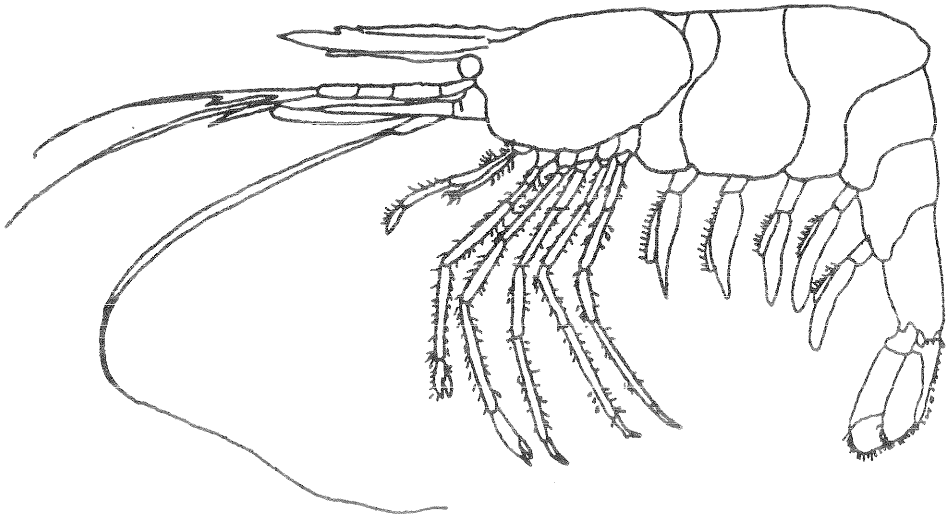
KENTUCKY CAVE SHRIMP

RECOVERY PLAN



U.S. Fish and Wildlife Service
Atlanta Georgia

RECOVERY PLAN

for

Kentucky Cave Shrimp (*Palaemonias ganteri* Hay)

Prepared by:

Arthur T. Leitheuser
4315 South Kirkwood, #104
Houston, Texas 77072

for

U.S. Fish and Wildlife Service
Southeast Region
Atlanta, Georgia

Approved: [signature]
Acting Regional Director, U.S. Fish and Wildlife Service

Date: 10/7/88

Disclaimer

This is the completed Kentucky Cave Shrimp Recovery Plan. It has been approved by the U.S. Fish and Wildlife Service. It does not necessarily represent official positions or approvals of cooperating agencies, and it does not necessarily represent the views of all individuals who played a role in preparing this plan. This plan is subject to modification as dictated by new findings, changes in the species' status, and completion of tasks described in the plan. Goals and objectives will be attained and funds expended contingent upon appropriations, priorities, and other constraints.

Acknowledgements should read as follows:

U.S. Fish and Wildlife Service. 1988. Kentucky Cave Shrimp Recovery Plan. U.S. Fish and Wildlife Service, Atlanta, Georgia. 47 pp.

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PART I

INTRODUCTION

The Kentucky cave shrimp, Palaemonias ganteri Hay (Figures 1 and 2), is only known from the Mammoth Cave National Park region of central Kentucky. Mammoth Cave National Park is located in Barren, Edmonson, and Hart Counties, Kentucky, and is bisected by the Green River (Figure 3). The subsurface of the park and adjacent area, especially south of the Green River, is known to contain extensive cave systems (Figure 4). According to Quinlan and Ewers (1981) "approximately 320 miles of surveyed passage" are known from this area, "but it would not be unrealistic to infer that more than 1,000 miles of man-size passage exist." The Mammoth Cave system accounts for approximately 300 miles of this total. Detailed descriptions of the Mammoth Cave National Park area are available in Barr and Kuehne (1971), Quinlan and Ewers (1981), and Quinlan et al. (1983).

Palaemonias ganteri was first described by Hay (1901) from the Roaring River passage of Mammoth Cave, Edmonson County, Kentucky, on the basis of 12 individuals collected in August 1901. These specimens are deposited in the National Museum of Natural History (Smithsonian Institution) under the catalog numbers of the United States National Museum (USNM 270000). Hay (1902) later described the habitat of the type locality:

"Roaring River, a passage which is never visited, except by the collector, is reached by a low and very muddy and difficult passage which turns off the main route a short distance beyond Echo River. The mouth of the passage is said to be 2 miles from the entrance of the cave. At times of high water the entire passage, as well as contiguous portions of the main cave, are flooded, but usually the water is confined to a series of small pools among the rocks and mud of the floor of the passage and the stream at the end. Roaring River itself is a stream some 15 or 20 feet wide, and an average depth of 1 foot. It flows with a steady current and is known to be part of Echo River."

According to Hay (1901) the shrimp was "named for Mr. H. C. Ganter, the manager of the cave who, through his deep interest in the scientific study of its fauna and flora, was led to afford me exceptional facilities for making my observations."

The type locality can be more specifically referred to as the "Shrimp Pools," a name first used by Barr (1967). Early maps referred to this area as Aquarius Avenue. According to Barr (1967), "The Shrimp Pools in the Roaring River passage are residual flood pools approximately 3 meters higher than low water level in Roaring and Echo Rivers," that are seasonally filled by floods during a period of heavy rains in the late fall and early winter. Hay (1902) located shrimp by examining "the bottoms and the water of the clear pools." These pools are clearly synonymous with the residual flood pools described by Barr.

Palaemonias ganteri was first proposed as a threatened species on January 12, 1977 (U.S. Department of the Interior 1977). The proposal was withdrawn December 10, 1979 (U.S. Department of the Interior 1979), to comply with the 1978 Amendments to the Endangered Species Act of 1973, that required withdrawal of all pending proposals if not finalized one year after passage of the amendments. R. W. Bouchard (Chairman, Crustacean Specialist Group, Species Survival Commission, International Union for the Conservation of Nature and Natural Resources) submitted a petition dated December 12, 1979, for an emergency listing of P. ganteri on the List of Endangered and Threatened Wildlife and Plants of the United States and supplemented the petition with a letter dated January 1, 1980. On March 28, 1980, a notice was published (U.S. Department of the Interior 1980a) announcing the acceptance of this petition and an advanced notice of proposed rules. On October 17, 1980, a proposal to list P. ganteri as an endangered species and to establish the Roaring River passage of the Mammoth Cave system in Kentucky as critical habitat was published (U.S. Department of the Interior 1980b).

Throughout this period the issue of the status of P. ganteri became intimately tied to Lock and Dam No. 6 located on the Green River at Brownsville, Kentucky. The lock and dam was implicated by some groups as being responsible for the apparent decline in populations of P. ganteri. Local interest groups quickly took sides, and the shrimp and its protection received a great deal of publicity.

In an attempt to gain a better understanding of the shrimp and its biology and distribution, a proposal was submitted (Holsinger and Leitheuser 1981) to work on P. ganteri. The proposal was approved on September 9, 1981 (Federal Grant administered to Old Dominion University Research Foundation by the National Park Service, Grant Contract Number CX-5000-1-1037), for a 12-month study. Objectives of Phase I (October 1, 1981 to March 31, 1982) and Phase II (April 1982 to September 30, 1982) included a literature review, verification of distribution of the shrimp at localities previously reported in the literature, survey results of other areas capable of supporting shrimp, the establishment of population densities, definition of habitat requirements, and the establishment of areas that require additional research. The results of Phase I (Holsinger and Leitheuser 1982a) and Phase II (Holsinger and Leitheuser 1982b) were submitted to the regional chief scientist, Southeast Region, National Park Service.

Subsequent funding was procured through the National Park Service to continue research. Objectives for continued studies included monitoring of population densities, determination of size classes, sex ratios and growth rates, continued analysis of habitat requirements, and continued analysis of the distribution of the species. The results of Phase III (October 1, 1982, to March 31, 1983), Phase IV (April 1, 1983, to September 30, 1983), Phase V (October 1, 1984, to September 30, 1985) have already been reported or are in press (Holsinger and Leitheuser 1983; Leitheuser and Holsinger 1983; Leitheuser et al. 1985; and Whitman et al., in press).

During this period, two public hearings were conducted, and an extensive review of all available information on the shrimp was made. A proposal to list the species was published. Palaemonias ganteri was added as an endangered species to the List of Endangered and Threatened Wildlife and Plants of the United States, and the Roaring River passage of Mammoth Cave was designated as critical habitat on October 12, 1983 (U.S. Department of the Interior 1983). Although the shrimp has been a controversial issue in the Mammoth Cave National Park area, the listing of the species is expected to be an overall benefit to assist in the protection of the unique cave environment and its associated fauna. All groups involved seem to agree that the unique cave environment and fauna should be protected.

Description

The Kentucky cave shrimp is a small freshwater decapod crustacean in the family Atyidae. The species is characterized by rudimentary eyestalks lacking facets of pigmentation, subequal first and second chelae, and terminal tufts of setae on each of the chelae. Palaemonias ganteri Hay is distinguished from its closest relative P. alabamae Smalley, the Alabama cave shrimp, by having more than 15 dorsal teeth on the rostrum and more than 15 spinelike setae on the appendix masculina (Hobbs, Hobbs, and Daniel 1977). Hatchlings are approximately 3 mm total length and adults up to 30 mm (Holsinger and Leitheuser 1983). Additional references to taxonomy and species identification are available in Ortmann (1918), Fage (1931), Chace (1943, 1954, and 1959), Smalley (1961), Cooper (1975), and Pennak (1978). Drawings may be obtained from Hay (1901 and 1902); Fage (1931); and Hobbs, Hobbs, and Daniel (1977). Photographs are available in Barr and Kuehne (1971) and Leitheuser and Holsinger (1983).

Distribution

The Kentucky cave shrimp is endemic to the Mammoth Cave National Park region of central Kentucky. The known distribution of the species, prior to its addition to the Federal Endangered Species List (Figure 5), was from five localities in the Mammoth Cave system (Holsinger and Leitheuser 1982a and 1982b, Leitheuser 1984) within the boundaries of Mammoth Cave National Park, including four within the Echo River Spring Groundwater Basin and one within the Pike Spring Groundwater Basin (Quinlan and Ray 1981).

Present known distribution of the species (Figure 6) has been extended to include most of the base level passages in the Echo River Spring Groundwater Basin (Holsinger and Leitheuser 1982b and 1983; Leitheuser, unreported data); five localities in the Pike Spring Groundwater Basin (Holsinger and Leitheuser 1982b; Leitheuser and Holsinger 1983; Leitheuser, unreported data); and one each in the Mile 205.7 Spring (Leitheuser and Holsinger 1983), Suds Spring (Leitheuser, unreported data), and McCoy Blue Spring Groundwater Basins (Leitheuser and Holsinger 1983). In addition, previously unreported and recently discovered habitat include Sandhouse Cave in the Double Sink Groundwater Basin, Ganter Cave, and Lee Cave in the Turnhole Spring Groundwater Basin and Running Branch Cave (Leitheuser, unreported data). Some evidence suggests that Sandhouse Cave may represent an overflow route from the Turnhole Spring Groundwater Basin (J. A. Ray, Mammoth Cave National Park Geological Staff, personal communication, 1982; Leitheuser, unreported data).

The current known distribution of the shrimp includes nine distinct Groundwater Basins in the Mammoth Cave National Park region (Quinlan and Ray 1981, Figure 6). Three of these basins (the Echo River Spring, Ganter Cave, and Running Branch Cave Groundwater Basins) are located more or less entirely within Mammoth Cave National Park. Two other basins (Mile 205.7 Spring and Pike Spring) extend well beyond the east boundary of the park. Approximately one-third of the Mile 205.7 Spring and one-half of the Pike Spring Groundwater Basins are located on private lands. Although Sandhouse Cave is located in Mammoth Cave National Park, the majority of the Double Sink Groundwater Basin is located on private lands southwest of the park. The only locality known to contain shrimp in the Turnhole Spring Groundwater Basin, Snake River in Lee Cave, is located within Mammoth Cave National Park. The majority of this basin, however, is located on private lands south of the park. The remaining basins known to contain shrimp (McCoy Blue Spring and Suds Spring Groundwater Basins) are both entirely on private lands east of Mammoth Cave National Park. Ganter Cave, Running Branch Cave, and McCoy Blue Spring are all on the north side of the Green River, which bisects Mammoth Cave National Park, while remaining basins are on the south side of the river.

Present possible distribution of the shrimp is hypothesized to include the following localities and groundwater basins: Buffalo Creek Blue Hole, Buffalo Creek Groundwater Basin on the north side of Green River, Mammoth Cave National Park; Cedar Sink, Turnhole Spring, and Hawkins River in Proctor Cave, Turnhole Spring Groundwater Basin, on the south side of the Green River, Mammoth Cave National Park; Mill Hole and several localities in Whigpistle Cave, Turnhole Spring Groundwater Basin, on the south side of the Green River, private lands south of Mammoth Cave National Park; Vinegar Ridge Cave System, Bush Island Spring and Suds Spring Groundwater Basins, on the south side of the Green River, private lands east of Mammoth Cave National Park; several localities in the Fisher Ridge Cave System, Lawler Blue Hole and Suds Spring Groundwater Basins, on the south side of the Green River, private lands east of Mammoth Cave National Park; Lawler Blue Hole, Lawler Spring Groundwater Basin, on the south side of the Green River, private lands east of Mammoth Cave National Park; Nelly Spring, which is an overflow route from the McCoy Blue Spring Groundwater Basin, on the north side of the Green River, private lands east of Mammoth Cave National Park; Qualls Pit and Your Guess Spring, Your Guess Spring Groundwater Basin, on the north side of the Green River, private lands east of Mammoth Cave National Park; McCorkle Spring, McCorkle Spring Groundwater Basin, on the north side of the Green River, private lands east of Mammoth Cave National Park; and X Spring, X Spring Groundwater Basin, on the north side of the Green River, private lands east of Mammoth Cave National Park. Localities are further described in Holsinger and Leitheuser (1982b and 1983), Leitheuser and Holsinger (1983), Leitheuser et al. (1985), Quinlan and Ray (1981), Quinlan and Ewers (1981), and Quinlan et al. (1983).

