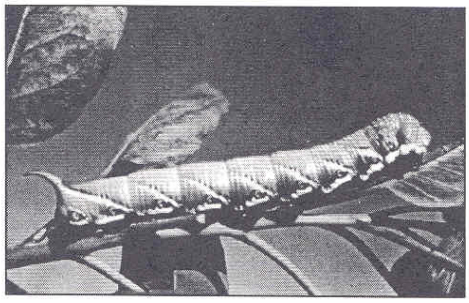
U.S. Fish & Wildlife Service

Draft Recovery Plan for the Blackburn's Sphinx Moth

(Manduca blackburni)



DRAFT RECOVERY PLAN

FOR THE

BLACKBURN'S SPHINX MOTH

(*Manduca blackburni*)

(October 2003)

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

Approved: XXXXXXXXXXXXXXXXXXXXXXXXXXXX
Regional Director, Region 1
U.S. Fish & Wildlife Service

Date: _____

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EXECUTIVE SUMMARY

Current Species Status: Blackburn's sphinx moth (*Manduca blackburni*) is federally listed as endangered. This taxon is currently known to occur on three of the seven major Hawaiian Islands. No known Blackburn's sphinx moth populations are entirely protected from the numerous factors threatening the species' recovery, and the moth is endangered throughout its range.

Habitat Requirements and Limiting Factors: Blackburn's sphinx moth is currently found in association with topographically diverse landscapes that contain low to moderate levels of non-native vegetation. Vegetation types that support Blackburn's sphinx moth include dry to mesic shrub land and forest from sea level to mid-elevations. Soil and climatic conditions, as well as physical factors, affect the suitability of habitat within the species' range. Impacts to the moth's habitat from urban and agricultural development, invasion by non-native plant species, habitat fragmentation and degradation, increased wildfire frequency, ungulates, and direct impacts to the moth from non-native parasitoids and insect predators have significantly reduced the species' range (A. Medeiros, U.S. Geological Survey-Biological Resource Division, pers. comm., 2001). Blackburn's sphinx moth is also susceptible to over-collection for personal collections or for trade. Needed conservation and recovery activities include protection, management, and restoration of habitat; out-planting of native *Nothocestrum* spp. (aiea) host plants; and a Blackburn's sphinx moth captive breeding or translocation program. This plan identifies 3 recovery units comprised of 13 management units which are geographic areas recently documented to contain Blackburn's sphinx moth populations and/or Blackburn's sphinx moth host plant populations and which shall be the focus of recovery actions. The 3 recovery units and their component management units contain habitat considered necessary for the long-term recovery of Blackburn's sphinx moth (*e.g.*, networks of suitable habitat patches and connecting lands).

Recovery Objectives: The overall objective of this recovery plan is to ensure the species' long-term conservation and to conduct research necessary to refine recovery criteria so that Blackburn's sphinx moth can be reclassified to threatened and eventually delisted. Interim goals include: (1) protect habitat known to

support extant populations and high-quality habitat known to have supported moth populations in the past; (2) stabilize moth populations within their known distributions; and (3) conduct research necessary to redefine recovery criteria. Reclassification is appropriate when a taxon is no longer in danger of extinction throughout a significant portion of its range. Because data upon which to base decisions about reclassification are incomplete for this species, downlisting and delisting criteria in this plan are preliminary.

Interim Downlisting Criteria: One Blackburn's sphinx moth population on each island of Hawaii, Kahoolawe, and Maui must be well-distributed, naturally reproducing, and stable or increasing in size through one to two El Niño events or for at least 5 consecutive years before downlisting is considered. Stable Blackburn's sphinx moth populations are defined in this recovery plan as those in which observed population declines are followed by a population increase to pre-decline levels. These criteria should provide for the maintenance of genetic variation that occurs in natural populations of Blackburn's sphinx moth by protecting all known, natural populations and the habitats upon which they rely. Furthermore, these criteria should provide some assurance that a single catastrophic event will not destroy all populations of this species. More specific downlisting criteria can be developed when completion of some of the recovery actions provides necessary information on the life history and ecology of this species and its host plants.

Interim Delisting Criteria: Before delisting of Blackburn's sphinx moth can be considered, all of the following three requirements must be met: (1) one population of the moth must be naturally reproducing and stable or increasing in size, through one to two El Niño events or a minimum of 5 consecutive years within the Kauai-Oahu Recovery Unit; (2) four populations of the moth must be naturally reproducing and stable or increasing in size, through one to two El Niño events or a minimum of 5 consecutive years on three different islands within the Maui Nui Recovery Unit (of those four, one within windward and one within leeward Maui Island); and (3) two populations of the moth must be naturally reproducing and stable or increasing in size, through one to two El Niño events or a minimum of 5 consecutive years within the Big Island (Hawaii Island) Recovery Unit. More specific delisting criteria can be developed when

completion of some of the recovery actions provides necessary information on the life history and ecology of this species and its host plants.

Specific Actions Needed:

1. Protect habitat and control threats.
2. Expand existing wild *Nothocestrum* spp. host plant populations.
3. Conduct additional research essential to recovery of Blackburn's sphinx moth.
4. Develop and implement a detailed monitoring plan for Blackburn's sphinx moth.
5. Reestablish wild Blackburn's sphinx moth populations within its historic range.
6. Develop and initiate a public information program for Blackburn's sphinx moth.
7. Validate recovery objectives.

Total Estimated Cost to Recovery ($1,000.'s):

Year	Need 1	Need 2	Need 3	Need 4	Need 5	Need 6	Need 7	Total
FY 1	930	0	35	200	0	15	5	**1,185**
FY 2	945	75	50	200	90	5	5	**1,370**
FY 3	920	75	50	0	90	1	5	**1,141**
FY 4	356	60	20	0	0	1	5	**442**
FY 5	356	60	20	0	0	1	5	**442**
FY 6	356	60	20	0	0	1	5	**442**
Total	**4,415**	**330**	**195**	**400**	**180**	**24**	**30**	**5,574**

Recovery Costs: $5,574,000. Some actions (*e.g.*, habitat protection) will benefit multiple listed species in addition to Blackburn's sphinx moth, so their costs are not wholly attributable to this species. Total estimated cost to recovery may be revised when completion of some of the recovery actions provides necessary information about Blackburn's sphinx moth and their biological requirements.

Date of Recovery: Downlisting could be initiated in 2008 if one Blackburn's sphinx moth population on each island of Hawaii, Kahoolawe, and Maui is well-

distributed, naturally reproducing, and stable or increasing in size through one to two El Niño events or for at least 5 consecutive years. A delisting and recovery date will be determined when additional information on the life history of Blackburn's sphinx moth is known.

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I. INTRODUCTION

A. BRIEF OVERVIEW

The final rule determining Federal endangered status for the Blackburn's sphinx moth (*Manduca blackburni*) was published in the February 1, 2000, *Federal Register* (U.S. Fish and Wildlife Service 2000) (a detailed explanation of this rule-making process for the Blackburn sphinx moth is given under the section entitled Conservation Measures, below). The recovery priority number for Blackburn's sphinx moth is 2C, per criteria published in the *Federal Register* on September 21, 1983 (U.S. Fish and Wildlife Service 1983). The priority is based on its being a full species (rather than a subspecies) with a high degree of threat, a high to moderate potential for recovery, and existing conflict between the species' recovery and development.

Population numbers are not known, but Blackburn's sphinx moth is believed to have declined over the past 100 years, probably as a result of habitat loss and mortality from non-native predators and parasitoids. This taxon is currently known to occur on three of the seven Hawaiian Islands where it historically occurred, including Hawaii, Maui, and Kahoolawe. Although some habitats are under public ownership and zoned for conservation purposes, no known Blackburn's sphinx moth-occupied habitat areas or populations are entirely protected, and the species is endangered throughout its range. The primary threats to the moth now include predation by ants and parasitic wasps that prey on the eggs and caterpillars, and the continued decline of its native larval host plants partly as a result of feral ungulates. Like other showy macro-Lepidoptera, Blackburn's sphinx moth is also susceptible to over-collection for personal collections or for trade.

Blackburn's sphinx moth is the only federally listed insect in the State of Hawaii. Relatively little research has been conducted on this species of sphinx moth, and the data regarding its habitat affinities and population status are lacking. As a result, the delisting and downlisting criteria in this recovery plan are interim in nature and will be revised as additional information is gathered on the Blackburn sphinx moth. The recovery actions in this plan emphasize: habitat

restoration, management, and protection; reestablishment of Blackburn sphinx moth populations within its historic range; and research.

B. SPECIES DESCRIPTION

The Blackburn's sphinx moth (moth) is one of Hawaii's largest native insects, with a wingspan of up to 12 centimeters (5 inches) (Figure 1). Like other sphinx moths in the family Sphingidae, it has long, narrow forewings, and a thick, spindle-shaped body tapered at both ends. It is grayish brown in color, with black bands across the apical (top) margins of the hind wings, and five orange spots along each side of the abdomen. The larva is a typical, large "hornworm" caterpillar, with a spine-like process on the dorsal (upper) surface of the eighth abdominal segment (Figure 2). Caterpillars occur in two color forms, a bright green or a grayish form. This variation in color does not appear until the fifth instar (the fifth stage between molts) (E. Van Gelder, U.S. Geological Survey-Biological Resources Division, and S. Conant, University of Hawaii, *in litt*., 1998). Both color forms have scattered white speckles throughout the dorsum (back), with the lateral (side) margin of each segment bearing a horizontal white stripe, and segments four to seven bearing diagonal stripes on the lateral margins (Betsy Gagné, Hawaii Department of Land and Natural Resources, pers. comm., 1998; Zimmerman 1958).

The moth is closely related to the tomato hornworm (*Manduca quinquemaculata*) and has been confused with this species. The moth was described by Butler (1880) as *Protoparce blackburni*, and named in honor of the Reverend Thomas Blackburn who collected the first specimens. It was later believed to be the same species as the tomato hornworm (*Sphinx celeus* Hubner = *Sphinx quinquemaculatus* Hawthorn) by Meyrick (1899), and then treated as a subspecies (Rothschild and Jordan 1903, as cited by Riotte 1986) and placed in the genus *Phlegethontius* (Zimmerman 1958). Riotte (1986) demonstrated Blackburn's sphinx moth is a distinct taxon in the genus *Manduca*, native to the Hawaiian Islands, and reinstated it as a full species, *Manduca blackburni*. D'Abrera (1986) tentatively considered *Manduca blackburni* to be a synonym of *Manduca quinquemaculata*, but subsequent authors (Howarth and Mull 1992; Nishida 1994) have disagreed with this view, and the findings of Riotte (1986) are

Figure 1. Photograph of Blackburn's sphinx moth adult, used with permission of Betsy Gagné.

Figure 2. Photograph of Blackburn's sphinx moth larvae, used with permission of Betsy Gagné.

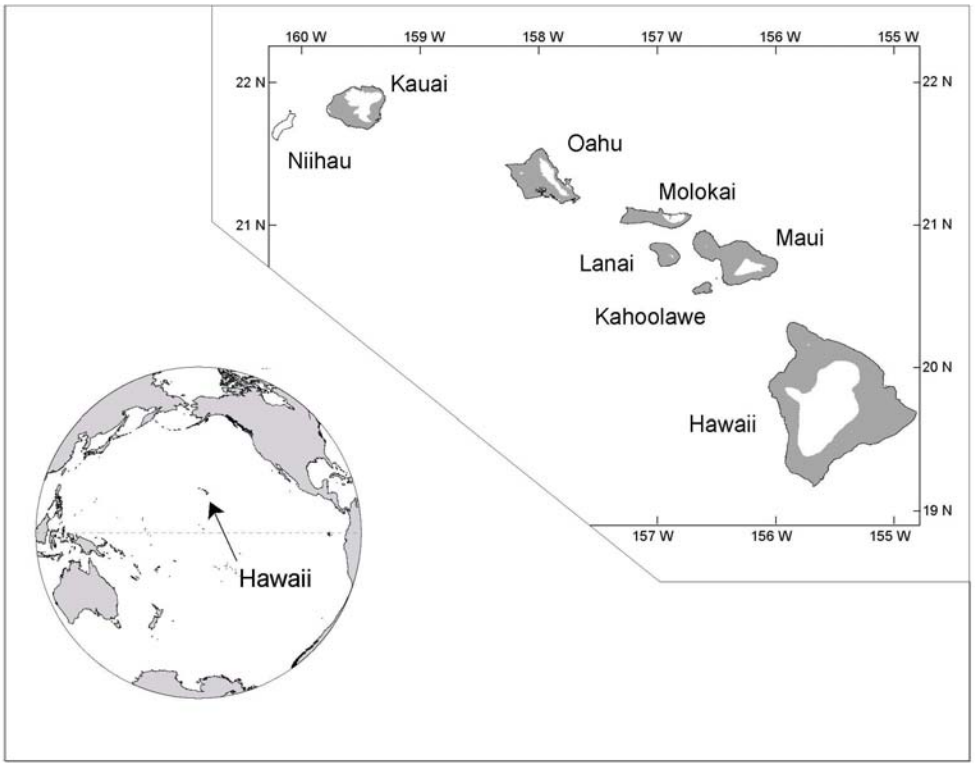
accepted. Several different common names have also been used for this species, including the tomato hawkmoth (Swezey 1924), tobacco hornworm (Browne 1941), the Hawaiian tobacco worm (Swezey 1931; Timberlake *et al.* 1921), the Hawaiian tomato hornworm (Fullaway and Krauss 1945; Zimmerman 1958), the Blackburn hawkmoth (Hawaiian Entomological Society 1990; Howarth and Mull 1992), and Blackburn's sphinx moth. The name Blackburn's sphinx moth is used here.

In Hawaii, Blackburn's sphinx moth can be confused with the related sweet potato hornworm (*Herse cingulata*), although the adult Blackburn's sphinx moth can be distinguished by orange rather than pink dorsal abdominal spots, with black borders on both the front and back margins of each segment, and a broader, marginal black band on the hind wing. The larval Blackburn's sphinx moth differ from those of the tomato hornworm and tobacco hornworm by having two dark longitudinal stripes on the head capsule, although this is not always the case. Stripes are usually apparent in the grey larval morph but not always in the green larval morph (E. Van Gelder and S. Conant, *in litt*., 1998).

C. BIO-GEOGRAPHICAL OVERVIEW

The Hawaiian archipelago includes large volcanic islands as well as the numerous shoals and atolls of the northwestern Hawaiian Islands. The main Hawaiian Islands include Hawaii, Maui, Kahoolawe, Lanai, Molokai, Oahu, Kauai, and Niihau (Figure 3). The islands were formed sequentially by basaltic lava that emerged from a hot spot in the earth's crust located near the current southeastern coast of the island of Hawaii (Stearns 1985). It is widely accepted that the native flora and fauna of the Hawaiian Islands arrived by wind and ocean currents, as passengers on or inside other organisms, or as in the case of some fauna, on their own power, to evolve over the course of millions of years into one of the most highly speciated and diverse natural environments found anywhere in the world (Wagner and Funk 1995). Below, we provide brief geographical descriptions of the Hawaiian Islands discussed in this draft recovery plan.

Figure 3. The position of the main Hawaiian islands and the chain within the Pacific Ocean.



Hawaii

The island of Hawaii is the largest, highest, and youngest of the eight major islands, and it has an area of 10,458 square kilometers (4,038 square miles). It was formed by five, interconnected shield volcanoes (Hualalai, Mauna Kea, Mauna Loa, Kilauea, and Kohala Mountains) (shield volcanoes are characterized by a broadly rounded, dome-shaped profile). The Kohala Mountains, at the northeastern portion of the island, are the oldest and reach an elevation of about 1,344 meters (4,408 feet) above sea level. Mauna Kea volcano rises to 4,204 meters (13,792 feet) (Department of Geography 1998) and is inter-connected with Mauna Loa by an extensive saddle. Hualalai volcano, located on the western side of the island, rises to an elevation of 2,520 meters (8,269 feet). The two active volcanoes on the island, Mauna Loa and Kilauea, have elevations of 4,168 meters (13,674 feet) and 1,247 meters (4,093 feet), respectively.

Hawaii lies within the trade wind belt (Mueller-Dombois 1985), and moisture derived from the Pacific Ocean is carried to the island by north-easterly trade winds. Heavy rains fall when moist air is driven upward by windward mountain slopes (Wagner *et al.* 1999). Considerable moisture reaches the lower leeward slopes of the saddle, but these slopes dry out rapidly as elevation increases. Thus, the leeward and saddle areas of Mauna Kea and Mauna Loa tend to be dry.

Maui

Maui, the second largest island in Hawaii at 1,888 square kilometers (729 square miles) area, was formed by the eruptions of 2 large shield volcanoes, the older West Maui volcano on the west side, and the larger, but much younger, Haleakala volcano to the east. Stream erosion has cut deep valleys and ridges into the originally shield-shaped West Maui volcano. The highest point on West Maui is Puu Kukui at 1,764 meters (5,788 feet) elevation, which has an average rainfall of 1,020 centimeters (400 inches) per year, making it the second wettest spot in Hawaii (Department of Geography 1998). East Maui's Haleakala Mountain, reaching 3,055 meters (10,023 feet) in elevation, has retained its classic shield shape with the most recent eruptions occurring in the last 220 years on the

southeastern slopes. Rainfall on the slopes of Haleakala is extremely variable, with its windward (northeastern) slope receiving the most precipitation.

Geologically, Maui is part of the four-island complex comprising Maui, Molokai, Lanai, and Kahoolawe, known collectively as Maui Nui. During the last Ice Age about 12,000 years ago when sea levels were about 160 meters (525 feet) below their present level, it is possible the four islands were connected by a broad lowland plain (Department of Geography 1998). This land bridge may have allowed the movement and interaction of the islands' flora and fauna and contributed to the close relationships of their biota of present (Hobdy 1993).

Kahoolawe

The island of Kahoolawe comprises some 117 square kilometers (45 square miles). Located in the lee of Haleakala, the island lies approximately 11 kilometers (6.7 miles) from East Maui. The highest point is the rim of an extinct volcano at 450 meters (1,477 feet) above sea level (Department of Geography 1998). The estimated annual precipitation is approximately 50 centimeters (20 inches), with most of it falling from November through March. In addition to the low precipitation, Kahoolawe has the highest mean wind velocity of the Hawaiian Islands (Department of Geography 1998).

Cattle from an early cattle industry and feral goats (*Capra hircus*) largely denuded the island beginning in the 1800's. Kahoolawe was later utilized as a military bombing target from 1941 through the 1980's. Current restoration work and erosion control have been hampered by an ongoing program to safely locate and dispose of unexploded ordnance on the island.

Molokai

The island of Molokai, the fifth largest in the Hawaiian Islands chain, encompasses an area of about 689 square kilometers (266 square miles) (Department of Geography 1998). Three shield volcanoes make up most of the land mass of Molokai: West Molokai Mountain, East Molokai Mountain, and a volcano which formed Kalaupapa Peninsula (Department of Geography 1998).

The East Molokai Mountains rise 1,515 meters (4,970 feet) above sea level and comprise roughly 50 percent of the island's area (Department of Geography 1998). Topographically, the windward side of East Molokai differs from the leeward side. Precipitous cliffs line the northern windward coast and deep inaccessible valleys dissect the coastal area. The annual rainfall on the windward side ranges from 190 to 380 centimeters (75 to 150 inches) or more, distributed throughout the year. The soils are poorly drained and high in organic matter. Much of the native vegetation on the northern part of East Molokai is intact because of its relative inaccessibility to humans and non-native animals, although feral ungulates have begun to access some of these areas in recent years (Department of Geography 1998).

Lanai

Lanai is a small island totaling about 360 square kilometers (139 square miles) in area. Blocked from the trade winds in the lee or rain shadow of the more massive West Maui Mountains, Lanai was formed from a single shield volcano built by eruptions at its summit and along three rift zones. The principal rift zone runs in a northwesterly direction and forms a broad ridge whose highest point, Lanaihale, has an elevation of 1,027 meters (3,370 feet) (Department of Geography 1998). Annual rainfall on the summit of Lanaihale is 76 to 102 centimeters (30 to 40 inches), but only measures 25 to 50 centimeters (10 to 20 inches) over much of the rest of the island (Department of Geography 1998).

Oahu

The island of Oahu is the second oldest of the main Hawaiian Islands, and is the third largest with a total land area of 1,546 square kilometers (597 square miles). The island was formed by two shield volcanoes, now the Koolau and Waianae Mountain Ranges. The tallest point on the island is Mount Kaala within the Waianae Range, which reaches an elevation of 1,020 meters (4,003 feet). The two mountain ranges are separated by a large, upland plain and a lowland, emergent, coastal plain. The highest precipitation on the island falls on the windward side of the Koolau Mountains, approximately 635 centimeters (250 inches) annually. Other parts of the island vary from extremely dry to mesic.

Approximately 80 percent of the State's population resides on Oahu (Department of Geography 1998).

Kauai

The island of Kauai is the oldest of the main Hawaiian Islands and its geologic age is reflected in its greatly sculpted and eroded topography. Its land area is 1,430 square kilometers (552 square miles) and it reaches a maximum height on Kawaikini at 1,598 meters (5,243 feet). Mount Waialeale is the wettest spot in the Hawaiian Islands and annually receives 1,128 cm (444 inches) of rain. The island was formed by one large shield volcano approximately 5 million years ago, and the interior mountains have been highly eroded to form large canyons within the Waimea region and precipitous cliffs on the northern Na Pali Coast. Many areas of Kauai still contain significant stands of native vegetation, in dry, mesic areas (medium-moisture supply), and in wetter areas (Department of Geography 1998).

