U.S. Fish & Wildlife Service

Recovery Plan for the Kauai Cave Arthropods

Kauai Cave Wolf Spider
(Adelocosa anops)
and the
Kauai Cave Amphipod
(Spelaeorchestia koloana)

Kauai Cave Wolf Spider used with permission of Bill Mull.

Kauai Cave Amphipod used with permission of Bill Mull.

RECOVERY PLAN FOR THE

KAUAI CAVE ARTHROPODS:

The Kauai Cave Wolf Spider (*Adelocosa anops*)

and the Kauai Cave Amphipod *(Spelaeorchestia koloana)*

Region 1
U.S. Fish and Wildlife Service
Portland, Oregon

Approved: David Wesley
Acting Regional Director, Region 1
U.S. Fish and Wildlife Service

Date: APR 28 2006

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Electronic copies of this recovery plan may be found at:

http://pacific.fws.gov/ecoservices/endangered/recovery/default.htm
http://endangered.fws.gov/recovery/index.html

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Executive Summary

Current Species Status: The Kauai cave wolf spider (*Adelocosa anops*) and the Kauai cave amphipod (*Spelaeorchestia koloana*) are obligate cave-dwelling arthropods restricted to the Hawaiian island of Kauai. They have only been found in the Koloa Basin of the island of Kauai where lava tubes and other cave bearing rock are present. Currently, the Kauai cave wolf spider, a predator, is only regularly encountered in a single cave where 16 to 28 individuals have been found during regular monitoring visits (U.S. Fish and Wildlife Service, unpublished data 1996 through 2005). During recent visits, the Kauai cave amphipod has been regularly observed in 3 caves, their numbers typically ranging from 8 to 40, but greater than 300 individuals have been encountered in 1 of these caves, likely in response to periodic food enhancement conducted by research biologists (U.S. Fish and Wildlife Service, unpublished data 1996 through 2005). No population estimates currently exist for these arthropods. Given the limited range of the spider, it is likely its population is extremely small and especially vulnerable. Since the Kauai cave amphipods have been found in caves scattered through the Koloa District, they likely have a considerably larger population and/or populations. The existence of amphipods in geographically separate areas, may make them less vulnerable than the Kauai cave wolf spider to catastrophic events that might impact a single cave. Urban and agricultural development as well as quarrying operations within the area threaten the habitat of these cave arthropods, and non-native species likely prey upon or compete with them for limited food resources. Human visitation and use of caves are potentially serious threats as is urban and commercial pesticide use and the use of bio-control agents. Extended drought may also threaten these species by altering the high-humidity environment to which these arthropods are adapted and facilitating invasion by non-native species.

Habitat Requirements and Limiting Factors: Both the Kauai cave wolf spider and the Kauai cave amphipod have low reproductive rates compared to their non-cave dwelling counterparts (Howarth 1981; Foelix 1982). Food is limiting in most cave systems and this appears to be true in the Koloa caves as well. These species likely live in inaccessible mesocaverns (voids and inaccessible passages) as well as large cave passages which means their populations are almost certainly greater than the numbers observed. However, few of the known caves in the Koloa District provide appropriate habitat for these arthropods which are typically only found in the Dark and Stagnant Air Zones (two of five cave zones typified by low air movement, elevated relative humidity, and reduced temperature fluctuations) of caves and require high humidity conditions (Bousfield and Howarth 1979; Hadley *et al.* 1981; Ahearn and Howarth 1982). The limited number of occupied caves greatly limits our knowledge of the life history requirements of these arthropods.

Given the cryptic nature of caves and the uncertain distribution of inaccessible mesocaverns, our knowledge of the distribution and population status of these two species is greatly limited.

Recovery Priority Number: The recovery priority number for both the Kauai cave wolf spider and Kauai Cave amphipod is 1, on a scale of 1C (highest) to 18 (lowest; see Appendix B) indicating a high degree of threat and high recovery potential.

Critical Habitat: On April 9, 2003, we (the U.S. Fish and Wildlife Service) designated critical habitat for the Kauai cave arthropods (U.S. Fish and Wildlife Service 2003a). The critical habitat designation consists of 14 units whose boundaries encompass an area of approximately 110 hectares (272 acres) on the island of Kauai, Hawaii.

Recovery Goal and Objectives: The ultimate goal of the recovery program is to restore and maintain multiple self-sustaining populations of these Kauai cave arthropods, which will allow them to be reclassified to threatened status and eventually removed from the Federal List of Endangered and Threatened Wildlife and Plants. To reach the recovery goal, the target objectives are: (1) stabilize and increase self-sustaining populations of the Kauai cave arthropods throughout their range; (2) ensure the protection and conservation of quality habitat; and (3) reduce and/or eliminate impacts from known threats.

Recovery Criteria: The criteria outlined in this recovery plan provide for maintenance of the majority of the genetic diversity of the Kauai cave arthropods and provides assurance that a catastrophic event will not reduce population viability of the Kauai cave arthropods.

The species can be considered for downlisting to threatened status when nine populations, spread across the known range are shown to be: (1) self-sustaining populations (contain representatives of all generations, sexes, and age classes over a sustained period of time); (2) stable or increasing (intrinsic growth rate (λ) is greater than or equal to 1) over a monitoring period of at least 10 consecutive years; (3) protected from non-native/predatory species, human visitation to caves, bio-control agents, pesticides, development, or other damaging land uses; and (4) with the habitat being utilized in a fashion consistent with conservation (protecting cave habitat from future development, preventing disturbance to cave interiors via gating, and protecting and/or restoring the vegetation which lies over the cave).

Delisting of both species may be considered when 12 populations, spread across the known range, are shown to be: (1) self-sustaining; (2) stable or increasing (intrinsic growth rate (λ) is greater than or equal to 1) over a monitoring period of at least 10 consecutive years; (3) protected from non-native/predatory species, human visitation to caves, bio-control agents, pesticides, development, or other damaging land uses; and (4) with the habitat being utilized in a fashion consistent with conservation.

A post-delisting monitoring plan and agreement to continue post-delisting monitoring must be in place at the time of delisting. Monitoring populations following delisting will verify the ongoing recovery and conservation of the species and provide a means of assessing the continuing effectiveness of management actions.

Actions Needed:

1. Protect known populations of the Kauai cave wolf spider and cave amphipod and their subterranean habitats from human-caused destruction or degradation.

2. Improve or enhance the habitat of occupied and previously occupied caves through landscaping measures that are likely to increase subterranean food resources.

3. Conduct research to address essential conservation needs for the species, including non-damaging mark recapture studies, surveys for additional occupied habitat or restorable cave habitat, the potential for translocation of animals, and discovery and protection of occupied caves or caves with suitable habitat.

4. Conduct public outreach to facilitate better public understanding of and support for conservation of these cave arthropods.

5. Validate recovery objectives.

6. Develop and implement a post-delisting monitoring plan as necessary.

Estimated Cost of Recovery Actions: The estimated cost of recovering the Kauai cave arthropods is $3,445,000.

Date of Recovery: Because recovery objectives and criteria are defined in terms of long-term population stability, reestablishing or locating new populations of the Kauai cave arthropods, and controlling threats, we anticipate that it will take considerable time and effort to recover these species. Therefore, we expect that recovery will take approximately 30 years and the estimated recovery date is the year 2036.

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A. BRIEF OVERVIEW

The Kauai cave wolf spider (*Adelocosa anops*) and the Kauai cave amphipod (Spelaeorchestia koloana) (collectively the Kauai cave arthropods) represent monotypic genera, both of which are only known from caves, subterranean cracks, and mesocaverns (voids and inaccessible passages) of the Koloa Volcanic Series on the island of Kauai, Hawaii (Figure 1) (Bousfield and Howarth 1976). The cave amphipod is a detritivore, feeding on plant material, especially roots that penetrate into the caves, while the cave wolf spider is a predator which feeds opportunistically on other cave inhabitants, including the cave amphipod (Howarth 1983). As with other obligate cave-dwelling species, the Kauai cave arthropods are restricted to specific habitats or zones within subterranean habitats.

We, the U.S. Fish and Wildlife Service, listed both the Kauai cave arthropods as endangered species on January 14, 2000 (U.S. Fish and Wildlife Service 2000a) and designated critical habitat for both arthropods on April 9, 2003 (U.S. Fish and Wildlife Service 2003a). Recovery priority numbers ranging from 1C to 18 (1C being highest priority) are assigned to each listed species based on degree of threat, recovery potential, taxonomic status, and conflict with human activites (U.S. Fish and Wildlife Service 1983a, b; Appendix B). Recovery priority numbers with a letter designation of “C” indicate conflict with human economic activity. Both species’ recovery priority number is 1, indicating a high degree of threat, a high recovery potential, and their taxonomic status as a monotypic genera which is given a higher priority than a species or subspecies.

The Koloa Series Lava Flows (Lagenheim and Clague 1987) represent the most recent volcanic activity on the island of Kauai, with the youngest rocks dating to about 600,000 years before present (Macdonald *et al.* 1960). Lava tube systems throughout most of the island are far older than those of the Koloa Series, most caves having long since collapsed or filled with sediments (Howarth 1981).

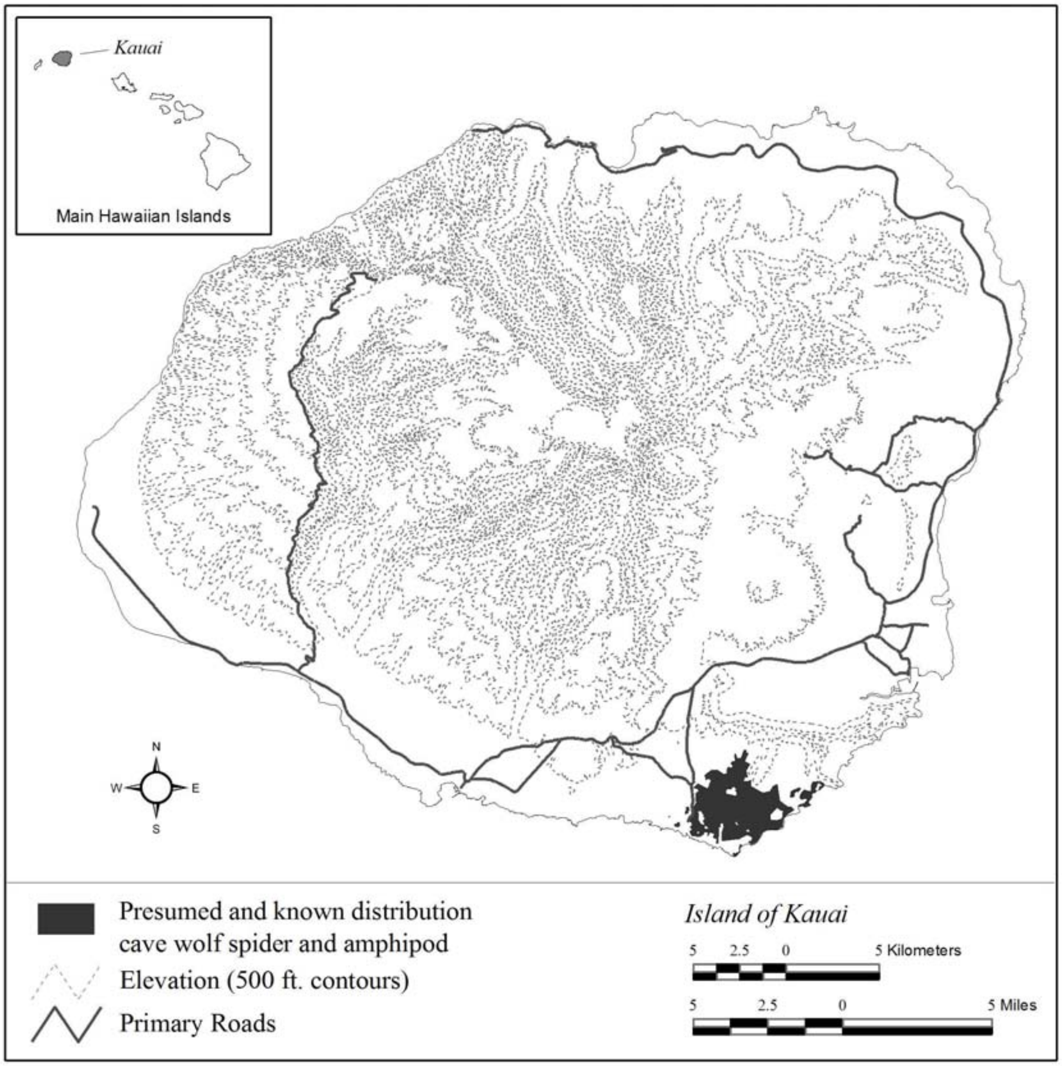

Figure 1. Island of Kauai.
Presumed or known distribution of the Kauai cave wolf spider and Kauai cave amphipod.