Ecology and Life History

Feeding Preferences:

The Kentucky cave shrimp is a non-selective grazer. Studies of fecal pellets (Holsinger and Leitheuser 1983) indicated the presence of sand grains, generally amorphous mucus or other cementing material that may be either sedimentary or microbial in nature, exoskeletons of protozoans, insects and other unidentified organisms, fungal hyphae and spores, algal cells and miscellaneous other unidentified material. A relatively complex and poorly studied community consisting of bacteria, fungi, protozoans and minute crustaceans proliferate on the detritus and are found throughout the stream sediments in caves of the Mammoth Cave National Park region. The shrimp feed on these organisms by grazing on the surface layers of sediments. Terminal tufts of setae on the chelae trap microorganisms and other food items, along with some sediment, which are all moved toward the mouth parts where they are scraped off and ingested.

Attempts to determine the feeding preferences of the shrimp showed the importance of micro- and larger fauna to both the ecology of the shrimp and to the entire aquatic cave community in the Mammoth Cave region. Investigations of bacteria show quantifiable and qualitative differences among habitats (Leitheuser et al. 1984, Leitheuser 1984). Investigations on stream interstitial communities have revealed an assemblage of nematodes, oligochaetes, rotifers, ostracods, copepods, midge larvae, tardigades, and possibly zoea in cave stream sediments (Leitheuser et al. 1984, 1985). Preliminary analysis of cave stream sediments has also yielded quantifiable numbers of diatoms (Leitheuser et al. 1984). In some samples, diatoms alone were sufficient to support small populations of grazers (Leitheuser, unpublished data). Fungi are virtually unstudied in cave streams.

Since a relatively complex and varied community exists that may be utilized by grazers, it has been hypothesized that the shrimp, being nonselective and blind, ingests all of these organisms as food items. It is now accepted that the food chain base in cave streams is more complex than previously realized. However, not only are the shrimp, and several other organisms, dependent upon this community for a food supply, but the entire food chain base is highly susceptible to perturbations (Leitheuser et al. 1984, 1985).

A review of shrimp feeding preferences and studies on food sources is available in Holsinger and Leitheuser (1982b and 1983), Leitheuser and Holsinger (1983), and Leitheuser et al. (1984). A large amount of unpublished data is presently being compiled for publication.

Habitat Requirements:

The Kentucky cave shrimp is nonterritorial. However, the shrimp does have specific habitat requirements, and it has adapted to a highly specialized and restricted environment. This environment consists of the parameters characteristic of the cave systems in the Mammoth Cave National

Park region. The caves are extensive in development and include both complex networks of interconnected and active underground streams and cover a large basin influenced by surface activities, including both natural and human-induced events. Natural events, primarily precipitation, greatly influence the underground environment through direct input of organics, detritus, and other food items that form the base of the food web for the cave system. In an ecological context, the cave system is thought to represent a very unique and relatively simple ecosystem since boundaries to the system are well-defined. According to Barr and Kuehne (1971), "The absence of light prevents primary production of food, except in probably negligible quantities by chemosynthetic autotrophs such as sulphur and iron bacteria." Heterotrophs populating the cave system depend upon food imported to the system through trogloxenes, accidentals, and nutrient-laden water. Therefore, food is scarce and population densities are low. Obviously, any event that affects the groundwater basin known to contain shrimp will have a direct impact on the species. Groundwater basins in the Mammoth Cave National Park region are defined and described in Quinlan and Ewers (1981), Quinlan and Ray (1981), and Quinlan et al. (1983).

Cover, Shelter, and Reproductive Site Requirements:

The Kentucky cave shrimp has no cover or shelter requirements within its habitat. This habitat, located within cave systems, is a relatively simple ecosystem lacking light. The shrimp are well adapted to the environment and have no need of shelter from predators since other mechanisms to avoid predation have evolved in response to the unique environment (Leitheuser and Holsinger 1983). Shrimp require deeper pools, as opposed to very shallow riffles, where the stream currents are minimal (Leitheuser and Holsinger 1983). As long as base level cave streams with slow to moderate flow are available, the shrimp will have suitable habitat, at least in terms of depth, flow, cover, and shelter. The shrimp are free-swimming and unable to utilize cover, such as rocks, on the stream bottom.

Although ovigerous females have been sighted throughout the year (Holsinger and Leitheuser 1982a, 1982b, and 1983; Leitheuser and Holsinger 1983), no shrimp have been observed mating. It is not known whether specific habitat requirements for reproduction are necessary. However, reproductive site requirements are probably the same as general habitat requirements since little variation in habitat is available and the species does not migrate to any extent.

Reproductive Characteristics:

Kentucky cave shrimp hatch from oblong eggs, approximately 1.0 by 1.2 mm, which are carried by mature females under the abdomen (Leitheuser, unpublished data). Up to 33 eggs have been counted from a single female shrimp (Leitheuser, unpublished data). Unfortunately, since the eggs may hatch at varying times from the same clutch, the average fecundity is still undetermined. It is not unusual to observe female shrimp carrying only a few eggs at a time (Leitheuser, unpublished data). This may be the result of previous hatching of additional eggs. Larval development is completely unknown.

Age at sexual maturity and both minimum and maximum breeding ages are unknown. However, mature females observed to carry oocytes of ova range in size from 18 mm to 26 mm total length. Maximum observed size for the species is 30 mm total length; however, individuals in excess of 25 mm total length are uncommon. Additional information on growth and life span are presented in the section on population biology.

Shrimp with oocytes (Figure 2) or attached ova have been sighted at all times of the year (Holsinger and Leitheuser 1983; Leitheuser, unpublished data). It is probable that reproduction occurs continuously rather than seasonally; however, some evidence exists to suggest seasonal reproduction subsequent to flooding events (Holsinger and Leitheuser 1982b and 1983, Leitheuser and Holsinger 1983). These flooding events are thought to bring in additional food supplies that "trigger" reproduction.

Oocytes may be resorbed during periods of low food availability and later develop as conditions improve (Holsinger and Leitheuser 1983; Leitheuser, unpublished data). There is some evidence to indicate that a single female is capable of reproducing more than one time in their lifetime (Leitheuser, unpublished data). On the other hand, one aquarium specimen partially resorbed oocytes that were still clearly visible over one year from the data of capture. This suggests that the shrimp is capable of retaining a viable reproductive status for very long periods of time in anticipation of an improvement in conditions (e.g., adequate food supply) to ensure survival of the young or to await fertilization by the male.

Female shrimp which are at some stage of reproductive development (i.e., either with oocytes or ova present) account for approximately 28 percent of the individuals in some populations (Leitheuser, unpublished data). Not all populations have been evaluated for this same data.

Population Biology

Food Supply:

Organic input to the cave ecosystem is through sinking streams, sinkholes, ponors, and other geological features on the surface. The primary input is during flooding events, which are the result of heavy rainfall, and occur at irregular periods throughout the year. Also, bacteria and micro- and larger fauna are transported into the system through the same means, forming the base of the food web. Shrimp are grazers and feed upon these organisms by scraping the surface of cave stream sediments. The food supply is, therefore, limited and dependent upon natural phenomena. However, this food supply is highly susceptible to perturbations (Leitheuser *et al*. 1984 and 1985; Leitheuser, unpublished data).

Predation:

Rainbow trout, Salmo gairdneri Richardson, have been observed eating the shrimp in prime cave habitat (Leitheuser and Holsinger 1983). The trout are an introduced species to the Green River Basin (Clay 1962 and 1975) and are regularly stocked seven times each year at two localities in the vicinity of Mammoth Cave National Park (Leitheuser and Holsinger 1983). There is some evidence to indicate that trout may have successfully adapted to taking refuge in the cold subterranean waters in the Mammoth Cave National Park area by utilizing cave fauna, including shrimp, as a food source (Leitheuser and Holsinger 1983; Leitheuser, unpublished data). It is quite possible that a few established trout may significantly alter the size of shrimp populations and create a serious management problem for the species (Leitheuser and Holsinger 1983; Leitheuser, unpublished data).

Fecundity:

An indirect value of fecundity may be obtained through data accumulated on ovigerous females. The number of eggs carried by an ovigerous female may range as high as approximately 30 eggs. Although numerous females have been observed to carry eggs, and these have been counted or estimated, it is difficult to establish a norm for the number carried. The problem lies in the tendency for hatching to occur over some unknown period of time. During this period, hatchlings leave the female once they are ready. It is therefore possible to observe ovigerous females carrying from 1 to 30 eggs, and rarely more. Even the same female may be observed to have successively fewer eggs over some period of observations. All data are unpublished.

Based upon a collection of data over a one-year period (June 1984 through May 1985), the number of females with oocytes was 11.5 to 12.1 percent (percentage varies due to one observation that included an estimate of numbers of females with oocytes) while the number with ova was 15.5 percent. The total number of females observed carrying oocytes and/or ova over this period of time was 27.0 to 27.1 percent for all observations. All data are unpublished.

It is not known whether the species is capable of reproducing more than once in its lifetime, although this is assumed. There is some data to indicate that females may reproduce more or less continuously (Leitheuser, unpublished data).

Sex Ratios:

The actual sex ratio of shrimp populations is unknown. In order to determine sex of an individual it is necessary to examine the shrimp under a microscope, unless, of course, distinguishing characteristics such as oocytes or ova are present. Determination of sex ratios of natural populations may be possible through the use of an anesthetic to slow metabolic rates (Holsinger and Leitheuser 1983). This has not been attempted due to logistical problems associated with in situ observations of anesthetized shrimp.

Longevity:

Data on the periodicity of ecdysis are very tentative. It appears that the shrimp molts on the average of once every 40 to 50 days (Holsinger and Leitheuser 1983). Unfortunately, data were obtained for only a few individuals of various sizes maintained in aquaria. Several problems should be pointed out with these data. First, there is some possibility that aquaria were not provided with sufficient food material to maximize growth rates (i.e., the food supply may have been limiting). Second, data were obtained for several individuals with a range in size from approximately 8 mm to 26 mm total lengths. Periodicity of ecdysis may be size dependent and therefore would vary from one size class to another. For example, smaller individuals may molt more frequently than larger ones, representing faster growth rates.

Growth is relatively slow. Aquarium studies have resulted in life span estimates of 10 to 15 years (Holsinger and Leitheuser 1983).

Population Density:

Localities from which shrimp have been collected, observed, or reported have not been mapped with sufficient precision to allow the direct calculation of population densities. It is, however, possible to estimate relative population densities over a section of passage known to contain shrimp. The resulting "population density estimate" is based upon only one dimension, that of length of the passage. Population densities appear to be highly variable. Shrimp density has been reported (Holsinger and Leitheuser 1982b and 1983) to vary from 0.002 shrimp/foot to 0.200 shrimp/foot. It has also been noted that population densities appear to vary over time in each specific locality (Holsinger and Leitheuser 1983). For example, one locality varies from a density of 0.022 shrimp/foot to 0.148 shrimp/foot (Holsinger and Leitheuser 1983). The passages from which these data were obtained were approximately 3 to 12 feet wide and 1 to 3 feet deep (Leitheuser, unpublished data).

Population Estimates:

Population estimates for each groundwater basin are tentatively determined to be as follows (refer to Figure 6): McCoy Blue Spring Basin - unknown; Suds Spring Basin - at least 500 individuals; Mile 205.7 Spring Basin - at least 50 individuals; Pike Spring Basin - approximately 5,000 to 10,000 individuals; Echo River Spring Basin - at least 750 individuals; Turnhole Spring Basin - unknown; Double Sink Basin - unknown; Ganter Spring Basin - at least 150 individuals; Running Branch Spring Basin - at least 300 individuals.

Habitat Requirements

The areas inhabited by the Kentucky cave shrimp are typically large base level cave passages and associated tributaries characterized by slow flow, abundant quantities of organic matter, and coarse to fine grain sand

and coarse silt sediments. Shrimp are also found in some of the large overflow passages between drainage basins (e.g., Roaring River, which is a low level overflow route from the Turnhole Spring Groundwater Basin to the Echo River Spring Groundwater Basin); however, populations are often small due to the effect of flooding events that may result in fortuitous distribution caused by fast flow. The type locality, an area now referred to as the Shrimp Pools (Barr 1967), is indicative of numerous pools left by receding flood waters that contain an inconsistent or even occasionally nonexistent shrimp population. Flood pools contain shrimp which have been washed out of their primary habitat (e.g., Mystic River) during flooding events (Holsinger and Leitheuser 1982b, Leitheuser and Holsinger 1983).