D. BLACKBURN'S SPHINX MOTH BIOLOGY, DISTRIBUTION, AND STATUS

Very few specimens of the moth had been seen since 1940, and after a concerted effort by staff at the Bishop Museum to relocate this species in the late 1970's, it was considered to be extinct (Gagné and Howarth 1985). In 1984, a single population was rediscovered on Maui (Riotte 1986), and subsequently, populations on two other islands were rediscovered. Currently it is known only from populations on Maui, Kahoolawe, and Hawaii. Moth population numbers are known to be small based upon past sampling results, however, no reasonably accurate estimate of population sizes have been determinable at this point due to the adult moths' wide-ranging behavior and its overall rarity (A. Medeiros, U.S. Geological Survey-Biological Resources Division, pers. comm., 1998; E. Van Gelder and S. Conant, *in litt*., 1998). Before humans arrived, dry and mesic shrub land and forest covered about 823,283 hectares (2,034,369 acres) on all the main islands (Hawaii Natural Heritage Program, *in litt*., 2000), and it is likely the moth inhabited much of that area (Riotte 1986). Reports by early naturalists indicate the

species was once widespread and abundant, at least during European settlement on nearly all the main Hawaiian Islands (Riotte 1986).

The moth has been recorded from the islands of Kauai, Kahoolawe, Oahu, Molokai, Maui, and Hawaii (Figure 4), and has been observed from sea level to 1,525 meters (5,000 feet) elevation. Most historical records were from coastal or lowland dry forest habitats in areas receiving less than 127 centimeters (50 inches) annual rainfall. On the island of Kauai, the moth was recorded only from the coastal area of Nawiliwili. Populations were known from Honolulu, Honouliuli, and Makua on leeward Oahu, and Kamalo, Mapulehu, and Keopu on Molokai. On Hawaii, it was known from Hilo, Pahala, Kalaoa, Kona, and Hamakua. It appears this moth was historically most common on Maui, where it was recorded from Kahului, Spreckelsville, Makena, Wailuku, Kula, Lahaina, and West Maui. Historical records are lacking for the island of Kahoolawe. The moth has been observed there only in very recent years during biological surveys conducted for various restoration activities on the island.

Sphingid moths in general are known to exploit nutritious but low-density, low-apparency host plants such as vines and sapling trees (Kitching and Cadiou 2000). Larvae of the Blackburn's sphinx moth feed on plants in the nightshade family (Solanaceae). The native host plants are trees within the genus *Nothocestrum* (aiea) (Riotte 1986), on which the larvae consume leaves, stems, flowers, and buds (B. Gagné, Hawaii Department of Land and Natural Resources, pers. comm., 1994). However, many of the host plants recorded for this species are not native to the Hawaiian Islands, and include *Nicotiana tabacum* (commercial tobacco), *Nicotiana glauca* (tree tobacco), *Solanum melongena* (eggplant), *Lycopersicon esculentum* (tomato), and possibly *Datura stramonium* (Jimson weed) (Riotte 1986). Documented larval Blackburn's sphinx moth host plant observations are summarized below in Table 1.

In general, sphingid moths can develop from egg to adult in as little as 56 days (Williams 1947), but pupae may remain in a state of torpor (inactivity) in the soil for up to a year (B. Gagné, pers. comm., 1994; Williams 1931). Adult sphingid moths have been found throughout the year (Riotte 1986) and are known to feed on nectar. In general, sphingids are known to live longer than most moths

Figure 4. Current and historic distribution of Blackburn's sphinx moth and host plant species**.**

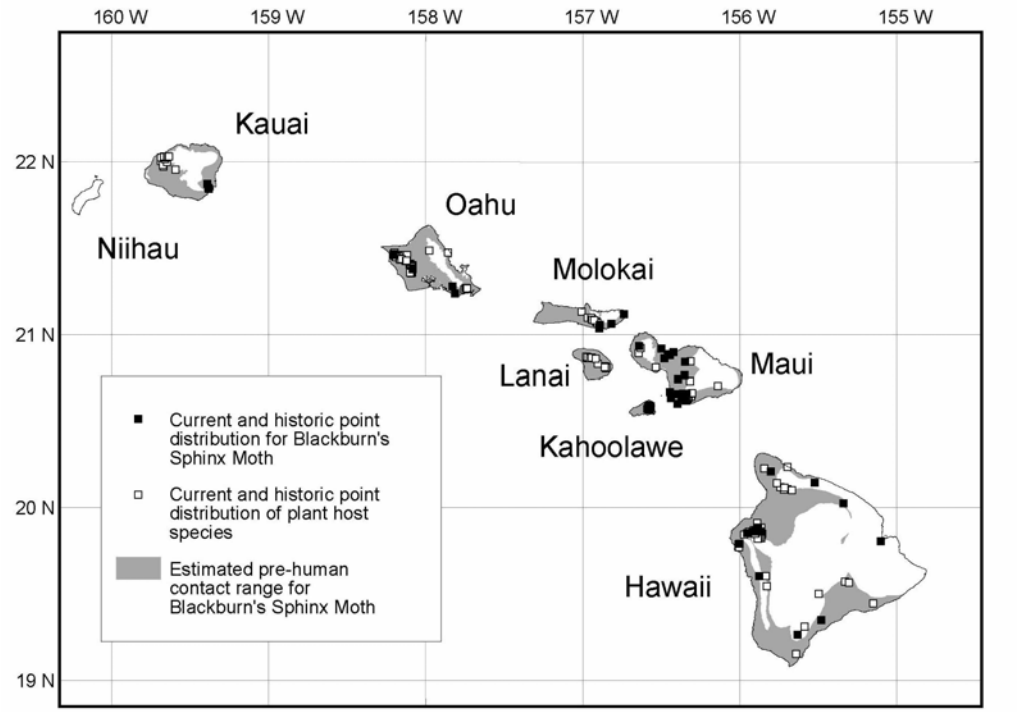


Table 1. Documented larval Blackburn's sphinx moth host plant observations.

Host Plant	# of Observations
* *Nothocestrum latifolium* (aiea)	numerous
* *Nothocestrum breviflorum* (aiea)	numerous
* *Solanum* spp. (native shrub)	once
Lycopersicon esculentum (tomato)	twice
Nicotiana glauca (tree tobacco)	numerous
Solanum melongena (egg plant)	twice
Nicotiana tabacum (commercial tobacco)	numerous

* native to Hawaiian Islands

because of their ability to feed and take in water from a variety of sources, rather than relying only upon stored fat reserves. Because they live longer than most moths, female sphingid moths have less time pressure to mate and lay eggs, and often will take more time in locating the best host plants for egg laying (Kitching and Cadiou 2000).

In their 1998 study, Van Gelder and Conant never observed Blackburn's sphinx moth adults feeding or attempting to feed on artificial flowers or natural *Ipomea* spp. (native morning glory) flowers within their enclosures, and captive-reared adult moths lived no longer than 12 days. However, two field observations of feeding Blackburn's sphinx moth adults have been made, one within the Kanaio Beach area of southeast Maui, where Blackburn's sphinx moth adults were documented to be feeding upon the nectar of the native Hawaiian morning glory species, *Ipomea indica* (D. Hopper, U.S. Fish and Wildlife Service, *in litt*., 1997). The second observation was made in the upper Kanaio Natural Area Reserve where a single Blackburn's sphinx moth adult was also documented to be feeding upon the nectar of *I. indica* (D. Hopper, U. S. Fish and Wildlife Service, *in litt*., 2002). It is expected the native Hawaiian species of caper, *Capparis sandwichiana* and *Plumbago zeylanica* are also likely native adult Blackburn's sphinx moth food sources. All three species, *C. sandwichiana, P. zeylanica*, and *I. indica* bear flowers which possess some characters suggestive of moth

pollination, including nocturnal anthesis (opening at night), light coloration, or the emittance of strong fragrances (*C. sandwichiana*) upon opening. Notable differences in proboscis length between the sexes ranging from 14 to 38 millimeters (6 to 15 inches) have been documented (E. Van Gelder and S. Conant, *in litt*., 1998). If further research demonstrates the validity of this potential characteristic of Blackburn's sphinx moth sexual dimorphism, the difference may indicate a division of adult foraging resources in the wild.

Blackburn's sphinx moth larvae sightings have only been documented between the months of October and May, but adult moths have been found throughout the year (Riotte 1986). During 14 surveys conducted between August 15, 1996 and May 29, 1997, Van Gelder and Conant (in litt., 1998) noted the presence of eggs on host plants and substantial variation in larval length throughout the Blackburn's sphinx moth "season." Van Gelder and Conant (in litt., 1998) hypothesized that Blackburn's sphinx moth either produce eggs during more than one generation each "season," or produce eggs during a single generation with an extended adult emergence time and/or laying period of several weeks.

E. BLACKBURN'S SPHINX MOTH HABITAT

Plant species composition in the moth's habitat varies considerably depending on location and elevation, but some of the most common native plants in areas where the moth occur are *Diospyros sandwicensis* (lama) trees, *Rauvolfia sandwicensis* (hao) trees, *Reynoldsia sandwicensis* (ohe) trees, *Pouteria sandwicensis* (alaa, aulu, elaa, or kaulu) trees, *Dodonaea viscosa* (aalii) shrubs, *Erythrina sandwicensis* (wiliwili), and *Myoporum sandwicense* (naio) shrubs (Cabin *et al.* 2000; G. Roderick, University of California, Berkeley, and R. Gillespie, University of California, Berkeley, *in litt*., 1997; E. Van Gelder, and S. Conant, *in litt*., 1998; Wagner *et al.* 1999; K. Wood, National Botanical Garden, Kauai, *in litt*., 2001a, b).

The largest populations of Blackburn's sphinx moths, on Maui and Hawaii, are associated with trees in the genus *Nothocestrum* (E. Van Gelder and S. Conant, *in litt*., 1998). For example, the large stand of *Nothocestrum* trees within the

Kanaio Natural Area Reserve, Maui, is likely the largest in the State (A. C. Medeiros, U.S. Geological Survey-Biological Resources Division, *et al.*, *in litt*., 1993), and may explain why the moth occurs with such regularity in the Kanaio area (A. Medeiros, U.S. Geological Survey-Biological Resources Division, pers. comm., 1994). *Nothocestrum* is a genus of four species endemic to the Hawaiian Islands (Symon 1999). *Nothocestrum* species currently occur on Kauai, Oahu, Molokai, Lanai, Hawaii, and Maui. One species, *N. longifolium*, primarily occurs in wet forests, but can occur in mesic forests as well. Three species, *N. latifolium, N. breviflorum*, and *N. peltatum*, occur in dry to mesic forests, the habitat in which the moth has been most frequently recorded. Moth larvae have been documented feeding on two *Nothocestrum* species, *N. latifolium* and *N. breviflorum*; it is likely that *N. peltatum* and *N. longifolium* are suitable host plants for larval moths as well. This is supported not only by the fact that they are closely related to known larval hosts, but also because there are past historical records of the moth occurring on the islands of Kauai and Oahu, where *N. latifolium* is not abundant and *N. breviflorum* does not occur. Furthermore, the species is known to feed on a variety of native and non-native Solanaceae.

On Molokai, moth habitat includes vegetation consisting primarily of mixed-species, mesic and dry forest communities composed of native and introduced plants (Hawaii Natural Heritage Program, *in litt*., 2000). Although Molokai is not known to currently contain a moth population, past moth sightings on Molokai have been reported and the island does contain native *Nothocestrum* larval host plants, including *N. longifolium* and *N. latifolium*, as well as adult host plants and restorable, manageable areas associated with these existing host plants (K. Wood, *in litt*., 2001a). Because of its proximity to Maui (home to the most persistent and largest population) and the fact that Molokai supports large stands of *N. latifolium*, researchers believe the moth could re-establish itself on the island and become a viable population(s) in the future (F. G. Howarth, Bishop Museum, pers. comm., 2001).

The federally endangered larval host plant, *Nothocestrum breviflorum*, as well as adult host plants occur in the areas on Hawaii Island supporting populations of the moth (M. Bruegmann, U. S. Fish and Wildlife Service, pers. comm., 1998) and there are many recorded associations of eggs, larvae, and adult

moths with this plant species. This tree species is primarily threatened by habitat conversion associated with development; competition from non-native species such as *Schinus terebinthifolius* (Christmas berry), *Pennisetum setaceum* (fountain grass), *Lantana camara* (lantana), and *Leucaena leucocephala* (haole koa); browsing by cattle; fire; random environmental events such as prolonged drought; and reduced reproductive potential due to the small number of existing individuals (U.S. Fish and Wildlife Service 1994a).

Although *Nothocestrum* species are not currently reported from Kahoolawe, there were very few surveys of this island prior to the intense ranching activities, which began in the middle of the 19th century, and the subsequent use of the island as a weapons range for 50 years. Prior to their removal, goats also played a major role in the destruction of vegetation on Kahoolawe (Cuddihy and Stone 1990). It is likely the reappearance of some vegetation as a result of the removal of the goats and the cessation of military bombing activities has allowed the moth to inhabit the island. On Kahoolawe, moth larvae feed on the non-native *Nicotiana glauca*, which appears to support development of the larval stage during non-drought years. However, the native *Nothocestrum* are more stable and drought-resistant than the *Nicotiana glauca*, which dies back significantly during especially dry years (A. Medeiros, pers. comm., 2001). Therefore, it appears likely that long-term survival of the moth on Kahoolawe will require the planting of *Nothocestrum latifolium* (A. Medeiros, pers. comm., 1998).

F. THREATS TO THE RECOVERY OF BLACKBURN'S SPHINX MOTH

1. Habitat Loss and Degradation

Dry to mesic forest habitats in Hawaii have been severely degraded due to past and present land management practices including ranching, the impacts of introduced plants and animals, wildfire, and agricultural development (Cuddihy and Stone 1990). Due to these factors, *Nothocestrum peltatum* on Kauai and *N. breviflorum* on Hawaii are now federally listed as endangered species (published in the *Federal Register* on February 25, 1994 (U.S. Fish and Wildlife Service 1994b) and March 4, 1994 (U.S. Fish and Wildlife Service 1994a) respectively).

Although all *Nothocestrum* species are not presently listed as endangered or threatened, the entire genus is declining and considered uncommon (Hawaii Natural Heritage Program, *in litt*., 2000; A.C. Medeiros *et al.*, *in litt*., 1993). For example, while *Nothocestrum latifolium* presently occurs at moderate densities at Kanaio Natural Area Reserve (Hawaii Natural Heritage Program, *in litt*., 1993), there has been a complete lack of seedling survival (A.C. Medeiros *et al.*, *in litt*., 1993) and the stand is being degraded by goats (A.C. Medeiros *et al.*, *in litt*., 1993; F. G. Howarth, Bishop Museum, pers. comm., 1994; S. Montgomery, Bishop Museum, pers. comm., 1994). Goats have played a major role in the destruction of dryland and mesic forests throughout the Hawaiian Islands (Stone 1985; van Riper and van Riper 1982).

Before humans arrived, dry to mesic shrub land and forest covered about 823,283 hectares (2,034,369 acres) on all the main islands (Hawaii Natural Heritage Program, *in litt*., 2000), and it is likely Blackburn's sphinx moth inhabited much of that area (Riotte 1986). Reports by early naturalists indicate the species was once widespread and abundant on nearly all the main Hawaiian Islands during European settlement (Riotte 1986). Because the moth was once so widespread and sphinx moths are known to be strong fliers, we believe it is likely inter-island dispersal of the species occurred to some degree prior to the loss of much of its historical habitat. Currently, the areas of dry to mesic shrub and forest habitats below 1,525 meters (5,000 feet) that are, or could potentially be, suitable for Blackburn's sphinx moth are approximately 148,588 hectares (367,161 acres). Thus it appears the moth's range has declined on the order of 82 percent since humans arrived in Hawaii 1,600 years ago (Hawaii Natural Heritage Program, *in litt*., 2000; Kirch 1982).

Figures 5 through 12, illustrate the probable range of Blackburn's sphinx moth habitat prior to human arrival between the elevations of sea level and 1,500 meters (5,000 feet) (shaded areas) and proposed recovery and management units on seven Hawaiian islands.

2. Localized Extirpation

In addition to, or perhaps because of, habitat loss and fragmentation, Blackburn's sphinx moths are also susceptible to seasonal variations and weather

Figure 5. Three proposed recovery units on seven Hawaiian islands.

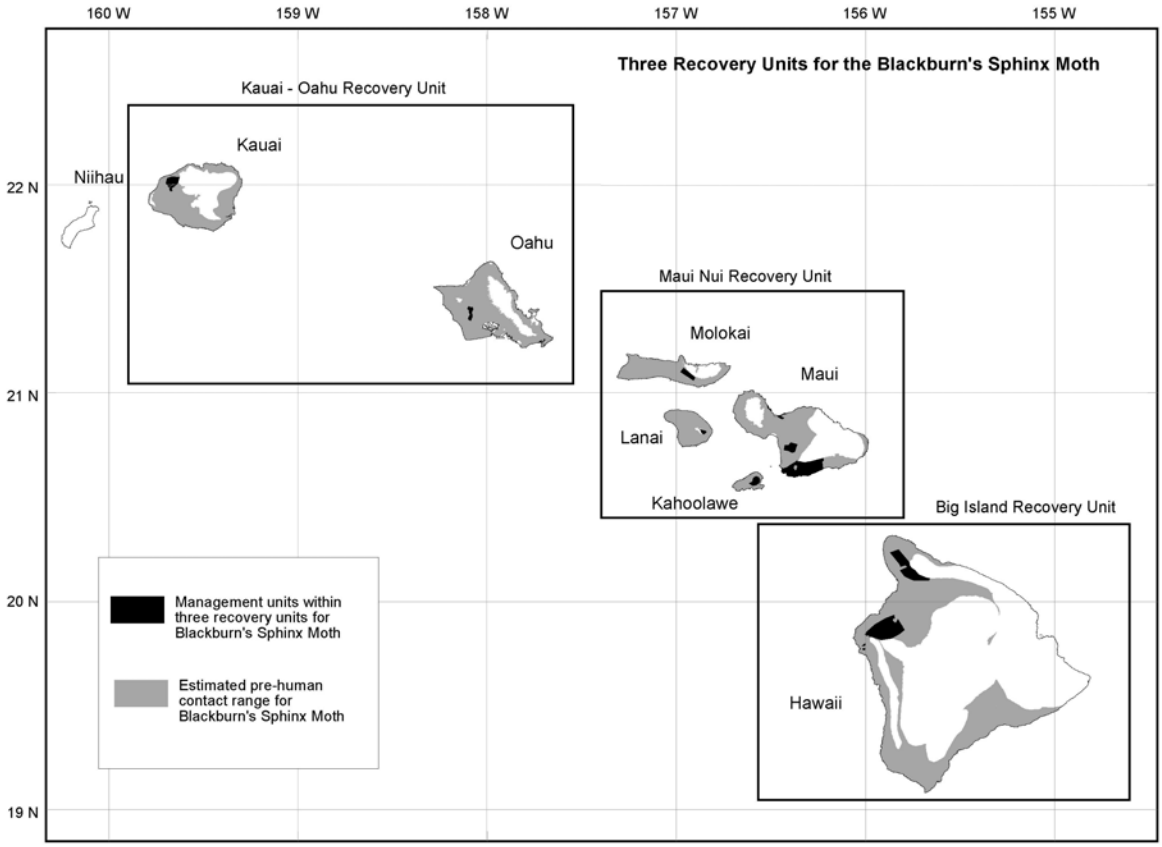


Figure 6. Historic distribution of Blackburn's sphinx moth habitat and proposed management unit on Kauai.

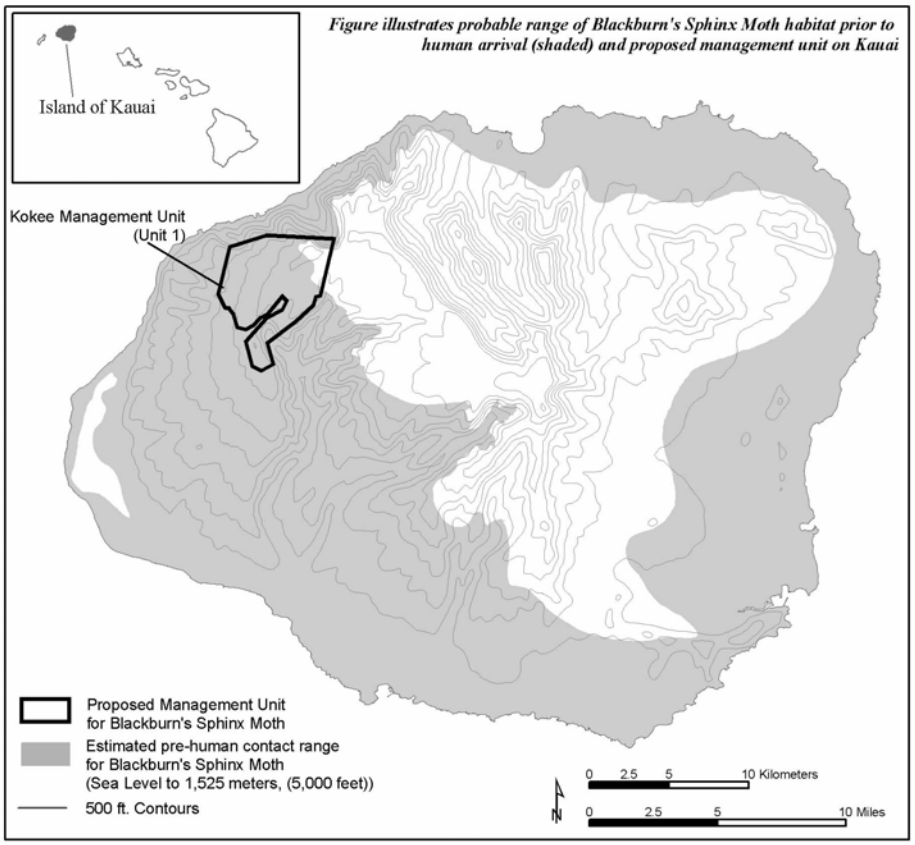


Figure 7. Historic distribution of Blackburn's sphinx moth habitat and proposed management unit on Oahu.