Therefore, these unique species are restricted to a relatively small area of Kauai Island within the Koloa District (Figure 2) (Howarth 1981).

Although many caves in the Koloa District have been surveyed, most do not contain the optimal climatological conditions required by cave-dwelling organisms, including the Kauai cave arthropods. Of the caves surveyed to date, the cave wolf spider has only been documented to occur in five caves, and currently is only observed regularly in one of these caves. The cave amphipod has been documented to occur in nine caves, and is currently observed regularly

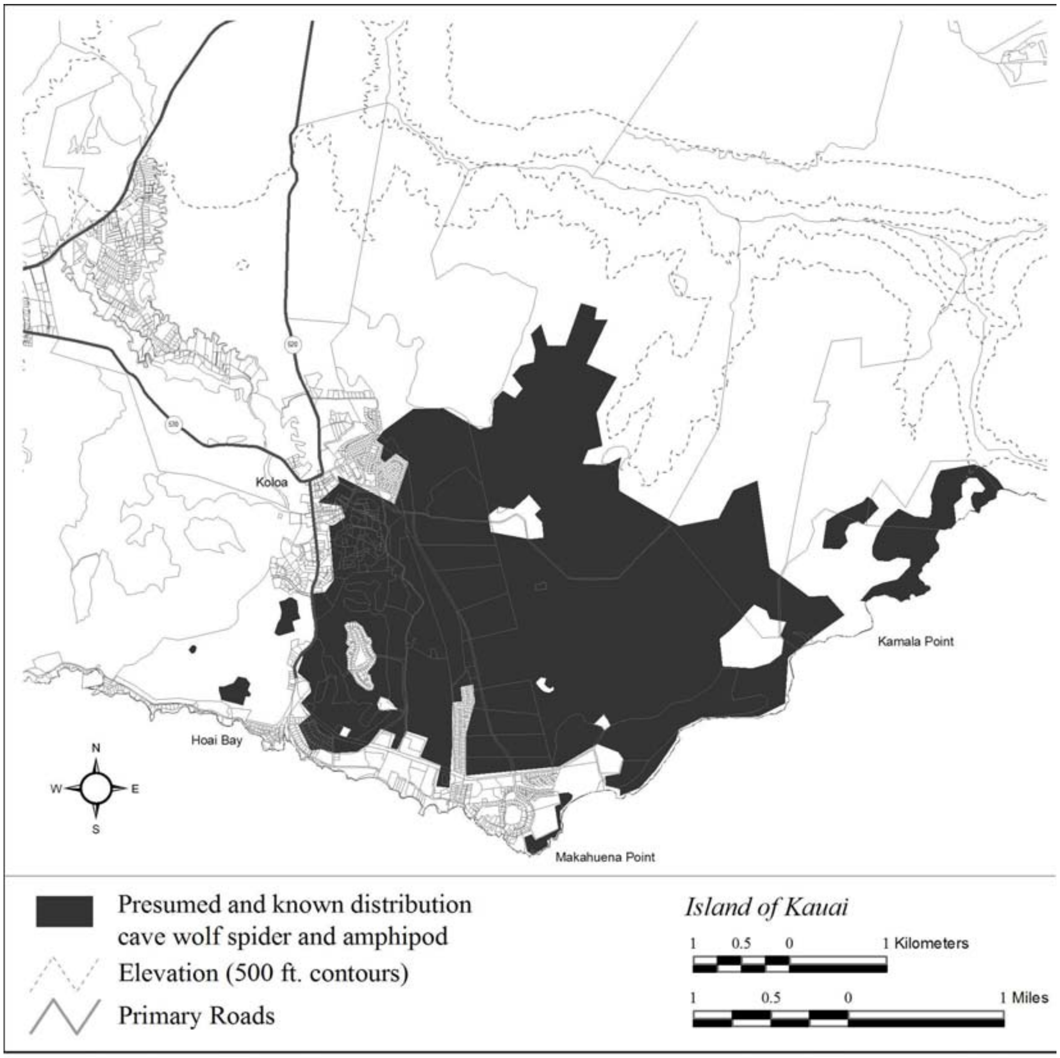

Figure 2. Presumed and known distribution of the Kauai cave wolf spider and amphipod.

in three of these caves. Due in part to sampling regimes, only two of these caves contain “sizable” or regularly observed self-sustaining populations of amphipods. Other organisms frequently co-inhabit these caves. The endemic Hawaii cave isopod (*Hawaiioscia parvituberculata*) is occasionally observed, as are a number of non-native (alien) arthropods that are facultative cave-dwellers (“troglophiles”; *e.g.*, American cockroach (*Periplaneta americana*), brown violin spider (*Loxosceles rufescens*), and the spitting spider (*Scytodes longipes*) (U.S. Fish and Wildlife Service, unpublished data 1996 through 2005)).

Since Polynesian and European arrival, the Koloa District has undergone drastic and rapid change (Cuddihy and Stone 1990). Palaeontological finds indicate, prior to Polynesian colonization, the area supported vegetation indicative of a wide range of habitats (xeric to mesic) (Burney *et al.* 2001), but human alteration of the landscape, typically with the use of fire for agricultural purposes, led to the removal of native vegetation (Cuddihy and Stone 1990). With European colonization, the rate of habitat destruction increased as new agricultural crops and practices were established (*e.g*., sugar cane cultivation, ranching). In addition, numerous non-native, invasive plants readily colonized these areas, contributing to alteration of the above-ground habitats (Howarth 1981). European agricultural practices, including burning of cane and over-grazing by goats and cattle, greatly accelerated the rates of erosion and soil loss (Cuddihy and Stone 1990; Burney *et al.* 2001). Sedimentation as well as intentional filling of caves has likely contributed to habitat loss for these and other cave-dwelling organisms (Bousfield and Howarth 1976; Berger *et al.* 1981; Howarth and Stone 1993).

Modern development of the Koloa District is not restricted to areas suitable for agriculture (*i.e.*, well developed soils). Continued development for housing and tourism also occurs in rocky areas originally spared by earlier agricultural development, leading to the potential destruction of the remaining cave habitat (caves, subterranean cracks, and mesocaverns) in the area. While development is currently one of the most serious threats to the habitat of these arthropods, cave habitat is also vulnerable to alteration from increased human entry and vandalism (Howarth 1982; Culver 1992; D. Hopper, U.S. Fish and Wildlife Service, *in litt*.1999a; Culver *et al*. 2000), pesticides, and non-native, invasive wildlife species, most of which either compete with the endangered cave species for food resources or directly prey on them (Howarth 1973; A. Asquith, U.S. Fish and Wildlife Service, *in litt*. 1994a; D. Hopper, U. S. Fish and Wildlife Service, *in litt*. 1999b).

B. DESCRIPTION AND TAXONOMY

1. Kauai Cave Wolf Spider

The Kauai cave wolf spider (*Adelocosa anops*) is a member of the wolf spider family, Lycosidae. Spiders in this family have a world-wide distribution and are characterized by a distinctive eye pattern, including two particularly large eyes located within the middle row of eyes (Foelix 1982). While wolf spiders are typically visual predators, the most conspicuous physical character of the Kauai cave spider is its complete lack of eyes (Figure 3). This character is unique among wolf spiders and, in part, provides justification for the recognition of a separate genus for this taxon (Gertsch 1973). Other species of wolf spider have reduced eyes, including another cave-adapted species on the island of Hawaii, but the Kauai cave wolf spider is the only lycosid in which the eyes are entirely absent. Adults of the Kauai cave wolf spider are about 12.7 to 19.0 millimeters (0.5 to 0.75 inches) in total body length with a reddish-brown carapace, pale to silvery abdomen, and beige to pale orange legs.

The hind margin of each chelicera (biting jaw) bears three large teeth, two situated basally (on the bottom), and the third at the distal (far) end of the chelicera. The tibiae (the fifth segment of the leg) of the two anterior pairs of legs have four pairs of ventral spines, and the tarsi (ultimate segments) and metatarsi (mid-leg segment) of all legs bear unusually long, silky, and shiny trichobothria (sensory hairs). Dr. Frank Howarth of the Bishop Museum first discovered the Kauai cave wolf spider in Koloa in 1971, and it was formally described by Willis Gertsch of the Bishop Museum (Gertsch 1973).

2. Kauai Cave Amphipod

The Kauai cave amphipod (*Spelaeorchestia koloana*) (Figure 4) was discovered in some of the same caves as the Kauai cave wolf spider in 1971 (Bousfield and Howarth 1976). Because of the unusual attributes of a highly reduced pincher-like condition of the first gnathopod (thoracic appendage) and the second gnathopod being mitten-like in both sexes, this taxon is placed in

Figure 3. Kauai cave wolf spider with egg case; used with permission of Gordon Smith.

Figure 4. Kauai cave amphipod; used with permission of Bill Mull.

its own unique genus (*Spelaeorchestia*) within the family Talitridae (Bousfield and Howarth 1976). This species is also distinctive in its lack of eye facets, lack of pigmentation, and extremely elongate, spiny, post-cephalic appendages. Adult cave amphipods are 7 to 10 millimeters (0.25 to 0.4 inches) in length with a slender, laterally compressed body and a hyaline cuticle, giving it a shiny, translucent appearance. The second pair of antenna are slender and elongate, with the flagellum (terminal antennal segments) only slightly longer than the peduncle (proximal antennal segments). Peraeopods (abdominal walking legs) are very elongate, with slender, tapering claws. All pleopods (swimming legs) are reduced, with branches vestigial or lacking. Uropods (tail plates or appendages) 1 and 2 have well-developed stocks, and brood plates in the mature female are vestigial or entirely absent (Bousfield and Howarth 1976).

C. LIFE HISTORY

1. Kauai Cave Wolf Spider

Unlike most spiders, wolf spiders do not hunt with the use of a web, relying on their sensory structures, camouflage, stealth, and swiftness to capture prey. The Kauai cave wolf spider may either stalk its prey or utilize sit-and-wait ambush tactics (Howarth 1981). Lacking eyes, it is believed vibration as well as tactile and chemosensory cues are of primary importance in prey detection and capture. While the cave wolf spider will likely consume the endemic cave amphipod, as with most species of spider it will prey on virtually any other cave inhabitant it can capture and kill, including alien spiders.

The cave wolf spider has a very low rate of reproduction when compared to terrestrial wolf spiders of similar size (Howarth 1981; Foelix 1982). Howarth (in Gertsch 1973) reported a female with an egg sac containing 14 spiderlings and it is believed that 30 offspring or fewer are produced per brood (Howarth 1981; Wells *et al*. 1983); this is far less than the clutch size exhibited by most terrestrial wolf spiders which may have 100 to 300 spiderlings per brood. Based on captured individuals, it is estimated this species takes up to a year to reach sexual maturity (Howarth 1981). Similar K-reproductive strategies (low reproductive rate; high investment in off-spring; long period to maturity for off-spring) are observed in other cave-dwelling species (Howarth 1981).

2. Kauai Cave Amphipod

The Kauai cave amphipod is a detritivore and has been observed feeding on the roots of *Pithecellobium dulce* (Manila tamarind) and *Ficus* sp. (fig), rotting roots, sticks, branches, and other plant material washed into, or otherwise carried into caves, as well as the fecal material of other arthropods. While some of this woody material is derived from root masses of plants, some has been intentionally provided by researchers as a food source for the amphipods and other cave arthropods, since root systems are now greatly reduced or absent from some caves. In one of the known occupied caves, woody material is periodically washed in via a perennial stream. Amphipods and other cave detritivores (*e.g.*, isopods, millipedes) are often numerous around decomposing woody material on the cave floor. When disturbed, the Kauai cave amphipod typically moves slowly away from the disturbance rather than jumping like other amphipods.

Nothing is known of the reproductive biology of this amphipod. It is thought that the cave amphipod has a low reproductive rate. Although it is not known how many offsprings are produced per brood, the presence of a vestigial brood plate or the complete lack of a brood plate suggests that a small number of large-sized offsprings are produced (Poulson and White 1969; Bousfield and Howarth 1976).