Virtually any base level cave stream in the cave systems of the Mammoth Cave National Park region is suitable potential habitat for the shrimp. The interconnected passages are sometimes complex and difficult to study. Many are as yet undiscovered or unexplored. However, passages with base level cave streams may be expected to contain shrimp if they are within a groundwater basin known to contain the species. The most likely place to locate the species is at the pooled water level that corresponds with low or base level water levels in the Green River (Holsinger and Leitheuser 1982b). Shrimp have been located as high as 35 to 40 feet above base level in passages that are directly connected to known habitat at the lower water level (Leitheuser, unpublished data). It would be reasonable to expect that this would hold true for passages up to 50 to 60 feet above base level. However, the occurrence of shrimp in passages this high should be expected to be rare.

Input of organics to the cave streams is primarily through surface runoff during flooding events and occurs during periods of high rainfall and maximum soil saturation (Leitheuser and Holsinger 1983, Leitheuser et al. 1984). Reversal of flow at springs on the Green River provides nutrient input to localized areas of the cave system and may be important to some populations (Holsinger and Leitheuser 1982b and 1983). A relatively complex and poorly studied community consisting of bacteria, protozoans, and minute crustaceans proliferate on the detritus and provide the basis of the food chain. These organisms, as well as smaller stream interstitial organisms, are known to be sufficient in density to support populations of grazers, including shrimp, at all times of the year, even up to several months after the last flooding or rainfall event of sufficient magnitude to greatly affect input of organisms (Leitheuser et al. 1984; Leitheuser, unpublished data). A summary of work completed and proposed projects on bacteriological colonization studies and aquatic microfauna biomass studies is presented in Leitheuser et al. (1984).

Additional information on the habitat characteristics of specific localities is available in Holsinger and Leitheuser (1982a, 1982b, and 1983), Leitheuser and Holsinger (1983), and Leitheuser et al. (1984).

The land use and land cover associations for land within the groundwater basins known to contain shrimp consist primarily of cropland, pasture, confined livestock feeding operations, and other agricultural operations for lands located outside the Mammoth Cave National Park boundaries. Several significant streams occur on the same lands, all of which ultimately drain directly into the cave systems through sinking streams, ponors, sinkholes, and other geological features (Quinlan and Ewers 1981, Quinlan and Ray 1981, Quinlan et al. 1983). Land cover associations within Mammoth Cave National Park consist primarily of a deciduous forest consisting of oak, hickory, shortleaf pine, mixed hardwoods, and red cedar. Historically, the American chestnut was also present in the area; however, this species was lost to disease (blight). Although most of the park area was logged prior to receiving protection within Mammoth Cave National Park (between 1939 and 1941), the forest includes all stages of growth, with the exception of old growth stands.

Agricultural practices on land within groundwater basins known to contain shrimp include cropland producing corn, soybeans, tobacco, summer fallow and hay, pasture land for both cattle and horses, and confined pig lots and feeding operations.

Specific environmental parameters required by the Kentucky cave shrimp are relatively unknown. A general paucity of information exists regarding environmental parameters and water quality in the Mammoth Cave National Park region (Leitheuser et al. 1984). However, Leitheuser has collected data for several specific localities known to contain major populations of shrimp within the Echo River Spring Groundwater Basin in Mammoth Cave National Park in association with studies of stream interstitial communities (Leitheuser, unpublished data). In addition, specific conductivity, dissolved oxygen, water temperature, water level, and precipitation data are available for a variety of habitats, some of which include or are immediately adjacent to known shrimp habitat (Leitheuser, unpublished data).

Reasons for Status

The shrimp is threatened by contamination of the groundwater flowing into its habitat. Several nearby communities either have inadequate sewage treatment facilities or lack such facilities altogether (Environmental Protection Agency 1981). The resulting potentially contaminated groundwater can enter the cave systems of Mammoth Cave National Park, including primary habitat of the shrimp (Quinlan and Ewers 1981, Quinlan and Ray 1981, Quinlan et al. 1983). An additional potential threat is the entry of contaminants from traffic accidents and roadside businesses. One incident in 1979 caused the death of aquatic cave organisms in a part of the Mammoth Cave system, and in a 1980 incident, a truck carrying toxic cyanide salts overturned on Interstate Highway 65, just south of Mammoth Cave National Park (U.S. Department of the Interior 1983).

Recent examples of potential groundwater contamination include the following. On May 28, 1985, a tanker truck overturned on Interstate Highway 65 near the Cumberland Parkway interchange spilling cresol (P. L. Veluzat and H. T. Holman, Division of Resource Management, Mammoth Cave National Park, Mammoth Cave, Kentucky, personal communication, 1985). The Kentucky Environmental Protection Agency and Kentucky Department of Emergency Services were able to contain the spill prior to leakage into the underground cave systems in the area. The spill was completely contained and adequately cleaned up.

A spill of hazardous synthetic solvents occurred near the 59-mile marker of Interstate Highway 65 on November 12, 1985 (P. L. Veluzat and H. T. Holman, personal communication, 1985). The site was near the Green River and may have affected shrimp habitat. Fortunately, the Kentucky State Police, with the assistance of consultants from the Kentucky Division of Water, were able to contain the spill and avoid significant environmental damage.

Another recent incident occurred within groundwater basins known to potentially affect shrimp habitat on November 15, 1985, when a train derailed approximately 1 mile south of Cave City (P. L. Veluzat and H. T. Holman, personal communication, 1985). The derailment included two tanker cars that contained approximately 900 gallons each of an unidentified pesticide and methyl alcohol. The Kentucky Department of Emergency Services successfully contained the spill prior to leakage into the cave systems.

These examples, and others, are significant since the primary drainage in the region is through the extensive and interconnected cave systems that extend over a wide geographic area (Palmer 1981, Quinlan and Ewers 1981, Quinlan and Ray 1981, Quinlan et al. 1983). Input of potentially harmful substances from the surface is almost immediately transported into the cave systems (Leitheuser et al. 1984 and 1985, Quinlan and Ewers 1981, Quinlan et al. 1983). Depending upon prevailing circumstances, substances spilled into the cave systems may require between several hours to two or three weeks to completely flow through the system to the Green River (Quinlan, unpublished data).

The McCoy Blue Spring, Suds Spring, and part of the Mile 205.7 Spring Groundwater Basin are located in oil fields where oil and natural gas wells are still being drilled. Brine from the wells is commonly washed into a convenient sinkhole or into the Green River. Brine may, under either circumstance, affect suitable shrimp habitat. It is also common for drillers in the area to pull out well casings. This may lead to intrusion into caves of oil, gas, and brine from the deeper strata that underlie the relatively shallow cave bearing strata (Leitheuser et al. 1984; T. O'Dell, Kentucky Division of Oil and Gas, Lexington, Kentucky, personal communication, 1985; P. L. Veluzat and H. T. Holman, personal communication, 1985).

A large geological fault that runs in a north-south direction has (primarily since March 1985) been extensively worked for oil. This field runs close to the east boundary of Mammoth Cave National Park and extends north to the Green River directly through the Suds Spring and along the east edge of Mile 205.7 Spring Groundwater Basins. Development of this area has been done almost exclusively by independent and wildcat drillers. Drilling in this area is not cost effective for large companies, since the return on wells is at the low end of the profit scale. Many area drillers require a return of approximately 10 barrels of oil per day to reach a cost effective profit margin. Wells in the Mammoth Cave region vary from dry to a production of 10 to 12 barrels/day with an average at about 3 barrels/day. Even though return is low, development of wells has occurred at an aggressive rate since March 1985 and was still going strong at about 60 to 70 percent of the original zeal as of late November 1985; however, development was significantly reduced by mid-1986 (P. L. Veluzat and H. T. Holman, personal communication, 1985). Although no known problems have occurred with cave fauna being affected by gas and oil development and spills, this is considered to have the potential for causing complete extirpation of the cave fauna in an entire groundwater basin.

A recent example of an incident that had the potential for causing problems with the cave fauna occurred on August 19, 1985 (P. L. Veluzat and H. T. Holman, personal communication, 1985). A major fire on the Coghil property, an approximately 400-acre area located at Tommy John's Crossing on the south side of the Green River immediately east of Mammoth Cave National Park, involved five oil storage tanks. The fire was contained, and contamination problems were prevented due to the quick intervention of the Kentucky Environmental Protection Agency and the Kentucky Department of Emergency Services. Containment occurred only 300 feet from Mammoth Cave National Park boundaries on land known to overlie shrimp habitat.

Prior to Federal acquisition of lands that now comprise Mammoth Cave National Park, several wells were drilled for oil and gas (P. L. Veluzat and H. T. Holman, personal communication, 1985). Unfortunately, due to poor record-keeping, the location of these wells is, in many cases, unknown. Two wells on Mammoth Cave National Park lands, which are within groundwater basins known to contain shrimp, were recently sealed and capped to protect the park's natural resources. These projects were completed on September 14, 1985. Prior to sealing, both wells were found to be open, and one contained approximately 300 feet of standing oil; both had the potential for adversely affecting the Mammoth Cave system (P. L. Veluzat and H. T. Holman, personal communication, 1985).

Agricultural development in the Mammoth Cave National Park region also has the potential for affecting the cave fauna, since agricultural practices may contribute to erosion of surface land draining into the cave system. Siltation has been observed in the cave system for many years; however, very little data have been acquired to support the hypothesis that it is the direct result of agricultural development (J. F. Quinlan, Mammoth Cave National Park Geological Staff, Mammoth Cave, Kentucky, personal communication, 1983). Virtually all drainage in the area is known to occur through the extensive cave systems. The region is covered extensively with sinking streams, sinkholes, ponors, and other geological features that allow the rapid introduction of runoff from eroded land; this may result in siltation or the introduction of fertilizers, herbicides, and pesticides into the cave systems (Palmer 1981; Quinlan and Ewers 1981; Quinlan and Ray 1981; Quinlan _et al_. 1983; J. F. Quinlan, personal communication, 1983). Although no effort has been made to document this potential threat, the possibility exists that it may have occurred in the past or may be occurring at present. The large size of the area reduces the possibility that casual observations by volunteers and professionals will document these potential threats during the course of other studies (J. F. Quinlan, personal communication, 1983).

The Kentucky cave shrimp is not utilized for commercial, recreational, or educational purposes. Scientific utilization has predominantly been through direct observations. However, since its discovery, the shrimp has been collected on several occasions (refer to introduction section). In addition, recent studies by Leitheuser have included the collection of voucher specimens from known localities and the use of shrimp in aquarium studies. Some of the aquarium studies have resulted in shrimp mortality. The extent of past collections is not considered to have had a significant impact on known populations of shrimp. Present collection permit requirements by the U.S. Fish and Wildlife Service, National Park Service, and the Commonwealth of Kentucky are adequate to ensure that utilization of the species for scientific purposes does not hinder or impair these populations.

Although not originally identified as a threat to the Kentucky cave shrimp (U.S. Department of the Interior 1983), the introduction of rainbow trout to the watersheds that include the Mammoth Cave National Park region may be of significance. Leitheuser (Leitheuser and Holsinger 1983) has observed Salmo gairdneri Richardson eating the shrimp in Pike Spring. The population of trout is relatively small but seems to be well-established, as is evidenced by subsequent sightings (Leitheuser, unpublished data) of trout in known shrimp habitat. The trout, which is an introduced species to the Green River Basin (Clay 1962 and 1975), may have successfully adapted to taking refuge in the cold subterranean waters in the Mammoth Cave National Park area and to utilizing cave fauna as a food source (Leitheuser and Holsinger 1983). Detailed accounts of trout sightings and releases into nearby regularly stocked waters is discussed by Leitheuser and Holsinger (1983). This is a potentially serious management problem for the entire aquatic cave fauna and deserves further consideration.

U.S. Fish and Wildlife Service and National Park Service regulations are adequate to protect this species from taking. The threats to its habitat are primarily from sources outside of the park over which the National Park Service has no control.

The Commonwealth of Kentucky's Kentucky Nature Preserves Commission has determined this species to be endangered in Kentucky (Branson et al. 1981). That designation, however, carries no legal protection.

The Commonwealth of Kentucky has few regulations pertaining to the monitoring and documentation of gas and oil development and spills that may occur on lands affecting shrimp habitat (J. F. Quinlan, personal communication, 1985; G. A. Schindel, Office of Groundwater Management, Kentucky Division of Water, Frankfort, Kentucky, personal communication, 1985; P. L. Veluzat and H. T. Holman, personal communication, 1985). No effort has been made to document potential threats and hazards to the cave fauna from these activities. Also, this aspect of regulatory considerations was not addressed in the listing of the shrimp (U.S. Department of the Interior 1983).

The very small estimated population size of the species at the time of listing (approximately 500 individuals) made it stand out as being extremely vulnerable to extinction. Since the time of listing, new populations have been discovered within the groundwater basins originally known to contain shrimp, and in six other groundwater basins. Population estimates from the nine groundwater basins presently known to contain shrimp range from approximately 7,000 to 12,000 individuals.