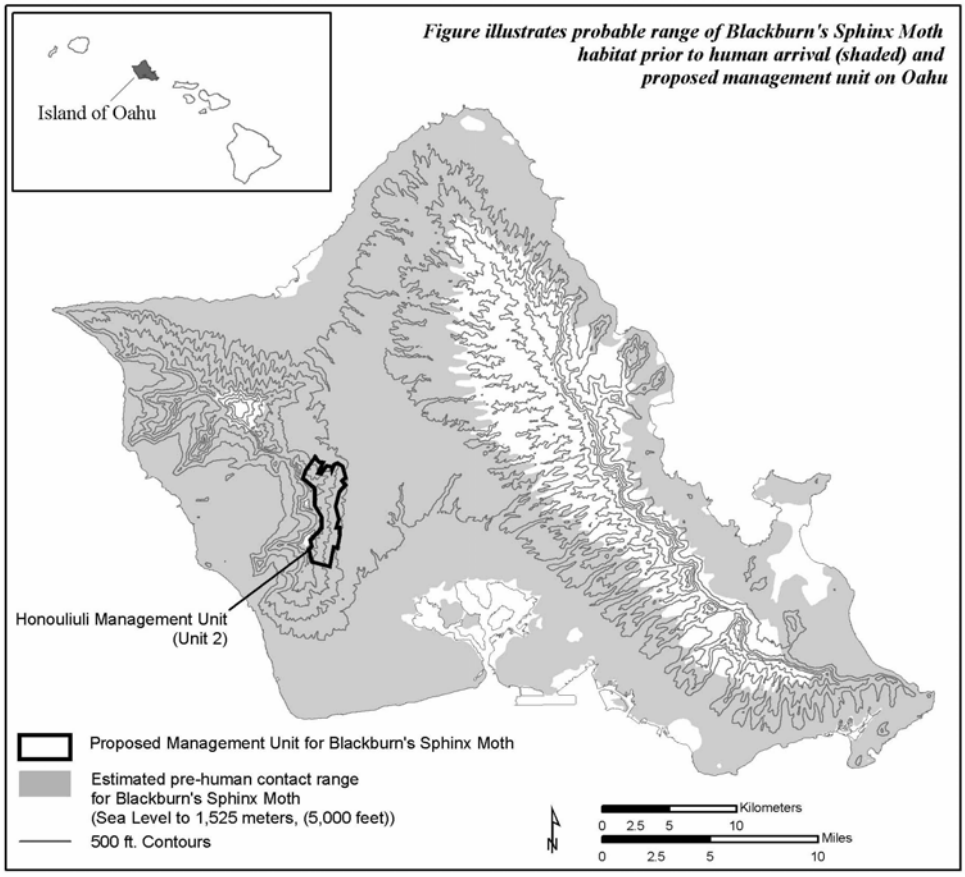


Figure 8. Historic distribution of Blackburn's sphinx moth habitat and proposed management units on Maui.

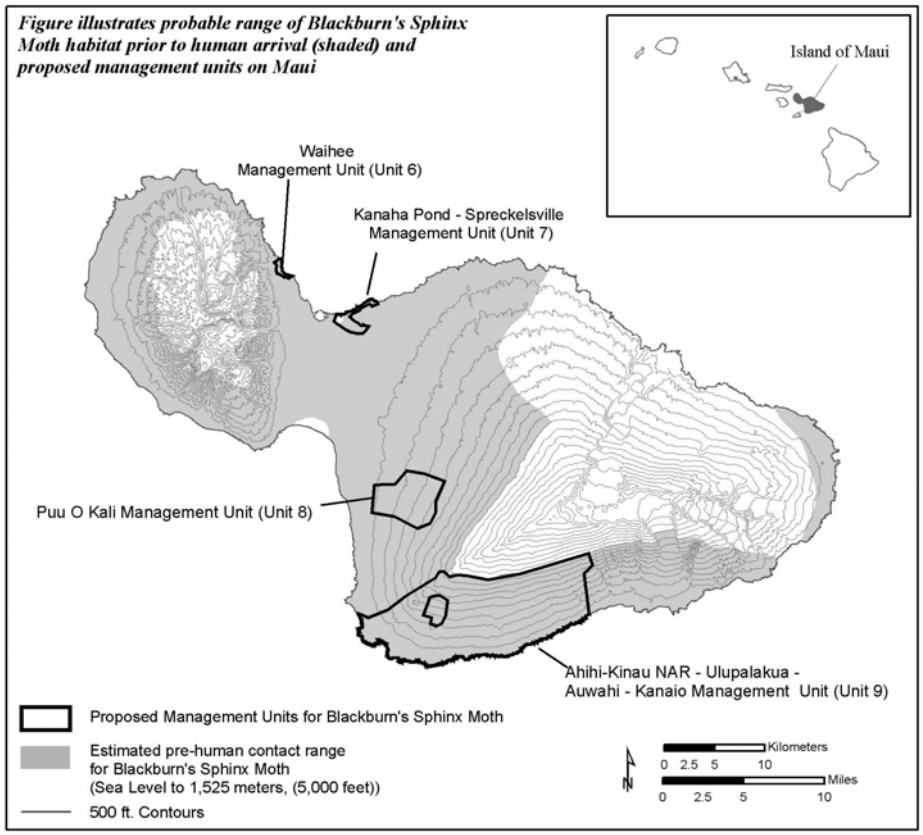


Figure 9. Historic distribution of Blackburn's sphinx moth habitat and proposed management unit on Molokai.

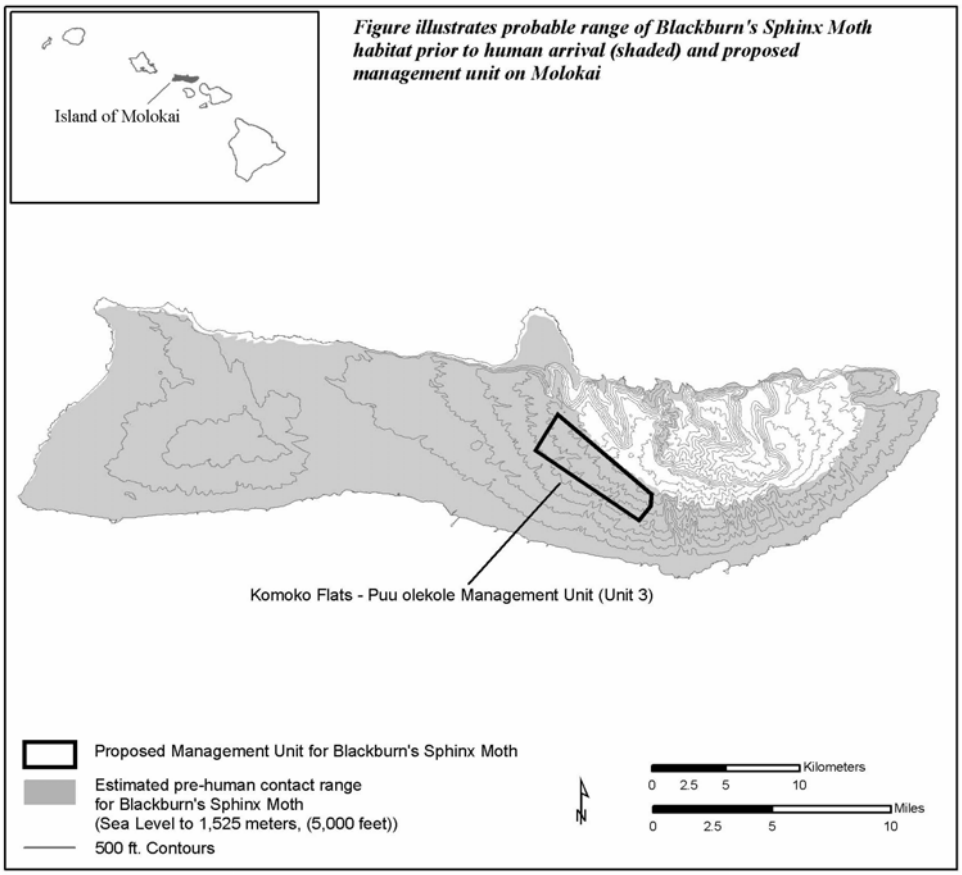


Figure 10. Historic distribution of Blackburn's sphinx moth habitat and proposed management unit on Lanai.

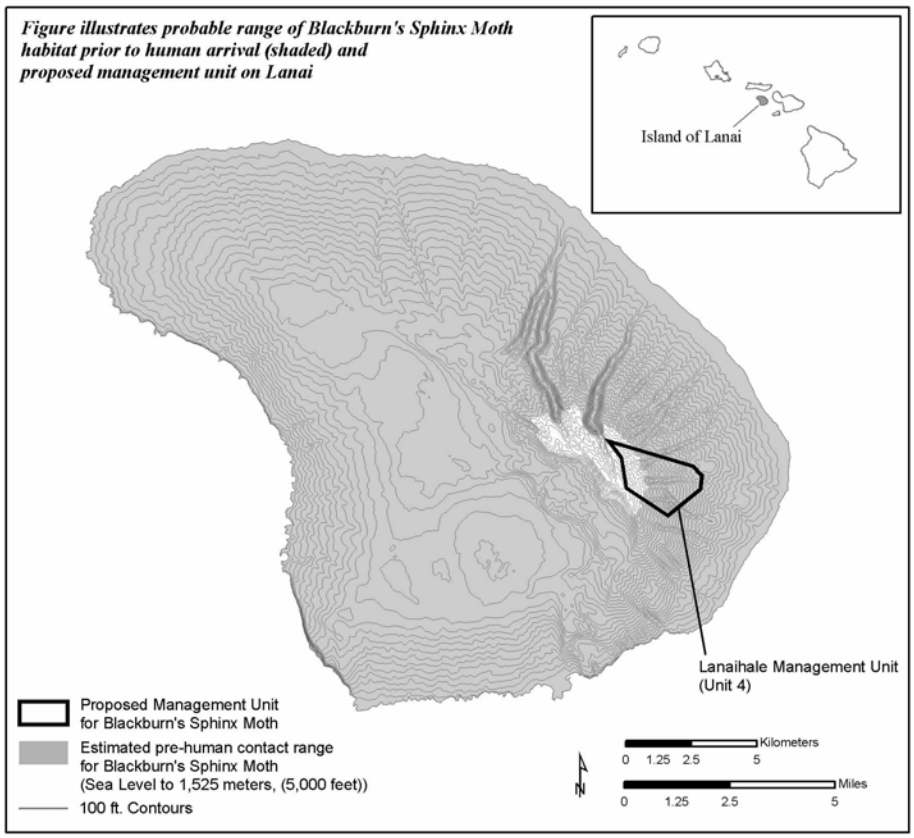


Figure 11. Historic distribution of Blackburn's sphinx moth habitat and proposed management unit on Kahoolawe.

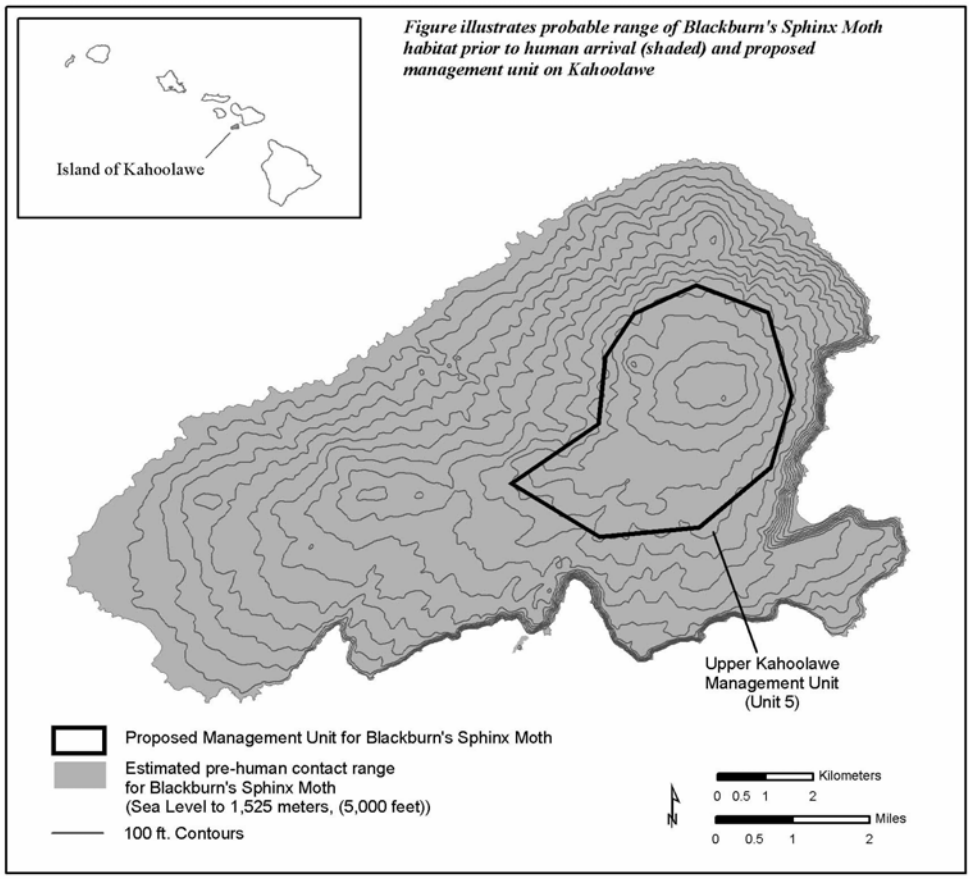
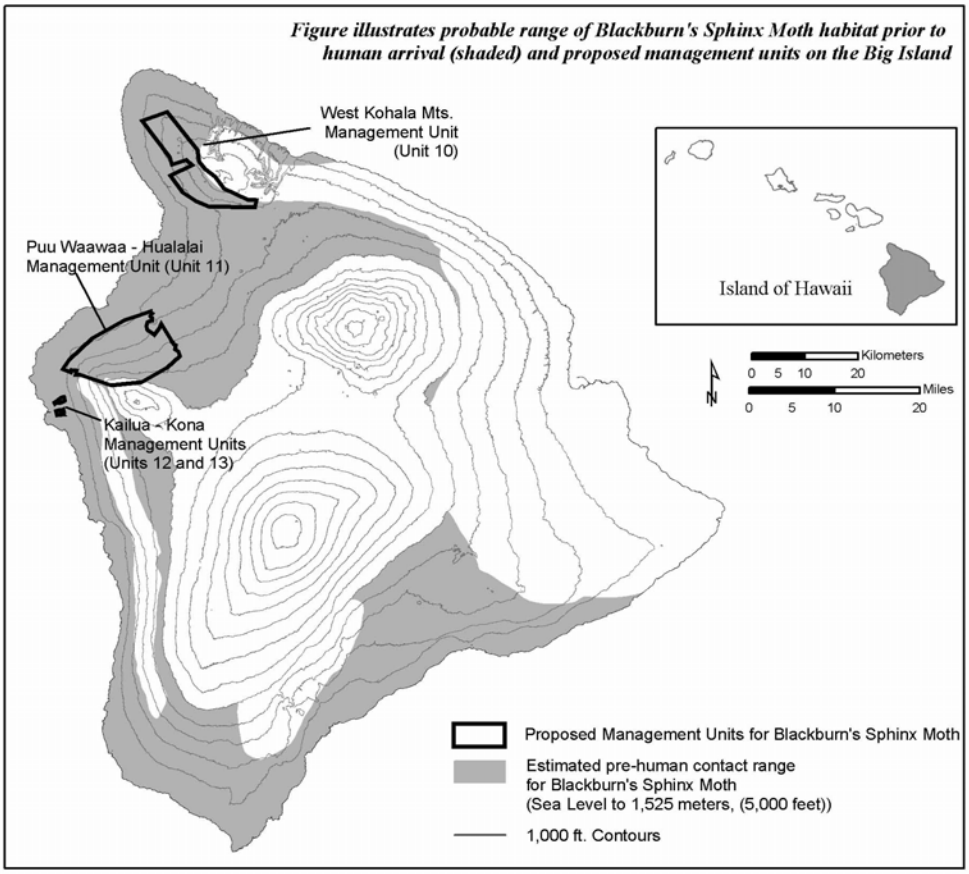


Figure 12. Historic distribution of Blackburn's sphinx moth habitat and proposed management units on Hawaii.



fluctuations affecting their quality and quantity of available habitat and food. For example, during times of drought, it is expected nectar availability for adult moths will decrease. During times of decreased nectar availability, life spans of individuals may not be affected, but studies with butterflies have shown marked decreases in reproductive capacity for many species (Center for Conservation Biology Update 1994). In another study, Janzen (1984) reported that host plant availability directly affected sphingid reproductive activity. In fact, for some lepidopteran (butterflies and moths) species, if nectar intake is cut in half, reproduction is also cut approximately in half. Such resource stress may occur on any time scale, ranging from a few days to an entire season, and a pattern of continuous long-term adult feeding stress could affect the future viability of a population (Center for Conservation Biology Update 1994).

Often, habitat suitability for herbivorous insects is determined by factors other than host plant occurrence or density. Microclimatic conditions (Thomas 1991; Solbreck 1995) and predator pressure (Roland 1993; Roland and Taylor 1995; Walde 1995) are two such widely reported factors. In a study of moth population structure, habitat patch size and the level of sun exposure were shown to affect species occupancy, while patch size and the distance from the ocean coast were reported to affect moth density (Forare and Solbreck 1997). Moth populations in small habitat patches were more likely to become extinct (Forare and Solbreck 1997).

3. Vandalism (Through Collection)

Rare butterflies and moths are highly prized by collectors and an international trade exists for insect specimens which are sought for both live and decorative markets, as well as the specialist trade that supplies hobbyists, collectors, and researchers (Morris *et al.* 1991; Williams 1996). The specialist trade differs from both the live and decorative market in that it concentrates on rare and threatened species (U.S. Department of Justice, *in litt*., 1993). In general, the rarer the species, the more valuable it is and prices may exceed U.S. $2,000 for rare specimens (Morris *et al.* 1991). For example, during a 4-year investigation, we executed warrants and seized over 30,000 endangered and/or protected butterflies and beetles with a wholesale commercial market value of about U.S.

$90,000. The defendant, who was convicted, sold these rare butterflies and beetles in malls and state fairs (United States Department of Justice, *in litt*., 1993). In another case, of the approximately 2,375 butterflies seized, at least 13 species were protected under the Endangered Species Act, and another 130 species were protected on lands administered by the Department of Interior (United States Department of Justice, *in litt*., 1993). The three men involved were convicted of poaching and commercial trade of butterflies protected under the Endangered Species Act (Williams 1996).

Sphinx moths, in general, are sought by collectors and as early as the 1950s there was a standing reward for specimens of another rare Hawaiian sphinx moth (*Tinostoma smargditis*) (Zimmerman 1958). Specimens of Blackburn's sphinx moth have already been secured and traded by collectors and institutions (D. Preston, Bishop Museum, pers. comm., 1994). There are unconfirmed reports that specimens of Blackburn's sphinx moth from the Maui site have appeared on the collection market (A. Medeiros, pers. comm., 1998). The federally listed status of this species may have increased its attractiveness to collectors (United States Department of Justice, *in litt*., 1993) and may have likely increased the threat of un-permitted collecting. Unrestricted collecting and handling for scientific purposes are known to impact populations of other species of rare Lepidoptera (Murphy 1988), and are considered significant threats to Blackburn's sphinx moth. Because of the high value accorded such rarities, field collectors often take all individuals available (Morris *et al.* 1991). Even limited collection from the small populations of Blackburn's sphinx moth could have deleterious effects on its reproductive and/or genetic viability and significantly contribute to the eventual extinction of this species.

4. Non-native Arthropods

The geographic isolation of the Hawaiian Islands restricted the number of original successful colonizing arthropods and resulted in the development of an unusual fauna. Only 15 percent of the known insect families are represented by the native insects of Hawaii (Howarth 1990). Some groups that often dominate continental arthropod faunas, such as social Hymenoptera (group-nesting ants, bees, and wasps), are entirely absent from the native Hawaiian fauna. Accidental

introductions from commercial shipping and air cargo to Hawaii have now resulted in the establishment of over 2,500 species of alien arthropods (Howarth 1990; F.G. Howarth, Bishop Museum, *et al.*, *in litt*., 1994), with a continuing establishment rate of 10 to 20 new species per year (Nishida 1997). In addition to the accidental establishment of non-native species, private individuals and government agencies began importing and releasing non-native predators and parasites for biological control of pests as early as 1865. This resulted in the introduction of 243 non-native species between 1890 and 1985, in some cases with the specific intent of reducing populations of native Hawaiian insects (Funasaki *et al.* 1988; Lai 1988). Alien arthropods, whether purposefully introduced or accidental, pose a serious threat to Hawaii's native insects, through direct predation, parasitism, and competition for food or space (Howarth and Medeiros 1989; Howarth and Ramsay 1991).

Ants:

Ants, family Formicidae within the order Hymenoptera, are not a natural component of Hawaii's arthropod fauna, and native species evolved in the absence of predation pressure from ants. Ants can be particularly destructive predators because of their high densities, recruitment behavior, aggressiveness, and broad range of diet (Reimer 1993). Because they are generalist feeders, ants may affect prey populations independent of prey density, and may locate and destroy isolated individuals and populations (Nafus 1993a). At least 36 species of ants are known to be established in the Hawaiian Islands, and at least 3 particularly aggressive species have severely affected the native insect fauna (Zimmerman 1948). Most ant species have winged reproductive adults and once established anywhere in the State, they are likely to colonize suitable habitats on all islands in time.

By the late 1870s, the big-headed ant (*Pheidole megacephala*) was present in Hawaii and its predation on native insects was noted by Perkins (1913) who stated, "it may be said that no native Hawaiian Coleoptera insect can resist this predator, and it is practically useless to attempt to collect where it is well established. Just on the limits of its range one may occasionally meet with a few native beetles, *e.g.*, species of *Plagithmysus*, often with these ants attached to their legs and bodies, but sooner or later they are quite exterminated from these localities."

With few exceptions, in Hawaiian habitats where the big-headed ant is present, native insects, including most moths, are eliminated (Gagné 1979; Gillespie and Reimer 1993; Perkins 1913). The big-headed ant generally does not occur at elevations higher than 600 meters (2,000 feet), and is also restricted by rainfall, rarely being found in particularly dry (less than 35 to 50 centimeters (15 to 20 inches) annually) or wet areas (more than 250 centimeters (100 inches) annually) (Reimer *et al.* 1990). The big-headed ant is also known to be a predator of eggs and caterpillars of native Lepidoptera, and can completely exterminate populations (Zimmerman 1958). This ant occurs at all of the Maui Blackburn's sphinx moth management units and is a direct threat to these populations (A.C. Medeiros *et al.*, *in litt*., 1993). Big-headed ants also occur on Kahoolawe and Hawaii (A. Medeiros, pers. comm., 1998).