3. Kauai Cave Arthropods

As with other obligate cave-dwelling arthropods, the Kauai cave arthropods are largely restricted to the “Dark Zone” (see section D below for a description) of caves, subterranean cracks, and mesocaverns with limited air flow. However, they can occasionally be found where daily external climatic changes still influence the cave microhabitat (*i.e.*, “Transition Zone”) as long as there is no surface light penetration. The occupied microclimates within caves, subterranean cracks, and mesocaverns of the Koloa District are relatively constant, with temperatures ranging from 23 to 26 degrees Celsius (73 to 78 degrees Fahrenheit) and high relative humidity (typically at or near 100 percent) (Bousfield and Howarth 1976; U.S. Fish and Wildlife Service, unpublished data 1998). Such micro-climatic conditions appear to be necessary for survival, or are preferred by these arthropods and other Hawaiian cave-dwelling species (Hadley *et al.* 1981; Ahearn and Howarth 1982). Howarth has shown that these arthropods occupy the mesocaverns in the surrounding rocky substrate and will readily enter larger passages, where they may be observed, when microclimate conditions in the larger passages become favorable (Howarth 1983).

Like other cave-dwelling organisms, the Kauai cave arthropods exhibit behaviors that suggest reduced metabolism relative to related above-ground taxa. This is apparent both in the spider's outward behavior as well as their rate of oxygen consumption (Hadley *et al*. 1981). As observed within its cave environment, the Kauai cave wolf spider does not expend large amounts of effort moving quickly through the cave environment as does its close epigean (surface-dwelling) relatives. While epigean wolf spiders are extremely active and swift-moving, the Kauai cave wolf spider spends long periods waiting motionless or moving slowly and deliberately over the cave floor. If disturbed, the spider may run for a short distance, but quickly stops and returns to its normal slow pace or again becomes motionless. Similarly, the Kauai cave amphipod is slow moving relative to other marine or terrestrial amphipods.

Both Howarth (1983) and Huppop (1985) have postulated that cave-dwelling species, such as the Kauai cave arthropods, may be adapted to cope with low levels of oxygen and/or elevated concentrations of carbon dioxide (see section D). The ability to survive and thrive under these conditions has been confirmed by field observations in known Stagnant Air Zones (see section D below) (Howarth and Stone 1990) as well as under controlled laboratory experiments. Hadley *et al.* (1981) conducted experiments with Hawaiian wolf spiders, the cave-dwelling species (*Lycosa howarthi*), and a related surface-dwelling species (*Lycosa* sp.). These researchers found the surface-inhabiting spider had a higher metabolic rate, requiring 2.5 times more oxygen than did its cave-dwelling relative. The reduced need for oxygen better allows these spiders to survive in Stagnant Air Zones. Given the ability of at least some cave-dwelling species to cope with reduced oxygen and elevated carbon dioxide, as well as their ability to inhabit mesocaverns, it seems likely many cave-dwelling species are able to reside in areas not readily surveyed by biologists. Hence, cave animal habitats typically extend well beyond surveyable passages and connect other large caverns and passages either accessible or inaccessible to researchers (Howarth 1983).

Both the Kauai cave wolf spider and amphipod are sensitive to habitat climatic conditions. They, as well as other cave-dwelling species, require a habitat with high ambient humidity or they quickly die of dessication (Barr 1968; Ahearn and Howarth 1982; Howarth and Stone 1990). Caves lacking high humidity conditions do not typically contain cave-dwelling species in Hawaii or elsewhere (Howarth 1983). For this reason, Hawaiian caves with even small amounts of air-flow typically lack cave-dwelling animals since air circulation usually reduces ambient humidity levels. In addition, caves with reduced humidity appear to be far more prone to invasion by alien cave-dwelling species. On Kauai, the alien cave-dwelling brown violin spider has been observed to become a dominant member in caves where conditions appear to be sub-optimal (*i.e.*, reduced relative humidity) for native cave-dwelling animals (see sections D and F) (U.S. Fish and Wildlife Service, unpublished data 1998).

D. HABITAT DESCRIPTION

1. The Koloa Basin of Kauai

Caves currently known to be occupied by the Kauai cave wolf spider and amphipod include both lava tubes and subterranean passages in up-raised, calcareous marine deposits (limestone and beachstone). The lava tubes and mesocaverns within the local basalt flows were formed by the Koloa Series Volcanic eruptions that occurred between 600,000 years and 1.5 million years ago (Macdonald *et al.* 1960; Langenheim and Clague 1987). In addition to these lava tubes, there are a number of calcareous geologic features (*i.e.*, up-raised marine deposits, limestone) present along portions of the southeastern coast of Kauai which lie adjacent to the Koloa Volcanic flows. Like the volcanic cave-bearing rock in the area, the calcareous cave-bearing rock also contains inaccessible mesocaverns and passages that provide habitat for cave-dwelling animals (Howarth 1991). It is likely the Kauai cave wolf spider and cave amphipod invaded younger limestone formations from adjacent, older lava tubes (Bousfield and Howarth 1976).

Although the Koloa Volcanics cover large portions of western Kauai, the flows of the Koloa Basin represent the youngest of those flows. Lava tubes are not common in the north and east-central portion of Kauai. This is attributable to the greater age of the flows (*i.e*., more developed soils) and weather patterns that keep these portions of the island wetter. These factors have resulted in the sedimentation and filling of older lava tubes. In contrast, the Koloa Basin lies in the rain shadow of Haupu Ridge and is much drier. Compared to the older flows of the Koloa Series to the north, soil development in the Koloa Basin has been poor. The Waikomo-Kalihi-Koloa soil association, which covers most of the Koloa Basin, is shallow, rarely exceeding 1 meter (3 feet 3 inches) (Foote *et al*. 1972). These factors have contributed to a relatively high density of lava tubes persisting in the area.

2. Cave Zonation

Howarth (1991) divided cave habitats into five distinct zones. These are: (1) the Entrance Zone, where light penetration is high and surface vegetation is typically present; (2) Twilight Zone, which extends from the point where vegetation ends to where light no longer penetrates; (3) Transition Zone, where there is no light penetrance, but where daily external climatic changes still influence the cave microhabitat; (4) Dark Zone, which maintains its own microhabitat with little influence by surface air temperatures; and (5) Stagnant Air Zone, an area similar to the Dark Zone, but where air circulation is extremely low, oxygen influx from the surface is limited, and the ambient gas composition is primarily controlled by *in situ* decomposition of organic material (Howarth and Stone 1990; Howarth 1991). Cave-dwelling animals are typically found within and are most strongly associated with the Dark and Stagnant Air Zones.

Both the Dark and Stagnant Air Zones are characterized by low air movement which results in reduced temperature fluctuations and elevated relative humidity. Typically, this is the result of a particular cave section being a “dead end" passage and/or having internal geologic features, shapes, or orientation that greatly reduce air flow, such as a low ceiling(s), collapsed ceiling, or small squeeze passage(s). Under such conditions, water vapor may be trapped, creating conditions of high relative humidity. In some cases, the Dark Zone may have elevated carbon dioxide concentrations. The Stagnant Air Zone, or "bad-air" zone, is found either deep in a dead end passage or is otherwise largely isolated from passages that readily connect with the other cave zones. In the Stagnant Air Zone, high carbon dioxide and reduced oxygen concentrations prevent most facultative cave-inhabiting species or troglophiles (can generally live places other than caves) from colonizing these areas, but these conditions are apparently preferred by most cave-dwelling species (only found in caves) such as the Kauai cave arthropods (Howarth and Stone 1990). Both the Transition Zone and even the Twilight Zone may occasionally contain cave-dwelling species, but this is rare. Some cave-inhabiting species may share portions of the Dark and Stagnant Air Zones with cave-dwelling species, but are typically far less abundant in these two zones (Howarth and Stone 1990). The reduced abundance or absence of non-native (alien) predators (see section F on Threats), suggests alien predators may be poorly adapted to the Dark Zone (U.S. Fish and Wildlife Service, unpublished data 2000). This hypothesis deserves further research and, if substantiated, could contribute to conservation efforts for the endangered fauna (see section G). Barriers could be built to allow the air to remain still and saturated with water vapor, allow the substrate to remain moist, and allow the potential evaporation rate to be negligible.

The trophic organization of caves is much different than surface communities (caves are typically regarded as food-limited). Terrestrial ecosystems rely on photosynthesizing plants to provide a foundation for the upper trophic levels of the food web. Deep caves lack plants and typically rely on nutrient input from surface environments. Nutrient import in many mainland cave systems comes from the use of cavern spaces by trogloxenic species (temporary cave visitors), such as roosting bats. These trogloxenes provide a food base which is derived from surface foraging areas and deposited in roosting caves in the form of guano (Culver 1986). These nutrient sources serve as growing media for nonphotosynthetic chemotrophs (an organism that oxidises such compounds as hydrogen sulfide to obtain energy; the organism does not use light to produce food) such as fungi and bacteria which, in turn, serve as a food source for other obligate cave animals, fulfilling a similar role as do plants in surface ecosystems. Other cave systems rely almost entirely upon plant and detrital debris being washed into the cave by surface water, which then provides a food base for animals living within the cave (Barr 1968; Howarth 1983; Culver *et al.* 2000).

Hawaiian caves lack trogloxenic organisms in numbers sufficient to provide an adequate food base, relying instead on the penetrating roots of surface plants which are then grazed upon by cave-inhabiting species. For this reason, Hawaiian cave habitats must be close enough to terrestrial plant communities to provide sufficient quantities of root biomass in order to support healthy cave-inhabiting communities. This requirement means that woody, long-lived plants need to be present over the cave to ensure a dependable food supply is available. While some food import can occur from organic and detrital material being washed into caves, this is a relatively uncommon scenario in Hawaiian cave ecosystems.

The majority of caves in the Koloa District known to regularly contain one or both of the Kauai cave arthropods, are shallow (*i.e.*, near surface) lava tubes that contain Dark Zone habitats with relatively warm, constant temperatures, and high relative humidity. The Koloa District is unique in that it is one of the few places in Hawaii where limestone or karst geologic features occur as deep deposits, capable of forming extensive subterranean habitats.

Due to a number of factors, both anthropogenic and natural (*e.g.*, degradation of caves due to geologic processes; see section E), only three caves (which currently regularly support cave arthropods [U.S. Fish and Wildlife Service, unpublished data 1996 through 2005]) with Dark Zone attributes are known to exist, on the island of Kauai. Anthropogenic factors have greatly accelerated the rate of natural habitat degradation, range constriction, and fragmentation (see section F).

E. CURRENT AND HISTORIC RANGE AND POPULATION STATUS

The Kauai cave wolf spider and Kauai cave amphipod represent monotypic genera, both of which are only known from caves, subterranean cracks, and mesocaverns throughout the Koloa Volcanic Series on the island of Kauai, Hawaii. Since its discovery in 1971, the Kauai cave wolf spider has been reported from five caves distributed across the Koloa Volcanic Series. These caves have been named: Koloa Cave 1, Koloa Cave 2, Kiahuna Mauka Cave, Kiahuna Makai Cave, and the Quarry Cave. Since its discovery in 1971, the Kauai cave amphipod has been reported from nine caves. These caves consist of: Koloa Cave 1, Koloa Cave 2, Kiahuna Mauka Cave, Kiahuna Makai Cave, Quarry Cave, By-Pass Cave, Cave 1927C, Cave 3179, and Saint Rafael Church Cave.

1. The Kauai Cave Wolf Spider

Currently, the Kauai cave wolf spider is only known to regularly occupy a single cave system, referred to here as Koloa Cave 2 located in the southwest corner of the range of the cave arthropods. Since annual to biannual monitoring first began in 1996, this cave has routinely contained 16 to 28 spiders per monitoring visit (U.S. Fish and Wildlife Service, unpublished data 1996 through 2005). Both sub-adult and adult spiders are regularly observed and females with egg sacs are occasionally seen. Recently (November 2005) new-born spiders were observed in Koloa Cave 2 and, for the first time, photo-documented (Figure 5). These observations suggest this cave and the surrounding cave-bearing rock contains a healthy breeding population of cave wolf spiders. In an adjacent cave (Koloa Cave 1), about 200 to 300 meters (260 to 390 feet) away, there is only a single record from 1998 of an adult cave wolf spider being present (U.S. Fish and Wildlife Service, unpublished data 1996 through 2000, 2002, 2005). This is likely due to the drier conditions of the latter cave. Koloa Caves 1 and 2 are lava tubes that parallel one another and which are likely connected by small mesocaverns inaccessible to humans.