Several factors may lead to increased siltation of the cave systems, including forest clearing, forest alteration, agricultural practices, general erosion, surface drainage, and passage barriers. Increased siltation may cause a decline in the available food supply for grazer populations, like the Kentucky cave shrimp, by limiting the available habitat for stream interstitial fauna (Leitheuser, unpublished data). This fauna is a large and significant portion of the food web base in aquatic cave streams and is very habitat specific (e.g., preferring fine to medium sand rather than silts and clays) (Leitheuser, unpublished data). Lock and Dam No. 6 on the Green River near Brownsville was implicated as being responsible for the decline in shrimp populations between 1967 and 1981 (U.S. Department of the Interior 1980b and 1983, Lisowski and Poulson 1979). The apparent population decline referred to above was an artifact of inadequate monitoring procedures and efforts. However, the dam does have the potential for causing increased siltation in the base level cave streams of Mammoth Cave National Park. The Green River Dam on the Green River at Greenville, Kentucky, may cause the same siltation and is more likely to do so since the river water level is maintained at an artificially high level of approximately 8 to 12 feet above normal subsequent to flood events (Leitheuser, unpublished data; J. F. Quinlan, personal communication, 1983; G. A. Schindel, personal communication, 1983).

PART II

RECOVERY

A. RECOVERY OBJECTIVES

The primary objectives of this recovery plan are to: (1) downlist *Palaemonias ganteri* to threatened status and (2) delist the species when the tasks outlined in this plan have been accomplished and *P. ganteri* no longer requires the protection of the Endangered Species Act. The requirements for downlisting to threatened status are the protection of viable, reproducing populations in five groundwater basins currently known to support the species or found to support it in the future. To delist the species, protection for the foreseeable future of viable, reproducing populations in nine groundwater basins currently supporting *P. ganteri* or found to support it in the future is required.

B. STEP-DOWN OUTLINE

1 Conduct surveys to determine the location and extent of all areas supporting shrimp.

2 Conduct life history and other research required to determine what constitutes a viable population.

2.1 Conduct life history research to determine sex ratios, fecundity, survival rate, mortality rate, rate of increase, turnover rate, longevity, food supply, viable population size, and protection needed to ensure continued existence of the species.

2.2 Continue hydrological studies of the Mammoth Cave area.

2.2.1 Continue the delineation of groundwater basins.

2.3 Determine the biotic and abiotic water quality parameters essential to the survival of the species.

3 Conduct research to determine factors adversely impacting the species and means to eliminate or reduce such impacts.

3.1 Determine the effects of pesticide contamination.

3.2 Determine the effects of water pollution and siltation.

3.3 Determine the effects of development.

3.3.1 Evaluate the effects of roads on water quality.

3.3.2 Evaluate transportation corridors and traffic patterns within the sinkhole plain.

4 Monitor population status.

4.1 Monitor status of all populations and regularly evaluate habitat quality.

4.2 Monitor surface and underground perturbations which threaten the species.

5 Maintain adequate water quality.

5.1 Bring sewage treatment facilities up to adequate standards.

5.2 Evaluate mechanisms for preventing pollution from private septic systems and implement actions required to prevent pollution of cave systems if necessary.

5.3 Reduce or eliminate siltation from artificially high water levels.

5.4 Prevent perturbations to surrounding land which adversely affect the cave system through regulations pertaining to land use practices.

5.4.1 Develop and implement a plan to ensure that drilling for oil and natural gas is conducted in a manner which protects the cave system.

5.4.2 Develop and implement a plan to ensure that agricultural and forestry practices are conducted in a way which does not adversely affect the cave system.

5.5 Develop and implement a plan to ensure that spills of toxic substances from traffic accidents or other sources do not enter the cave system.

6 Protect the shrimp from introduced predators.

6.1 Develop and implement a plan to ensure that trout releases and stocking practices do not adversely affect the shrimp.

7 Periodically reevaluate the recovery plan, including the criteria for recovery of the species, to ensure that it is adequate to provide protection for the species.

8 Produce and conduct public education programs.

8.1 Produce and conduct public awareness programs.

8.2 Produce and conduct educational tours/programs/flyers/articles.

8.3 Produce and conduct a program to develop public appreciation of karst terrains, water quality, the unique ecosystems and their biota, perturbation effects, endangered species legislation, and species protection/recovery.

C. NARRATIVE OUTLINE

1 Conduct surveys to determine the location and extent of all areas supporting shrimp. An intensive survey of all areas outside the currently known range of the species that may contain the shrimp should be conducted. This will provide for accurate delineation of the shrimp's range and permit implementation of other recovery activities in a timely and appropriate manner.

2 Conduct life history and other research required to determine what constitutes a viable population. Successful implementation of this recovery plan will require the acquisition of additional data on the species and its environment.

2.1 Conduct life history research to determine sex ratios, fecundity, survival rate, mortality rate, rate of increase, turnover rate, longevity, food supply, viable population size, and protection needed to ensure continued existence of the species. Data currently available on these aspects of the ecology and life history of *P. ganteri* are insufficient for proper protection of the species and recovery planning. Holsinger and Leitheuser (1982b and 1983) and Leitheuser *et al.* (1985) discussed the initiation and importance of studies on the interstitial fauna of both surface and cave streams in the Mammoth Cave region. This is important for two reasons. First, this fauna is the primary food supply of *P. ganteri*. Also, these faunal communities are indicators of specific habitats and reflect changes in habitat and/or water quality (R. L. Whitman, Indiana University Northwest, Gary, Indiana, personal communication, 1985). Continued studies of this important community are needed. A preliminary report on recent studies is forthcoming (Whitman *et al.*, in press). Determinations of what constitutes a viable population and its protection are required for accomplishment of the primary objectives of this plan.

2.2 Continue hydrological studies of the Mammoth Cave area. The hydrology of caves in the Mammoth Cave region is very complex. Increased knowledge is essential to the success of any biological work in the base level stream passages. Current studies of the hydrology of caves in the region should be continued and expanded to include studies on additional groundwater basins found to support the shrimp.

2.2.1 Continue the delineation of groundwater basins. Dye tracing, conducted primarily by James F. Quinlan, Joe A.

Ray, and Timothy J. Schafstall (Mammoth Cave National Park Geological Staff), and cartography efforts by numerous cavers, have produced a tremendous amount of information on relationships of passages and delineation of groundwater basins. Cave diving has recently become another important technique for data collection. This work has been necessary for the success of National Park Service funded studies. Without the information obtained from these sources and the cooperation of these groups, biological work in the caves of the region would be severely limited in productivity. Continued delineation of groundwater basins and exploration of the complex cave systems is highly recommended.

2.3 Determine the biotic and abiotic water quality parameters essential to the survival of the species. Biotic monitoring of water quality should be initiated in the Mammoth Cave region. Abiotic monitoring of water quality has recently been initiated by James F. Quinlan through cooperation with the Kentucky Division of Water and the U.S. Geological Survey. This work should continue.

3 Conduct research to determine factors adversely impacting the species and means to eliminate or reduce such impacts.

3.1 Determine the effects of pesticide contamination. It is not known whether pesticides used in the Mammoth Cave region have any harmful effect on the cave fauna, including P. ganteri. Baseline data need to be obtained in cooperation with the appropriate agencies.

3.2 Determine the effects of water pollution and siltation. Although it is generally accepted that water pollution and increased siltation may have a negative impact on P. ganteri, more data need to be obtained. Cooperative efforts with the Kentucky Division of Water, U.S. Geological Survey, National Park Service, and U.S. Fish and Wildlife Service are recommended.

3.3 Determine the effects of development. Uncontrolled development in the Mammoth Cave region is viewed as potentially harmful to P. ganteri. Potentially harmful effects of development need to be properly identified and monitored.

3.3.1 Evaluate the effects of roads on water quality. Road building in the Mammoth Cave region increases runoff by providing a surface for water flow. The natural process of channeling water flow over soil and forest litter slows down the flow of water, allows for some degree of seepage, and reduces erosion. Roads may provide cause for concern by increasing flow rates and siltation. This needs to be further studied. Also, the tar surface of roads contains an abundance of petroleum distillates that may be harmful to P. ganteri. The potential effect on the shrimp should be studied and quantified.

3.3.2 Evaluate transportation corridors and traffic patterns within the sinkhole plain. The large area south of Green River, referred to as the sinkhole plain, drains directly into P. ganteri habitat or into the Green River upstream of P. ganteri habitat. Therefore, any spills or accidents involving harmful substances may affect the cave fauna. This is especially applicable to traffic on Interstate 65.

4 Monitor population status. Recent studies by A. T. Leitheuser established baseline data for most of the known shrimp populations. Continued studies are necessary to produce comparison data and to determine trends in these populations. Previous part-time monitoring methods used in the park are inadequate. Visitation to the Mammoth Cave region only once or twice per month severely limits the extent to which populations located in the largest known cave system in the world can be monitored. It is only possible to very sporadically monitor populations in this manner. Data on the shrimp obtained by sporadic observations over the 80-year period prior to initiation of studies funded by the National Park Service yielded little data of value for monitoring population status. The only adequate method of monitoring populations, surveying for new populations, tracking local conditions, etc., is through the use of personnel who can be at the park continuously during the low-water survey period.

4.1 Monitor status of all populations and regularly evaluate habitat quality. In order to obtain meaningful data on the status of shrimp populations and their habitat, it will be necessary to resurvey each population on a regular basis.

4.2 Monitor surface and underground perturbations which threaten the species. Several examples of accidents and spills that resulted in a potentially hazardous situation for the aquatic cave fauna, including P. ganteri, have been identified. It is recommended that monitoring of these events be continued by local authorities, researchers, and state and Federal agencies. Information dissemination procedures need to be established to keep all appropriate groups informed.

5 Maintain adequate water quality. The protection of P. ganteri is highly dependent upon the maintenance of good water quality throughout its range.

5.1 Bring sewage treatment facilities up to adequate standards. The entire Mammoth Cave region is utilizing sewage treatment facilities that are inadequate. Local interest groups, primarily the Caveland Sanitation Authority in cooperation with the National Park Service, are attempting to rectify this situation through acquisition of funds and subsequent building of proper facilities. This project must be completed to ensure that most of the major sources of improperly treated sewage no longer contribute to the degradation of water quality.

5.2 Evaluate mechanisms for preventing pollution from private septic systems and implement actions required to prevent pollution of cave systems if necessary. Although the Caveland Sanitation Authority has made significant progress toward solving the pollution problems in the area and the proposed facilities will handle most sewage problems in the cities south of the Green River, many private homes in the region will still be utilizing septic tanks. The effluent from these systems often may go directly into the cave systems. If so, a solution to this problem may eventually be needed.

5.3 Reduce or eliminate siltation from artificially high water levels. Although Lock and Dam No. 6 has been implicated by some groups as being responsible for perturbations to the aquatic cave fauna, no data exist to verify this assertion. There appears to be a significant increase in siltation of base level cave streams; however, this is more likely a result of the long periods of time during which the Green River is maintained at an artificially high water level subsequent to major flooding events. These high water levels result from releases originating at the Green River Dam, Greensburg, Kentucky. Further research into this practice should be conducted and analyzed with regard to possible perturbations to the fauna in the Mammoth Cave system.

5.4 Prevent perturbations to surrounding land which adversely affect the cave system through regulations pertaining to land use practices. The Mammoth Cave region currently has few regulations with regard to land use practices. Regulations required to protect the cave systems should be identified, established, and enforced.

5.4.1 Develop and implement a plan to ensure that drilling for oil and natural gas is conducted in a manner which protects the cave system. The development of oil and gas drilling along the east boundary of Mammoth Cave National Park has often been conducted in a manner inconsistent with conventional standards for habitat protection. Cooperation among the appropriate agencies and enforcement of existing regulations would ensure that shrimp habitat is not adversely affected by these activities.

5.4.2 Develop and implement a plan to ensure that agricultural and forestry practices are conducted in a way which does not adversely affect the cave system. The practices of disking cropland and subsequently allowing the topsoil, albeit unintentional, to be washed into the cave systems during flooding events should be discouraged. This results in high quantities of silt being washed into the caves. Further, insecticide spraying practices need to be analyzed to determine their effect on cave fauna.

Most of the Mammoth Cave region is under some form of pressure to be logged for trees. The standard practice is often to clearcut an area. This may result in increased siltation in the cave systems and should only be conducted when adequate land cover is maintained to protect land surfaces from erosion.

5.5 Develop and implement a plan to ensure that spills of toxic substances from traffic accidents or other sources do not enter the cave system. The appropriate agencies responsible for monitoring and planning the route of potentially harmful substances must work in cooperation with the National Park Service and the U.S. Fish and Wildlife Service to become aware of possible perturbations to the aquatic fauna. Traffic should be either rerouted to avoid the area altogether or slowed down considerably and given an escort by the appropriate agency to reduce the possibility of accidents. In addition, the agencies responsible for monitoring and cleaning up spills of harmful substances should be consulted prior to use of highways in the sensitive Mammoth Cave region.

6 Protect the shrimp from introduced predators. The shrimp is highly susceptible to some introduced predators and should be protected from possible reduction or even extirpation of some populations by eliminating this predation.