The Argentine ant (*Iridomyrmex humilis*) was discovered on the island of Oahu in 1940 (Zimmerman 1941) and is now established on all seven islands. Unlike the big-headed ant, the Argentine ant is primarily confined to elevations higher than 500 meters (1,600 feet) in areas of moderate rainfall (Reimer *et al.* 1990). This species can reduce populations or even eliminate native arthropods at high elevations in Haleakala National Park on Maui (Cole *et al.* 1992). On Maui, within 16 kilometers (10 miles) of the largest Blackburn's sphinx moth population, Argentine ants are significant predators on pest fruit flies (Wong *et al.* 1984). Argentine ants have also been reported on the islands of Kahoolawe and Hawaii (A. Asquith, U. S. Fish and Wildlife Service, pers. comm., 1998; A. Medeiros, pers. comm., 1998).

The long-legged ant (*Anoplolepis longipes*) appeared in the State in 1952 and now occurs on Oahu, Maui, and Hawaii (Reimer *et al.* 1990). It inhabits elevations under 600 meters (2,000 feet), in rocky areas with low to high annual rainfall (Reimer *et al.* 1990). Direct observations indicate that Hawaiian arthropods are susceptible to predation by this species (Gillespie and Reimer 1993) and Hardy (1979) documented the disappearance of most native insects from Pua'alu'u in the Kipahulu District on Maui after the area was invaded by the long-legged ant.

At least two species of fire ants, *Solenopsis geminata* and *S. papuana*, are also significant threats (Gillespie and Reimer 1993; Reagan 1986) and occur on all of the seven islands (Reimer *et al.* 1990). Ants, including the fire ant, *S. geminata*, are known to be the most signficant and consistent mortality factor on eggs, and probably larvae, of the butterfly *Hypolimnas bolina* (common eggfly) in Guam, even where both predator and prey are native (Nafus 1993a, 1993b). *Solenopsis geminata* occurs in both the two, large Maui Blackburn's sphinx moth management units (A. Medeiros, pers. comm., 1998). *Solenopsis geminita* is also known to be a significant predator on pest fruit flies in Hawaii (Wong and Wong 1988). *Solenopsis papuana* is the only abundant, aggressive ant that has invaded intact mesic forest above 600 meters (2,000 feet) and is still expanding its range in Hawaii (Reimer 1993).

Ochetellus glaber (No Common Name), a recently reported ant introduction, occurs in the same habitat utilized on Kahoolawe by Blackburn's sphinx moth (A. Medeiros, pers. comm., 1998). *Ochetellus glaber* has been found in relatively high numbers foraging on shrubs of *Nicotiana* spp. where Blackburn's sphinx moth eggs and larvae occur. In one instance, large numbers of *O. glaber* were observed emerging from a dead Blackburn's sphinx moth larvae they had either predated or scavenged (A. Medeiros, pers. comm., 1998). During the same study on Kahoolawe, Medeiros noted a large proportion of tagged Blackburn's sphinx moth eggs disappeared without hatching, potentially indicating high egg predation most likely by ants, but perhaps dislodged by birds or by high winds (A. Medeiros, pers. comm., 1998).

Parasitic Wasps:

Hawaii also has a limited fauna of native Hymenoptera wasp species, with only two native species in the family Braconidae (Beardsley 1961), neither of which are known to parasitize Blackburn's sphinx moth. In contrast, other species of Braconidae are common predators (parasitoids) on the larvae of the tobacco hornworm and the tomato hornworm in North America (Gilmore 1938). There are now at least 74 non-native species, in 41 genera, of braconid wasps established in Hawaii, of which at least 35 species were purposefully introduced as biological control agents (Nishida 1997). Most species of alien braconid and ichneumonid

wasps that parasitize moths are not host-specific, but attack the caterpillars or pupae of a variety of moths (Funasaki *et al.* 1988; Zimmerman 1948, 1978) and have become the dominant larval parasitoids even in intact, high-elevation, native forest areas of the Hawaiian Islands (F.G. Howarth *et al.*, *in litt*., 1994; Zimmerman 1948). These wasps lay their eggs within the eggs or caterpillars of Lepidoptera. Upon hatching, the wasp larvae consume internal tissues, eventually killing the host. At least one species established in Hawaii, *Hyposoter exiguae* (No Common Name), is known to attack the tobacco hornworm and the related tomato hornworm in North America (Carlson 1979). This wasp is recorded from all seven islands except Kahoolawe and Lanai (Nishida 1997) and is a recorded parasitoid of the lawn armyworm (*Spodoptera maurita*) on tree tobacco on Maui (Swezey 1927). Because of the rarity of Blackburn's sphinx moth, no documentation exists of alien braconid and ichneumonid wasps parasitizing the species. However, given the abundance and the breadth of available hosts of these wasps, they are considered significant threats to the moth (Gagné and Howarth 1985; Howarth 1983; Howarth *et al.*, *in litt*., 1994; F. G. Howarth, pers. comm., 1994).

Small wasps in the family Trichogrammatidae parasitize insect eggs, with numerous adults sometimes developing within a single host egg. The taxonomy of this group is confusing, and it is unclear if Hawaii has any native species from this family (Nishida 1997; J. Beardsley, University of Hawaii, pers. comm., 1994). Several alien species are established in Hawaii (Nishida 1997), including *Trichogramma minutum* (No Common Name), which is known to attack the sweet potato hornworm in Hawaii (Fullaway and Krauss 1945). In 1929, the wasp *Trichogramma chilonis* (No Common Name) was purposefully introduced into Hawaii as a biological control agent for the Asiatic rice borer (*Chilo suppressalis*) (Funasaki *et al.* 1988). This wasp parasitizes the eggs of a variety of Lepidoptera in Hawaii, including sphinx moths (Funasaki *et al.* 1988). Williams (1947) found 70 percent of the eggs of Blackburn's sphinx moth to be parasitized by a *Trichogramma* wasp that was probably *Trichogramma chilonis*. Over 80 percent of the eggs of the alien grass webworm (*Herpetogramma licarsisalis*) in Hawaii are parasitized by these wasps (Davis 1969). In Guam, *Trichogramma chilonis* effectively limits populations of the sweet potato hornworm (Nafus and Schreiner 1986), and the sweet potato hornworm is considered under complete biological

control by this wasp in Hawaii (Lai 1988). While this wasp probably affects Blackburn's sphinx moth in a density-dependent manner (Nafus 1993a), and theoretically is unlikely to directly cause extinction of a population or the species, the availability of more abundant, alternate hosts (any other lepidopteran eggs) may allow for the extirpation of Blackburn's sphinx moth by this or other egg parasites as part of a broader host base (Howarth 1991; Nafus 1993b; Tothill *et al.* 1930).

Parasitic Flies:

Hawaii has no native parasitic flies in the family Tachinidae (Nishida 1997). Two species of tachinid flies, *Lespesia archippivora* and *Chaetogaedia monticola*, were purposefully introduced to Hawaii for control of army worms (Funasaki *et al.* 1988; Nishida 1997). These flies lay their eggs externally on caterpillars, and upon hatching, the larvae burrow into the host, attach to the inside surface of the cuticle, and consume the soft tissues (Etchegaray and Nishida 1975b). In North America, *Chaetogaedia monticola* is known to attack at least 36 species of Lepidoptera in 8 families, including sphinx moths; *Lespesia archippivora* is known to attack over 60 species of Lepidoptera in 13 families, including sphinx moths (Arnaud 1978). These species are on record as parasites of a variety of Lepidoptera in Hawaii and are believed to depress populations of at least two native species of moths (Lai 1988). Over 40 percent of the caterpillars of the monarch butterfly (*Danaus plexippus*) on Oahu are parasitized by *Lespesia archippivora* (Etchegaray and Nishida 1975a) and the introduction of a related species to Fiji resulted in the extinction of a native moth there (Howarth 1991; Tothill *et al.* 1930). Both of these species occur on Maui and Hawaii (Nishida 1997) and are direct threats to Blackburn's sphinx moth.

Based on the findings discussed above, non-native predatory and parasitic insects are considered significant factors contributing to the reduction in range and abundance of Blackburn's sphinx moth, and in combination with habitat loss and fragmentation, are a serious threat to its continued existence. Some of these non-native species were intentionally introduced by the State of Hawaii's Department of Agriculture or other agricultural agencies (Funasaki *et al.* 1988) and importations and augmentations of lepidopteran parasitoids continues. Although

the State of Hawaii requires new introductions be reviewed before release (Hawaii State Department of Agriculture, *in litt*., 1994), post-release biology and host range cannot be predicted from laboratory studies (Gonzalez and Gilstrap 1992; Roderick 1992) and the purposeful release or augmentation of any lepidopteran predator or parasitoid is a potential threat to the recovery of Blackburn's sphinx moth (Gagné and Howarth 1985; Simberloff 1992).

As Table 2 indicates, the assemblage of potential alien predators and parasites on each island may differ. Furthermore, the arthropod community may differ from area to area even on the same island based upon elevation, temperature, prevailing wind pattern, precipitation, or other factors (Nishida 1997). Conserving and/or restoring moth populations in multiple locations should decrease the likelihood that the effect of any single alien parasite or predator or combined pressure of such species could result in the diminished vigor or extinction of the moth.

Tables 3 through 5 present the various Blackburn's sphinx moth predators, parasites, and competitors as documented by E. Van Gelder and S. Conant's 1998 study.

5. Inadequacy of Existing Regulatory Mechanisms

Alien predatory and parasitic insects are significant factors contributing to the reduction in Blackburn's sphinx moth abundance, and may be the most serious current, direct threat to its continued existence. Some of these alien species were intentionally introduced by the State of Hawaii's Department of Agriculture or other agricultural agencies (Funasaki *et al.* 1988) and importations and augmentations of lepidopteran parasitoids is still a potential threat. Federal regulations for the introductions of biological control agents have not adequately protected this species (Lockwood 1993). Presently, there are no Federal statutes requiring review of biological control agents before their introduction, and the limited Federal review process requires consideration of potential harm only to economically important species (Miller and Aplet 1993). Although the State of Hawaii requires pre-release review of new introductions (Hawaii Division of Forestry and Wildlife, Hawaii Revised Statues Chapter150A), post-release biology

Table 2. Some of the potential non-native insect predators and parasites of Blackburn's sphinx moth.

Order / Family	**Genus / Species:**	**Islands on which the species has been reported:**	**Island(s) on which the species has not been reported:**
Diptera Tachinidae	*Chaetogaedia monticola* (Tachinid fly)	Hawaii, Kauai, Lanai, Maui, Molokai, Oahu	Kahoolawe
Diptera Tachinidae	Lespesia archippivora (Tachinid fly)	Hawaii, Kauai, Maui, Molokai, Oahu	Kahoolawe, Lanai
Hymenoptera Formicidae	*Anoplolepis longipes* (long-legged ant)	Hawaii, Kauai, Maui, Oahu	Kahoolawe, Lanai, Molokai
Hymenoptera Formicidae	*Linepithema humilis* (Argentine ant)	Hawaii, Kahoolawe, Kauai, Lanai, Maui	Molokai, Oahu
Hymenoptera Formicidae	*Ochetellus glaber* (No Common Name)	Hawaii, Kahoolawe, Kauai, Maui, Oahu	Lanai, Molokai
Hymenoptera Formicidae	*Pheidole megacephala* (big-headed ant)	Hawaii, Kahoolawe, Kauai, Lanai, Maui, Molokai, Oahu	----------
Hymenoptera Formicidae	*Solenopsis geminita* (fire ant species)	Hawaii, Kauai, Lanai, Maui, Molokai, Oahu	Kahoolawe
Hymenoptera Formicidae	*Solenopsis papuana* (fire ant species)	Hawaii, Kauai, Lanai, Maui, Molokai, Oahu	Kahoolawe
Hymenoptera Vespidae	*Vespula pennsylvanica* (yellow jacket wasp)	Hawaii, Kauai, Maui, Oahu	Kahoolawe, Molokai, Lanai
Hymenoptera Ichneumonidae	*Hyposoter exiguae* (No Common Name)	Hawaii, Kauai, Maui, Molokai, Oahu	Kahoolawe, Lanai
Hymenoptera Trichogrammatidae	*Trichogramma chilonis* (No Common Name)	Kauai, Oahu	Hawaii, Maui, Kahoolawe, Lanai, Molokai
Hymenoptera Trichogrammatidae	*Trichogramma minutum* (No Common Name)	Hawaii, Lanai, Molokai, Oahu	Kauai, Kahoolawe, Maui

Table 3. Known Blackburn's sphinx moth predators.

Common Name	Scientific Name	Moth stage affected
1. big-headed ant	*Pheidole megacephala*	eggs, larvae, adults
2. predatory wasps	*Polistes* spp.	eggs, larvae
3. Japanese white-eye bird	*Zosterops japonicus*	larvae
4. common myna bird	*Acridotheres tristis*	larvae
5. lizards	various spp.	larvae
6. northern cardinal	*Cardinalis cardinalis*	larvae
7. northern mockingbird	*Mimus polyglottos*	larvae
8. jumping spiders	Saltcidae family	larvae

Table 4. Known Blackburn's sphinx moth parasites/parasitoids.

Common Name	Scientific Name	Moth stage affected
1. Trichogramma wasps	*Trichogramma* spp.	eggs

Table 5. Known Blackburn's sphinx moth competitors.

Common Name	Scientific Name (Family, Genus, Species)	Moth stage affected
1. white lined sphinx moth (larvae)	Sphingidae: *Hyles lineata*	larvae
2. white lined sphinx moth (adult)	Sphingidae: *Hyles lineata*	adults
3. sweet potato hornworm moth (larvae/adults)	Sphingidae: *Agrius cingulata*	adults
4. Hawaiian sphinx moth (adults)	Sphingidae: *Hyles calida*	adults
5. Japanese white-eye bird	Zosteropidae: *Zosterops japonicus*	adults
6. oleander hawkmoth (larvae)	Sphingidae: *Daphis nerii*	larvae
7. painted lady butterfly (larvae)	Nymphalidae: *Vanessa cardui*	larvae

and host range cannot be predicted from laboratory studies (Gonzalez and Gilstrap 1992; Roderick 1992) and the purposeful release or augmentation of any lepidopteran predator or parasitoid is a potential threat to Blackburn's sphinx moth (Gagné and Howarth 1985; Simberloff 1992).

G. CONSERVATION EFFORTS AND PREVIOUS FEDERAL ACTIONS

An initial comprehensive Notice of Review for Invertebrate Animals was published in the *Federal Register* on May 22, 1984 (U.S. Fish and Wildlife Service 1984). In this notice, we identified Blackburn's sphinx moth as a category 3A taxon. Category 3A taxa were those for which we had persuasive evidence of extinction. We published an updated Notice of Review for animals on January 6, 1989 (U.S. Fish and Wildlife Service 1989). Although Blackburn's sphinx moth had been rediscovered by 1985, in the 1989 Notice of Review, this taxon was again identified as category 3A. In the next Notice of Review on November 15, 1994 (U.S. Fish and Wildlife Service 1994c), this species was reclassified as a category 1 candidate for listing. Category 1 candidates were those taxa for which we had on file sufficient information on biological vulnerability and threats to support preparation of listing proposals. Beginning with our February 28, 1996, Notice of Review (U.S. Fish and Wildlife Service 1996), we discontinued the designation of multiple categories of candidates, and only those taxa meeting the definition of former category 1 candidates are now considered candidates for listing purposes. In this Notice of Review, we identified Blackburn's sphinx moth as a candidate species. A proposed rule to list Blackburn's sphinx moth as endangered was published on April 2, 1997 (U.S. Fish and Wildlife Service 1997b). In the September 19, 1997, Notice of Review (U.S. Fish and Wildlife Service 1997a), this species was included as proposed for endangered status.

In the proposed listing rule, we indicated designation of critical habitat for the moth was not prudent because we believed a critical habitat designation would not provide any additional benefit beyond that provided through listing as endangered.

A final rule listing Blackburn's sphinx moth as endangered was published in the *Federal Register* on February 1, 2000 (U.S. Fish and Wildlife Service 2000).

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. In the final listing rule, we determined that critical habitat designation for the moth would be prudent, but we indicated that we were not able to develop a proposed critical habitat designation for the species at that time due to budgetary and workload constraints.

On June 2, 2000, the U.S. District Court for the District of Hawaii, in the case of Center for Biological Diversity v. Babbitt and Clark, Civ. No. 99-00603 (D. Haw.), ordered us to designate critical habitat for Blackburn's sphinx moth. 50 CFR §424.02 defines critical habitat to be the specific areas currently 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.

We proposed to designate critical habitat for the endangered Blackburn's sphinx moth at seven sites located on the islands of Hawaii, Kahoolawe, Maui, and Molokai. The proposed critical habitat boundaries include a total of approximately 40,240 hectares (99,433 acres), the majority of which is State-owned land. A complete copy of the proposal to designate critical habitat for this species was published in the *Federal Register* (U.S. Fish and Wildlife Service 2002) on June 13, 2002.

The Endangered Species Act provides several other opportunities for the conservation of listed endangered and threatened species. Listed species receive recognition and 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 modification or

degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns such as breeding, feeding, or sheltering (50 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. Section 10(a)(1) of the Endangered Species Act gives us the authority to issue permits to non-Federal and private entities for the take of threatened or endangered species when such taking is incidental to, and not the purpose of, carrying out otherwise lawful activities and to researchers when the taking is for scientific purposes, or for enhancement of propagation or survival. 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 195D4). Hawaii State law prohibits taking of endangered wildlife and encourages conservation by State government agencies. "Take" as defined by Hawaii State law means "to harass, harm, pursue, wound, kill, trap, capture, or collect endangered or threatened. . . species. . . or to attempt to engage in any such conduct" [Hawaii State Division of Forestry and Wildlife, Hawaii Revised Statues 195D4].

H. OVERALL RECOVERY STRATEGY

1. Methods Used to Identify Recovery and Management Units

Establishment of recovery units can be a useful recovery tool, especially for species occurring across wide ranges with multiple populations, varying ecological pressures, or differing threats in different parts of their range. Recovery units are defined as geographically or otherwise identifiable subunits of the listed entity that individually are necessary to conserve the demographic robustness, genetic robustness, important life history stages, or some other feature necessary for long-term sustainability of the entire listed entity. For purposes of this

recovery plan, a management unit is a prescribed area within a recovery unit for which specific actions are planned for implementation. Management units might require different management, perhaps because of differing threats in differing geographic areas. Recovery units are not management units, they are essential population units. It is possible for a single recovery unit to be comprised of several management units. A jeopardy analysis for a species may be based on an assessment of impacts to a recovery unit(s) when that unit(s) is documented as necessary to both the survival and recovery of the species in a final recovery plan.

We considered several methods of analysis and many aspects of the moth's biology in making a preliminary identification and delineation of the recovery units and component management units necessary for the recovery of Blackburn's sphinx moth. We evaluated all areas that contain dry and mesic habitats as well as data on known moth occurrence. The best scientific information available was analyzed, including peer-reviewed scientific publications; unpublished reports by researchers; the rule listing the species (U.S. Fish and Wildlife Service 2000); the Blackburn's sphinx moth Recovery Outline (U. S. Fish and Wildlife Service, *in litt*., 2000); the Hawaii Natural Heritage Program 2000 database (Hawaii Natural Heritage Program, *in litt*., 2000); field trip reports in our Pacific Islands Fish and Wildlife Office files; peer-reviewed responses to the proposed critical habitat rule; and responses to our moth critical habitat outreach package mailed to Federal, State, and private land managers, and other interested parties.

Blackburn's sphinx moth is short-lived, extremely mobile, and rare; hence population densities are not easily determined (Janzen 1984; A. Medeiros, pers. comm., 1998; G. Roderick and R. Gillespie, *in litt*., 1997; E. Van Gelder and S. Conant, *in litt*., 1998). Even if the threats responsible for the decline of the moth were controlled, the persistence of existing populations is hampered by the small number of extant populations and the small number of individuals in known populations. This circumstance makes the moth more vulnerable to extinction due to a variety of natural processes. Small populations are particularly vulnerable to reduced reproductive vigor caused by inbreeding depression, and they may suffer a loss of genetic variability over time due to random genetic drift, resulting in decreased evolutionary potential and ability to cope with environmental change (Center for Conservation Update 1994; Lande 1988). Small populations are also

demographically vulnerable to extinction caused by random fluctuations in population size and sex ratio and to catastrophes such as hurricanes (Lande 1988). We believe the existing Blackburn's sphinx moth populations on Kahoolawe, Hawaii, and Maui are insufficient to ensure the long-term survival of the species. Re-establishing the species to a diverse set of habitats and climates within its former range is necessary to remove the long-term risk of range-wide extinction of the species due to catastrophic events and the numerous direct threats to the species and its habitat (U.S. Fish and Wildlife Service 1997b).

Janzen (1984) described the characteristics of tropical sphingid moths found in a Costa Rican National Park. In general, adult sphingids are nocturnal or crepuscular (dusk-flying) and regularly drink with a long proboscis from many kinds of sphingophilous flowers while hovering in front of them. Sphingophilus flowers are characterized by lightly-colored, tubular corollas, evening athesis (opening), and nocturnal nectar and scent production (Haber and Frankie 1989). Fecundity was unknown, but estimated in the hundreds if the female can feed freely.

Particularly helpful in understanding the recovery needs of sphingids is Janzen's description of the adult moth's biological characteristics: they have large latitudinal ranges; feed heavily over a long period of time and extensively at spatially particulate resources relatively fixed in location (*i.e.*, they feed on specific resources spread throughout the landscape); live for weeks to months; lay few eggs per night; probably oviposit (deposit eggs) on many host plant individuals and repeatedly visit many of them; have less synchronous eclosion (emergence from the pupa) during the rainy season than other moths; migrate; and are highly mobile, repeatedly returning to the same food plants.

