detection of changes in water quality stemming from pollution or other causes. Monthly data collection over a three-year period will be required to establish baseline mean values and normal seasonal variation in these values. Depending on the extent of variation, two to four visits per year thereafter may be sufficient for long-term monitoring programs.

5.2 **Estimate population size and monitor population trends.** A protocol to ensure standardized and comparable population trend data should be developed; the existing mark-recapture data should be sufficient to calculate the effort needed to determine population trends at Madison Saltpetre Cave and Steger's Fissure. Baseline quantitative estimates of population size at all sites, using mark-recapture or other methods, are needed. Baseline data at each site should include estimates on at least a twice-per-year basis for two years. Long-term monitoring of population sizes can be conducted at index sites, such as the Cave Hill sites, Front Royal Caverns and Linville Quarry Cave No. 3. The frequency of estimates needed for long-term monitoring will depend on the extent of variability in the baseline data.

5.3 **Develop methods for and conduct life history and population viability studies.** This task will initially involve testing new methods to collect specimens for marking. The current method of baiting with shrimp, although successful at most sites, may result in biased sampling due to differential response to the bait among sexes and developmental stages (see Abundance and Life History section). The apparently female and adult-biased population structure must be verified by other collection methods. The unbiased sampling method should be used to conduct Recovery Task 5.2, generating data that can then be used to determine population viability and trajectory.

Some consideration should also be given to culturing these isopods in a laboratory/hatchery environment for research, pesticide testing, education purposes, or other such purposes.

6. Implement a program to facilitate recovery progress.

An informal recovery group should meet as necessary to ensure effective and cooperative implementation of the recovery program. Primary responsibility for establishing and coordinating this group will lie with the U.S. Fish and Wildlife Service. The recovery group should comprise representatives of the U.S. Fish and Wildlife Service, Virginia Cave Board, Virginia Department of Game and Inland Fisheries, Virginia Division of Natural Heritage, The Nature Conservancy, Cave Conservancy of the Virginias, and, possibly, local land use planners and managers and other identified stakeholders. This group will review the progress of the recovery efforts, determine imminent recovery needs, and recommend modifications to the recovery plan based on new data.

In addition, participation teams comprised largely of local stakeholders should be convened as needed to coordinate implementation of specific recovery activities. In particular, the commitment of several key local partners, including the Lord Fairfax Planning District Commission, the Friends of the Shenandoah River, Skyline Caverns, Inc., and especially the Front Royal Grotto, to the Front Royal Caverns project extends well beyond 1997; these partners should be represented on the participation team for this site. Similar local cooperators should be included on participation teams for all the species occurrence sites, including a representative of the Local Emergency Planning Committees in each county.

The participation teams should identify potential long-term sources of funding to conduct needed work, including private matching funds contributed by not -for-profit groups. As appropriate, participation plans should be developed to ensure effective implementation of specific recovery actions.

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PART III: IMPLEMENTATION

The following Implementation Schedule outlines actions and estimated costs for the recovery program. It is a guide for meeting the recovery objectives discussed in Part II of this plan. This schedule indicates task priorities, task numbers, task descriptions, duration of tasks, the responsible agencies, and estimated costs. Responsible agencies identified as cooperators in the recovery effort, and estimated costs are provided as non-binding guidelines for funding needs. These recovery actions, when accomplished, should bring about recovery of the species and protection of its habitat.

Key to Recovery Task Priorities (column 1 in Implementation Schedule):

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 significant decline in species population/habitat quality or some other significant negative impact short of extinction.

Priority 3- All other actions necessary to provide for full recovery of the species.

Key to Responsible Agencies (columns 5 and 6):

USFWS	=	U.S. Fish and Wildlife Service
R5 ES	=	Region Five, Ecological Services Division
USGS	=	U.S. Geological Survey
EPA	=	U.S. Environmental Protection Agency
VDGIF	=	Virginia Department of Game and Inland Fisheries
VDNH	=	Virginia Division of Natural Heritage
CCV	=	Cave Conservancy of the Virginias
NSF	=	National Science Foundation
VCB	=	Virginia Cave Board
TNC	=	The Nature Conservancy
VRNSS	=	The Virginia Region of the National Speleological Society

IMPLEMENTATION SCHEDULE

Madison Cave Isopod Recovery Plan

September 1996

Priority	Task Description	Number	Duration	Responsible Agencies USFWS	Responsible Agencies Others	Cost Estimates ($000) FY1	FY2	FY3	Comments
1	Determine the number of genetic populations.	1	2 yrs	R5 ES	VDGIF VDNH CCV NSF	15	20	--	
1	Delineate the recharge zones of the isopod's deep karst aquifer habitat.	3.1	5 yrs	R5 ES	USGS VDGIF VDNH Contracts	30	25	25	Additional 25/yr x 2 yrs
1	Monitor the effects of land use patterns on potential and identified recharge zones of deep karst aquifers.	3.2	ongoing	R5 ES	USGS EPA VDGIF VDNH Contracts	10	10	10	Additional 10/yr x 7 yrs
2	Search for additional populations.	2	ongoing	R5 ES	VDGIF VDNH VCB	5	5	5	Additional 5/yr x 2 yrs
2	Enforce existing regulations to protect *A. lira* and its deep aquifer habitat.	4.1	ongoing	R5 ES	VDGIF VCB	1	1	1	Additional 1/yr x 7 yrs
2	Encourage cooperation among landowners and governmental and non-governmental agencies in working toward long-term protection of *A. lira* and its habitat.	4.2	ongoing	R5 ES	VDGIF VDNH TNC VCB CCV VRNSS	10	15	15	Additional funds as needed

Madison Cave Isopod Recovery Implementation Schedule, September 1996

Priority	Task Description	Task Number	Duration	Responsible Agencies USFWS	Responsible Agencies Others	Cost Estimates ($000) FY1	Cost Estimates ($000) FY2	Cost Estimates ($000) FY3	Comments
2	Characterize the habitat requirements of *A. lira* and monitor habitat conditions.	5.1	2 yrs	R5 ES	VDGIF VDNH Contracts	2	2	--	
2	Estimate population size and monitor population trends.	5.2	10 yrs	R5 ES	VDGIF VDNH Contracts	3.5	3.5	3.5	Additional 3.5/yr x 7 yrs
2	Develop methods for and conduct life history and population viability studies.	5.3	10 yrs	R5 ES	VDGIF VDNH Contracts	5	3	3	Additional 2/yr x 7 yrs
3	Implement a program to facilitate recovery progress.	6	ongoing	R5 ES	TNC VCB VDGIF VDNH CCV	1.5	1.5	1.5	Additional 1.5/yr x 7 yrs

List of Reviewers

In accordance with U.S. Fish and Wildlife Service policy (USFWS and NOAA 1994), peer review of the technical/agency draft Madison Cave Isopod Recovery Plan was solicited from John R. Holsinger of Old Dominion University and Dan Feller of the Maryland Division of Natural Heritage. Comments were subsequently received from Dr. Holsinger and have been incorporated into this final plan.

A total of six reviewers submitted comments on the draft plan. These comments were considered during preparation of this final plan, and have been incorporated into the text as appropriate. Copies of the comments and the U.S. Fish and Wildlife Service's response to them are on file in the Service's Chesapeake Bay Field Office. The Service appreciates both the quality of the draft plan prepared by Dr. Daniel Fong and the quality of comments received from the following individuals.

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