6.1 Develop and implement a plan to ensure that trout releases and stocking practices do not adversely affect the shrimp. Although present releases of trout are at areas that are distant from most shrimp habitat, these introduced species are gaining access to the cave systems. Additional studies of the effect of trout on shrimp populations are necessary. A trout survey of the Green River should be conducted to determine their current distribution in the river. It may become necessary to remove trout currently utilizing the cave and to limit access of additional trout to the cave systems through the erection of nets at appropriate springs. However, standard nets will prove to be inadequate for this purpose due to the dynamic nature of flow patterns, especially during flooding events, in the Mammoth Cave region.

7 Periodically reevaluate the recovery plan, including the criteria for recovery of the species, to ensure that it is adequate to provide protection for the species. The information gained from future studies of the shrimp and its environment will require

regular careful review to ensure that the criteria and tasks identified in this recovery plan are adequate to accomplish the objectives.

8 Produce and conduct public education programs. The results of studies on the shrimp and other fauna of the cave systems should be transcribed and presented in a format that will increase awareness of the unique cave fauna and its susceptibility to perturbations. The recovery effort for the shrimp is more likely to succeed if the support of local groups and residents is obtained to maintain and improve the environmental quality in their communities.

8.1 Produce and conduct public awareness programs. Public awareness and education programs are needed to gain support for the recovery plan.

8.2 Produce and conduct educational tours/programs/flyers/articles. Incorporation of information on the shrimp into current tours of the Mammoth Cave system would increase public knowledge and involvement in the shrimp recovery effort. This already occurs to some extent through the support of the National Park Service Division of Interpretation. Increased dissemination could be effected through presentations to new guides each year. In addition, presentations to local groups should be encouraged and supported. This may be in the form of slide series, video tape series, etc. Information brochures and flyers should be completed for distribution to visitors to the region and to local groups. Publicity for endangered species issues and projects through the popularized magazines of state and Federal agencies and private organizations would also be an effective means of gaining support for shrimp recovery efforts.

8.3 Produce and conduct a program to develop public appreciation of karst terrains, water quality, the unique ecosystems and their biota, perturbation effects, endangered species legislation, and species protection/recovery. The most effective way to disseminate knowledge which may assist in the protection of cave fauna and its habitat is through a general appreciation rather than specifically keying in on one species.

LITERATURE CITED

Barr, T.C., Jr. 1967. Ecological Studies in the Mammoth Cave System of Kentucky I: The Biota. International Journal of Speleology, 3:147-204, pls. 37-64.

Barr, T.C., Jr., and R.A. Kuehne. 1971. Ecological Studies in the Mammoth Cave System of Kentucky II: The Ecosystem. Anales de Speleologie, Revue Trimestrielle, 26(1):47-96, 12 figs., 10 tbls.

Bouchard, R.W. 1979. Conservation Status Report on the Mammoth Cave Shrimp, Palaemonias ganteri (including cover letter dated December 12, 1979, and supplement dated January 1, 1980). Unpublished Manuscript, 9 pp., 8 figs., 1 app.

Branson, B.A., D.F. Harker, Jr., J.M. Baskin, M.E. Medley, D.L. Batch, M.L. Warren, Jr., W.H. Davis, W.C. Houtcooper, B. Monroe, Jr., L.R. Phillippe, and P. Cupp. 1981. Endangered, Threatened, and Rare Animals and Plants of Kentucky. Trans. Kentucky Acad. Sci., 42(3-4):77-89.

Chace, F.A., Jr. 1943. Two New Blind Prawns from Cuba with a Synopsis of the Subterranean Caridea of America. Proc. New England Zoo. Club, 22:25-40, pls. 5-7.

------. 1954. Two New Subterranean Shrimps (Decapoda: Caridea) from Florida and the West Indies, with a Revised Key to the American Species. Journ. Wash. Acad. Sci., 44(10):318-324, 2 figs.

------. 1959. Malacostraca. Pp. 869-901, figures 31.1-31.41 IN: W.T. Edmondson (ed.). Fresh-water Biology. Second Ed. New York: John Wiley and Sons, Inc.

Clay, W.M. 1962. A Field Manual of Kentucky Fishes. Kentucky Dept. of Fish and Wildlife Resources, Frankfort, KY, vii + 147 pp., 94 figs.

------. 1975. The Fishes of Kentucky. Kentucky Dept. of Fish and Wildlife Resources, Frankfort, KY, vii + 416 pp.

Cooper, J.E. 1975. Ecological and Behavioral Studies in Shelta Cave, Alabama, with Emphasis on Decapod Crustaceans. Ph.D. Dissertation, Univ. of Kentucky, Lexington, KY, xvi + 364 pp., 32 figs.

Environmental Protection Agency. 1981. Final Environmental Impact Statement: Mammoth Cave Area: Kentucky: Wastewater Facilities. EPA 904/9-81-076. Atlanta, GA.

Fage, L. 1931. Crustaces Amphipodes et Decapodes. Pp. 361-374, figs. 1-21 IN: Bolivar, C., and R. Jeannel (eds.). Biospeologica LXI: Campagne Speciogique dans l'Amerique du nord en 1928 (Premiere

Series). Archives de Zoologie Experimentale et Generale, 71:293-499, 212 figs.

Hay, W.P. 1901. Two New Subterranean Crustaceans from the United States. Proc. Biol. Soc. Wash., 14:179-180.

------. 1902. Observations on the Crustacean Fauna of the Region About Mammoth Cave, Kentucky. Proc. U.S. Nat. Mus., 25(1285):223-236, 1 fig.

Hobbs, H.H., Jr., H.H. Hobbs, III, and M.A. Daniel. 1977. A Review of the Troglobitic Decapod Crustaceans of the Americas. Smith. Contr. Biol., 244:v + 183 pp., 70 figs., 1 tbl.

Holsinger, J.R., and A.T. Leitheuser. 1981. Ecological Analysis of the Kentucky Cave Shrimp, Palaemonias ganteri Hay, a Proposal to the National Park Service. Norfolk, Virginia: Old Dominion University Research Foundation. ODURF Number USDI-81-1181-684, iii + 107 pp., 18 figs., 16 app.

------. 1982a. Ecological Analysis of the Kentucky Cave Shrimp, Palaemonias ganteri Hay, at Mammoth Cave National Park (Phase I). Norfolk, Virginia: Old Dominion University Research Foundation, U.S. Dept. of the Interior, National Park Service Contract Number CX-5000-1-1037, iii + 34 pp., 11 figs., 4 tbls.

------. 1982b. Ecological Analysis of the Kentucky Cave Shrimp, Palaemonias ganteri Hay, at Mammoth Cave National Park (Phase II). Norfolk, Virginia: Old Dominion University Research Foundation, U.S. Dept. of the Interior, National Park Service Contract Number CX-5000-1-1037, v + 64 pp., 16 figs., 14 tbls.

------. 1983. Ecological Analysis of the Kentucky Cave Shrimp, Palaemonias ganteri Hay, at Mammoth Cave National Park (Phase III). Norfolk, Virginia: Old Dominion University Research Foundation, U.S. Dept. of the Interior, National Park Service Contract Number CX-5000-1-1037, iii + 31 pp., 9 figs., 3 tbls.

Leitheuser, A.T. 1984. Ecological Analysis of the Kentucky Cave Shrimp, Palaemonias ganteri Hay, at Mammoth Cave National Park. Central Kentucky Cave Survey Bull., 1:72-80.

Leitheuser, A.T., and J.R. Holsinger. 1983. Ecological Analysis of the Kentucky Cave Shrimp, Palaemonias ganteri Hay, at Mammoth Cave National Park (Phase IV). Norfolk, Virginia: Old Dominion University Research Foundation, U.S. Dept. of the Interior, National Park Service Contract Number CX-5000-1-1037, vi + 44 pp., 44 figs.

Leitheuser, A.T., J.R. Holsinger, R. Olson, N.R. Pace, and R.L. Whitman. 1984. Ecological Analysis of the Kentucky Cave Shrimp, Palaemonias ganteri Hay, at Mammoth Cave National Park (Phase V Progress Report). Norfolk, Virginia: Old Dominion University Research Foundation, U.S. Dept. of the Interior, National Park Service Contract Number CX-5000-1-1037, ii + 15 pp.

------. 1985. Ecological Analysis of the Kentucky Cave Shrimp, Palaemonias ganteri Hay, at Mammoth Cave National Park (Phase V). Norfolk, Virginia: Old Dominion University Research Foundation, U.S. Dept. of the Interior, National Park Service Contract Number CX-5000-1-1037, vii + 102 pp., 26 figs., 5 tbls.

Lisowski, E.A., and T.L. Poulson. 1979. Impacts of Lock and Dam Six on Baselevel Ecosystems in Mammoth Cave. Pp. 48-54, 2 figs., IN: Cave Research Foundation 1979 Annual Report. Yellow Springs, Ohio: Cave Research Foundation.

Ortmann, A.E. 1918. Higher Crustaceans (Malacostraca). Pp. 828-850, figs. 1303-1318, IN: H.B. Ward and G.C. Whipple. Freshwater Biology. New York: John Wiley and Sons, Inc.

Palmer, A.N. 1981. A Geological Guide to Mammoth Cave National Park. Teaneck, New Jersey: Zephyrus Press, xiv + 196 pp., 104 figs.

Pennak, R.W. 1978. Freshwater Invertebrates of the United States (Second Ed.). New York: John Wiley and Sons, Inc., xv + 803 pp., 548 figs.

Quinlan, J.F., and R.O. Ewers. 1981. Hydrogeology of the Mammoth Cave Region, Kentucky. Pp. 457-495, 28 figs., IN: T.G. Roberts (ed.). GSA Cincinnati '81 Field Trip Guidebooks. American Geological Institute, Washington, D.C., Vol. 3.

Quinlan, J.F., and J.A. Ray. 1981. Groundwater Basins in the Mammoth Cave Region, Kentucky Showing Springs, Major Caves, Flow Routes, and Potentiometric Surface. Occ. Pub. No. 1. Mammoth Cave, Kentucky: Friends of the Karst.

Quinlan, J.F., R.O. Ewers, J.A. Ray, R.L. Powell, and N.C. Krothe. 1983. Ground-water Hydrology and Geomorphology of the Mammoth Cave Region, Kentucky, and the Mitchell Plain, Indiana (Field Trip 7). Pp. 1-85, 48 figs., IN: R.H. Shaver and J.A. Sanderson (eds.). Field Trips in Midwestern Geology: Geol. Soc. of America and Indiana Geol. Sur., Vol. 2.

Smalley, A.E. 1961. A New Cave Shrimp from Southeastern United States (Decapoda, Atyidae). Crustaceana, 3(2):127-130, 1 fig.

U.S. Department of the Interior. 1977. Endangered and Threatened Wildlife and Plants. Federal Register 42:2507.

------. 1979. Endangered and Threatened Wildlife and Plants. Federal Register 44:70796.

------. 1980a. Endangered and Threatened Wildlife and Plants. Federal Register 45:20502.

------. 1980b. Endangered and Threatened Wildlife and Plants. Federal Register 45:68975.

------. 1983. Endangered and Threatened Wildlife and Plants. Federal Register 48:46337.

Whitman, R.L., A.V. Gochee, A.T. Leitheuser, and J.R. Holsinger. In Press. Stream Interstitial Meiofauna Communities and Related Abiotic Factors in the Mammoth Cave Region. Norfolk, Virginia: Old Dominion University Research Foundation.

PART III
IMPLEMENTATION SCHEDULE

KEY TO IMPLEMENTATION SCHEDULE COLUMNS 1 & 4

General Category (Column 1):

Information Gathering - I or R (Research)

1. Population status
2. Habitat status
3. Habitat requirements
4. Management techniques
5. Taxonomic studies
6. Demographic studies
7. Propagation 7. Other
8. Migration
9. Predation
10. Competition
11. Disease
12. Environmental contaminant
13. Reintroduction
14. Other information

Acquisition - A

1. Lease
2. Easement
3. Management agreement
4. Exchange
5. Withdrawal
6. Fee title

Other - O

1. Information and education
2. Law enforcement
3. Regulations
4. Administration

Management - M

1. Propagation
2. Reintroduction
3. Habitat maintenance and manipulation
4. Predator and competitor control
5. Depredation control
6. Disease control
7. Other management

Priorities within this section (Column 4) have been assigned according to the following:

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.