Sphingid caterpillars are known to feed heavily over a long time period and eat limited types of foliage, typically plants rich in toxic small molecules (*e.g.*, in the family Solanaceae). Since sphingids search widely for local good conditions, Janzen concluded that isolated habitats may have difficulty supporting sphingid populations (*i.e.*, connectivity between habitat areas is necessary to support wide-ranging sphingid species). In another study of sphingids, adults were reported to travel greater distances to pollinate and visit flowers than those distances traveled by other insect pollinators or even hummingbirds (Linhart and Mendenhall 1977).

Ehrlich and Murphy (1987) noted populations of herbivorous insects such as lepidopterans are often regulated by environmental factors, such as weather conditions, and thus small populations can be particularly at risk of extinction. Ehrlich and Murphy identified a number of principles important for the conservation of herbivorous insects. First, in most cases, a series of diverse demographic units will typically be needed to conserve or recover a species. Second, where possible, corridors among the sites should be established to promote re-colonizations in areas where the species once occurred. Lastly, they noted that when populations are very sensitive to environmental changes and limited information is available on the species population biology, it is easy to underestimate the recovery needs of such insects.

Murphy *et al.* (1990) also noted that reviews of butterfly population ecology demonstrate that environmental factors play important roles in determining butterfly population dynamics. They stated that most documented population extinctions have resulted from habitat deterioration combined with extreme weather events. Decreases in the quality or abundance of larval host plants and adult nectar sources are caused by changes in plant community composition, particularly changes associated with succession, disturbance, and grazing regimes. But, because many butterfly species are especially sensitive to thermal conditions, habitat changes which disrupt micro-climatic regimes can cause habitat deterioration without elimination of plant resources. Ehrlich and Murphy (1987) noted several patterns within typical butterfly populations: a number of subpopulations within a given species meta-population (an assemblage of local populations inhabiting spatially distinct habitats) are often extirpated and later re-colonized; and a given species may not be present in many of its habitat remnants, including within those containing the highest host plant diversity.

Although our knowledge of the moth's historical range is incomplete, we believe the existing natural habitats needed to support viable populations of the moth are too small, isolated, and seriously threatened to ensure its long-term protection or recovery, particularly in light of the foraging needs of adult sphingid moths (Janzen 1984) and the apparent wide-ranging Blackburn's sphinx moth foraging habits (Hawaii Natural Heritage Program, *in litt*., 2000; F. Duvall,

Division of Forestry and Wildlife, pers. comm., 2001; B. Gagné, Hawaii Department of Land and Natural Resources, pers. comm., 2001; D. Hopper, *in litt*., 1997, 2002). Long-term recovery of the species will require the protection and subsequent restoration of additional and larger areas of dry and mesic habitat that includes the Blackburn's sphinx moth larval and adult necessary biological requirements at different elevational and rainfall gradients to improve the likelihood of successful larval development and adult moth foraging (A. Medeiros, 1998; G. Roderick and R. Gillespie, *in litt*., 1997; E. Van Gelder and S. Conant, *in litt*., 1998). The long-term persistence of the existing populations would improve if they could be increased in size and if the connectivity among the populations was enhanced, thus promoting dispersal of individuals across intervening lands. Conserving and restoring moth populations in multiple locations would decrease the likelihood that the effect of any single alien parasite or predator or combined pressure of such species could result in the diminished vigor or extinction of the moth.

The islands of Molokai, Lanai, Oahu, and Kauai offer important examples of habitat for Blackburn's sphinx moth because these islands provide for the potential expansion beyond the species' current, limited range and for improved connectivity of the different populations. While the proposed management units on these islands are not known to currently harbor moth populations, preserving these habitat areas is important because some threats to the species are absent there (Table 1 shows that several of the potential moth predators and parasites are not reported from some of these islands). Likewise, because of these islands' distance from islands currently inhabited by the moth, we believe management units on these islands will be extremely important for the species' recovery as they will help to protect the species from extinction by catastrophic events, which could impact other more closely grouped populations (*e.g.*, those on Maui or on the island of Hawaii). For these reasons, we find that inclusion of management units on Molokai, Lanai, Oahu, and Kauai identified as containing the host plants and necessary habitat is necessary for the recovery of the species even if they do not currently contain known moth populations.

The approach to identifying recovery and management units used in this draft recovery plan addresses the numerous risks to the long-term survival and

recovery of Blackburn's sphinx moth by employing two widely recognized and scientifically accepted methods for promoting viable populations of imperiled species-- (1) creation or maintenance of multiple populations to reduce the threat of a single or series of catastrophic events extirpating the species; and (2) increasing or providing for the increase in size of each population in the respective recovery units to a level where the threats of genetic, demographic, and normal environmental uncertainties are diminished (Meffe and Carroll 1996; U.S. Fish and Wildlife Service 1997c; Tear *et al.* 1995).

In general, the larger the number of populations and the larger the size of each population, the lower the probability of extinction (Meffe and Carroll 1996; Raup 1991). This basic conservation principle of redundancy applies to Blackburn's sphinx moth. By maintaining viable management unit populations in the three identified recovery units, the threats represented by a fluctuating environment are reduced and the species has a greater likelihood of achieving long-term survival and recovery.

Due to the species' presently reduced range, Blackburn's sphinx moth is now more susceptible to the variations and weather fluctuations affecting quality and quantity of available habitat and food. Furthermore, the moth is now more susceptible to direct pressure from numerous non-native insect predators and parasites. For these reasons and the reasons discussed above, those areas currently occupied would be inadequate to ensure the recovery of the species, and we have identified 3 recovery units comprised of 13 management units on 7 of the main Hawaiian Islands.

2. Necessary Biological Requirements

In determining which areas to identify as Blackburn's sphinx moth management units, we must consider those physical and biological features necessary for the recovery of the species, and which may require special management considerations and protection. These include, but are not limited to, space for individual and population growth and for normal behavior; food, water, or other nutritional or physiological requirements; cover or shelter; and sites for breeding, reproduction, or egg laying.

The necessary biological requirements for Blackburn's sphinx moth include specific habitat components identified as necessary for the primary biological needs of foraging, sheltering, maturation, dispersal, breeding, and egg laying, and are organized by life cycle stage. The necessary biological requirements needed by Blackburn's sphinx moth larvae for foraging, sheltering, maturation, and dispersal are the two documented host plant species within the endemic *Nothocestrum* genus (*N. latifolium* and *N. breviflorum*) and the dry and mesic habitats between the elevations of sea level and 1,525 meters (5,000 feet) and receiving between 25 and 250 centimeters (10 and 100 inches) of annual precipitation which currently support or historically have supported these plants. The necessary biological requirements required by Blackburn's sphinx moth adults for foraging, sheltering, dispersal, breeding, and egg production are native, nectar-supplying plants, including but not limited to *Ipomoea indica* (and other species within the genus *Ipomoea*), *Capparis sandwichiana*, and *Plumbago zeylanica* and the dry to mesic habitats between the elevations of sea level and 1,525 meters (5,000 feet) and receiving between 25 and 250 centimeters (10 and 100 inches) of annual precipitation which currently support or historically have supported these plants.

Both the larval and adult food plants are found in undeveloped areas supporting mesic and dry habitats, typically receiving less than 250 centimeters (100 inches) of rain per year and are located between the elevations of sea level and 1,525 meters (5,000 feet). Vegetative communities in these areas include native plants, and in some instances, introduced plant species (A. Medeiros, pers. comm., 1998; G. Roderick and R. Gillespie, *in litt*., 1997; E. Van Gelder and S. Conant, *in litt*., 1998).

Although Blackburn's sphinx moth larvae feed on the non-native *Nicotiana glauca*, we do not consider this plant to be a necessary biological requirement for the identification of management units. As previously discussed, the native *Nothocestrum* species are more stable and persistent components of dry to mesic forest habitats than the *Nicotiana glauca*. *Nicotiana glauca* is a short-lived species that may disappear from areas during prolonged drought (A. Medeiros, 1998) or during successional changes in the plant community (F. G. Howarth, pers. comm., 2001; Symon 1999). Many studies have shown that insects, and particularly

lepidopteran larvae, consume more food when the food has a relatively high water content (Murugan and George 1992). Relative consumption rate and growth have been reported to decrease for many sphingids (closely related to Blackburn's sphinx moth) when raised on host plants or diets with a relatively low water content (Murugan and George 1992). *Nicotiana glauca's* vulnerability to drought conditions suggests that its water content frequently may not be suitable for optimal growth of Blackburn's sphinx moth larvae.

The restoration of native host species for the moth and other endangered species may also require the control or elimination of non-native vegetation. Additionally, unlike the *Nothocestrum* species, *Nicotiana glauca* is more likely to occur in habitats less suitable due to their occupation by alien insect predators (D. Hopper, *in litt*., 1997, 2002; Symon 1999). Therefore, in comparison with *Nicotiana glauca*, the native *Nothocestrum* species better fulfill the primary biological needs of the moth larvae. For all of these reasons, we are not considering *Nicotiana glauca* as a necessary biological requirement for the identification of management units at this time.

3. Criteria Used To Identify Recovery and Management Units

Recovery Units

As discussed in the Methods section, we believe Blackburn's sphinx moth is now more susceptible to variations and weather fluctuations affecting quality and quantity of available habitat and food due to the species' presently reduced range. Furthermore, the moth is now more susceptible to direct pressure from numerous non-native insect predators and parasites. For these reasons and the reasons discussed above, those areas currently occupied by the moth (Maui, Kahoolawe, and Hawaii) would be inadequate to ensure the recovery of the species, and we have therefore used the criteria described below to identify 3 recovery units comprised of 13 management units on 7 of the main Hawaiian Islands: the Kauai-Oahu Recovery Unit; the Maui Nui Recovery Unit; and the Big Island (Hawaii Island) Recovery Unit (see Figure 5). The three recovery units are grouped beginning with the Kauai-Oahu Recovery Unit, located in the northwest corner of the main island chain. The Maui Nui Recovery Unit, situated within the

middle of the chain and to the southeast of the Kauai-Oahu Recovery Unit, includes four islands: Molokai, Maui, Lanai, and Kahoolawe. The Big Island Recovery Unit is located on a single island, Hawaii, and is the most southeasterly of the main islands.

The primary criterion used to identify these three recovery units included the priority need to encompass an extended portion of the moth's former range. Blackburn's sphinx moth previously occupied the full extent of the main Hawaiian Islands. Establishing and restoring the moth to three widely-spaced recovery units distant from each other within the main island chain will offer the best protection to the species from the possibility of severe habitat loss due to catastrophic events as discussed in the Methods section and elsewhere in this recovery plan. By maintaining viable populations in a majority of the component management units within all three proposed recovery units, the threats represented by a fluctuating environment are reduced and the species has a greater likelihood of achieving long-term survival and recovery.

Management Units

We used several criteria to identify and select the 13 management units comprising the 3 recovery units. We began with all areas that we believe are currently occupied by the moth (units on Hawaii, Kahoolawe, and Maui) (Table 6). We then added other unoccupied lands within the historic range containing the necessary biological requirements that are needed for recovery of the species (units on Kauai, Oahu, Molokai, and Lanai). As discussed in the Methods section, in deciding which unoccupied areas were needed for recovery, we based our decision on the amount of available habitat remaining that could potentially support the moth, the biology of the moth, and information gained from the conservation of other herbivorous insects. We gave preference to lands that: (a) are known to contain largely intact assemblages of the host plant(s) communities; and (b) form contiguous, relatively large areas of suitable habitat.

Regular flight distances of sphingids in Central America may be greater than 10 kilometers (6.2 miles) (Janzen 1984), and given the large size and strong flight capabilities of Blackburn's sphinx moth, the species is believed to use large areas of habitat. Therefore, moth population linkages will likely be enhanced if

Table 6. Recovery units and their component management units for Blackburn's sphinx moth (in hectares and acres, by island and land ownership [area estimates reflect management unit boundaries, not necessary biological requirements within]).

Kauai - Oahu Recovery Unit: Two Management Units					
Management Unit	**Island**	**State**	**Federal**	**Private**	**Total**
1. Kokee Unit-unoccupied	Kauai	3,516 ha 8,688 ac	0 ha 0 ac	0 ha 0 ac	3,516 ha 8,688 ac
2. Honouliuli Unit-unoccupied	Oahu	3 ha 6 ac	0 ha 0 ac	1,369 ha 3,383 ac	1,372 ha 3,389 ac
Kauai - Oahu Recovery Unit Total:	----------	3,519 ha 8,694 ac	0 ha 0 ac	1,369 ha 3,383 ac	4,888 ha 12,077 ac
Maui Nui Recovery Unit: Seven Management Units					
Management Unit	**Island**	**State**	**Federal**	**Private**	**Total**
3. Kamoko Flats - Puukolekole Unit-unoccupied	Molokai	551 ha 1,362 ac	0 ha 0 ac	1,278 ha 3,158 ac	1,829 ha 4,520 ac
4. Lanaihale Unit-unoccupied	Lanai	0 ha 0 ac	0 ha 0 ac	511 ha 1,263 ac	511 ha 1,263 ac
5. Upper Kahoolawe Unit-occupied	Kahoolawe	1,878 ha 4,641 ac	0 ha 0 ac	0 ha 0 ac	1,878 ha 4,641 ac
6. Waihee Unit (Windward Maui)-occupied	Maui	.55 ha 1.38 ac	0 ha 0 ac	116 ha 287 ac	116.55 ha 288.38 ac
7. Kanaha Pond - Spreckelsville Unit (Windward Maui)-occupied	Maui	363 ha 899 ac	2 ha 4 ac	114 ha 281 ac	479 ha 1,184 ac
8. Puu O Kali Unit (Leeward Maui)-unoccupied	Maui	1,791 ha 4,425 ac	0 ha 0 ac	959 ha 2,369 ac	2,750 ha 6,794 ac
9. Ahihi-Kinau NAR - Ulupalakua-Auwahi - Kanaio Unit (Leeward Maui)-occupied	Maui	11,056 ha 27,318 ac	1 ha 2 ac	4,161 ha 10,281ac	15,218 ha 37,601 ac
Maui Nui Recovery Unit Total:	----------	15,639.55 ha 38,646.38 ac	3 ha 6 ac	7,139 ha 17,639 ac	22,781.55 ha 56,291.38 ac
Big Island Recovery Unit: Four Management Units					
Management Unit	**Island**	**State**	**Federal**	**Private**	**Total**
10. West Kohala Mountains Unit-occupied	Hawaii	4,375 ha 10,811 ac	0 ha 0 ac	7,569 ha 18,703 ac	11,944 ha 29,514 ac

Table 6. Continued.

Big Island Recovery Unit: Four Management Units (continued)					
Management Unit	**Island**	**State**	**Federal**	**Private**	**Total**
11. Puu Waawaa - Hualalai Unit-occupied	Hawaii	12,847 ha 31,746 ac	0 ha 0 ac	5,264 ha 13,007 ac	18,111 ha 44,753 ac
12. Kailua-Kona North Unit-unoccupied	Hawaii	6 ha 15 ac	0 ha 0 ac	119 ha 294 ac	125 ha 309 ac
13. Kailua-Kona South Unit-unoccupied	Hawaii	105 ha 258 ac	0 ha 0 ac	0 ha 0 ac	105 ha 258 ac
Big Island Recovery Unit Total:	----------	17,333 ha 42,830 ac	0 ha 0 ac	12,952 ha 32,004 ac	30,285 ha 74,834 ac
All Recovery Units Total:	----------	36,491.55 ha 90,170.38 ac	3 ha 6 ac	21,460 ha 53,026 ac	57,954.55 ha 143,202.38 ac

proposed management units occur in large contiguous blocks or within a matrix of undeveloped habitat (McIntyre and Barrett 1992; A. Medeiros, 1998; S. Montgomery, Bishop Museum, pers. comm., 2001; G. Roderick and R. Gillespie, *in litt*., 1997; E. Van Gelder and S. Conant, *in litt*., 1998). To the extent possible with the limited potential habitat remaining, we have attempted to account for the wide-ranging behavior of the moth. Since Blackburn's sphinx moth is believed to be a strong flier and is able to move many kilometers from one area to another, areas of larval or adult presence and feeding may be separated from similar habitat areas and still serve important functions in maintaining moth populations.

Some small habitat areas are also suitable for Blackburn's sphinx moth larvae (*e.g.*, Units 6, 7, 12, and 13 discussed below) and are necessary for the recovery of the moth since such habitats may facilitate adult moth dispersal and promote genetic exchange between populations located on different islands. These areas also provide nectar resources and sheltering opportunities required by the adult moth. As discussed earlier, small, geographically isolated populations may be subject to decreased viability caused by inbreeding depression, reductions in effective population size due to random variation in sex ratio, and limited capacity to evolve in response to environmental change-highlighting the need for the enhanced population connectivity potentially provided by the small habitat areas (Soulé 1987).

Blackburn's sphinx moth populations fluctuate from year to year and season to season, apparently correlated with environmental and climatic variation. The moth is likely sensitive to thermal conditions and habitat changes which disrupt its micro-climatic requirements. Therefore, identified management unit boundaries include dry and mesic habitats containing the necessary biological requirements along wide elevational gradients to better ensure adult moth foraging needs up and downslope within its range. Furthermore, the boundaries include elevational gradients to better ensure larval host plant availability during periods of drought. The growth rates of larvae for many closely related sphingid species are reported to decrease when their host plants lack suitable water content. In fact, suitable host plant water content can improve the later fecundity of the adult stage (Murugan and George 1992). It is believed numerous habitat elevations, containing the various necessary biological requirements, are necessary for successful recovery of the species (Ehrlich and Murphy 1987; Murphy and Weiss 1988; Murphy *et al.* 1990; Shaffer 1987) to minimize the effects of annual localized drought conditions throughout different areas of the species' host plant range (Murugan and George 1992).

Many sphingid studies have shown that air temperature restricts adult feeding activity above a certain temperature (usually 30 degrees Celsius) (Herrera 1992). This highlights the importance of protecting sufficiently large habitat areas throughout the Blackburn's sphinx moth range to ensure nectar resource availability as temperatures change within the habitat range seasonally, during the night, and along elevational gradients. Increasing the potential for adult dispersal will help to alleviate many threats, thus, habitat which provides the necessary biological requirements associated with adult dispersal and feeding is necessary for the recovery of Blackburn's sphinx moth.

Management units are identified on those Hawaiian Islands where Blackburn's sphinx moth's biological requirements considered necessary for the recovery of the species are known to occur. This will allow the species the ability to persist and re-colonize areas where it has become extirpated due to catastrophic events or demographic stochasticity (randomness) (Shaffer 1987). For example, on the island of Kauai in 1992, Hurricane Iniki blew over large areas of native forest leaving open areas where non-native plants became established and created

paths for further invasion of non-native animals, both of which have been identified as threats to the survival of the moth.

Small habitats tend to support small populations, which frequently are extirpated by events that are part of normal environmental variation. The continued existence of such satellite populations requires the presence of one or more large reservoir populations, which may provide colonists to smaller, outlying habitat patches (Ehrlich and Murphy 1987). Based on recent field observations of the moth, we believe the species currently occurs within two regional populations on separate islands, one centered in the Kanaio area of leeward East Maui (Units 8 and 9) and one centered near Puu Waawaa-Hualalai (Unit 11) of Hawaii Island, north of Kailua-Kona (F. G. Howarth, pers. comm., 2001; A. Medeiros, 1998). Both of these two areas contain populations of the moth regarded as probable source areas or "reservoirs" (Murphy *et al.* 1990) for dispersing or colonizing moth adults. We are also identifying management units (*e.g.*, Auwahi Forest and portions of Ulupalukua Ranch, both within Unit 9; and Unit 5 on Kahoolawe) that are large, mixed-quality habitat patches containing the necessary biological requirements and located within several kilometers of the two potential reservoir populations. Because of their current occupancy and their proximity to larger populations, it appears likely that they will be the areas most rapidly re-colonized by the moth after potential extirpations.

The identification of small habitat areas close to the two large reservoir areas is also included to promote genetic variability in the moth population, contributing to the long-term persistence and recovery of the species. These areas will serve as stepping stones or corridors for dispersing adult moths or as overflow habitat during particularly fecund years, which could be very important to the integrity of moth populations. For example, adult moths observed at Ahihi-Kinau Natural Area Reserve (Unit 9) on Maui may have originated from larval host plants located in the Kanaio Natural Area Reserve (also Unit 9), while moths seen near the two Kailua-Kona management units (Units 12 and 13) may have originated from the Puu Waawaa-Hualalai management unit (Unit 11). The Blackburn's sphinx moth populations inhabiting these smaller habitat areas appear to be taking advantage of lower elevation adult native host plants and non-native host plants such as tree tobacco upon which the larval stage is often observed

feeding. In addition, these small habitat areas may be able to support persistent moth populations independent of the reservoir areas, significantly contributing to recovery of the species.

Natural areas of suitable native, dry to mesic habitat containing at least one *Nothocestrum* plant adjacent or near other *Nothocestrum* populations are included in the proposed management units. We have included suitable habitat without *Nothocestrum* larval host plants, provided it contained the necessary adult biological requirements, including but not limited to *Ipomoea* species, *Capparis sandwichiana* or *Plumbago zeylanica*. This is especially true for areas lying between or adjacent to large populations of *Nothocestrum* species and which could serve as a flight corridor or 'stepping stone' to other larger host plant habitat areas. An area may also serve as a stepping stone when it contains adult native host plants thereby providing foraging opportunities for adults. Areas with larval non-native host plants (*e.g.*, Units 6 and 7 on Maui and Unit 5 on Kahoolawe) may also serve as areas for population expansion during especially wet years when the non-native larval host plants experience rapid growth. Natural areas of primarily native vegetation containing the necessary larval or adult stage biological requirements and where habitat could support a moth population and increase the potential for recovery are also included as management units. The identification and protection of a management unit not known to currently contain a moth population (*i.e.*, the unit on Molokai), but which contains the necessary biological requirements and lacks some of the serious threats to the species, (see Table 1) will enhance population expansion and connectivity, thereby improving the likelihood of the species' recovery.