Prior to an April 2000 visit, a small, but persistent population of cave wolf spiders was known to be present in a third cave, Kiahuna Makai (Makai: coastal,

Figure 5. Kauai cave wolf spider with new-born spiders; used with permission of Gordon Smith.

in reference to down-slope of the mountainous interior) Cave, located in the middle portion of the range of the cave arthropods. Annual to biannual monitoring visits have been conducted from 1998 through 2004. One to four individuals have been observed per visit through October of 1999, after which no wolf spiders have been observed in this cave (U.S. Fish and Wildlife Service, unpublished data 1998 through 2004). Providing a reason for the decline or disappearance of the wolf spider can only be speculative, but the regular presence of brown violin spiders in this cave, as well as a lengthy drought in the Hawaiian Islands, may have had a serious combined impact on the wolf spiders through competition, predation, and dessication of the cave environment. Surveys have not been conducted since 2004, when the new landowner denied permission to the Service to monitor the cave due to liability concerns.

The cave wolf spider has been recorded in Kiahuna Mauka (Mauka: mountain, in reference to up-slope of the coast) Cave, located approximately 883 meters (2,896 feet) from Kiahuna Makai Cave. This cave contains the largest known population of the Kauai cave amphipod, with the wolf spider being observed on six occasions: a juvenile spider in 1996, a juvenile spider in 1997, two adult spiders during a single monitoring visit in 1998, an adult spider in March 2004, two adult spiders and a juvenile spider in October 2004, and an adult spider in February 2005 (U.S. Fish and Wildlife Service, unpublished data 1996 through 2005). The absence of spiders, in this case during the 1999 through 2003 surveys, may be in response to a noticeable decrease in humidity levels within the cave. The reappearance of wolf spiders in this cave suggests the ability of these spiders to re-colonize caves when conditions become suitable.

The Quarry Cave, a coastal cave derived from calcareous marine deposits, is located in the southeast corner of the range of the cave arthropods. This cave is located within a large limestone bench that follows the coastline. There have been sporadic visits to the Dark Zone of this cave where the cast skin of one wolf spider was recently observed (F. Howarth, Bishop Museum, pers. comm., 2002).

2. The Kauai Cave Amphipod

The Kauai cave amphipod is currently known to regularly occupy three caves in the Koloa District. It commonly occurs with the wolf spider in Koloa Cave 2, but in relatively low numbers (8 to 32 individuals per monitoring visit) (U.S. Fish and Wildlife Service, unpublished data 1996 through 2005).

The cave amphipod has been most abundant in Kiahuna Mauka Cave where numbers have ranged from 11 to 306 individuals (U.S. Fish and Wildlife Service, unpublished data 1996 through 2005). Prior to 1998, amphipod numbers ranged from 11 to 40 individuals, but after 1 to 2 pounds of supplemental food (dry wood) was deposited in this cave (spring of 1998), amphipod numbers climbed dramatically, peaking at 306 observed individuals. It is possible that the observed increases were due to amphipods being drawn into the area from the surrounding subterranean cracks and mesocaverns by the increased food supply

(Howarth 1983). However, at their peak (after food supplementation), juvenile and subadult numbers were nearly twice that of the adults, whereas prior to food supplementation, the adult to juvenile ratio was less pronounced. The high juvenile to adult ratio suggests the supplemental food may have led to a population increase of the resident amphipods. The surface area above this cave is currently managed as a golf course fairway. As a result, the above-surface area receives regular watering, resulting in a consistently saturated (*i.e.*, high relative humidity) Dark Zone, which is beneficial to the resident amphipods.

Sporadic surveys of the Dark Zone of the Quarry Cave have found the cave amphipod to be present in numbers to suggest a population (up to 51), but they have not been observed during every visit (U.S. Fish and Wildlife Service, unpublished data 1998, 2000 through 2005).

The Kauai cave amphipod has also been periodically observed in six other caves in the Koloa District. The Kauai cave amphipod was noted as present on the wet floor of Kiahuna Makai cave by Dr. Mike Kido, three to four years prior to 1994 (M. Kido, *in litt*. 1994). The memo doesn't mention the specific year or number of amphipods seen. The amphipod has not been seen in this cave since that time.

During wetter years, the Kauai cave amphipod has been recorded from the Koloa Cave 1, but in very low numbers. The cave amphipod has not been observed in this cave since 1997 when seven individuals were seen (U.S. Fish and Wildlife Service, unpublished data 1996 through 2000, 2002, 2005).

The By-Pass Cave, located adjacent to Waikomo Road in the upper northwestern corner of the range of the cave arthropods, was discovered in the fall of 1999 when heavy equipment punctured the cave roof while grading the new Koloa By-Pass Road. This cave had previously been open to the surface and there were signs of human use of the cave from Polynesian to the modern era (post World War II), but the cave had been partially filled and sealed with topsoil as recently as 20 years ago. In a 1999 survey, 40 cave amphipods, as well as a few cave isopods, were detected (D. Hopper, *in litt*. 1999b). After the survey was completed and the cave was mapped, the cave was resealed and the road was diverted to avoid further impacts to the cave. A park was constructed over the cave and native plants were used in landscaping which are likely to provide the necessary roots for food for the amphipods.

Cave 1927C is a newly discovered cave and associated mesocaverns. A single Kauai cave amphipod was observed in the cave after humidity experiments were conducted by Bishop Museum staff in 2002. This corroborates the hypothesis that these arthropods live within the intermediate-sized voids in lava and colonize caves where their preferred environment is approximated (Howarth *et al.* 2003).

The Kauai cave amphipod was observed in Cave 3179 in June 1972 when part of the cave was moist. This cave was not revisited until 2002. The cave was truncated by the construction of the Cane Haul Road and only the upper 22 meters (75 feet) of the original 45 meters (150 feet) of the cave survives. Currently, the cave is too short and dry to support the obligate cave species (Howarth *et al.* 2003).

Saint Rafael Church Cave is located in the upper middle portion of the range of the cave arthropods and was only surveyed on one occasion; amphipods were found (A. Asquith, *in litt.* 1994a). Since then, the entrance to the cave has not been relocated and its current condition is unknown.

F. REASONS FOR DECLINE AND CURRENT THREATS

1. Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range

With the establishment of Polynesian populations in the Hawaiian Islands 1,800 years ago, endemic plant communities throughout the lowlands began to be exposed to anthropogenic modifications (Kirch 1982; Cuddihy and Stone 1990; Allen 1997; Athens 1997). Polynesians utilized fire to clear land (Kirch 1982), destroying perennial plants growing above caves, subterranean cracks, and mesocaverns. Wet lowlands were especially prized for taro cultivation, but some Polynesian settlements also diverted water to create more arable lands in drier habitats. Much of the land preparation resulted in the clearing of native perennial vegetation.

With European contact and colonization (starting in 1778), land modifications accelerated over large areas with a wider diversity of habitats being affected. European settlers also frequently used fire to clear land for cattle ranching and growing agricultural crops, further destroying plants growing above cave habitat. The establishment of introduced ungulates such as cattle (*Bos taurus*), goats (*Capra hircus*), and sheep (*Ovis aries*), both managed and feral populations, have greatly altered the vegetative communities of the islands, resulting in the denuding of vast areas and soil disturbance, preventing plant regrowth, and greatly accelerating erosion (Cuddihy and Stone 1990; Hobdy 1993). Along with the above modifications, Europeans also introduced alien plants and converted vast areas into grasslands to support ranching operations, resulting in the destruction of cave food chains since grasses and many of the dominant, non-native perennials do not provide adequate root systems for herbivorous cave-dwelling species such as the amphipod.

Beginning in 1835, the cultivation of sugar cane became an important economic venture in Hawaii, with pineapple cultivation becoming important some time around 1900 (Cuddihy and Stone 1990). The cultivation of both sugar cane and pineapple were present in the Koloa District. This agricultural activity cleared large surface areas of native, perennial vegetation, resulting in the destruction of root systems necessary for cave ecosystems. The frequent crop rotation and heavy rain in many of these areas significantly increased erosion and soil loss. Increased erosion has resulted in increased soil deposition within many low elevation caves, subterranean cracks, and mesocaverns (Howarth 1981). Soil deposition rates have increased dramatically over the past 200 years, with greater than 2 meters (6.5 feet) of soil being deposited at one site in the Poipu area during that period. This recent 2 meter (6.5 feet) deposition accounts for approximately 50 percent of the sediment deposited over a period of 6,700 years at this coastal site (Burney *et al.* 2001). Much of the Koloa/Poipu area was cleared and many caves with openings or mesocaverns located in areas of arable soil were filled with erosional deposits, intentionally filled for public safety concerns, or were used as garbage pits (Howarth 1973; A. Asquith, U.S. Fish and Wildlife Service, *in litt*. 1994b). All of the caves where the Kauai cave arthropods are currently known to exist show signs of filling with sediments (Howarth 1981).

Recent land uses pose a renewed threat to rocky cave-containing areas located in substandard agriculture land. Many of the newer land uses do not rely on the presence of deep, well-developed soils. Current development includes the construction of roads, houses, golf courses, and a quarrying operation (Howarth 1981; Mueller-Dombois and Howarth 1981; Howarth and Stone 1993; KPMG Peat Marwick 1993; Burney *et al.* 2001). Modern technologies allow the importation of soils into otherwise unsuitable sites. As a result, the most recent development plans have the potential to include areas with rocky substrates that had not been modified previously for agricultural purposes.

Previous land uses have destroyed cave and mesocavern habitats and have isolated some of the cave-dwelling arthropod populations. Even with the protection of known, occupied caves, habitat destruction continues to be a threat to these species since undetected subterranean cracks and mesocaverns that likely provide important habitat, corridors, and refugia for these cave-dwelling species occur throughout the Koloa District. Ongoing and anticipated future development in the Koloa District will likely result in further destruction and fragmentation of Kauai cave species habitat. Intervening caves, subterranean cracks, and mesocaverns being destroyed or filled with soil may confine populations of cave-dwelling species to caves without climatic refugia (*e.g.*, cracks and mesocaverns with high relative humidity), increasing chances of local extinction during periods of prolonged drought. Smaller, isolated populations of cave arthropods will have a greater likelihood of extinction due to chance events, and their isolation means these areas will not be able to receive recruits from or provide colonists to adjacent cave systems.

Caves, subterranean cracks, and mesocaverns are periodically exposed to the surface environment during construction activities and this can result in the dessication of cave habitat and provide access to alien species (see below). When caves are exposed during construction activities, most are backfilled with the intent to fill the subterranean mesocaverns that might weaken or compromise the overlying structure(s). Hence, construction frequently results in outright destruction of cave habitats.

Urbanization typically results in large areas being covered by asphalt or other artificial surfaces which lack or have only limited permeability. Rain water is diverted into storm drains and lined gutter or drainage systems, resulting in reduced local ground water recharge. This may greatly reduce humidity levels within caves, subterranean cracks, and mesocaverns, degrading or eliminating habitat for these species.

Human visitation to and uses of caves are recognized as being a serious threat (Culver 1986). Cave ecosystems are affected by the following activities: used as sites for dumping and filling; contaminated by surface sources of toxic chemicals from spills, pesticides, and waste disposal which enter caves via streams and/or ground-water seepage; and mining and quarrying. In addition, Polynesians utilized caves as burial sites and many of the caves in the Koloa District show signs of this use (Hammatt and Tomonari Tuggle 1978; Hammatt *et al.* 1988). It is not known if Polynesian use of such cave systems impacted the Hawaiian cave arthropods. Caves often attract curiosity seekers who, in most cases, have no intent to damage the geologic or cultural features within caves, or harm the indigenous wildlife (Howarth 1982, 1983; Culver 1986). However, cave ecosystems are sensitive to even minor human intrusion and disturbance, and it is often necessary to limit human entry into caves to protect the resident organisms and their habitat.

The narrow passages in many caves increase the chances that human visitors may inadvertently and unknowingly crush or injure ground-dwelling cave-inhabiting species. Human use of caves can result in the destruction of food resources such as root systems, which are critical to most Hawaiian cave systems. Cave visitors may leave trash or toxic materials in caves, both of which can have devastating effects. In Hawaiian caves, discarded food and trash can attract arthropods (*e.g*., cockroaches) that can compete with the resident cave-dwelling animals, and elevated numbers of such scavengers may attract non-native predators (*e.g*., centipedes, spiders) that may prey on the natural cave inhabitants (see Disease and Predation section below). Discarded trash can also attract social insects such as ants which have had a devastating impact in cave systems in Texas (U. S. Fish and Wildlife Service 1994) and have likely had similar impacts in Hawaii (Howarth 1985; Cole *et al.* 1992).

Nicotine, contained in cigarette smoke, is a powerful insecticide that can have devastating effects in the cave environment (Howarth 1982). Due to the confined and still air typically encountered in the Dark Zones of caves, cigarette smoke is not readily carried out of the cave and it may disperse into cave-dwelling animal-occupied mesocaverns, or upward onto the walls and ceiling of the cave, areas that would otherwise not be affected by human activities in the larger passages. In a similar fashion, use of open fires in caves and cave openings may have massive, unseen impacts on cave-dwelling species both from the release of toxic fumes as well as from drying the cave interior, reducing relative humidity (Howarth 1982).

2. Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

Direct overutilization of the Kauai cave arthropods is not known to be a factor.

3. Disease and Predation

We are currently unaware of any diseases affecting the Kauai cave arthropods. Non-native predators are known to feed on mainland cave-dwelling species (U.S. Fish and Wildlife Service 1994) and are assumed to compete with resident cave-dwelling animals for common food resources which are already in low supply. In the Hawaiian Islands, Howarth (1981) has documented the replacement of an endemic cave-dwelling spider (*Erigone stygius*) by a non-native web-building cave-dwelling spider (*Nesticus mogera*). While the Kauai cave wolf spider will feed on introduced cockroaches, small alien spiders, and other introduced cave-dwelling species, there is good evidence to suggest that it is preyed upon by the non-native brown violin spider (*Loxosceles rufescens*; A. Asquith, *in litt*. 1994a, b; D. Hopper, *in litt*. 1999b), which also feeds on resident arthropods that otherwise serve as prey for the cave wolf spider. Web-building spiders, such as the brown violin, may pose a particularly serious threat since webs present a method of predation to which the Kauai cave wolf spider and cave amphipod are likely not adapted (Howarth 1981). Violin spiders make a strong, disorganized ground web, in which the remains and living specimens of the cave wolf spider have been found entangled (D. Hopper, *in litt.*, 1999b). Lastly, the introduced lesser brown scorpion (*Isometrus maculatus*) and centipedes (*Scolopendra* spp.) have both been observed in some of the caves inhabited by the endemic cave-dwelling species and the generalized diet of these predators would certainly include both the Kauai cave wolf spider and amphipod.

4. Inadequacy of Existing Regulatory Mechanisms

When a species is listed as endangered or threatened under the Endangered Species Act, it is automatically added to the State of Hawaii's list of protected species (Hawaii State Division of Forestry and Wildlife, Hawaii Revised Statues 195D4). Hawaii State Law prohibits taking of endangered wildlife and encourages conservation by State government agencies. On April 9, 2003, critical habitat for the Kauai cave arthropods was designated (U.S. Fish and Wildlife Service 2003a). The critical habitat designation consists of 14 units whose boundaries encompass an area of approximately 110 hectares (272 acres) on the island of Kauai, Hawaii. We are unaware of any threats the species face due to the inadequacy of existing regulatory mechanisms.

5. Other Natural or Manmade Factors

Of great importance is household pesticide use and its potential impacts to cave ecosystems. Urban and household use of pesticides is often higher and less target-specific than pesticide use for agricultural crops (Hawaii Office of State Planning (HOSP) 1992). For example, numerous household and resort pesticide applications are for subterranean pests such as the Formosan ground termite (*Coptotermes formosanus*) as well as a variety of turf pests such as ants and cutworms, which feed on root systems. Hence, moisture runoff and recharge that originates in urban areas may inadvertently deliver high concentrations of insecticides or other pesticides (*e.g*., herbicides, fungicides) into cave and mesocavern habitats, with potentially devastating effects on the Kauai cave arthropods and other cave animals.

The presence of septic tanks and leaching fields associated with urban development in cave-bearing rock is likely of mixed benefit to the Kauai cave animals. Leaching fields would increase soil moisture levels and elevate the relative humidity within local caves, and could result in increased food import (*i.e.*, detritus). However, they are equally likely to be a source of toxic and caustic wastes in the form of household cleaners such as drain-cleaners, bleach, and discarded chemicals.

Bio-control agents (living organisms used to control pests) are usually perceived as preferable to the use of chemicals because they represent less of a threat to human health and generally do not stimulate resistance in pests. Some of these organisms, however, attack species other than their intended targets and have caused or contributed to the decline and extinction of several Hawaiian insects (Howarth 1983, 1991). Several entomopathogens (including nematodes, fungi, and bacteria) are available or are under development for use as biological pesticides. They are isolated from moist soil and would likely survive and do well in subterranean environments. The native Hawaiian cave fauna would be highly susceptible to this threat (Howarth 1991; Howarth *et al.* 2003). Unlike most pesticides, bio-control agents will not break down or decay. Should they become established, they may also spread to new areas with suitable host arthropods, and become impossible to eliminate.

All of the caves may be threatened by prolonged drought, which could be brought about by global climatic changes that may reduce rainfall, or by local alteration of the vegetation which may reduce infiltration into the caves and increase run-off. Prolonged drought or alteration of the vegetation may dessicate the cave interior, making it less accommodating to cave-dwelling animals (Howarth 1983). As a result of reduced humidity, Dark and Stagnant Air Zones may become more prone to invasion by damaging, non-native species such as the brown violin spider mentioned above.

Small populations are demographically vulnerable to extinction caused by random fluctuations in population size and sex ratio and to catastrophes such as hurricanes (Soulè 1983; Gilpin and Soulè 1986). In addition, the low reproductive potential of both cave species (less than 10 percent of their surface relatives) means that they require more time and space to recover from a disturbance than would similar animals living on the surface (F. Howarth, Bishop Museum, *in litt.* 2001).

6. SITE-SPECIFIC THREATS

(a) Koloa Caves

Koloa Caves 1 and 2 have been protected by the landowner under a cooperative agreement with the U.S. Fish and Wildlife Service. This cooperative agreement is currently in the process of being renewed. Both caves are currently protected in a preservation area. This preservation area is to be protected from future development and includes a long-term habitat enhancement and management plan. The habitat enhancement plan includes preventing disturbances to the cave interior with the protection of gates at cave openings and restoring the vegetation which lies over the caves. Surface areas above the caves will be landscaped with native plants which will provide a permanent food source for the cave arthropods. Despite this protective action, both of these caves are still vulnerable to other threats. Lack of food is a major threat to the Kauai cave arthropods living in these caves. The overlying area is dominated by alien grasses and non-native perennial vegetation which lack roots that penetrate into the cave, are toxic, or are not the food that the cave amphipods would normally eat (non-native perennials). Fire is also a threat to this area. Many of the non-native plants are highly vulnerable to fire, which is far more likely to occur with the current level of human activity in the area. Fire above the caves would likely kill any perennial plants that currently do provide roots into the caves and mesocaverns, further reducing the food base of the resident cave-dwelling arthropods.

Although not abundant, the brown violin spider has been found regularly in Koloa Cave 2. This spider is implicated in the predation of the cave wolf spider in Kiahuna Makai Cave (see below). All observations of this spider have been in the lower section, where the cave becomes drier and where the native cave-dwelling animals are less frequently encountered. While speculative, it is plausible the limited distribution of the violin spider is due to its poorer performance in cave areas which exhibit the characteristics of the true Dark Zone (*i.e.*, high humidity, reduced air movement).

(b) Cave 1927C

Cave 1927C is not gated and is vulnerable to unauthorized entry by humans. Because it is listed as a state archaeological site, occasional visits to the site are likely to occur. Insufficient food source is one of the threats to the arthropods in this cave. The overlying area is dominated by alien grasses and non-native perennial vegetation which lack roots that penetrate into the cave, are toxic, or are not the food that the cave amphipods would normally eat (non-native perennials). Many of the non-native plants are highly vulnerable to fire, which is far more likely to occur with the current level of human activity in the area. Fire above the cave would likely kill the non-native perennial plants that currently provide roots into the cave and mesocaverns further reducing the food base of the resident cave-dwelling animals.

(c) Cave 3179

Cave 3179 is also not protected by a gate and is vulnerable to unauthorized entry by humans, especially since it is located next to the Cane Haul Road. This cave is subject to similar threats mentioned for Cave 1927C, including insufficient food source and threat of fire.

(d) Kiahuna Caves

The Kiahuna Makai Cave is not gated, making the threats of human visitation, overuse, and vandalism more acute. This cave has shown signs of elevated human use which could impact the Kauai cave-dwelling arthropods if either of these species still utilize this cave (D. Hopper, *in litt*. 2000a, b).

The Kiahuna Makai Cave occurs below lands slated for residential development. Drought conditions may have affected the use of this cave by cave-dwelling species due to the reduced relative humidity of the Dark Zone (U.S. Fish and Wildlife Service, unpublished data 1996 through 2004). The non-native dry shrubland that overlies this cave is vulnerable to fire and its destruction could lead to accelerated degradation of the below-surface habitat by destroying the limited root-derived food base.

The Kiahuna Makai Cave contains a large number of the non-native, brown violin spiders, with as many as 26 of these spiders being counted during a single monitoring visit. While no direct observations of predation by the violin spider on the endangered wolf spider have been observed, observations of remains and living specimens of the cave wolf spider in the web of the violin spider and the steady decline of wolf spiders in the presence of violin spiders suggest these non-native spiders may be a significant threat to the Kauai cave wolf spider and may play an equally damaging role to other native cave-dwelling species. The absence of the violin spider from the extremely humid dark zones of other caves, where both the Kauai cave wolf spider and amphipod are most frequent, suggests the Dark Zone conditions are less suitable for the violin spider.

The Kiahuna Mauka Cave is gated and a native plant restoration program has begun above the cave system. It is in an area of private land with a security system. Current management of this area includes regular watering (golf course maintenance), which has contributed to the maintenance of saturated soils and a high humidity cave interior that favors cave-dwelling species and increases rates of cellulose decomposition (a source of food to native detritivores such as the amphipod). Lastly, although employed by the golf course, herbicides are sparingly used and no traces of common pesticide components were detected in soil or tissue samples from nonnative cockroaches that were collected and analyzed from either of the Kiahuna caves (U.S. Fish and Wildlife Service 2000b).

Insufficient food source is one of the threats to the cave arthropods in Kiahuna Mauka Cave. The majority of this cave system is under a maintained lawn adjacent to a golf course fairway. Prior to construction of the current golf course, this area was under cultivation for sugar cane. Hence, appropriate perennial vegetation, capable of providing root systems to plant-eating cave dwellers), have been absent from this site for many years. This population unit of amphipods has likely subsisted on old decaying roots and supplemental food provided by biologists in 1998, 2002, and 2005 (a total of four times). This population unit may decline or disappear if supplemental food is not periodically brought into the cave. A native plant restoration program has been implemented above the cave by the previous landowner to enhance the habitat of the species. The restoration has been hindered by an infestation of the rose beetle (*Adoretus sinicus* [Burmeister]), a non-native insect that eats the native outplanted vegetation.

(e) Quarry Cave

The entrance of the Quarry Cave is located in Mahaulepu Sinkhole. The sinkhole contains three entrances: a collapsed entrance located between the north and south ends, the top of the sinkhole, and an entrance at the north end which is currently gated (Burney *et al.* 2001). The sinkhole is currently under a 5-year lease with a renewable option. Dr. David Burney and Dr. Lida Pigott Burney have conducted archaeological studies and an ecological restoration program in the sinkhole and its surrounding areas since 1992. The ecological restoration program consists of landscaping the sinkhole and the surrounding area with native plant species that previously existed in the area (David Burney, National Tropical Botanical Gardens, pers. comm. 2005).

The habitat conditions within the entire Quarry Cave are not optimal for cave-dwelling arthropods, being drafty and of low relative humidity throughout most of the accessible parts. Food importation into this cave occurs primarily as a result of stream-borne detrital material rather than from the root systems of perennial plants. Although the bedrock in which this cave is located is being quarried, the quarrying activities are minor and do not, at this time, appear to be near the known population unit of the amphipod (U.S. Fish and Wildlife Service 2003a). However, it is likely other mesocaverns within calacareous deposits were previously destroyed by the quarrying operation. In addition, future increases in quarrying activity could negatively impact the underground spring that flows into this cave and/or cause the collapse of known or unknown caverns or mesocaverns.

(f) By-Pass Cave

This cave currently lacks an opening to the surface which protects it from direct human entry and/or vandalism. The primary known threat for this cave is low food abundance. Prior to re-closure of this cave, approximately 20 pounds of native wood were treated (*i.e.*, frozen) to kill non-native invertebrates and placed in the cave as a food source for the resident cave-dwelling species. The Koloa By-Pass Route was slightly rerouted and the land overlying the cave opening was annexed into an adjacent county park. Most of this cave lies beneath the county park and preservation of the cave should be compatible with use and management of the park.

(g) Saint Rafael Church Cave

The current condition of the Saint Rafael Church Cave is unknown at this time. We have been unable to relocate the cave entrance which is believed to be near a cemetery. However, it is likely the cave is subject to common threats such as inadequate food source, lack of proper humidity, and if there is an accessible entrance to the cave, threats from human visitation and alien species.