IMPLEMENTATION SCHEDULE

Kentucky cave shrimp (Palaemonias ganteri)

*1 GENERAL CATEGORY	PLAN TASK	TASK NUMBER	PRIORITY	TASK DURATION	RESPONSIBLE AGENCIES *2 FWS REGION	FWS DIVISION	OTHERS *3	ESTIMATED FISCAL YEAR COSTS *4 FY 1	FY 2	FY 3	COMMENTS/NOTES
I1, I14	Conduct surveys to determine the location and extent of all areas supporting shrimp.	1	2	3 years	4	FWE	NPS	15	15	15	
I1-3, I11	Conduct life history research to determine sex ratios, fecundity, survival rate, mortality rate, rate of increase, turnover rate, longevity, food supply, viable population size, and protection needed to ensure continued existence of the species.	2.1	2	3 years	4	FWE	NPS	18	18	18	Can be combined with Task No. 1 to obtain at reduced cost.
I14	Continue hydrological studies of the Mammoth Cave area.	2.2	2	Unknown	4	FWE	NPS, KDW	35	35	35	
I14	Continue the delineation of groundwater basins.	2.2.1	2	Unknown	4	FWE	NPS, KDW	5	5	5	
I3, I14	Determine the biotic and abiotic water quality parameters essential to the survival of the species.	2.3	1	3 years	4	FWE	NPS, KDW	24	5	5	
I12	Determine the effects of pesticide contamination.	3.1	2	Unknown	4	FWE	NPS	20	20	20	

IMPLEMENTATION SCHEDULE

Kentucky cave shrimp (<u>Palaemonias ganteri</u>)

*1 GENERAL CATEGORY	PLAN TASK	TASK NUMBER	PRIORITY	TASK DURATION	RESPONSIBLE AGENCIES *2 FWS REGION	RESPONSIBLE AGENCIES *2 FWS DIVISION	RESPONSIBLE AGENCIES *2 OTHERS *3	ESTIMATED FISCAL YEAR COSTS *4 FY 1	FY 2	FY 3	COMMENTS/NOTES
I12, I14	Determine the effects of water pollution and siltation.	3.2	1	Unknown	4	FWE	NPS	20	10	10	
I3, I14	Determine the effects of development.	3.3	2	Unknown	4	FWE	NPS	20	5	5	
I3, I14	Evaluate the effects of roads on water quality.	3.3.1	2	Unknown	4	FWE	NPS	25	5	5	
I3, I14	Evaluate transportation corridors and traffic patterns within the sinkhole plain.	3.3.2	2	Unknown	4	FWE	NPS	5	5	-0-	
I1, I14	Monitor status of all populations and regularly evaluate habitat quality.	4.1	1	Continuous	4	FWE	NPS, FWS	15	15	15	Can be combined with Task Nos. 1 and 2.1 to reduce cost.
I14	Monitor surface and underground perturbations which threaten the species.	4.2	2	Unknown	4	FWE	NPS	5	5	5	
M3, M7	Bring sewage treatment facilities up to adequate standards.	5.1	1	Unknown	4	FWE	NPS, KDW	*	*	*	*Unknown

IMPLEMENTATION SCHEDULE

Kentucky cave shrimp (*Palaemonias ganteri*)

*1 GENERAL CATEGORY	PLAN TASK	TASK NUMBER	PRIORITY	TASK DURATION	RESPONSIBLE AGENCIES *2 FWS REGION	RESPONSIBLE AGENCIES *2 FWS DIVISION	RESPONSIBLE AGENCIES *2 OTHERS *3	ESTIMATED FISCAL YEAR COSTS *4 FY 1	ESTIMATED FISCAL YEAR COSTS *4 FY 2	ESTIMATED FISCAL YEAR COSTS *4 FY 3	COMMENTS/NOTES
I12, M3, M7	Evaluate mechanisms for preventing pollution from private septic systems and implement actions required to prevent pollution of cave systems if necessary.	5.2	2	Unknown	4	FWE	NPS, KDW	15	*	*	*Unknown
M3, M7	Reduce or eliminate siltation from artificially high water levels.	5.3	2	Unknown	4	FWE	NPS, KDW, COE	*	*	*	*Unknown
I14, M3, M7	Develop and implement a plan to ensure that drilling for oil and natural gas is conducted in a manner which protects the cave system.	5.4.1	2	Unknown	4	FWE		12	*	---	*Unknown
I14, M3, M7	Develop and implement a plan to ensure that agricultural and forestry practices are conducted in a way which does not adversely affect the cave system.	5.4.2	2	Unknown	4	FWE	NPS, SCS	12	*	---	*Unknown. Can be combined with Task No. 4.4.1 to reduce costs.

IMPLEMENTATION SCHEDULE

Kentucky cave shrimp (Palaemonias ganteri)

*1 GENERAL CATEGORY	PLAN TASK	TASK NUMBER	PRIORITY	TASK DURATION	RESPONSIBLE AGENCIES *2			ESTIMATED FISCAL YEAR COSTS *4			COMMENTS/NOTES
					FWS		OTHERS *3				
					REGION	DIVISION		FY 1	FY 2	FY 3	
I14, M3, M7	Develop and implement a plan to ensure that spills of toxic substances from traffic accidents and other sources do not enter the cave system.	5.5	1	1 year	4	FWE	NPS	12	-0-	-0-	
M4	Develop and implement a plan to ensure that trout releases and stocking practices do not adversely affect the shrimp.	6.1	2	2 years	4	FWE	NPS, KDFWR	*	---	-0-	*Unknown
M7	Periodically reevaluate the recovery plan, including the criteria for recovery of the species, to ensure that it is adequate to provide protection for the species.	7	2	Continuous	4	FWE		-0-	-0-	-0-	
O1	Produce and conduct public awareness programs.	8.1	3	Continuous	4	FWE	NPS	-0-	-0-	-0-	
O1	Produce and conduct educational tours/programs/flyers/articles.	8.2	3	1 year	4	FWE	NPS	12	-0-	-0-	

IMPLEMENTATION SCHEDULE

Kentucky cave shrimp (*Palaemonias ganteri*)

*1 GENERAL CATEGORY	PLAN TASK	TASK NUMBER	PRIORITY	TASK DURATION	RESPONSIBLE AGENCIES *2			ESTIMATED FISCAL YEAR COSTS *4			COMMENTS/NOTES
					FWS						
					REGION	DIVISION	OTHERS *3	FY 1	FY 2	FY 3	
O1	Produce and conduct a program to develop public appreciation of karst terrains, water quality, the unique ecosystems and their biota, perturbation effects, endangered species legislation, and species protection/ recovery.	8.3	3	1	4	FWE	NPS	12	-0-	-0-	Can be combined with Task No. 8.2 to reduce costs.

*1 - See page 28, entitled "Key to Implementation Schedule - Columns 1 and 4."

*2 - FWS - Fish and Wildlife Service
FWE - Fish and Wildlife Enhancement
NPS - National Park Service
KDW - Kentucky Division of Water
COE - U.S. Army Corps of Engineers
SCS - U.S. Department of Agriculture, Soil Conservation Service
KDFWR - Kentucky Department of Fish and Wildlife Resources

*3 - Other agencies' responsibility would be of a cooperative nature or projects funded under a contract or grant program. In some cases contracts could be let to universities or private enterprises.

*4 - All estimates are for FWS funds only (in thousands).

LIST OF REVIEWERS

Mr. William T. Austin
Caveland Sanitation Authority
Highway 335
Horse Cave, Kentucky 42749

Dr. Thomas C. Barr, Jr.
Morgan School of Biological Sciences
University of Kentucky
Lexington, Kentucky 40506

Dr. Raymond W. Bouchard
Crustacean Specialist Group
Species Survival Commission
International Union for Conservation
of Nature and Natural Resources
7500 Seaview Avenue
Wildwood Crest, New Jersey 08260

Mr. John A. Branstetter
Caveland Sanitation Authority
314 Woodlawn Avenue
Horse Cave, Kentucky 42749

Mr. Donald E. Coons
Rural Route 3
Cave City, Kentucky 42127

Dr. Nicholas C. Crawford
Center for Cave and Karst Studies
Department of Geography and Geology
Western Kentucky University
Bowling Green, Kentucky 42101

Mr. Dave Foster
American Cave Conservation Association
P.O. Box 409
Horse Cave, Kentucky 42729-0409

Mr. Tom Aley
Ozark Underground Laboratory
Protem, Missouri 65733

Mr. Dick Franz
Florida State Museum
University of Florida
Gainesville, Florida 32611

Mr. Russell Galipeau
National Park Service
Richard B. Russell Federal Building
75 Spring Street, S.W.
Atlanta, Georgia 30303

Mr. Wayne Davis
Kentucky Department of Fish and
Wildlife Resources
#1 Game Farm Road
Frankfort, Kentucky 40601

Mr. Donald F. Harker, Jr.
Kentucky Division of Water
Fort Boone Plaza
18 Reilly Road
Frankfort, Kentucky 40601

Dr. John R. Holsinger
Department of Biological Sciences
Old Dominion University
Norfolk, Virginia 23508

Dr. Francis G. Howarth
Cave Species Specialist Group
Special Survival Commission
International Union for Conservation
of Nature and Natural Resources
Department of Entomology
Bernice P. Bishop Museum
P.O. Box 19000-A
Honolulu, Hawaii 96819

Dr. Julian J. Lewis
Department of Biology
University of Louisville
Louisville, Kentucky 40292

Mr. Edward M. Lisowski
308 West Nevada
Urbana, Illinois 61801

Mr. John MacGregor (2 copies)
Kentucky Department of Fish and
Wildlife Resources
Arnold L. Mitchell Building
#1 Game Farm Road
Frankfort, Kentucky 40601

Mr. Richard Hannan, Director (3 copies)
Kentucky Nature Préserves Commission
407 Broadway
Frankfort, Kentucky 40601

Superintendent (3 copies)
Mammoth Cave National Park
Mammoth Cave, Kentucky 42259

Dr. Norman R. Pace
Department of Biology
Jordan Hall, Room #138
Indiana University
Bloomington, Indiana 47405

Dr. Arthur N. Palmer
Department of Earth Sciences
State University College
Oneonta, New York 13820

Dr. Thomas L. Poulson
Department of Biological Sciences
Box 4348
University of Illinois
Chicago Circle, Illinois 60680

Dr. Rudolph Prins
Department of Biology
Western Kentucky University
Bowling Green, Kentucky 42101

Dr. James F. Quinlan, Jr. (3 copies)
Uplands Research Laboratory
P.O. Box 8
Mammoth Cave National Park
Mammoth Cave, Kentucky 42259

Mr. Joseph A. Ray
P.O. Box 293
Cave City, Kentucky 42127

Mr. Geary M. Schindel
Kentucky Division of Water
Fort Boone Plaza
18 Reilly Road
Frankfort, Kentucky 40601

Dr. Richard L. Whitman
Department of Biology
Indiana University Northwest
3400 Broadway
Gary, Indiana 46408

Mr. Ronald C. Wilson (3 copies)
1019 Maplewood Drive, #211
Cedar Falls, Iowa 50613

Mr. Richard B. Zopf
830 Xenia Avenue
Yellow Springs, Ohio 45387

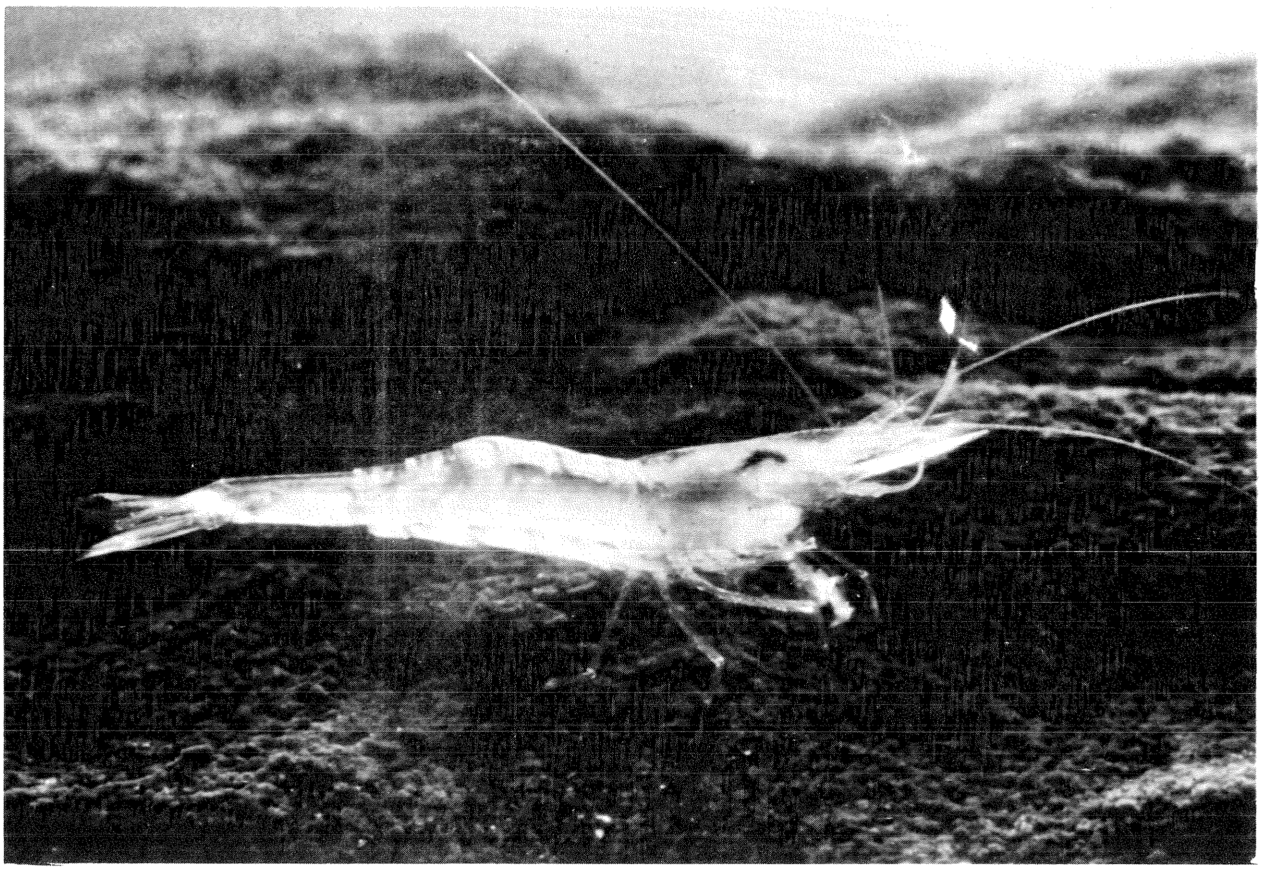


Figure 1. The Kentucky cave shrimp, Palaemonias ganteri Hay, Photograph by Chip Clark.