The areas we are identifying as management units provide some or all of the known necessary biological requirements for this species. These areas are found on seven of the main Hawaiian Islands between the elevations of sea level to 1,525 meters (5,000 feet) within dry to mesic shrub lands or forests containing one or more populations of the adult host plants, or one or more populations of *Nothocestrum latifolium* or *Nothocestrum breviflorum*. Identified management unit boundaries include aggregations of native host plant habitat for both larvae and adults, and encompass the areas and flight corridors believed necessary to sustain moth populations.

In summary, the long-term survival and recovery of Blackburn's sphinx moth requires the identification, recovery, and restoration of management units on several of the main Hawaiian Islands. Specifically, before the moth can be considered recovered, all of the following three requirements must be met: 1) one population of the moth must be naturally reproducing and stable or increasing in size, through one to two El Niño events or a minimum of 5 consecutive years within the Kauai-Oahu Recovery Unit; 2) four populations of the moth must be naturally reproducing and stable or increasing in size, through one to two El Niño events or a minimum of 5 consecutive years on three different islands within the Maui Nui Recovery Unit (of those four, one within windward and one within leeward Maui Island); and 3) two populations of the moth must be naturally reproducing and stable or increasing in size, through one to two El Niño events or a minimum of 5 consecutive years within the Big Island (Hawaii Island) Recovery Unit.

Seven of the 13 identified management units are currently not known to be occupied by Blackburn's sphinx moth. To recover the species, it will be necessary to conserve suitable habitat in some of these unoccupied units, which in turn will allow for the establishment of additional Blackburn's sphinx moth population(s) through natural recruitment or managed re-introductions. Establishment of these additional moth population(s) will increase the likelihood that the species will survive and recover in the face of normal and random events (*e.g.*, hurricanes, fire, alien species introductions, etc.) (Mangel and Tier 1994; Pimm *et al*. 1998; Stacy and Taper 1992).

The lack of scientific data on Blackburn's sphinx moth life history makes it impossible for us to develop a quantitative model (*e.g.*, population viability analysis) to identify the optimal number, size, and location of management units (Bessinger and Westphal 1998; Ginzburg *et al.* 1990; Karieva and Wennergren 1995; Menges 1990; Murphy *et al*. 1990; Taylor 1995). At this time, we are only able to conclude that the current size and distribution of the extant populations are not sufficient to expect a reasonable probability of Blackburn's sphinx moth's long-term survival and recovery. Therefore, we used the best available information, including scientific opinion of non-Fish and Wildlife Service scientists, to identify 13 management units. Recovery of more than seven

management units (see Delisting Criteria), could improve the species' stability and further increase the probability that the species will recover; however, establishing and/or conserving seven viable moth populations within the three recovery units as described in the delisting criteria will provide the species with a reasonable expectation of persistence and recovery, even with the high potential that one or more of these populations will be temporarily lost as a result of normal or random adverse events (Mangel and Tier 1994; Pimm *et al.* 1998; Stacey and Taper 1992).

The 13 management units identified for Blackburn's sphinx moth currently contain a total of approximately 57,954.55 hectares (143,202.38 acres) (Table 6), unless new research indicates that management and recovery efforts should focus elsewhere.

The three Blackburn's sphinx moth recovery units and their component management units are described below.

Kauai - Oahu Recovery Unit:

The Kauai - Oahu Recovery Unit is comprised of two management units one each on the islands of Kauai and Oahu. Currently, neither management unit is known to be occupied by the moth.

Management Unit 1 - Kokee Management Unit (Kauai)

Management Unit 1 consists of approximately 3,516 hectares (8,688 acres) of montane, mesic forests of Kauai. It is bounded on the northwest by the rugged Na Pali coast, to the south by the steep valleys of Waimea canyon, and to the east by wet montane forests and bogs. Vegetation consists primarily of mixed-species mesic and dry forest communities composed of native and introduced plants (Hawaii Natural Heritage Program, *in litt*., 1993). *Nothocestrum longifolium* and *Nothocestrum peltatum* host plants are located within small and isolated clusters within this unit (K. Wood, *in litt*., 2001b).

Although Kauai historically harbored a moth population, no observations have been documented on the island in recent times. However, the unit does currently contain populations of *Nothocestrum longifolium* and *Nothocestrum*

peltatum host plants and restorable, manageable areas associated with these host plants. Because Kauai is the furthest island from extant moth populations within the Hawaiian Islands chain, this unit would most likely require reintroduction to re-establish the species there. However, because of Kauai's distance from moth-inhabited islands, we expect this unit will be extremely important for the species' recovery as it would help to protect the species from extinction by catastrophic events that could impact other populations occurring in more closely-grouped islands (*e.g*., the Maui-Nui Recovery Unit). Furthermore, conserving and restoring moth populations in multiple locations such as this area on Kauai will decrease the likelihood that the effect of any single alien parasite or predator or combined pressure of such species and other threats could result in the diminished vigor or extinction of the moth.

Management Unit 2 - Honouliuli Management Unit (Oahu)

Management Unit 2 consists of approximately 1,372 hectares (3,389 acres) encompassing portions of the dry, mid-elevation Waianae Mountains of Oahu contained within Honouliuli Preserve. The Preserve is owned by a private landowner and is managed by The Nature Conservancy of Hawaii. It is bounded on the north by the Kolekole Pass through the Waianae Mountains; to the south by lower elevation ridges, gullies, and valleys; to the east by the pineapple fields along Kunia Road; and to the west by the summit ridge of the Waianae Mountains. Vegetation consists primarily of mixed-species, mesic and dry forest communities composed of native and introduced plants (Hawaii Natural Heritage Program, *in litt*., 1993). The larval host plants *Nothocestrum longifolium* and *Nothocestrum latifolium* are present on the preserve (J. Lau, Hawaii Natural Heritage Program, *in litt*., 2001).

Although Oahu historically harbored a moth population, no observations have been documented on the island in recent times. However, the unit does currently contain a sizeable number of *Nothocestrum longifolium* and a small number of *Nothocestrum latifolium* host plants, as well as areas that can be managed for restoration. Because Oahu is not in close proximity to existing moth populations within the Hawaiian Islands chain, this unit would most likely require reintroduction to re-establish the species there. However, because of Oahu's distance from moth-inhabited islands, we expect this unit will be extremely

important for the species' recovery as it would help to protect the species from extinction by catastrophic events that could impact other populations occurring in more closely-grouped islands (*e.g.*, the Maui-Nui Recovery Unit). Furthermore, conserving and restoring moth populations in multiple locations such as this area on Oahu will decrease the likelihood that the effect of any single alien parasite or predator or combined pressure of such species and other threats could result in the diminished vigor or extinction of the moth.

Maui Nui Recovery Unit:

The Maui Nui Recovery Unit is comprised of seven management units: one each on the islands of Molokai, Lanai, and Kahoolawe, and four on the island of Maui. Currently the management units on Kahoolawe and Maui are known to be occupied by the moth.

Management Unit 3 - Komoko Flats - Puukolekole Management Unit (Molokai)

Management Unit 3 consists of approximately 1,829 hectares (4,520 acres) on State and private land, encompassing portions of the higher, yet drier portions of east Molokai. It is bounded on the north by wet forests, to the south by drier coast land, to the east by rugged, dry gullies and valleys, and to the west by dry to mesic, lowland forest. Natural features within the unit include numerous forested ridges and gullies. Vegetation consists primarily of mixed-species mesic and dry forest communities composed of native and introduced plants (Hawaii Natural Heritage Program, *in litt*., 2000).

This unit is part of the historical range of the moth, and while the unit is not known to currently contain a moth population, it does contain native *Nothocestrum* host plants, including *N. longifolium* and *N. latifolium* (Wood, *in litt*., 2001a) as well as adult native host plants. Because Unit 3 contains both larval and adult native host plants and is in close proximity to the large Maui population, it is necessary for Blackburn's sphinx moth recovery because it would allow the species to expand into a former part of its historical range in very close proximity to its current range on the island of Maui. Furthermore, it may facilitate dispersal and provide a flight corridor for moths eventually migrating to the island of Oahu, which is also part of its historical range.

Due to its proximity to the island of Maui where the current and presumed highest historical concentration of Blackburn's sphinx moth occurred, and because this unit contains dry and mesic habitats which are known both currently and historically to support the larval and adult native host plants, scientists believe that the Blackburn's sphinx moth will re-establish itself on this unit over time (F. Howarth, pers. comm., 2001). Furthermore, this unit lacks some of the serious potential threats to the moth which include three ant and one wasp species (see Table 2). Conserving and restoring moth populations in multiple locations decreases the likelihood that the effect of any single alien parasite or predator or the combined pressure of such species and other threats could result in the diminished vigor or extinction of the moth. Including this unit also reduces the possibility of the species' extinction from catastrophic events impacting the existing populations on other islands. Recovery habitat within this area on Molokai is complementary to existing and planned management activities of the landowners. The proposed management unit lies within a larger, existing conservation area to be managed for watershed conservation and the conservation of endangered and rare species. The landowners, State and Federal resource agencies, and local citizens groups are involved with these planned natural resource management activities on Molokai.

Managment Unit 4 - Lanaihale Management Unit (Lanai)

Management Unit 4 consists of approximately 511 hectares (1,263 acres) encompassing portions of the Lanaihale Ridge on Lanai. It is bounded on the north, south, and east by dry, low to mid-elevation shrub lands and many prominent dry gulches. Vegetation consists primarily of mixed-species mesic and dry forest communities composed of native and introduced plants including large stands of kiawe (*Prosopis pallida*) (Hawaii Natural Heritage Program, *in litt*., 1993) and native *Nothocestrum latifolium* plants.

Lanai is the only island, of the seven identified for recovery efforts, for which there is no historical record of Blackburn's sphinx moth occurrence. Due to its proximity to the island of Maui where the presumed highest historical concentration of Blackburn's sphinx moth occurred and because it contains dry and mesic habitats which are known, both currently and historically to support the larval host plants, researchers believe Blackburn's sphinx moth probably inhabited

the island at one time and could again support a population of the moth in the future (F. G. Howarth, pers. comm., 2001). The lack of a historical record of Blackburn's sphinx moth occurrence on Lanai is probably only due to the fact that the island supported fewer moths and this island was never subjected to collecting efforts sufficient to detect the moth. Conserving and restoring moth populations in multiple locations such as this area on Lanai will decrease the likelihood that the effect of any single alien parasite or predator or combined pressure of such species and other threats could result in the diminished vigor or extinction of the moth. Recovering this unit for the moth will also reduce the possibility of the species' extinction from catastrophic events impacting the existing populations on other islands.

The identified unit on Lanai is also important for Blackburn's sphinx moth recovery because it harbors both larval and adult host plants and contains habitats that can and will be managed for restoration. Furthermore, its close proximity to the large Maui population may enhance dispersal and migration corridors and population recruitment potential. Establishing a Blackburn's sphinx moth management unit within this area of the Lanaihale Ridge is complementary to existing and planned management activities of the landowner. The identified management unit lies within a larger, existing conservation area to be managed for watershed conservation, sustainable forestry emphasizing the use of native plants, and the conservation of endangered and rare species. These management activities include restoration of native habitat for several rare and listed endangered plants on the Lanaihale Ridge. The landowner, State and Federal resource agencies, and local citizens groups are involved with these natural resource management activities on Lanai.

Management Unit 5 - Upper Kahoolawe Management Unit (Kahoolawe)

Management Unit 5 consists of approximately 1,878 hectares (4,641 acres), encompassing portions of the upper elevational contour of Kahoolawe, approximately all land above 305 meters (1,000 feet) in elevation. Kahoolawe is located approximately 11 kilometers (6.7 miles) south of Maui Island and is approximately 11,655 hectares (28,800 acres) in total land area. The entire island is dry and dominated by non-native plants which occupy and surround the area identified as a management unit. Natural features within the unit include the main

caldera, Lua Makika, and Puu Moaulaiki. Vegetation consists primarily of mixed-species mesic and dry forest communities composed of native and introduced plants (Hawaii Natural Heritage Program, in litt., 1993).

This unit contains a large moth population, which may or may not be part of the larger Maui populations. No native *Nothocestrum* species currently occur in this unit, but numerous native adult host plants are common throughout the unit. Currently, the entire island is devoid of ungulates and is managed for control of fire and non-native species to some degree. Because the unit harbors adult native host plants and is in close proximity to the large Maui moth population, this unit is important for Blackburn's sphinx moth recovery and would improve dispersal and migration corridors and thus expand population recruitment potential (P. Higashino, Kahoolawe Island Reserve Commission, pers. comm., 2001).

Management Unit 6 - Waihee Unit (Windward Maui)

Management Unit 6 consists of approximately 116.55 hectares (288.38 acres) encompassing portions of the northern west Maui coast. It is bound on the north by the ocean, to the south by Highway 340, to the west by the Waihee River, and to the east by Waiehu Point. Natural features within the unit include Waihee Point and remnant coastal dune communities. Vegetation consists primarily of mixed-species dry coastal shrub land communities composed of native and introduced plants, including non-native larval host plants (F. Duvall, *in litt*., 2002; Hawaii Natural Heritage Program, *in litt*., 2000).

Although devoid of naturally occurring *Nothocestrum* spp., the unit contains adult moth native host plants, and recent observations of both larvae and adults have been documented in the Waihee area. This unit is also considered important for the species' recovery because evidence indicates that it provides refuge for moths dispersing to other larger areas. Although this unit is lower in elevation than areas currently containing *Nothocestrum* plants, the persistent occurrence of Blackburn's sphinx moth within the Kanaha Pond State Wildlife Sanctuary and other nearby areas indicates this site provides habitat for this area's moth population and plays an important role in the species' population dynamics. Based upon an understanding of this species and other moth species' flight capabilities and migrational needs, we believe that recovery of this area will

contribute to the available matrix of undeveloped habitat necessary as refugia for Blackburn's sphinx moths migrating to other areas of existing suitable host plant habitat on Maui (McIntyre and Barrett 1992; Roderick and Gillespie 1997; Van Gelder and Conant 1998; A. Medeiros, 1998; S. Montgomery, pers. comm., 2001).

Management Unit 7 - Kanaha Pond - Spreckelsville Management Unit (Windward Maui)

Management Unit 7 consists of approximately 479 hectares (1,184 acres) encompassing portions of the Kahului coast land and the Kanaha Pond State Wildlife Sanctuary on Maui. It is bounded on the south by the Kahului Airport and the Hana Highway, on the north by the ocean, on the east by sugarcane fields, and to the west by the town of Kahului. Natural features within the unit include Kanaha Pond and remnant coastal dune communities. Vegetation consists primarily of mixed-species, dry coastal shrub land communities composed of native and introduced plants, including non-native larval host plants (Hawaii Natural Heritage Program, *in litt*., 2000).

Although devoid of naturally occurring *Nothocestrum* spp., the unit contains adult moth native host plants, and recent observations of both larvae and adults have been documented in the Kanaha-Spreckelsville area. This unit is also considered necessary for the species' recovery because evidence indicates that it provides refuge for moths dispersing to other larger areas. Because the Kanaha Pond portion of this unit is a State Wildlife Sanctuary, some of the area is currently managed to benefit resident native species and should benefit the moth and its host plants to some extent (F. Duvall, pers. comm., 2001). Although this unit is lower in elevation than areas currently containing *Nothocestrum* plants, the persistent occurrence of Blackburn's sphinx moth within the Kanaha Pond State Sanctuary and other nearby areas indicates this site provides habitat for this area's moth population and plays an important role in the species' population dynamics. Based upon an understanding of this species and other moth species' flight capabilities and migrational needs, we believe that recovery of this area will contribute to the available matrix of undeveloped habitat necessary as refugia for Blackburn's sphinx moths migrating to other areas of existing suitable host plant habitat on Maui (McIntyre and Barrett 1992; Roderick and Gillespie 1997; Van Gelder and Conant 1998; A. Medeiros, pers. comm., 1998; S. Montgomery, pers. comm., 2001).

Management Unit 8 - Puu O Kali Management Unit (Leeward Maui)

Management Unit 8 consists of approximately 2,750 hectares (6,794 acres) encompassing portions of the leeward slope of Haleakala, and adjacent portions of the upper, southeast isthmus. The unit is bounded on the north and to the south by pasture lands, to the east by the lower slopes of Haleakala below the area of Kula, and on the west by the coastal town of Kihei. Natural features within the unit include widely spread, remnant dry forest communities, rugged aa lava flows (one of two types of lava flows found in the Hawaiian Islands, characterized by having a very rough, spiny, or rubbly surface), and numerous cinder cones including the highly visible, Puu O Kali. Vegetation consists primarily of mixed-species mesic and dry forest communities composed of native and introduced plants, with smaller amounts of dry coastal shrub land (Hawaii Natural Heritage Program, *in litt*., 1993). Currently, this management unit is not known to be occupied by the moth but is necessary for the species' recovery because it contains native nectar-supplying plants for adults, and areas within this unit provide temporary (ephemeral) habitat for migrating Blackburn's sphinx moths.

Management Unit 9 - Ahihi-Kinau Natural Area Reserve - Ulupalakua - Auwahi - Kanaio Management Unit (Leeward Maui)

Management Unit 9 consists of approximately 15,218 hectares (37,601 acres) encompassing portions of the leeward slope of Haleakala. The unit is bounded on the northeast by the 1,525 meters (5,000 feet) elevation contour of Haleakala Volcano, to the south by the ocean, to the east by the dry coast and slopes toward Kaupo Gap, and on the west by the Haleakala Southwest Ridge. Natural features within the unit include widely spread, remnant dry forest communities, rocky coastline, numerous cinder cones, and some of the most recent lava flows on Maui. Vegetation consists primarily of mixed-species mesic and dry forest communities composed of native and introduced plants, with smaller amounts of dry coastal shrub land (Hawaii Natural Heritage Program, *in litt*., 1993).

This unit contains what is probably the largest, extant moth population or meta-population. This unit is necessary because it contains both native (*Nothocestrum latifolium*) and introduced larval host plants as well as numerous nectar-supplying plants for adult moths. In addition to providing necessary habitat

for the Maui meta-population, areas within this unit may provide temporary (ephemeral) habitat for migrating Blackburn's sphinx moths and includes manageable and restorable areas for Blackburn's sphinx moth host plant recovery.

Big Island Recovery Unit:

The Big Island Recovery Unit is comprised of four management units all located on the Big Island (Hawaii Island). Currently, units 10 and 11 are known to be occupied by the moth.

Management Unit 10 - West Kohala Mountains Management Unit (Hawaii)

Management Unit 10 consists of approximately 11,944 hectares (29,514 acres) encompassing portions of the southwestern slopes of the Kohala Mountains on the island of Hawaii. It is bounded on the south by non-native grass land and dry coast land, on the north and east by mesic to wet uplands of the Kohala Mountains, and to the west by drier, non-native grass lands and coastal habitats.

Vegetation consists primarily of mixed-species mesic and dry forest communities composed of native and introduced plants, with smaller amounts of dry coastal shrub land (Hawaii Natural Heritage Program, in litt., 1993). Both *Nothocestrum latifolium* and *Nothocestrum breviflorum* occur in this area, but this unit requires additional surveys to locate all extant *Nothocestrum* spp. and to locate potential areas for restoration. Recently, a single adult moth sighting was documented for this unit. Portions of this unit may provide refugia for dispersing moths and serve as a corridor to other areas of suitable habitat, and may include manageable and restorable areas for moth recovery.

Management Unit 11 - Puu Waawaa - Hualalai Management Unit (Hawaii)

Management Unit 11 consists of approximately 18,111 hectares (44,753 acres) encompassing portions of the flows and northwest slopes of the Hualalai volcano on the island of Hawaii. It is bounded on the south by the Kailua-Kona region and large expanses of barren lava flows, on the north by Parker Ranch and large expanses of non-native grass lands, to the east by upper slopes of Hualalai volcano, and to the west by lava flows and coast land. Natural features within the unit include the Puu Waawaa cinder cone and significant stands of native, dry

forest including large numbers of *Nothocestrum breviflorum* host plants (L. Perry, Hawaii Department of Land and Natural Resources, *in litt*. 2001). Vegetation consists primarily of mixed-species mesic and dry forest communities composed of native and introduced plants, with smaller amounts of dry coastal shrub land (Hawaii Natural Heritage Program, *in litt*., 2000).

Frequent and persistent observations of both moth larvae and adults throughout this unit indicate that this area contains the largest population of Blackburn's sphinx moth on the island of Hawaii. In addition to providing habitat for this population, identified lands in Unit 11 provide refugia for migrating moths to other areas of existing suitable host plant habitat. As previously discussed, given the large size and strong flight capabilities of Blackburn's sphinx moth, support for moth population linkages requires some habitat areas in large contiguous blocks or within a matrix of undeveloped habitat (McIntyre and Barrett 1992; A. Medeiros, pers. comm., 1998; S. Montgomery, pers. comm., 2001; G. Roderick and R. Gillespie, *in litt*., 1997; E. Van Gelder and S. Conant, *in litt*., 1998).

Management Unit 12 - North Kailua-Kona Management Unit (Hawaii)

Management Unit 12 consists of approximately 125 hectares (309 acres) on State and private land, encompassing portions of rugged lowland forest within the boundary of the Kailua-Kona township on the island of Hawaii. It is bounded on the south by Kailua-Kona town, on the north by rugged lava flows, to the west by coastal non-native plant communities, and to the east by residential housing areas. Natural features within the unit include rugged lava flows. Vegetation consists primarily of mixed-species mesic and dry forest communities composed of native and introduced plants, with smaller amounts of dry coastal shrubland (HINHP 2000). This unit is essential to the species' recovery because it contains the adult moth's nectar food plants and the federally endangered larval host plant, *Nothocestrum breviflorum*. Lands in Unit 12 will provide habitat for this area's moth population. Additionally, based upon an understanding of this species and other moth species' flight capabilities and migrational needs, we believe that this area contributes to the available matrix of undeveloped habitat important as refugia for moths migrating to other areas of existing suitable host plant habitat (McIntyre and Barrett 1992; Roderick and Gillespie 1997; Van Gelder and Conant 1998; A. Medeiros, pers. comm., 1998; S. Montgomery, pers. comm., 2001).