G. CONSERVATION EFFORTS

The Kauai cave wolf spider and cave amphipod were listed as endangered species on January 14, 2000 (U.S. Fish and Wildlife Service 2000a). An endangered species is defined in section 3 of the Endangered Species Act as any species that is in danger of extinction throughout all or a significant portion of its range. A threatened species is defined as any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

The Endangered Species Act provides several opportunities for the conservation of listed endangered and threatened animals and plants. Listed animal species receive protection against take. The term “take” is defined as to harass, harm, shoot, wound, kill, trap, capture, or attempt to engage in any such conduct. “Harm” is further defined to include significant habitat modifications or degradation where it actually kills or injures listed species by significantly impairing essential behavioral patterns that may affect breeding, feeding, or sheltering (50 Code of Federal Regulations (CFR) 17.3). Federal agencies must ensure that their actions do not jeopardize the continued existence of a listed species or adversely modify its designated critical habitat. The Endangered Species Act also prohibits possessing, selling, delivering, carrying, transporting, or shipping in interstate or foreign commerce any listed fish or wildlife species except as permitted under provisions of section 10 of the Endangered Species Act.

When a species is listed as endangered or threatened under the Endangered Species Act, it is automatically added to the State of Hawaii’s list of protected species (Hawaii State Division of Forestry and Wildlife, Hawaii Revised Statues 1995). Hawaii State Law prohibits taking of endangered wildlife and encourages conservation by State government agencies.

Critical habitat for the Kauai cave arthropods was designated on April 9, 2003 (U.S. Fish and Wildlife Service 2003a). 50 CFR §424.02 defines critical habitat to be the specific areas occupied by a species on which are found those physical or biological features that are necessary for the recovery of the species and that may require special management considerations or protection, and those areas unoccupied by a species that the Secretary of Interior has determined to also be essential for the recovery of the species. "Conservation" is further defined as the use of all methods and procedures that are necessary to bring any endangered or threatened species to the point at which the measures provided by the Endangered Species Act are no longer necessary. The critical habitat designation consists of 14 units whose boundaries encompass an area of approximately 110 hectares (272 acres) on the island of Kauai, Hawaii. This critical habitat designation requires us to consult under section 7 of the Endangered Species Act with regard to actions carried out, funded, or authorized by a Federal agency.

A number of programs within the U.S. Fish and Wildlife Service provide funds and incentives for the protection of federally listed species. For example, in Fiscal Year 2005, $5.7 million was awarded to 72 projects in 38 states and 1 territory under the Private Stewardship Grants Program to undertake conservation projects on private land for endangered, threatened, and other at risk species.

In 1995 the U.S. Fish and Wildlife Service entered into a cooperative agreement with Kukuiula Development Company (Hawaii), LLC that included conservation measures for the Kauai cave arthropods. Although this cooperative agreement has expired, it is currently in the process of being renewed with the landowner. The cooperative agreement included a cave preservation management plan for Koloa Caves 1 and 2 (considered together as a single unit), Cave 1927C, and Cave 3179. The goals of the plan were to reduce threats that affect the endangered cave arthropods, stabilize their populations, and maintain their ecosystem into the future. The long-range goal is to contribute to the recovery of the two species and their eventual removal from the List of Threatened and Endangered Wildlife and Plants. The plan has relied on experimentally modifying the surface and interior environments in caves that do not currently support either species. The proposed plan is adaptive, changing as the results of monitoring and research become available, since the conservation needs of these species are not fully understood.

In 1997, the Federal Highways Administration informally consulted with us to avoid or minimize their impacts to a cave uncovered during a road construction project (Koloa By-Pass Road; see “By-Pass Cave” section above). Working in cooperation with the county and a private landowner, this cave was protected from potential damage due to road construction when the road was slightly diverted to avoid the cave and minimize impacts to the area above the cave. Supplemental food was placed in the cave prior to re-sealing the entrance and the cave opening was annexed into an adjacent county park. Improvements to the area above the cave by the Kauai Department of Parks (the installation of a watering system and the planting of two genera of trees, *Senna* sp. and *Erythrina* sp.) are likely to enhance the arthropods’ habitat by providing plant roots in the cave and helping maintain a high humidity environment. Unfortunately, monitoring the biotic responses to these conservation efforts is not possible at this time because the cave was sealed.

In 2004, Grove Farm Company, Inc. was awarded $18,810 from the U.S. Fish and Wildlife Service’s Private Stewardship Grant Program. The awarded funds will be used to gate the entrance of the Quarry Cave, protecting the endangered cave arthropods from human disturbances.

For the Kauai cave arthropods, habitat enhancement of unoccupied caves may be a viable recovery tool. Emphasis should be placed on protection and enhancement of known occupied caves and the discovery and protection of additional caves with suitable habitat. In addition, non-native predators, such as violin spiders, will need to be eradicated in a way that does not harm the native spider.

A summary of the known distribution, status, threats, and current management actions for the Kauai cave wolf spider and Kauai cave amphipod are presented in Table 1. Based on the known distribution of the Kauai cave amphipod, it is likely they exist in more population units and in larger numbers than the wolf spider. They may occur as far as 5 kilometers (3.1 miles) from one another.

Table 1. Distribution, current status, threats, and management activities for the Kauai cave wolf spider and Kauai cave amphipod. **Terms** are defined as: **Present**: observed during monitoring visits and in numbers suggesting a resident population; **Rare**: only observed periodically and not present in numbers that indicate a reproducing population; **Uncommon**: only observed once despite subsequent visits; **Unknown**: previously observed, no current information; **Never Observed**: not seen on any visits. The information below is based on the known distribution of the Kauai cave arthropods; this information is limited due to the inability to confirm their distribution except in known caves with openings that allow access.

CAVE	SPIDER STATUS	AMPHIPOD STATUS	KNOWN THREATS	CURRENT MANAGEMENT ACTIONS
Koloa Cave 1	Rare	Rare	Dry cave interior, non-native predators, low food abundance, drought, vulnerable surface habitats (fire), pesticides.	Access controlled by locking gate; surface area over cave is currently protected from future development by agreement with landowner.
Koloa Cave 2	Present	Present	Dry cave interior, non-native predators, low food abundance, drought, vulnerable surface habitats (fire), pesticides.	Access controlled by locking gate; periodic food supplement for amphipods; surface area over cave is currently protected from future development by agreement with landowner.
Cave 1927C	Never observed	Unknown	Dry cave interior, non-native predators, low food abundance, drought, vulnerable surface habitats (fire), pesticides, unauthorized human entry.	Surface area over cave is currently protected from future development by agreement with landowner.
Cave 3179	Never observed	Unknown	Dry cave interior, non-native predators, low food abundance, drought, vulnerable surface habitats (fire), pesticides, unauthorized human entry.	Surface area over cave is currently protected from future development by agreement with landowner.

Table 1. (Continued) Distribution, current status, threats, and management activities for the Kauai cave wolf spider and Kauai cave amphipod. **Terms** are defined as: **Present**: observed during monitoring visits and in numbers suggesting a resident population; **Rare**: only observed periodically and not present in numbers that indicate a reproducing population; **Uncommon**: only observed once despite subsequent visits; **Unknown**: previously observed, no current information; **Never Observed**: not seen on any visits.

CAVE	SPIDER STATUS	AMPHIPOD STATUS	KNOWN THREATS	CURRENT MANAGEMENT ACTIONS
Kiahuna Makai Cave	Rare	Uncommon	Dry cave interior, non-native predators, low food abundance, drought, vulnerable surface habitat(fire), pesticides, unauthorized human entry.	Not currently managed.
Kiahuna Mauka Cave	Rare	Present	Non-native predators, pesticides.	Access controlled by locking gate; periodic food supplementation for amphipods; surface area over cave managed as golf course; watering enhances cave habitat; cave habitat enhancement through surface habitat management from previous landowner (outplanting of native vegetation).
By-Pass Cave	Never observed	Unknown	Low food abundance.	Cave is closed; above surface watering and landscaping should enhance cave habitats.
Saint Rafael Church Cave	Never observed	Unknown	Dry cave interior, non-native predators, low food abundance, drought, vulnerable surface habitats (fire), pesticides, unauthorized human entry.	Not currently managed.
Quarry Cave	Rare	Present	Non-native predators, low food abundance, drought, vulnerable surface habitats (fire), pesticides, habitat destruction (quarry).	Access controlled by locking gate at one of three entrances.

II. Recovery

A. RECOVERY STRATEGY

The recovery of the Kauai cave arthropods will depend on several recovery actions:

1) Protect known populations of the Kauai cave wolf spider and cave amphipod and their subterranean habitats from human-caused destruction or degradation.

2) Improve or enhance the habitat of occupied and previously occupied caves through landscaping measures that are likely to increase subterranean food resources.

3) Conduct research to address essential conservation needs for the species, including non-damaging mark-recapture studies, surveys for additional occupied habitat or restorable cave habitat, the potential for translocation of animals, and discovery and protection of occupied caves or caves with suitable habitat.

4) Conduct public outreach to facilitate better public understanding of and support for conservation of these cave arthropods.

5) Validate recovery objectives.

6) Develop and implement a post-delisting monitoring plan as necessary.

B. RECOVERY GOAL AND OBJECTIVES

The ultimate goal of the recovery program is to restore and maintain multiple self-sustaining, viable populations of these Kauai cave arthropods, which will allow them to be reclassifed to threatened status and eventually removed from the Federal List of Endangered and Threatened Wildlife and Plants.

To reach the recovery goal the target objectives are:

1) Stabilize and increase self-sustaining populations of the Kauai cave arthropods throughout their range;

2) Ensure the protection and conservation of quality habitat;

3) Reduce and/or eliminate impacts from known threats.

C. RECOVERY CRITERIA

We set recovery criteria to serve as objective, measurable guidelines to assist us in determining when a species has recovered to the point that the protections afforded by the Endangered Species Act are no longer necessary. Downlisting or delisting is warranted when a listed species no longer meets the definition of threatened or endangered under section 3 of the Endangered Species Act. However, the actual change in listing status is not solely dependent upon achieving the recovery criteria set forth in a recovery plan; it requires a formal rulemaking process based upon an analysis of the same five factors considered in the listing of a species. The recovery criteria presented in this recovery plan thus represent our best assessment of the conditions that would most likely result in a determination that downlisting or delisting of the Kauai cave arthropods is warranted as the outcome of a formal five factor analysis in a subsequent regulatory rulemaking.

The recovery criteria for downlisting and delisting the Kauai cave arthropods are based on reaching population goals to ensure long-term viability and removing or reducing the known threats to the species, as discussed earlier in this plan. However, new threats may arise as recovery efforts continue. These new threats will need to be monitored and addressed appropriately. If these new threats should become significant, the recovery criteria below will need to be revised to address these threats.

In the recovery criteria that follow, we have identified the number of populations associated with caves that we feel are necessary to consider downlisting and delisting the cave arthropods. These numbers are based on the best available information, including: the nine caves that have been located to date that are known to presently or historically support Kauai cave arthropods and an additional four to six caves that have been identified as either suitable for cave arthropods or that may draw cave arthropods once the habitat has been restored. In addition, there are land formations, such as lava rock out-croppings, that indicate the potential presence of additional caves that may be suitable. These land formations were identified in the critical habitat rule for these species (U.S. Fish and Wildlife Service 2003a), and will be investigated for the presence of suitable habitat and cave arthropods, as funds become available. The number of caves with self-sustaining, stable populations, spread across the known range, represents what is necessary to protect against stochastic events such as flooding, cave-ins, exposure to contaminants, hurricanes that remove above ground vegetation, and disease. Several populated caves, spread across the known range, also provide opportunities for genetic exchange (possibly through translocation), resulting in the maintenance of genetic integrity for both species. In addition, since the wolf spider relies on the amphipod for food, several caves occupied by amphipods, spread across the known range, provide the spider the ability to move from areas of low numbers of amphipods to areas with greater numbers of amphipods.

It must be emphasized that the Kauai cave wolf spider is reliably known from only a single cave and appears to have disappeared or greatly declined from all other previously occupied caves. Downlisting criteria can not be met unless additional caves are found with small populations of the wolf spider or spiders are reintroduced to newly discovered caves with suitable habitat, and management leads them to become self-sustaining.

Specific downlisting and delisting criteria should be revisited as more is learned about Kauai cave arthropods. In the interim, we believe the recovery criteria detailed below are suitable and useful for guiding conservation efforts.