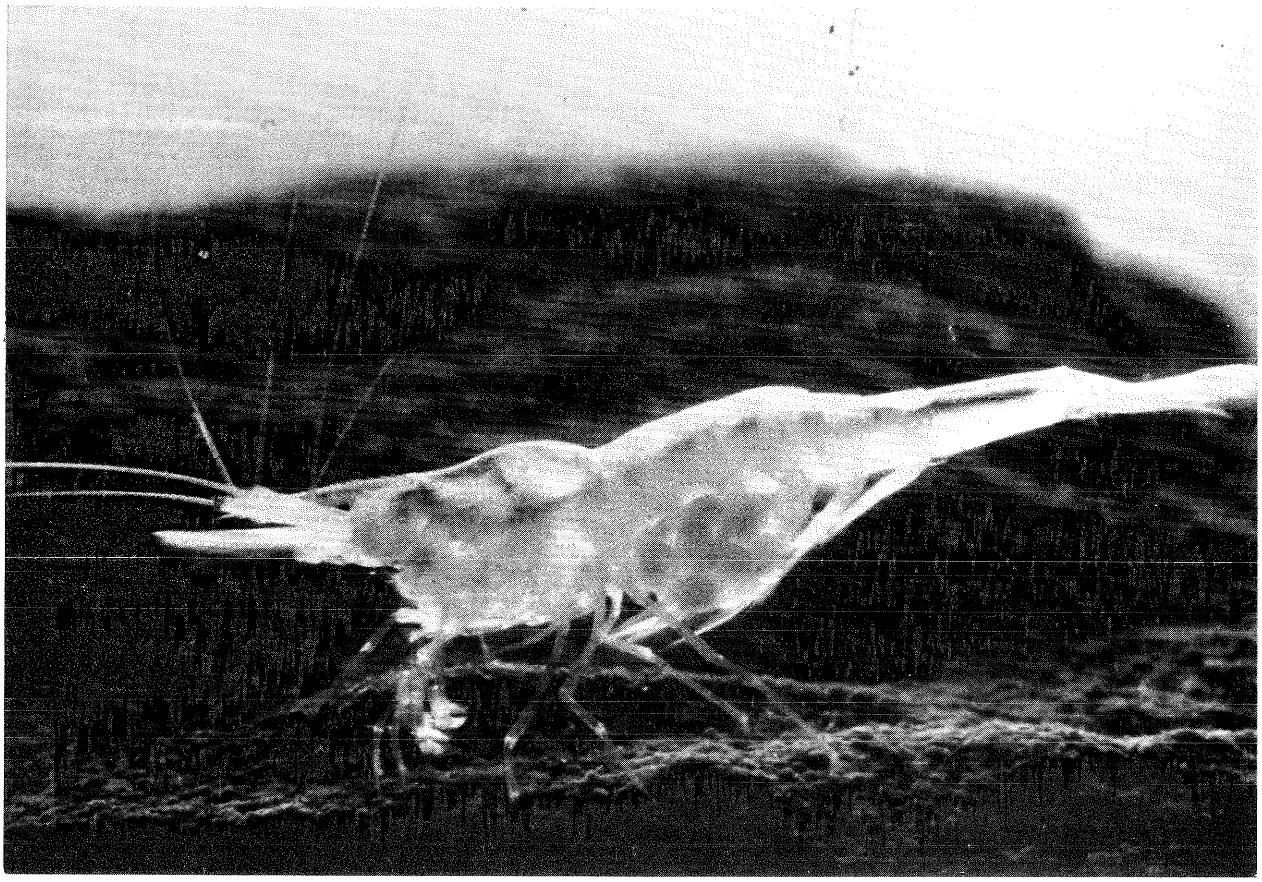


Figure 2. The Kentucky cave shrimp, Palaemonias ganteri Hay, showing developing oocytes at an early stage. Photograph by Chip Clark.

Figure 3. The Mammoth Cave region showing potentiometric surface, subsurface flow routes, and surface drainage. Figure 3 modified FROM: Quinlan and Ewers, 1981 (same as figure 3 IN: Quinlan et al. 1983).

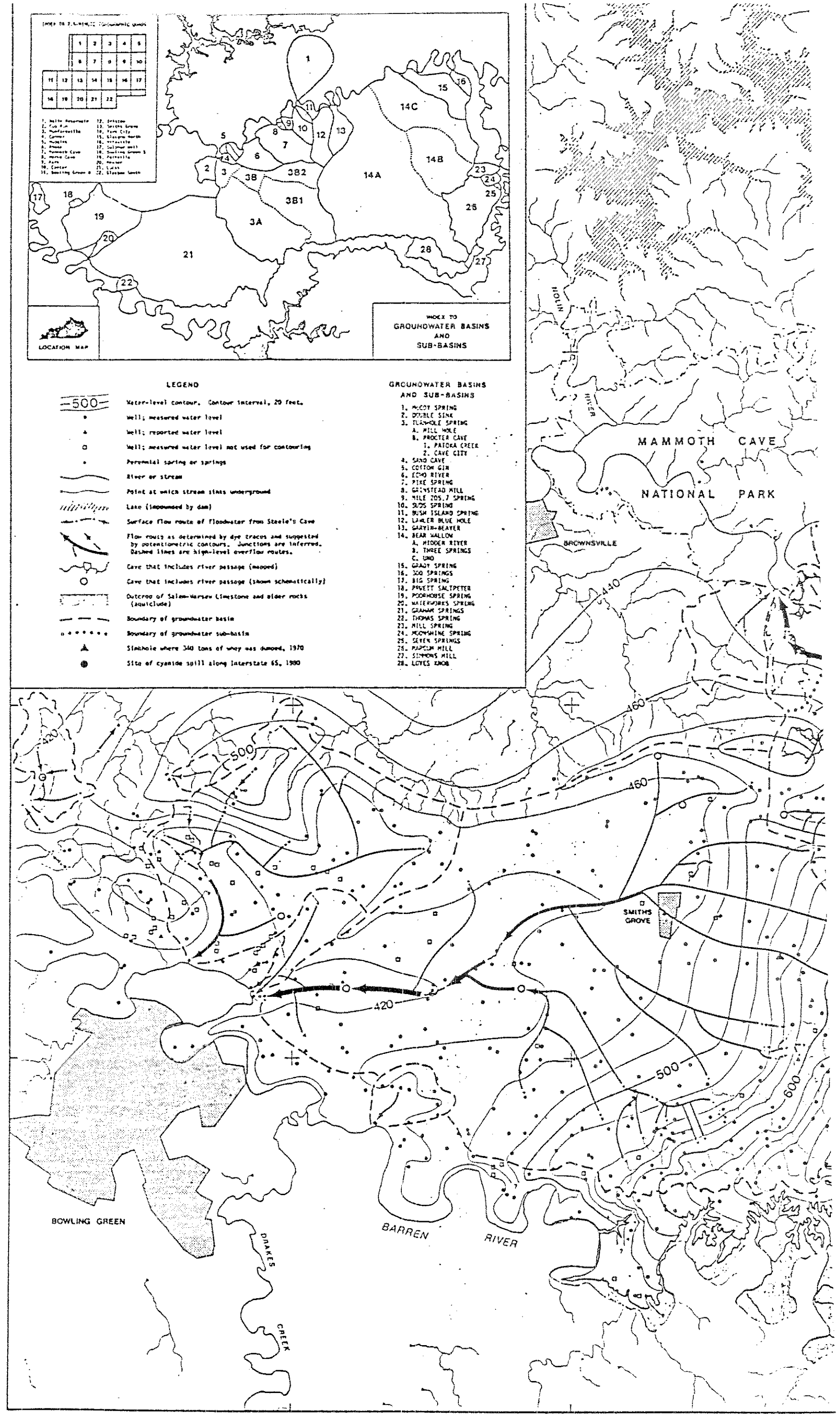
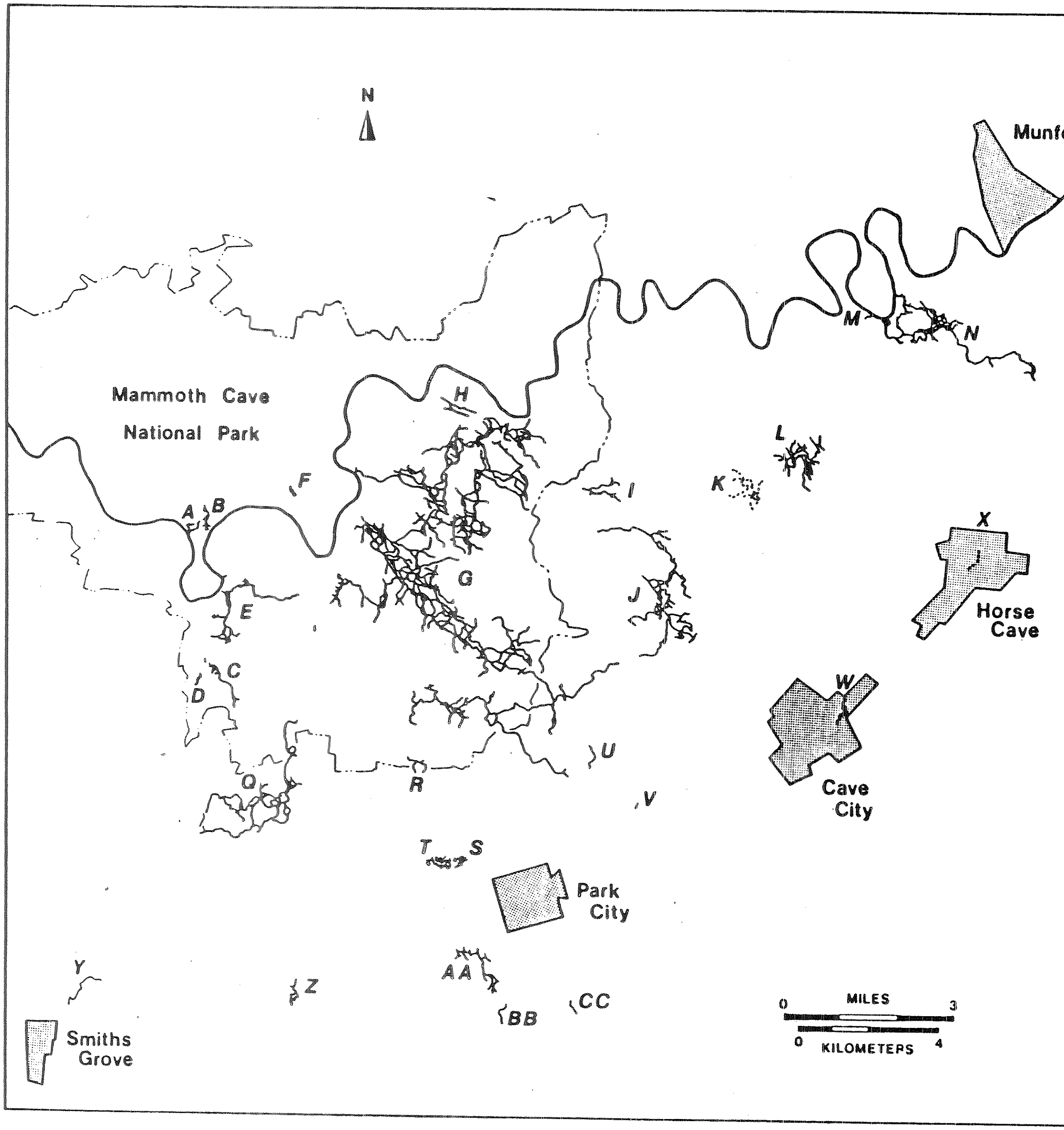

LOCATION MAP
INDEX TO GROUNDWATER BASINS AND SUB-BASINS
LEGEND
500
Water-level contour. Contour interval, 20 feet.
Well; measured water level
Well; reported water level
Well; measured water level not used for contouring
Perennial spring or springs
River or stream
Point at which stream sinks underground
Lake (impounded by dam)
Surface flow route of floodwater from Steele's Cave
Flow route as determined by dye traces and suggested by potentiometric contours. Junctions are inferred. Dashed lines are high-level overflow routes.
Cave that includes river passage (mapped)
Cave that includes river passage (shown schematically)
Outcrop of Salem-Warsaw Limestone and older rocks (aquiclude)
Boundary of groundwater basin
Boundary of groundwater sub-basin
Sinkhole where 340 tons of whey was dumped, 1970
Site of cyanide spill along Interstate 65, 1980
GROUNDWATER BASINS AND SUB-BASINS
1. McCOY SPRING
2. DOUBLE SINK
3. TURNHOLE SPRING
A. MILL HOLE
B. PROCTER CAVE
1. PATOKA CREEK
2. CAVE CITY
4. SAND CAVE
5. COTTON GIN
6. ECHO RIVER
7. PIKE SPRING
8. GRINSTEAD MILL
9. MILE 205.7 SPRING
10. SUDS SPRING
11. BUSH ISLAND SPRING
12. LAWLER BLUE HOLE
13. GARVIN-BEAVER
14. BEAR WALLOW
A. HIDDEN RIVER
B. THREE SPRINGS
C. UNO
15. GRADY SPRING
16. 300 SPRINGS
17. BIG SPRING
18. PRUETT SALTPETER
19. POORHOUSE SPRING
20. WATERWORKS SPRING
21. GRAHAM SPRINGS
22. THOMAS SPRING
23. MILL SPRING
24. MOONSHINE SPRING
25. SEVEN SPRINGS
26. MAPCUM MILL
27. SIMMONS MILL
28. LOVES KNOB
MAMMOTH CAVE
NATIONAL PARK
BROWNSVILLE
SMITHS GROVE
BOWLING GREEN
BARREN RIVER
DRAKES CREEK
420
440
460
500
600

Figure 4. Major caves in part of the Mammoth Cave region. Figure 7 modified FROM: Quinlan and Ewers, 1981 (same as Figure 7 IN: Quinlan et al. 1983).