Management Unit 13 - South Kailua Kona Management Unit (Hawaii)

Management Unit 13 consists of approximately 105 hectares (258 acres) of State land, encompassing portions of rugged lowland forest within the boundary of the Kailua-Kona township on the island of Hawaii. It is bounded on the south by Kailua-Kona town, on the north by rugged lava flows, to the west by coastal non-native plant communities, and to the east by residential housing areas. Natural features within the unit include rugged lava flows. Vegetation consists primarily of mixed-species mesic and dry forest communities composed of native and introduced plants, with smaller amounts of dry coastal shrubland (HINHP 2000). This unit is important for the species' recovery because it currently contains the adult moth's nectar food plants, and until recently, contained the federally endangered larval host plant, *Nothocestrum breviflorum*. We believe the area could be restored and made capable of supporting *Nothocestrum breviflorum* populations again. Lands in Unit 13 will provide habitat for this area's moth population. Additionally, based upon an understanding of this species and other moth species' flight capabilities and migrational needs, the we believe that this area contributes to the available matrix of undeveloped habitat important as refugia for moths migrating to other areas of existing suitable host plant habitat (McIntyre and Barrett 1992; Roderick and Gillespie 1997; Van Gelder and Conant 1998; A. Medeiros, pers. comm., 1998; S. Montgomery, pers. comm., 2001).

II. RECOVERY

A. OBJECTIVES AND CRITERIA

The overall objective of this recovery plan is to provide guidelines to ensure Blackburn's sphinx moth's long-term recovery. Given the relative lack of life history and demographic information, this recovery plan also provides prioritized recommendations for research that may redefine recovery criteria, thereby expediting the downlisting or delisting of this species. Interim goals include: (1) protect habitats known to support extant populations (habitat complexes); (2) stabilize populations within their known distributions (described habitat complexes); and (3) conduct research necessary to redefine recovery criteria. Reclassification of a species' listing status to threatened is appropriate when a taxon is no longer in danger of extinction throughout a significant portion of its range. Because data upon which to base current classification are incomplete, criteria for downlisting and delisting provided in this plan are preliminary.

1. Interim Downlisting Criteria

One Blackburn's sphinx moth population within one management unit on each island of Hawaii, Kahoolawe, and Maui must be well-distributed, naturally reproducing, and stable or increasing in size through one to two El Niño events or for at least 5 consecutive years before downlisting is considered. Stable Blackburn's sphinx moth populations are defined in this recovery plan as those in which observed population declines are followed by population increase to pre-decline levels. These criteria should provide for the maintenance of genetic variation that occurs in natural populations of Blackburn's sphinx moth by protecting known, natural populations and both the large and small habitats upon which they rely. Furthermore, these criteria should provide some assurance that a single catastrophic event will not destroy all populations of this species.

2. Interim Delisting Criteria

Before delisting of Blackburn's sphinx moth can be considered, the following requirements must be met: (1) one moth population within one

management unit must be naturally reproducing and stable or increasing in size, through one to two El Niño events or a minimum of 5 consecutive years within the Kauai-Oahu Recovery Unit; (2) four moth populations within four management units must be naturally reproducing and stable or increasing in size, through one to two El Niño events or a minimum of 5 consecutive years on three different islands within the Maui Nui Recovery Unit (of those four, one within windward and one within leeward Maui Island); and (3) two moth populations with two management units must be naturally reproducing and stable or increasing in size, through one to two El Niño events or a minimum of 5 consecutive years within the Big Island (Hawaii Island) Recovery Unit.

More specific downlisting and delisting criteria necessary for recovery can be developed when completion of some of the recovery actions provides necessary information on the life history and ecology of this species and its host plants.

B. STEP-DOWN OUTLINE OF RECOVERY ACTIONS

1. Protect habitat and control threats (overview)

    1.1 Identify and map significant, wild *Nothocestrum* spp. host plant populations

    1.2 Finalize delineation of recovery and management units

    1.3 Ensure long-term protection of habitat

    1.4 Identify and control threats to Blackburn's sphinx moths and their host plants

        1.4.1 Construct and maintain fencing around those areas containing *Nothocestrum* spp. host plants within the Blackburn's sphinx moth management units; remove ungulates

        1.4.2 Conduct alien weed control

1.4.3 Provide necessary wildfire protection

1.4.4 Propagate and maintain *Nothocestrum* spp. host plant genetic stock *ex situ*

1.4.5 Protect management units from human disturbance

1.4.6 Control and manage purposeful and accidental introduction of potential predators and parasites

1.4.7 Control other threats as appropriate

2. Expand existing wild *Nothocestrum* spp. host plant populations

2.1 Select populations for expansion or sites for new populations

2.2 Prepare sites within management units and out-plant species of *Nothocestrum* known to be larval host plants

3. Conduct additional research essential to recovery of the Blackburn's sphinx moth

3.1 Conduct research to confirm or discount *Nothocestrum longifolium* and *Nothocestrum peltatum* as suitable larval host plants

3.2 Determine adult Blackburn's sphinx moth host plant associations and potential limiting factors

3.3 Study the natural recruitment and fecundity of larval host plants (*Nothocestrum* spp.)

3.4 Determine annual Blackburn's sphinx moth life history cycle; investigate impacts of non-native predators and parasites

3.5 Conduct studies on the demography, dispersal, and genetics of the Blackburn's sphinx moth

3.6 Evaluate research results and implement adaptive management as necessary

4. Develop and implement a detailed monitoring plan for the Blackburn's sphinx moth

5. Re-establish and augment wild Blackburn's sphinx moth populations within its historic range

5.1 Investigate feasibility and desirability of Blackburn's sphinx moth translocation

5.2 Develop and implement specific plans for Blackburn's sphinx moth translocation

5.3 If necessary for translocation, develop methods for laboratory-rearing of Blackburn's sphinx moth

6. Develop and initiate a public information program for the Blackburn's sphinx moth

7. Validate recovery objectives

7.1 Refine/revise downlisting and delisting criteria as necessary

C. STEP-DOWN NARRATIVE OF RECOVERY ACTIONS

1. **Protect habitat and control threats** (overview)

Present information regarding threats potentially affecting the stability of extant Blackburn's sphinx moth populations on Hawaii, Maui, and Kaholawe and potential future Blackburn's sphinx moth populations on Lanai, Molokai, Oahu,

and Kauai are incomplete. However, some management activities are identifiable with currently available information on known threats such as wildfires, ungulates, non-native parasites, predators, invasive weeds, and urbanization. Habitat loss, especially the loss of larval and adult foraging habitat due to ungulates and non-native plants continues to be one of the greatest threats to this species. Until additional management units are identified, steps should be taken to protect the 13 currently proposed management units from degradation and disturbance (see Table 6). Steps may include fencing portions of the management units for the purpose of removing or controlling domestic and feral ungulates, implementing weed control programs, and wildfire management within identified, at-risk units.

1.1 Identify and map significant, wild *Nothocestrum* spp. host plant populations

It is believed that the known, persistent populations of Blackburn's sphinx moth are reliant upon large populations of two of the four endemic species of *Nothocestrum* host plants. As such, successful recovery of Blackburn's sphinx moth greatly depends upon perpetuation of its host plants, and this recovery plan largely reflects the recovery needs for the *Nothocestrum* genus as it does the recovery needs for Blackburn's sphinx moth.

Protection of the most stable and resilient populations of Blackburn's sphinx moth will involve locating significant (large) populations of the *Nothocestrum* host plants on all the major islands, mapping their precise locations, and providing this information to the relevant land managers. Of the four plant species in this genus, priority should be at first given to *Nothocestrum latifolium* and *Nothocestrum breviflorum*, the two documented larval Blackburn's sphinx moth host plant species within the genus. [Additional needed research (see action number 3.1) should verify or discount the suitability of *Nothocestrum longifolium* and *Nothocestrum peltatum* as larval host plants.]

In 2001, we contracted three researchers to survey for and/or to summarize known locations of moth host plants including *N. peltatum*, *N. longifolium*, *N. latifolium*, and *N. breviflorum*. New locations for

Nothocestrum species on Kauai, Oahu, Molokai, Lanai, and Hawaii Island were reported (J. Lau, *in litt*., 1993; L. Perry, *in litt*., 2001; K. Wood, *in litt*., 2001a, 2001b). Additional surveys should be conducted wherever there are reported or possible occurrences of each taxon. Occurrence data, including presence in or absence from previously reported sites (as well as site notes) and all relevant information for newly reported occurrences, should be carefully documented. Detailed site information (including directions, maps, global positioning system [GPS] data, and narratives) is recommended for each site.

1.2 Finalize delineation of recovery and management units

We have identified 3 recovery units and 13 component management units for Blackburn's sphinx moth. It will be necessary for the Blackburn's sphinx moth recovery team (development and assembly pending) to finalize and delineate boundaries for the 13 management units. In many cases, the range of Blackburn's sphinx moth will overlap with those of other listed taxa, and recovery and management units including multiple listed taxa from multiple recovery plans can be delineated and managed under a single management plan. For example, on the island of Hawaii, the larval Blackburn's sphinx moth host plant is *Nothocestrum breviflorum*, which is federally listed as endangered. Furthermore, on the island of Hawaii there are numerous federally listed plants within at least one of the four Blackburn's sphinx moth management units.

Management units should include areas of adequate size to allow for expansion of existing plant and moth populations as restoration activities proceed. Should additional areas of significant host plant populations be identified outside of the currently identified and proposed management units, they should also be considered for protection and management. Until additional information is obtained from the research actions (see action number's 3.1 - 3.6), the Blackburn's sphinx moth recovery and management units shall be identified as described. Divided among 7 of the main Hawaiian Islands are 3 recovery units each containing 2 or more component management units for a total of 13 management units.

1.3 Ensure long-term protection of habitat

The preservation of the Blackburn's sphinx moth management units is a primary concern. The protection currently provided to this species by various landowners should be continued and enhanced, and additional protective measures pursued as needed. This includes, but is not limited to, protection provided by Federal and State laws, regulations, and policies; management plans and policies of Federal, State, and private landowners; cooperative agreements, conservation easements, leases, potential Habitat Conservation Plans, and potential Safe Harbor Agreements.

Federal agencies are required by section 7 of the Endangered Species Act to ensure any action authorized, funded, or carried out by them is not likely to jeopardize the continued existence of any endangered or threatened species or destroy or adversely modify critical habitat. Section 7 further stipulates that all Federal agencies utilize their authorities in furthering the purposes of the Endangered Species Act by carrying out programs for the conservation of listed species. Endangered species management plans or other similar management plans for areas managed by the Department of the Army, Navy, National Park Service, and ourselves may contribute to the recovery of this species. We will provide technical guidance when requested or during the consultation process to develop and implement management plans for areas or projects where the moth and/or its critical habitat occurs.

The State of Hawaii can contribute to Blackburn's sphinx moth recovery by ensuring all State departments responsible for land zoning, permits, development projects, forestry projects, recreational programs, and other activities on their lands, are made aware of the presence of Blackburn's sphinx moth host plants on those lands. In addition, the State can review its proposed projects and ensure appropriate measures are taken to avoid, minimize, or mitigate potential impacts to the Blackburn's sphinx moth larval and adult host plants. In addition, the Department of Land and Natural Resources, Division of Forestry and Wildlife, Hawaii can consider development and implementation of long term management plans for each of the Blackburn's sphinx moth host plant populations on their lands.

Populations of Blackburn's sphinx moths and their host plants also occur on lands owned or managed by various private landowners. Steps could be taken to ensure all such landowners are aware of the presence of the listed taxa on their lands, and every effort made by Division of Forestry and Wildlife and/or us to assist the landowners, as necessary, in developing and implementing long-term management plans for the Blackburn's sphinx moth host plants on their lands will contribute to the long-term recovery of Blackburn's sphinx moth.

Through our Conservation Partnerships Program it is possible to develop voluntary habitat restoration programs with the goal of restoring moth management units through collaborative projects. The Conservation Partnerships Program seeks to implement large-scale conservation efforts for the benefit of native ecosystems by working cooperatively with private landowners, conservation organizations, community groups, and other government agencies. The Conservation Partnerships Program can provide cost-share funds, as well as information on habitat restoration techniques, native species, Safe Harbor Agreements, additional funding sources, required permits, and potential vendors of restoration services (*i.e.*, fence contractors, nurseries).

Safe Harbor assurances may be provided to non-Federal landowners ensuring that voluntary conservation actions on their property for listed species such as the moth covered by a Safe Harbor Agreement will not further restrict uses of their property, even if covered species have become more numerous or now occupy covered lands as a result of the property owner's management activities. Safe Harbor Agreements encourage landowners to manage their properties for the benefit of listed species, and must be designed to achieve a net conservation benefit to these species. Landowners who qualify for Safe Harbor assurances include private citizens, Tribes, States, local governments, businesses, organizations, and other non-Federal property owners.

1.4 Identify and control threats to Blackburn's sphinx moth and their host plants

For each Blackburn's sphinx moth host plant population, threats must be identified and prioritized, and threat management implemented to protect extant populations. Many threats have already been well documented, while others need to be further defined. New threats may become apparent as additional surveys, monitoring, and research are implemented. Once identified and the level of severity is assessed, threats must be controlled and managed. Known threats to Blackburn's sphinx moth and their host plants include: competition with non-native, invasive plants; wildfire; habitat degradation and herbivory by feral or uncontrolled ungulates; urbanization or similar development; seed and seedling destruction; introduced moth parasites/parasitoids; and introduced host plant diseases.

Threat control plans should be developed for each Blackburn's sphinx moth management unit. When applicable, threat control plans should be as comprehensive as possible, incorporating other management units when pertinent and other listed, proposed, and candidate taxa into one overall plan for recovery, restoration, and management of the habitats that support Blackburn's sphinx moth, its host plants, and other species. As currently identified, the potential primary habitat threats within the 13 Blackburn's sphinx moth management units are summarized in Table 7.

1.4.1 Construct and maintain fencing around those areas containing *Nothocestrum* spp. host plants within the Blackburn's sphinx moth management units; remove ungulates

The forests of Hawaii contain large numbers of goats, pigs, cattle, deer, sheep, and other introduced ungulates. Controlling these ungulates to the point where they are no longer impacting native vegetation is absolutely imperative for the recovery of Blackburn's sphinx moth, other listed species, and native Hawaiian habitats. The most effective method currently available for providing immediate protection from introduced ungulates is to fence discrete management

Table 7. Potential identified habitat threats within the 13 Blackburn's sphinx moth management units.

Kauai - Oahu Recovery Unit			
Management Unit	**Island**	**Ungulate threats**	**Other threats**
1. Kokee Unit	Kauai	cattle, goats	wildfire, weeds
2. Honouliuli Unit	Oahu	goats	wildfire, weeds
Maui Nui Recovery Unit			
Management Unit	**Island**	**Ungulate threats**	**Other threats**
3. Komoko Flats - Puukolekole Unit	Molokai	axis deer, cattle, goats cattle	wildfire, weeds
4. Lanaihale Unit	Lanai	axis deer, goats	wildfire, weeds
5. Upper Kahoolawe Unit	Kahoolawe	----------	wildfire, weeds
6. Waihee Unit (Windward Maui)	Maui	axis deer, goats	wildfire, weeds, urbanization
7. Kanaha Pond - Spreckelsville Unit (Windward Maui)	Maui	----------	wildfire, urbanization
8. Puu O Kali Unit (Leeward Maui)	Maui	axis deer, cattle, goats	wildfire, weeds, urbanization
9. Ahihi-Kinau NAR - Ulupalakua - Auwahi - Kanaio Unit (Leeward Maui)	Maui	axis deer, cattle, goats	wildfire, weeds, urbanization
Big Island Recovery Unit			
Management Unit	**Island**	**Ungulate threats**	**Other threats**
10. West Kohala Mtns. Unit	Hawaii	cattle, goats	wildfire, weeds, urbanization
11. Puu Waawaa - Hualalai Unit	Hawaii	cattle, goats	wildfire, weeds, urbanization
12. North Kailua-Kona Unit	Hawaii	cattle, goats	wildfire, weeds, urbanization
13. South Kailua-Kona Unit	Hawaii	cattle, goats	wildfire, weeds, urbanization

units, and then remove the ungulates from within the fenced areas. Although costly, this approach is an effective and feasible means of controlling introduced ungulates, as demonstrated during past projects within Hawaii Volcanoes and Haleakala National Parks and elsewhere. Eradication of introduced animals may be an option and, given sufficient public support, should be considered for certain moth management units.

The most effective strategy will probably be to use a combination of methods. Short-term, small-scale fencing can protect Blackburn's sphinx moth host plant populations under immediate threat from ungulates until longer-term, large-scale fencing projects are completed. However, even "small" exclosures should be built large enough to offset the negative impacts of the actual fencing and fence and site maintenance (*e.g.*, clearing of fence line and potential introduction of new weeds into the area). As a general guideline, minimum-sized exclosures should have their perimeters located at least 50 meters (162 feet) from the nearest individual *Nothocestrum* spp. host plant.

Fences should protect significant populations of Blackburn's sphinx moth host plants and include buffer areas of good-quality habitat. These buffer areas should be the focus of ongoing restoration and recovery efforts for Blackburn's sphinx moth and other rare and listed plants and animals.

Once the best method for fencing identified management areas (areas to receive specific, planned/active management such as fencing and weed control) is determined, fencing and maintenance plans should begin as soon as possible. Fences should be impervious to all ungulates found in the area including axis deer. Management units on those islands supporting axis deer populations will require specially designed and constructed fences to exclude this highly agile species. Ongoing inspection and maintenance of fences is necessary to ensure the continued exclusion of ungulates from the fenced areas.

When each fence is completed, all ungulates from within the exclosure should be removed. Eradication options may include baited hunting, snaring, and poisoning. Hunting from helicopters is also a highly effective eradication method, particularly for situations involving steep cliffs. Managers must realize the potentially detrimental impacts of these management activities. Soil and vegetation disturbance can create open areas for new alien species invasions, and inappropriate or careless activities can directly damage the Blackburn's sphinx moth host plants. Hunters and others who will be entering the management units should be appraised of the existence of the host plants so they do not inadvertently damage them.

After fence construction, ongoing monitoring for ungulates within the large fenced areas is necessary to verify their continued absence. Monitoring should include an analysis of the effects of the exclusion of ungulates, since their activities often helps to control certain alien weeds. Ungulate removal without subsequent alien plant management could encourage alien weed growth and allow them to overwhelm native plants including the Blackburn's sphinx moth host plants.

By fencing the at-risk areas within the 13 Blackburn's sphinx moth management units, the threat of current and future ungulate impact on the Blackburn's sphinx moth host plants can be halted or controlled. Fencing efforts should focus on the specific portions of management units currently containing host plants or those areas likely to support future out-planted host plants. We should develop cooperative programs with private landowners on lands containing Blackburn's sphinx moth or its host plants to help remove or minimize the impacts of current land uses. Table 8 summarizes which Blackburn's sphinx moth management units should receive priority attention regarding the threat of ungulates.

Table 8. Blackburn's sphinx moth management unit management/restoration priorities.

Kauai - Oahu Recovery Unit		
Management Unit	**Prior research required**	**Management/Recovery efforts (prioritized)**
1. Kokee Unit (Kauai)	1) Verify *Nothocestrum longifolium* & *Nothocestrum peltatum* host plant suitability	1) fencing of existing host plants 2) weed & ungulate removal/control 3) *Nothocestrum* spp. out-planting
2. Honouliuli Unit (Oahu)	1) Verify *N. longifolium* host plant suitability	1) fencing of existing host plants 2) *Nothocestrum* spp. out-planting 3) Periodically monitor for goat infiltration 4) weed control
Maui Nui Recovery Unit		
Management Unit	**Prior research required**	**Management/Recovery efforts (prioritized)**
3. Komoko Flats - Puukolekole Unit (Molokai)	-------	1) fencing of existing host plants 2) weed & ungulate removal/control 3) *Nothocestrum* spp. out-planting
4. Lanaihale Unit (Lanai)	-------	1) fencing of existing host plants 2) weed & ungulate removal/control 3) *Nothocestrum* spp. out-planting
5. Upper Kahoolawe Unit (Kahoolawe)	-------	1) weed control 2) *Nothocestrum* spp. out-planting
6. Waihee Unit (Windward Maui)	1) Research unit's suitability for *Nothocestrum latifolium* out-planting	1) fence priority areas 2) weed & ungulate removal/control 3) *Nothocestrum* spp. out-planting
7. Kanaha Pond - Spreckelsville Unit (Windward Maui)	1) Research unit's suitability for *Nothocestrum latifolium* out-planting	1) fence priority areas 2) *Nothocestrum* spp. out-planting
8. Puu O Kali Unit (Leeward Maui)	-------	1) fencing of existing host plants 2) weed & ungulate removal/control 3) *Nothocestrum* spp. out-planting
9. Ahihi-Kinau NAR - Ulupalakua - Auwahi - Kanaio Unit (Leeward Maui)	-------	1) fencing of existing host plants 2) weed & ungulate removal/control 3) *Nothocestrum* spp. out-planting

Table 8. Continued.

Big Island Recovery Unit		
Management Unit	**Prior research required**	**Management/Recovery efforts (prioritized)**
10. West Kohala Mtns. Unit	1) conduct more surveys for host plants	1) fencing of existing host plants 2) weed & ungulate removal/control 3) *Nothocestrum* spp. out-planting
11. Puu Waawaa - Hualalai Unit	1) conduct more surveys for host plants	1) fencing of existing host plants 2) weed & ungulate removal/control 3) *Nothocestrum* spp. out-planting
12. North Kailua-Kona Unit	-------	1) fencing of existing host plants 2) weed & ungulate removal/control 3) *Nothocestrum* spp. out-planting
13. South Kailua-Kona Unit	-------	1) fencing of existing host plants 2) weed & ungulate removal/control 3) *Nothocestrum* spp. out-planting

1.4.2 Conduct alien weed control

Because many alien weeds are known to be an important indirect threat to *Nothocestrum* spp., invasive weed control should be a priority management activity for the Blackburn's sphinx moth management units. The need for this management activity may increase if the removal of ungulates relieves grazing and browsing pressure on alien plants within fenced management units. Additionally, soil and vegetation disturbance by managers can create open areas for new alien species invasions, and inappropriate or careless activities can cause direct damage to the Blackburn's sphinx moth host plants. Steps should always be taken to minimize these effects.