1. Downlisting Criteria

Downlisting to threatened status may be considered for both species when nine populations of each species, spread across the known range, are shown to be:

1) Self-sustaining populations (contain representatives of all generations, sexes, and age classes);

2) stable or increasing (intrinsic growth rate (λ) is greater than or equal to 1) over a monitoring period of at least 10 consecutive years;

3) Protected from non-native, predatory species; human visitation of caves (dumping area, party site); bio-control agents; pesticides, development; or other damaging land uses such as quarrying, filling areas, rain water diversion due to surface areas being covered by asphalt or other artificial surfaces which lack or have only limited permeability; and

4) With the habitat being used in a fashion consistent with conservation (protecting cave habitat from future development, preventing disturbance to cave interiors via gating, and protecting and/or restoring the vegetation which lies over the cave).

2. Delisting criteria:

Delisting of both species may be considered when 12 populations, of each species, spread across the known range, are shown to be:

1) Self-sustaining (contain representatives of all generations, sexes, and age classes);

2) stable or increasing (intrinsic growth rate (λ) is greater than or equal to 1) over a monitoring period of at least 10 consecutive years;

3) Protected from non-native, predatory species, human visitation of caves (dumping area, party site), bio-control agents, pesticides, development, or other damaging land uses such as quarrying, filling areas, rain water diversion due to surface areas being covered by asphalt or other artificial surfaces which lack or have only limited permeability; and

4) With the habitat being used in a fashion consistent with conservation (protecting cave habitat from future development, preventing disturbance to cave interiors via gating, and protecting and/or restoring the vegetation which lies over the cave).

A post-delisting monitoring plan and agreement to continue post-delisting monitoring must be in place at the time of delisting. Monitoring populations following delisting will verify the ongoing recovery and conservation of the species and provide a means of assessing the continuing effectiveness of management actions.

D. RECOVERY ACTION NARRATIVE

1. Protect Known Populations of the Kauai Cave Wolf Spider and Cave Amphipod and their Subterranean Habitats from Human-Caused Destruction and Degradation.

1.1 Protect the caves from unauthorized human entry.

Human entry and use of caves threaten the survival of cave-dwelling arthropods both by intentional impacts such as vandalism and collecting, as well as by unintentional impacts such as trampling of arthropods and their food resources and introduction of toxic materials (*e.g.*, smoke, batteries). Discarded food and trash can attract arthropods (*e.g.*, cockroaches) that can compete with the Kauai cave spider, and elevated numbers of such scavengers may attract non-native predators (*e.g.*, centipedes, spiders) that prey on the natural cave inhabitants. Discarded trash can also attract social insects such as ants which have had a devastating impact in cave systems in Texas (U.S. Fish and Wildlife Service 1994) and have likely had similar impacts in Hawaii (Howarth 1985; Cole *et al.* 1992). Caves with populations of these arthropods should be closed to prevent unauthorized and/or uncontrolled human access. Whenever possible, a locking gate should be installed that employs durable materials that are not easily dismantled, while providing access to authorized persons to allow monitoring of the status of the arthropods and their habitat. Cave closure and access issues need to be developed with the support of local landowners, appropriate State agencies, and Hawaiian groups (*e.g.*, burial councils).

1.2 Protect/enhance plant communities over caves, subterranean cracks, and mesocaverns.

Overlying perennial native plant communities should be protected from loss and degradation, and enhanced. Overlying plant communities primarily made up of non-natives should be removed and native plant communities restored using plants known to serve as food sources (e.g., *Capparis sandwiciana*, *Myoporum sandwicensis*, and *Erythrina sandwicensis*) for the cave arthropods. Partnerships should be formed with private land owners and State and other Federal agencies such as the Hawaii Department of Land and Natural Resources and the U.S. Department of Agriculture Natural Resources Conservation Service to promote habitat restoration over caves.

In addition, these overlying habitats should be protected from wildfire that kills perennial vegetation and often results in the invasion of alien grasses and loss of plants with roots that penetrate caves and provide food. The restoration of degraded habitat over caves with appropriate vegetation communities (see Action 2.1 below) and the development of fire plans for these lands should be encouraged and supported.

1.3 Prevent new introductions of non-native predators and competitors and carry out management actions that eliminate or reduce existing non-native predators and competitors.

During monitoring and other authorized visits, potentially harmful, non-native species should be removed. This is particularly pertinent for species such as the brown violin spider, little brown scorpion, centipedes, and large cockroaches, all of which are non-native, generalist predators/foragers. If research suggests the control of such organisms can be accomplished through habitat management such as reducing air movement and/or increasing humidity levels, then these manipulations should be incorporated into the management goals (see Actions 2.2 and 3.4 below).

1.4 Prevent the introduction of harmful bio-control organisms and bio-pesticides throughout the State of Hawaii.

The intentional release of bio-control organisms or bio-pesticides has a long history of negative effects on the endemic Hawaiian biota. While bio-control agents may provide great hope for the protection of the State's economy and the integrity of its native ecosystems, all proposed bio-control agents, both new introductions as well as re-introductions, should be carefully considered and researched under section 7 of the Endangered Species Act with U.S. Department of Agriculture to ensure they pose no threat to native species, including the unique Hawaiian cave fauna. The Service should coordinate with Hawaii Department of Agriculture to study the effects of new bio-control organisms to native species before they are released.

1.5 Prevent contamination of the cave from human-associated activities such as urban and agricultural runoff and soil percolation of pollutants or other harmful chemicals including harmful pesticides.

Inappropriate and/or overuse of chemical herbicides, insecticides, and fungicides can have devastating effects on species living in subterranean habitats (soils, caves, and mesocaverns). Heavy use of such chemicals should be avoided above and adjacent to caves or mesocavern-containing habitats. Pesticides that pose the least possible hazard should be used sparingly in areas known to support cave arthropods or their habitat.

2. Improve or Enhance the Habitat of Occupied or Previously Occupied Caves through Landscaping that will Increase Subterranean Food Resources.

2.1 Plant and maintain surface vegetation that will provide root systems for herbivorous and detritivorous cave dwellers with an abundant and sustainable food resource.

Caves are typically regarded as being food-limited and recent work conducted in one of the Koloa caves supports this. Possibly the most important management activity for the recovery of these species is to manage the overlying habitat to encourage the growth of appropriate plants through weed control and outplanting and landscaping. Irrigation will allow roots to penetrate into the cave and provide a source of fresh vegetation and detritus for the cave amphipods. Increases in the amphipod population or other cave-dwelling detritivores should result in increases in prey for these spiders. To the extent possible, efforts should be made to outplant native and indigenous, nontoxic plants to enhance subterranean habitats for native cave-dwelling species. Non-native plants are known to provide food for the Kauai cave amphipod and can be used if the situation dictates such an action. As has occurred in some of the regularly monitored caves, pretreated detrital material may be placed in such caves to help supplement food reserves and to help maintain healthy populations of cave amphipods until appropriate overlying vegetation can be planted and become established. This will provide a long-term food supply to the cave-dwelling detritivores. Establishment of healthy plant root systems is already known to be a valid management tool, but research should be conducted to determine the best species of plants to use (*e.g.*, plant preferences, plant performance) (see Action 3.2 below).

2.2 Maintain consistent high humidity within the Dark Zone and increase humidity within the Stagnant Air Zones.
Terrestrial cave-dwelling organisms are largely restricted to cave environments with high relative humidity (100 percent). Evidence to support this environmental criteria for the Kauai cave amphipod has been provided by Miura and Howarth (1978). Increasing the relative, ambient humidity is largely achieved by reducing air velocity through the cave, but adequate soil moisture is also necessary. As such, caves with little or no air movement that retain moisture from rain and other water sources, provide the best habitat for cave-dwelling species. Cave humidity can be elevated by: (a) restricting air-flow in caves or passage ways; and (b) irrigating the surface habitat. Restricting air movement in caves to elevate ambient humidity levels has been used in a few experimental testings but has not been used for habitat management for cave dwellers. It should be attempted cautiously to determine if it has value as a management tool (see Action 3.4 below). Irrigation of surface habitats reduces fire risk of the overlying vegetation community and improves the health of the plant community.

3. Conduct Research to Address Essential Conservation Needs for the Species.

3.1 Conduct biannual or more frequent monitoring to determine population trends in caves and assess recovery actions.
Biological surveys resulting in verified records are the only reliable means to determine the presence of a species and to monitor population trends over time (Bogan *et al.* 1988). While the current monitoring does not provide population estimates, it does provide some measure of population health within the monitored caves.

Standardized techniques should be used for monitoring. Monitoring should occur at least biannually to establish information on population trends, identify possible threats, and initiate management actions in case a drop in numbers of the cave arthropods is observed. In addition, continued monitoring will provide some measure of success or failure of the management activities and allow for the implementation of adaptive management.

3.2 Evaluate research and monitoring results and implement adaptive management as necessary.

The results from research and monitoring should be evaluated and incorporated into the management process and used in the refinement of recovery objectives, as necessary.

3.3 Develop and conduct non-damaging mark-recapture studies to determine local population sizes and/or movement.

Mark-recapture studies are important for estimating population sizes of many species (England 1998; U.S. Fish and Wildlife Service 2003b). To date, no such studies have been undertaken with Hawaiian cave animals. Developing non-damaging methods of marking these arthropods will allow biologists to obtain needed information on the population size of these species.

3.4 Determine the most beneficial and appropriate plants to be used for habitat enhancement.

Numerous native and ornamental plants can be used for habitat enhancement over cave/mesocavern habitats. However, certain species are known to be particularly important with regard to providing nutrient input into Hawaiian cave systems. The native *Metrosideros polymorpha* (ohia tree) has roots known to be an important food source for a number of endemic cave-dwelling species on the island of Hawaii (Howarth 1981). Another endemic plant, *Capparis sandwichiana* (maiapilo), is believed to be an important food resource in caves located in drier climates

(Howarth 1981). Both of these plants have large roots that often enter caves and grow for extensive distances along the cave floor where they are fed upon by herbivorous and detritivorous cave dwellers. These plants and others should be tested to determine how they perform in the Koloa District in order to refine restoration and recovery actions for caves in these areas.

3.5 Develop and utilize molecular techniques to determine the status of populations (not to be conducted with the wolf spider until additional, healthy populations are discovered).

It is not known if the separate population units of the cave amphipod represent isolated populations or races, or if they are a single, panmictic population (random or non-selective mating within a breeding population) which exhibits regular gene-flow between population units. Developing molecular techniques to address this question is an important research need that could affect the recovery criteria for the cave amphipod. Information obtained from such molecular studies would be important not only for management of the cave amphipod, including reevaluation of the recovery criteria, but would provide information on the extent and connectivity of cave systems in the Koloa District. This information would have important implications for the Kauai cave wolf spider, which appears to be far more restricted in its current distribution. Given the limited number of cave wolf spiders and their restricted range any proposal to conduct such work with the wolf spider should be carefully evaluated by qualified biologists to ensure benefits outweigh potential harm to the species.

3.6 Conduct studies to determine if manipulation of cave climate improves habitat for the endangered cave arthropods and/or controls non-native species.

High ambient humidity is known to be an important habitat parameter for cave-dwelling animals and has been shown to play a role in the distribution of the Kauai cave amphipod (Miura and Howarth 1978). Taking steps to increase cavern humidity is a recommended management activity (see Action 2.2 above) that should be conducted and its effectiveness should be evaluated. Observations in the Kauai caves suggest that harmful, non-native species (*e.g*., brown violin spider) are not as abundant in areas where ambient humidity is high (100%). Managing caves by increasing the internal ambient humidity should increase population numbers of endangered cave-dwelling species and/or reduce threats associated with non-native predators/competitors.

3.7 Conduct surveys for additional occupied habitat or restorable cave habitat.

Given the limited number of caves from which the cave wolf spider and amphipod are currently known, finding more occupied caves will be critical if the Kauai cave-dwelling arthropods are to be down- or delisted. If additional occupied caves are not discovered, increased emphasis should be placed on protecting and restoring caves that have good potential for supporting populations of one or both of these arthropods in the future.

3.8 Conduct studies for the translocation of Kauai cave arthropods to unoccupied caves, implement as appropriate.

Given the current, known distribution of the both Kauai cave wolf spider and Kauai cave amphipod, it is not possible to achieve the outlined downlisting or delisting criteria unless additional occupied caves are discovered or populations become established in currently unoccupied caves. It is possible that wolf spiders and amphipods will disperse into known caves once recovery actions are implemented. However, should the wolf spider and amphipod remain absent from caves where conditions appear to be optimal, biologists should consider establishing new populations in such cave systems via translocation. This is not a conservation activity that has received attention and should be pursued only after serious consideration involving a number of qualified biologists (*e.g*, those with expertise with cave animals and/or with carrying out translocations).