MAJOR CAVES

NAME	MILES	KM	MAP COURTESY OF
A. BAT CAVE	1.1	1.8	NSTF
B. GANTER CAVE	1.9	3.0	NSTF
C. SMITH VALLEY CAVE	3.1	5.0	NSRSG
D. SOUTH CAVE	0.6	1.0	NSRSG
E. LEE CAVE	7.5	12.0	CRF
F. RUNNING BRANCH CAVE	0.8	1.2	NSTF
G. MAMMOTH CAVE (incl. Flint Ridge and Procter Caves)	225.	360.	CRF
H. GREAT ONYX CAVE	2.2	3.5	CRF
I. NORTHTOWN CAVE	2.5	4.0	NPS
J. ROPPEL CAVE	28.	45.	CKKC
K. FISHER RIDGE SYSTEM	4.1	6.6	A
L. CRUMP SPRING CAVE	10.6	17.0	JS
M. GARVIN CAVE	0.2	0.3	JH
N. HIDDEN RIVER COMPLEX	18.5	29.6	NPS, WKUKRT
O. GRADY'S CAVE	11.6	18.6	JS
P. BUCKNER SPRING CAVE	2.3	3.7	JS
Q. WHIGPISTLE CAVE	16.5	26.4	NPS
R. LONG CAVE	1.0	1.6	CRF
S. JAMES CAVE	8.2	13.1	GMA
T. COACH CAVE	3.3	5.3	GMA
U. INDIAN CAVE	0.6	1.0	GD
V. QUARRY CAVE	0.2	0.3	NPS
W. L & N CAVE	1.1	1.8	NPS, WKUKRT, GD
X. HIDDEN RIVER CAVE	-	-	Unmapped
Y. CRUMP CAVE	1.0	1.6	NPS
Z. EMERSON-GIFT HORSE	1.6	2.6	NPS, JB
AA. PARKER CAVE	5.5	8.8	NPS, WKUKRT
BB. PANDORA'S BOX	0.8	1.3	NPS, WKUKRT
CC. DEEP SINK	0.5	0.8	NPS, WKUKRT
TOTAL	360.1	576.1	

KEY TO MAP SOURCES: A--Anonymous, CKKC--Central Kentucky Karst Coalition, CRF--Cave Research Foundation, GD--George Deike, GMA--Glen Merrill and Associates, JB--Jim Borden, JH--Jack Hess, JS--Joe Saunders, NPS--National Park Service, NSRSF--Natural Sciences Resource Studies Group, NSTF--North Shore Task Force, WKUKRT--Western Kentucky University Karst Research Team. Not all mapped passages are shown.

Figure 4

Figure 5. Historically known distribution of the Kentucky cave shrimp, *Palaemonias ganteri* Hay. Modified FROM: Quinlan and Ray 1981.

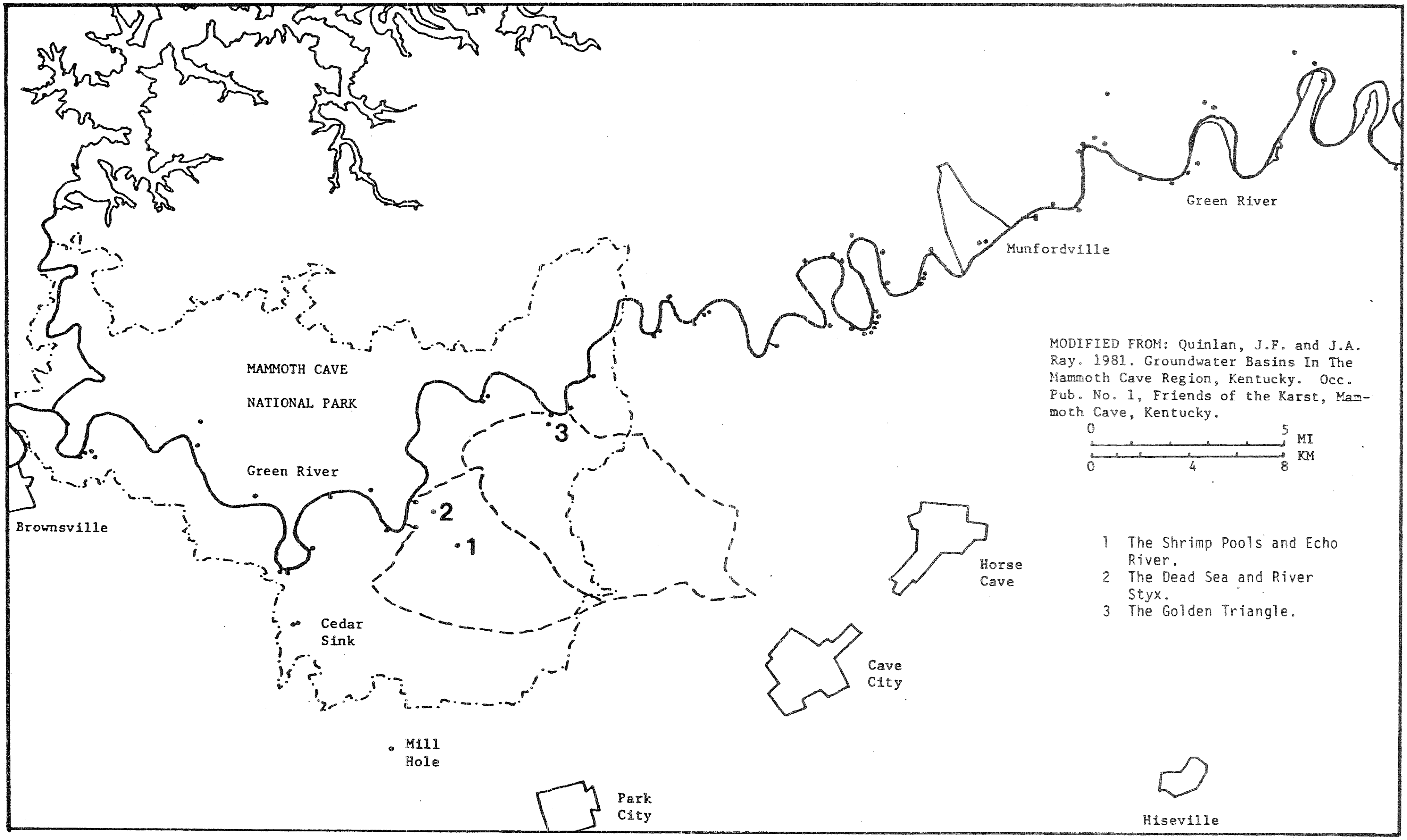
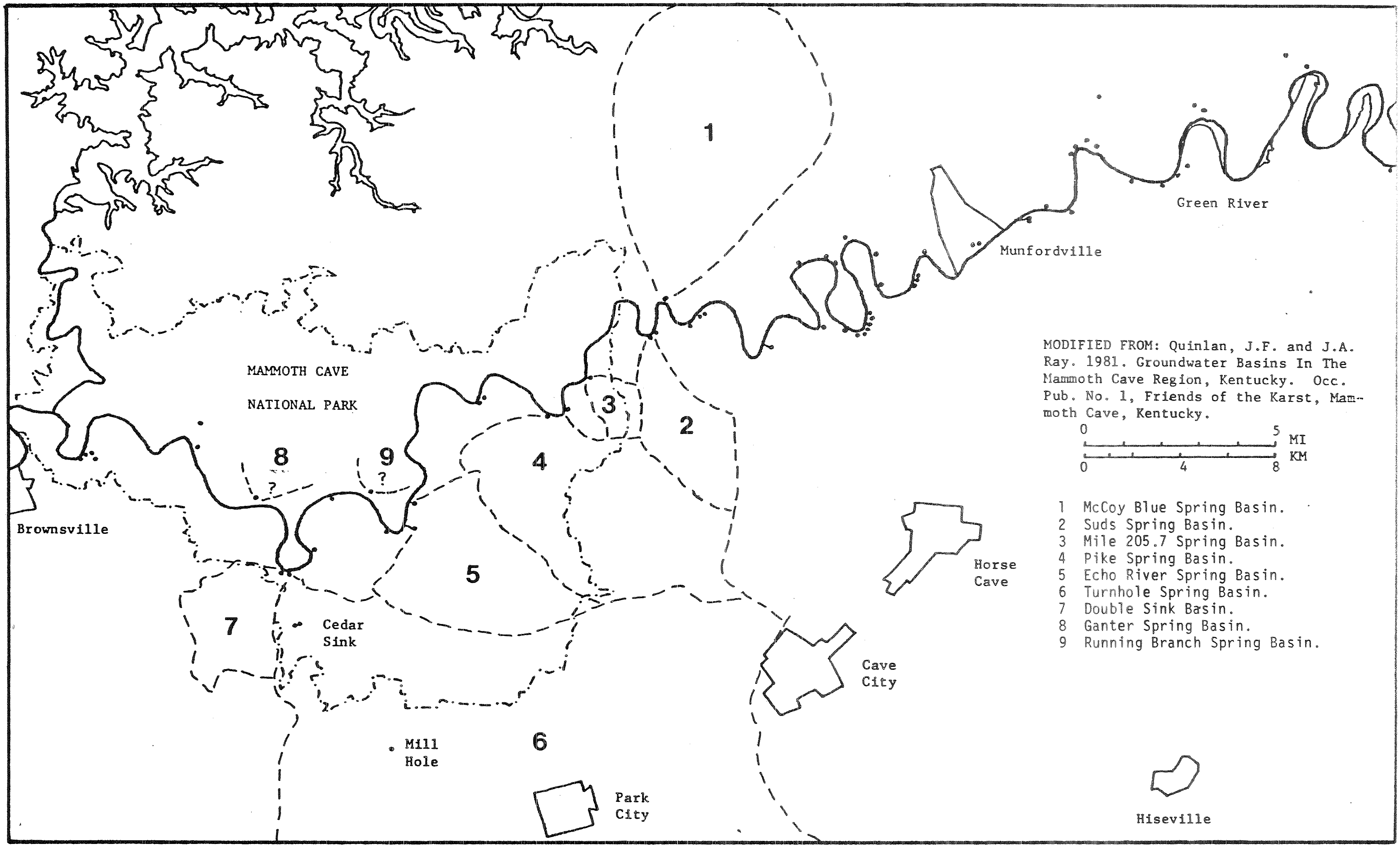

MAMMOTH CAVE
NATIONAL PARK
Green River
Green River
Munfordville
Brownsville
Cedar Sink
Mill Hole
Park City
Cave City
Horse Cave
Hiseville
1
2
3
MODIFIED FROM: Quinlan, J.F. and J.A. Ray. 1981. Groundwater Basins In The Mammoth Cave Region, Kentucky. Occ. Pub. No. 1, Friends of the Karst, Mammoth Cave, Kentucky.
0 5 MI
0 4 8 KM
1 The Shrimp Pools and Echo River.
2 The Dead Sea and River Styx.
3 The Golden Triangle.

Figure 5

Figure 6. Present known distribution of the Kentucky cave shrimp, *Palaemonias ganteri* Hay. Modified FROM: Quinlan and Ray 1981.

Figure 6


MAMMOTH CAVE
NATIONAL PARK
Brownsville
1
2
3
4
5
6
7
8
9
?
?
Cedar Sink
Mill Hole
Park City
Cave City
Horse Cave
Munfordville
Green River
Hiseville
MODIFIED FROM: Quinlan, J.F. and J.A. Ray. 1981. Groundwater Basins In The Mammoth Cave Region, Kentucky. Occ. Pub. No. 1, Friends of the Karst, Mammoth Cave, Kentucky.
0
5
MI
0
4
8
KM
1 McCoy Blue Spring Basin.
2 Suds Spring Basin.
3 Mile 205.7 Spring Basin.
4 Pike Spring Basin.
5 Echo River Spring Basin.
6 Turnhole Spring Basin.
7 Double Sink Basin.
8 Ganter Spring Basin.
9 Running Branch Spring Basin.