4. Conduct Public Outreach to Facilitate Better Public Understanding of and Support for Conservation of these Cave Arthropods.

The current plight of the obscure cave wolf spider and cave amphipod, and the ecosystem upon which they depend, is not commonly known to the residents of Koloa and Poipu. Effective outreach should contribute to public support for their conservation and serve to further inform local residents and businesses regarding their conservation needs, the regulatory requirements of the Endangered Species Act, and, very importantly, available recovery tools such as Safe Harbor Agreements, Habitat Conservation Plans, Federal funding through the Private Stewardship Grant Program and Recovery Land Acquisition Grant Program, and other voluntary actions that the landowners can take to conserve the species. Raising the level of awareness of endangered species issues at the community level is key to the success of the recovery of the cave wolf spider and cave amphipod.

5. Validate Recovery Objectives.

The scientific validity of the recovery objectives should be reviewed and downlisting and delisting criteria should be revised, as appropriate, as more information becomes available through monitoring and the adaptive management process proposed in Action 3.2.

6. Develop and Implement a Post-Delisting Monitoring Plan as Necessary.

A post-delisting monitoring plan will be finalized along with the delisting of the cave arthropods. Post-delisting monitoring will verify the ongoing recovery and conservation of the species and provide a means of assessing the continuing effectiveness of management actions.

Table 2 provides a cross-reference of recovery actions and listing factors.

Table 2. Cross-reference of recovery actions and listing factors for the Kauai cave wolf spider and the Kauai cave amphipod.

LISTING FACTOR	THREAT	STILL A THREAT	ACTION NUMBERS	RECOVERY CRITERIA
A - Present or threatened, destruction, modification, or curtailment of habitat or range.	Past, present, and future land modification due to agricultural practices, development, wildfire, and human visitation of caves	yes	1.1, 1.2 , 2.1, 2.2, 3.2, 4	1, 2, 3, 4
B - Overutilization for commercial, recreational, scientific, or educational purposes.	Not Applicable			
C - Disease or predation.	Non-native predators	yes	1.3, 2.2, 3.4, 3.6	1, 2, 3, 4
D - Inadequacy of existing regulatory mechanisms.	Not Applicable			
E - Other natural or manmade factors.	Pesticide, herbicide, and fungicide use, use of bio-control agents, and susceptibility to naturally occurring events such as storms or earthquakes	yes	1.2, 1.3, 1.4, 1.5, 3.1, 3.3, 3.4, 3.5, 3.7	1, 2, 3, 4

III. Implementation Schedule

The following Implementation Schedule outlines actions and estimated costs for the recovery of the Kauai cave arthropods and is a guide for meeting the objectives discussed in Part II of this plan. This schedule describes action priorities, action numbers, action descriptions, duration of actions, and the organizations involved and responsible for committing funds and estimated costs. When multiple organizations are listed as the responsible party, an asterisk is used to identify the lead entity.

The actions identified in the implementation schedule, when accomplished, should aid understanding of the current distribution and status of the Kauai cave arthropods, protect habitat for these species, stabilize the existing populations, and allow for an increase in population sizes and numbers.

A. RECOVERY ACTION PRIORITIES

The actions identified in the Implementation Schedule are those that in our opinion, are necessary to bring about the recovery of these species. However, the actions are subject to modification as dictated by new findings, changes in species status, and the completion of recovery actions. The priority for each action is given in the first column of the Implementation Schedule, and is assigned as follows:

Priority 1: An action that must be taken to prevent extinction or to prevent the species from declining irreversibly.

Priority 2: An action that must be taken to prevent a significant decline in the species' population or habitat quality, or to prevent some other significant negative impact short of extinction.

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

B. RESPONSIBLE PARTIES

In this table, we have identified agencies and other parties that we believe are primary stakeholders in the recovery process for the Kauai cave arthropods. Stakeholders are those agencies who may voluntarily participate in any aspect of implementation of particular actions listed within this recovery plan. Stakeholders may willingly participate in project planning, funding, provide technical assistance, staff time, or any other means of implementation. The list of potential stakeholders is not limited to the list below; other stakeholders are invited to participate. In some cases, the most logical lead agency (based on authorities, mandates, and capabilities) has been identified with an asterisk (*).

The listing of an agency in the Implementation Schedule does not require, nor imply a requirement or an agreement, that the identified agency implement that action(s) or secure funding for implementing an action(s). However, agencies willing to participate may benefit by being able to show in their own budgets that their funding request is for a recovery action identified in an approved recovery plan and is therefore considered a necessary action for the overall coordinated effort to recover these two species. Also, section 7(a)(1) of the Endangered Species Act (Act) directs all Federal agencies to utilize their authorities in furtherance of the purposes of the Act by carrying out programs for the conservation of threatened and endangered species.

We, the U.S. Fish and Wildlife Service, have the statutory responsibility for implementing this recovery plan. Only Federal agencies are mandated to take part in this effort. Recovery actions identified in this plan imply no legal obligations of the State and local government agencies or private landowners. However, the recovery of the Kauai cave wolf spider and the Kauai cave amphipod will require the involvement and cooperation of Federal, State, local, and private interests.

C. ACRONYM DEFINITIONS

C	An action that will be implemented on a routine basis once begun.
O	An action that is currently being implemented and will continue until action is no longer necessary.
DLNR	Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife
ES	U.S. Fish and Wildlife Service, Pacific Islands Fish and Wildlife Office, Honolulu, Hawaii
PL	Private Landowners
NRCS	U.S. Department of Agriculture, Natural Resource Conservation Service
BRD	U.S. Geological Survey, Biological Resources Division
BM	Bishop Museum
PNI	Participant not currently identified (academic, contractor, or other institution).
†	Indicates that some projects may have been completed or are in the process of being implemented
I	Total represents an estimate and actual costs may be higher.
*	Leading agency

Implementation Schedule for the Recovery Plan for the Kauai Cave Arthropods

Priority Number	Action Number	Action Description	Action Duration	Responsible Party	Total Cost Thru Year 20 ($1,000s)	Costs Estimates ($1,000s)					
						Year 1	Year 2	Year 3	Year 4	Year 5	Years 6-30
1	1.1	Protect the cave from unauthorized human entry.	O	ES*, PL	120†	20	20	20	20	20	20
1	1.2	Protect/enhance plant communities over caves, subterranean cracks, and mesocaverns.	O	ES*, PL, NRCS	814	160	200	160	140	120	34
1	1.3	Prevent new introductions of non-native predators and competitors an carry out management actions that eliminate or reduce the presence of non-native predators and competitors.	C	ES*, DLNR	45†	8	8	8	8	8	5
1	1.4	Prevent new introductions of bio-control organisms and bio-pesticides throughout the State of Hawaii.	C	ES*, DLNR	150	25	25	25	25	25	25
1	1.5	Prevent contamination of the cave from human-associated activities such as runoff and soil percolation of pollutants or other harmful chemicals including harmful pesticides.	C	ES*, PL*, DLNR	120	10	20	20	30	30	10
1	2.2	Maintain consistent high humidity within the Dark Zone and increase relative humidity within Stagnant Air Zones.	O	ES*, PL	21	5	5	3	3	3	2

Implementation Schedule for the Recovery Plan for the Kauai Cave Arthropods

Priority Number	Action Number	Action Description	Action Duration	Responsible Party	Total Cost Thru Year 20 ($1,000s)	Costs Estimates ($1,000s)					
						Year 1	Year 2	Year 3	Year 4	Year 5	Years 6-30
1	3.1	Continue biannual or more frequent monitoring to determine population trends in caves and assess recovery actions.	O	ES, PL	75	5	5	5	5	5	50
1	3.2	Evaluate research and monitoring results and implement adaptive management as necessary.	C	ES, PL*	60	10	10	10	10	10	10
1	3.7	Conduct surveys for additional occupied habitat or restorable cave habitat.	O	ES, DLNR*, PNI	64	12	12	10	10	10	10
2	2.1	Plant and maintain surface vegetation that will provide root systems for herbivorous and detritivorous cave dwellers with an abundant and sustainable food resource.	O	ES*, PL	45	10	10	7	7	7	4
3	3.3	Develop and conduct non-damaging mark-recapture studies to determine local population sizes and/or movement.	C	ES, BM*, BRD, PNI	220	40	40	40	40	40	20
3	3.4	Determine the most beneficial and appropriate plants to be used for habitat enhancement.	O	ES*, BRD, PNI	247	60	60	60	30	30	7

Implementation Schedule for the Recovery Plan for the Kauai Cave Arthropods

Priority Number	Action Number	Action Description	Action Duration	Responsible Party	Total Cost Thru Year 20 ($1,000s)	Costs Estimates ($1,000s)					
						Year 1	Year 2	Year 3	Year 4	Year 5	Years 6-30
3	3.5	Develop and utilize molecular techniques to determine the status of populations of amphipods (not to be conducted with the wolf spider until additional, healthy populations are discovered).	C	PNI	514	100	100	100	100	100	14
3	3.6	Conduct studies to determine if manipulation of cave climate can be used to improve habitat for the endangered cave animals and/or control non-native species.	O	ES*, PNI	312	60	60	60	60	60	12
3	3.8	Conduct studies for the translocation of Kauai cave arthropods to unoccupied caves, implement as appropriate.	10	ES, BM*, PNI	514	100	100	100	100	100	14
3	4	Conduct public outreach to facilitate better public understanding of and support for conservation of the cave animals.	O	ES*, PNI	54	10	10	10	10	10	4
3	5	Validate recovery objectives.	C	ES	60	10	10	10	10	10	10
3	6	Develop and implement a post-delisting monitoring plan as necessary.	6	ES	10	0	0	0	0	0	10
TOTAL COST TO RECOVERY					**3,445‡**	**645‡**	**695‡**	**648‡**	**608‡**	**588‡**	**261‡**

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C. PERSONAL COMMUNICATION

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APPENDIX A. RESPONSE TO COMMENTS ON THE DRAFT RECOVERY PLAN

We received two comment letters from the public on the draft recovery plan for the Kauai cave arthropods. The following issues are responses to these comments which were not otherwise responded to by directly incorporating changes into the text of the final recovery plan. The issues are organized by general subject matter.

EDITORIAL ISSUES

Issue: One commenter requested we refer to the cave animals as mesocavern animals and to identify the caves in accordance with the U.S. Board of Geographic Names.

Response: The cave names and the term cave animals have been used in other publications and we feel that it is still appropriate to refer to these areas and animals in that manner.

Issue: One commenter felt that the plan demeaned responsible cave users and that carrying capacities should be determined for each cave so that multiple users could access the caves.

Response: The plan describes impacts to the caves from unauthorized access by people. Since all the caves occur on private property any access to the caves must be granted by the landowner. If any landowner is interested in allowing access, the Service will be more than willing to discuss how to best implement such a plan with the landowner.

BIOLOGICAL ISSUES

Issue: One commenter felt that the plan improperly characterized the impact of collapsing lava tubes, that it increased habitat not decreased it, and that there was far more habitat than was identified in the plan. The commenter also felt that stagnant air zones did not provide appropriate habitat for the listed species.

Response: We feel the characterization of habitat described in the plan is appropriate and relies on the best scientific and commercial data available.

APPENDIX B. Endangered and Threatened Species Recovery Priority Number Guidelines*

Degree of Threat	Recovery Potential	Taxonomy	Conflict?†	Priority
High	High	Monotypic Genus	Yes	1C
			No	1
		Species	Yes	2C
			No	2
		Subspecies	Yes	3C
			No	3
	Low	Monotypic Genus	Yes	4C
			No	4
		Species	Yes	5C
			No	5
		Subspecies	Yes	6C
			No	6
Moderate	High	Monotypic Genus	Yes	7C
			No	7
		Species	Yes	8C
			No	8
		Subspecies	Yes	9C
			No	9
	Low	Monotypic Genus	Yes	10C
			No	10
		Species	Yes	11C
			No	11
		Subspecies	Yes	12C
			No	12
Low	High	Monotypic Genus	Yes	13C
			No	13
		Species	Yes	14C
			No	14
		Subspecies	Yes	15C
			No	15
	Low	Monotypic Genus	Yes	16C
			No	16
		Species	Yes	17C
			No	17
		Subspecies	Yes	18C
			No	18

* adapted from Listing and Recovery Priority Guidelines Federal Register 48:4309-43105
† priority is given to those species that are, or may be, in conflict with construction or other development projects or other forms of economic activity, designated by a "C" in the priority ranking system.

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