Effective weed control methods must be developed. Control methods may include, but are not limited to, removal by hand, local herbicide application, and biological control. Weed control should be aggressively implemented in the vicinity of the Blackburn's sphinx moth host plants, particularly within and around fenced management units. Weed control should be prioritized for each population, beginning in the immediate vicinity of existing host plants, and

continuing until control is achieved in the full management unit. Follow-up visits to each site are necessary to ensure weeds are permanently controlled, so sites should be monitored annually, or as needed, to determine when additional control activities are necessary. Control efforts should be supervised by experienced managers to ensure crews do not compact soil, damage root systems, or improperly apply herbicides.

Introduction of alien plants and other species to the State of Hawaii, and between islands within the State, needs to be better controlled to prevent further impact to the Blackburn's sphinx moth host plants and their habitats. In order to prevent the introduction of new, potentially detrimental alien species, support should be given to legislation, programs, or activities limiting the possibility of future introductions of alien species. The success of such programs or activities would contribute to the perpetuation of the Blackburn's sphinx moth host plants in this plan and the quality of all native ecosystems as well as agricultural concerns in the State of Hawaii.

1.4.3 Provide necessary wildfire protection

All 13 of the Blackburn's sphinx moth management units are at risk from wildfire. The plant communities which include *Nothocestrum* spp. within these 13 management units have undergone dramatic alteration within the last 200 years. A large factor in the alteration of these dry and mesic regions has been the creation of a frequent wildfire regime, a condition to which the native flora is not adapted (Blackmore and Vitousek 2000; Hughes *et al.* 1991). The current wildfire regime facilitates alien grass invasion into native plant communities including most habitats containing Blackburn's sphinx moth and its host plants. The impact of wildfire to these areas is a serious and immediate threat to the survival of the dry and mesic habitats supporting over one-third of Hawaii's threatened and endangered species including Blackburn's sphinx moth and its host plants (Blackmore and Vitousek 2000; Hughes *et al.* 1991).

Wildfire, invasion of fire-adapted alien plants, and ungulate disturbance and seed dispersal, have increased the susceptibility of

native areas to wildfire and increased the frequency of wildfire occurrence in Hawaii. These factors reduce the amount of forest cover for native species and livestock as well as some non-native game species (Blackmore and Vitousek 2000; Hughes *et al.* 1991). These pressures result in an intensification of feral ungulate herbivory into the resulting smaller, remaining native forest areas. Development and implementation of fuels management strategies at a landscape scale are the only measures that can effectively reduce the imminence of this particular threat (Blackmore and Vitousek 2000; Hughes *et al.* 1991).

Both prescribed burning and other fuels management techniques need further evaluation for application within the Blackburn's sphinx moth management units. However, in the interim, the management units intersected by or adjacent to major roads or highways would benefit from roadside wildfire fuels management treatments in the form of mechanical vegetation removal, grazing, and/or herbicide application. Plans to protect each site from fire should be developed and implemented. "Fire free" zones should be established, with hunters and other land users appraised of the dangers of smoking and open flames in dry or drought-prone, leeward areas. Fuel breaks with a minimum width of 6 meters (20 feet) should be constructed around the Blackburn's sphinx moth host plants wherever feasible and maintained as necessary. This minimum width is a guideline only and may not be sufficient to protect populations from fire in especially dry conditions.

Vegetation manipulation, such as replacing a highly flammable fuel with a less flammable fuel, may be another viable method for wildfire suppression in Hawaiian natural areas. Land managers still need more information to adequately address fire suppression in natural areas. Support should be given to programs or activities advancing our understanding of wildfire fuels management in Hawaii. The success of such programs or activities would contribute to the recovery of Blackburn's sphinx moth and its host plants and to the quality of all native ecosystems in Hawaii. Table 9 highlights the Blackburn's sphinx moth management units for which roadside wildfire management techniques should be a priority.

Table 9. Blackburn's sphinx moth recovery units requiring priority roadside wildfire management.

Kauai - Oahu Recovery Unit		
Management Unit	**Island**	**Requires additional priority fire management**
1. Kokee Unit	Kauai	✔
2. Honouliuli Unit	Oahu	-----
Maui Nui Recovery Unit		
Management Unit	**Island**	**Requires additional priority fire management**
3. Komoko Flats - Puukolekole Unit	Molokai	-----
4. Lanaihale Unit	Lanai	-----
5. Upper Kahoolawe Unit	Kahoolawe	-----
6. Waihee Unit (Windward Maui)	Maui	✔
7. Kanaha Pond - Spreckelsville Unit (Windward Maui)	Maui	✔
8. Puu O Kali Unit (Leeward Maui)	Maui	✔
9. Ahihi-Kinau NAR - Ulupalakua - Auwahi - Kanaio Unit (Leeward Maui)	Maui	✔
Big Island Recovery Unit		
Management Unit	**Island**	**Requires additional priority fire management**
10. West Kohala Mtns. Unit	Hawaii	✔
11. Puu Waawaa - Hualalai Unit	Hawaii	✔
12. North Kailua-Kona Unit	Hawaii	✔
13. South Kailua-Kona Unit	Hawaii	✔

1.4.4 Propagate and maintain *Nothocestrum* spp. host plant genetic stock *ex situ*

Although cultivation of Blackburn's sphinx moth host plants is not an adequate substitute for their preservation in the wild, cultivated populations of each species (especially *Nothocestrum latifolium* and *Nothocestrum breviflorum*) should be maintained as pools of genetic resources for reintroduction to appropriate sites and to safeguard against losses of genetic material due to catastrophe in wild populations. Additionally, the existence of cultivated plants may reduce any demand for field-collected specimens of these rare plants by providing a propagated source of those species for which there might be a horticultural and/or research interest.

For each identifiable population (either from extant sites or traceable, pure, cultivated material), genetic material (seeds) should be collected from as many individuals as is feasible. Collection methods and quantities of materials collected should be devised to minimally impact wild populations. All collected materials should be labeled accurately and should include, but not be limited to, exact origin and collection date.

Seeds of each host plant species should be collected and entrusted to seed banks for long-term storage using the best available techniques for preservation. Seeds in long-term storage should be periodically tested for viability and re-collected as necessary.

1.4.5 Protect management units from human disturbance

The specific areas containing the host plants within the 13 Blackburn's sphinx moth management units should be protected as much as possible from hikers, vehicles, and other possibilities of direct human disturbance. This protection effort should involve public awareness and information activities regarding the Blackburn's sphinx moth host plants, and native habitats in general, and should be done in

conjunction with public information activities for other listed taxa. Public information efforts are currently underway to ensure Army National Guard training exercises avoid sensitive areas.

Signs designating sensitive environmental areas and/or research areas should be placed near the most fragile sites where human contact may occur. "Sensitive Area: Please kokua (help) and tread lightly" signs should minimize entry and/or impact to these areas. However, such signs may not be necessary for some host plant populations in remote areas and/or areas not frequently visited, or where signs may attract undue attention to these populations, thereby exposing them to vandalism. The decision regarding sign placement should be based upon the circumstances surrounding each host plant population.

Where possible, access to roads and/or trails passing through Blackburn's sphinx moth host plant habitat should be allowed only for necessary management activities (*e.g.*, fire control, hunting, monitoring, etc.). Care should be taken at all times during road or trail maintenance in or near Blackburn's sphinx moth host plant habitat to avoid practices which could cause opening of canopies, excessive erosion, or damage to the plants or their habitat. If hiking is permitted in management areas, hikers should be informed of the presence of sensitive environments and of the precautions that should be taken to avoid disturbance of such areas (*e.g.*, cleaning of boots and clothing prior to hikers entering a sensitive area, the importance of staying on existing trails). All such activities should be closely monitored by the appropriate landowner or land manager.

1.4.6 Control and manage purposeful and accidental introduction of potential predators and parasites

Alien predatory and parasitic insects are important factors contributing to the reduction in Blackburn's sphinx moth abundance, and may be the most serious current, direct threat to the moth itself. Some of these alien species were intentionally introduced by the State

of Hawaii's Department of Agriculture or other agricultural agencies (Funasaki *et al.* 1988) and importations and augmentations of lepidopteran parasitoids are still potential threats. Federal regulations for the introductions of biological control agents have not adequately protected this species (Lockwood 1993).

Presently, there are no Federal statutes requiring review of biological control agents before their introduction, and the limited Federal review process requires consideration of potential harm only to economically important species (Miller and Aplet 1993). Although the State of Hawaii requires pre-release review of new introductions (Hawaii State Division of Forestry and Wildlife, Hawaii Revised Statues Chapter 150A), post-release biology and host range cannot be predicted from laboratory studies (Gonzalez and Gilstrap 1992; Roderick 1992) and the purposeful release of or population augmentation of any lepidopteran predator or parasitoid is a potential threat to Blackburn's sphinx moth (Gagné and Howarth 1985; Simberloff 1992). We need to work closely with the Hawaii State Department of Agriculture to ensure any future importations of control agents or augmentations of previously established biological control agents will not have a deleterious impact on Blackburn's sphinx moth.

1.4.7 Control other threats as appropriate

Should other threats to the survival and recovery of Blackburn's sphinx moth, such as additional parasites or alien weed plants, be identified as research actions are completed, appropriate management actions will need to be developed and implemented. Additional threats from human activities may be identified and will require new management steps as well.

2. Expand existing wild *Nothocestrum* spp. host plant populations

The *Nothocestrum* spp. host plant populations may expand naturally after management activities eliminate current threats. However, in certain instances,

populations may need to be augmented in order to enhance Blackburn's sphinx moth recovery and increase its likelihood of reclassification or delisting. Suitable sites for population augmentation should be selected after carefully evaluating whether introducing new individuals into the wild populations will negatively impact wild plants. Augmentation efforts should document the source of out-planted material and methods of out-planting and restoration.

2.1 Select populations for expansion or sites for new populations

The need for expanding current populations should be evaluated, and specific plans should be created for the augmentation of wild populations needing enhancement. Several of the Blackburn's sphinx moth management units are in need of some level of restoration. Restoration in the form of fencing existing *Nothocestrum* spp. populations and out-planting host plants to augment existing populations or create new populations may be efficient and cost-effective forms of recovery for these units. Table 8 above, summarizes the management and restoration priorities including host plant population expansion for each of the Blackburn's sphinx moth management units.

2.2 Prepare sites within management units and out-plant species of *Nothocestrum* known to be larval host plants

Prior to out-planting, each selected site must be prepared and protected appropriately, including the building of exclosures and controlling alien species within the exclosures. After sites are protected, *ex situ*-propagated seedlings should be added to existing wild populations in quantities and at times deemed appropriate. In order to maintain the integrity of the wild population's gene pool, the *ex situ*-propagated material should be from the same or adjacent sites. To prevent contamination of wild populations, the *ex situ* materials must be free from pests, diseases, and pathogens. Cultivated plants may have been grown in the presence of other pathogen-carrying plants, and wild populations may have lower resistance to such pathogens.

Care should also be taken to match soils if transplanting seedlings due to differences in water retention around the root areas (*i.e.*, if the surrounding

soil in the management unit is more absorptive than the nursery potting soil, the seedling roots could become overly-dry and the newly-transplanted specimen may weaken and/or die). Augmented populations should be maintenance of each site should begin after initial preparation and planting.

3. Conduct additional research essential to recovery of Blackburn's sphinx moth

Protecting and recovering habitat containing the native Blackburn's sphinx moth host plants or other necessary biological requirements is of major importance in reaching the ultimate goal of delisting Blackburn's sphinx moth. However, additional research is needed on the biology of Blackburn's sphinx moth and its host plants. Surveys for both the moth and its host plants are needed because current information is limited and the number of Blackburn's sphinx moth populations and the number of individuals needed for long-term survival should be determined. The initial efforts for developing standardized survey and monitoring techniques and collecting additional life history, demographic, and genetic information will be conducted on Blackburn's sphinx moth populations on the islands of Hawaii and Maui. As survey and monitoring techniques are developed for Blackburn's sphinx moth, they may be applied to the Blackburn's sphinx moth population on Kahoolawe and populations on other islands to determine Blackburn's sphinx moth abundance and distribution and to monitor population changes over time.

Completion of research actions will not only establish the distribution and abundance of Blackburn's sphinx moth and its host plants, but will also provide information on habitat requirements to improve management actions. With basic information on where Blackburn's sphinx moth and larval host plants are located, their resource needs can be better defined and threats better identified and managed. Management actions need to protect and restore habitats containing larval host plants as well as adult foraging areas. Impacts from predators and parasitoids will also have to be evaluated and addressed.

Basic natural history of Blackburn's sphinx moth (especially its current distribution) larval and adult host plant associations, and potential threats, must be

better understood. Furthermore, research should be conducted on the larval host plants regarding aspects of the life history, habitat, reproductive biology, optimum requirements for growth, and threats for each of the four *Nothocestrum* species to better understand the requirements for maintaining viable populations of these plants. The suitability of other plants, native and non-native, as suitable larval host plants (*e.g.*, *Solanum* spp.) should also be investigated. The following research actions are listed in order of priority:

3.1 Conduct research to confirm or discount *Nothocestrum longifolium* and *Nothocestrum peltatum* as suitable larval host plants

Larval Blackburn's sphinx moth feeding has been observed and documented on only two species of the endemic *Nothocestrum* genus, *N. latifolium* and *N. breviflorum*. Because there are past historical records of Blackburn's sphinx moth occurring on the islands of Kauai and Oahu, it is possible or even likely that *Nothocestrum peltatum* and *Nothocestrum longifolium* are suitable host plants for larval Blackburn's sphinx moth, but this needs to be confirmed through controlled studies or documented field observations. There are at least three possible explanations for past sightings of Blackburn's sphinx moth on Kauai and Oahu: (1) past sightings were actually observations of migrating or dispersing moths from distant populations; (2) *Nothocestrum latifolium* (known to be larval food source) was once found in greater numbers on Kauai and Oahu and supported a resident Blackburn's sphinx moth population(s); or, (3) Blackburn's sphinx moth population(s) inhabited both Kauai and Oahu and utilized *Nothocestrum peltatum* and/or *Nothocestrum longifolium* as larval food sources.

The federally endangered *Nothocestrum peltatum* is endemic to Kauai. The rare *Nothocestrum longifolium* is known from all the main islands except Niihau, but more extensive surveys need to be conducted on most islands to determine the size and distribution of the populations.

3.2 Determine adult Blackburn's sphinx moth host plant associations and potential limiting factors

The availability of adult foraging habitat is considered key to the survival of Blackburn's sphinx moth, however, adult host plant associations are poorly understood at this time. Obtaining better information on the habitat needs of adult Blackburn's sphinx moth and whether adult host plant availability and fecundity is a factor limiting the moth is critical and could result in the need to redefine the boundaries of the proposed management units. Protection and /or enhancement of adult foraging habitat could be a vital step in increasing population size since adult health will likely increase fecundity (Center for Conservation Biology Update 1994; Janzen 1984).

3.3 Study the natural recruitment and fecundity of larval host plants (*Nothocestrum* spp.)

Researchers have observed a lack of *Nothocestrum* spp. natural recruitment and fecundity within all of the Blackburn's sphinx moth management units containing the species (M. Bruegmann, pers. comm., 1998; A. Medeiros, pers. comm., 1998; K. Wood, *in litt*., 2001a, b). Most likely this trend is due to ungulate browsing and/or encroachment of non-native weed species. However, research should be conducted to determine the exact causes for *Nothocestrum* spp. decline so appropriate management actions can be implemented. Conversely, as core populations of Blackburn's sphinx moth host plants within management units are fenced from ungulate browsing and managed for wildfire, regular monitoring should be conducted to determine the effects of those management actions on seedling establishment.

Aspects of the growth of each *Nothocestrum* species needs to be studied, including growth and mortality of seedlings, growth and longevity of mature plants, optimum growing conditions, and limiting factors such as water, soil, and nutrient requirements. Factors affecting the reproductive success of each *Nothocestrum* species needs to be investigated, including seed viability, breeding system, pollinators, and factors affecting flowering and seed set. This

information is critical for the long-term recovery of the host plants and the moth.

3.4 Determine annual Blackburn's sphinx moth life history cycle; investigate impacts of non-native predators and parasites

A combination of the methods outlined in action number's 3.1 - 3.3 will help address questions regarding the annual life cycle of Blackburn's sphinx moth. Research should be conducted to determine the seasonal distribution of adult moths and how different habitats are utilized. This information is pertinent since moths are often found at great distances from known larval host plant areas. Composition of flora, invertebrate, bird, and other faunal populations within each management unit should be determined to gain better understanding of the relationships between these organisms and Blackburn's sphinx moth and its host plants.

Some past research efforts including Van Gelder and Conant's 1998 study have identified likely impacts from non-native predators and parasites, however, we believe additional research is needed to understand how these organisms may be limiting the moth's recovery and what might be done to minimize or control this threat. At the very least, it may be possible to learn how to suppress predator and parasite populations during important seasonal stages of the moth.

It is possible one or more Blackburn's sphinx moth management units may comprise a single population or meta-population. Future research should attempt to determine the necessary habitat areas (areas of the highest quality habitat) of known Blackburn's sphinx moth populations and obtain information on the demography of these populations including information on meta-population dynamics if they occur. These populations or meta-populations must demonstrate stability and/or resilience to natural environmental disturbances and/or demographic fluctuations. Stable Blackburn's sphinx moth populations are defined in this recovery plan as those in which observed population declines are followed by population increase to pre-decline levels. Such population rebounds will likely occur during years of greater than

average precipitation and the associated increase in growth and vigor of larval host plants and adult food plants. Hence, monitoring Blackburn's sphinx moth population trends to document stability or declines must include factors such as rainfall and the growth of host plants.

3.5 Conduct studies on the demography, dispersal, and genetics of Blackburn's sphinx moth

These studies will require development of non-invasive mark-recapture methods. Data from these studies should provide information on adult moth longevity and home range. Additional lab studies may be necessary to determine adult fecundity. These data should allow us to develop population viability models which can be used to guide and re-evaluate recovery criteria.

Genetics studies should be conducted on the known moth populations to better determine if there are differences between populations and to guide potential translocation efforts (see action numbers 5.1- 5.3).

3.6 Evaluate research results and implement adaptive management as necessary

The results of the above research actions should be evaluated and incorporated into the management process and used in the development of recovery objectives.

4. Develop and implement a detailed monitoring plan for Blackburn's sphinx moth

Biological surveys that result 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). Previous population estimates of Blackburn's sphinx moth have either been estimated without systematic surveys, or have been based upon limited and incomplete data. Standardized surveying and monitoring techniques should be developed.

To determine the number of occupied management units, surveys for pre-diapause larval clusters (to obtain estimates of recruitment) should be conducted. No less than half of the total number of management units identified within a population or meta-population distribution should be used to obtain this estimate. Ideally, the surveyed sample of management units should be distributed as evenly as possible across the area occupied by the population/sub-population to avoid potential error caused by correlation of suitability among nearby management units or subunits.

Using methodology to be developed on the islands of Maui and Hawaii (since they currently contain the largest Blackburn's sphinx moth populations), island-wide surveys and monitoring studies in suitable habitat should be carried out on the islands of Kahoolawe, Molokai, Lanai, Oahu, and Kauai to determine relative Blackburn's sphinx moth levels and population stability and distribution. In order to be effective, these studies must encompass all habitats and elevations where Blackburn's sphinx moth potentially occur. These studies may also reveal general information on adult foraging patterns and habitat associations.

Monitoring will be necessary to determine whether Blackburn's sphinx moth populations remain stable over time. Once current Blackburn's sphinx moth distribution and activity levels are known, monitoring programs should be implemented within occupied areas to monitor trends, such as population fluctuations, range increases or retractions, or newly identified threats. This monitoring should occur at least annually so any drop in population numbers can be quickly identified and management actions taken. Each island population identified by completed surveys should be monitored at least annually for 5 consecutive years, and then once every 3 years to establish information on population trends and possible threats.

5. Re-establish and augment wild Blackburn's sphinx moth populations within historic range

If re-establishment of Blackburn's sphinx moth host plant populations are successful (see action number 2), then the possibility of re-establishing the moth itself should be investigated to meet recovery objectives.

5.1 Investigate feasibility and desirability of Blackburn's sphinx moth translocation

Depending upon the results of action number 3.5, the appropriateness of re-introducing Blackburn's sphinx moth into wild situations should be assessed for unoccupied management units, especially for the Kauai - Oahu Recovery Unit, which is entirely unoccupied. Blackburn's sphinx moth individuals could then be translocated from existing, stable populations during years of high moth abundance to the management units where they are known or believed to have occurred historically, which would include the units on Kauai, Oahu, Molokai, and Lanai. Translocation of Blackburn's sphinx moth to the Kauai - Oahu Recovery Unit would also depend upon results obtained from research conducted for action number 3.1.

5.2 Develop and implement specific plans for Blackburn's sphinx moth translocation

Each translocation effort should be guided by a specific plan. Each plan should identify re-establishment sites within each management unit. The plan should also describe the methods to be used to ensure the translocated individuals are free from parasites and pathogens.

Prior to each translocation, each site within target management units must be prepared appropriately, including construction of exclosures and control of alien species therein, as necessary to protect the existing Blackburn's sphinx moth host plants. Newly re-established populations should be monitored carefully (see action number 4).

5.3 If necessary for translocation, develop methods for laboratory-rearing of Blackburn's sphinx moth

Blackburn's sphinx moth larvae or adults could also be translocated from laboratory-reared stock if sufficient numbers of the moth in existing, wild populations lack sufficient numbers for translocation purposes. The captive propagation effort should be guided by a captive propagation plan that describes the methods that will be used for the laboratory-rearing of

Blackburn's sphinx moth. The plan should also describe the methods to be used to ensure the captively-reared individuals are free from parasites and pathogens.

6. Develop and initiate a public information program for Blackburn's sphinx moth

An informed public will be more receptive to recovery of Blackburn's sphinx moth and its habitat. Public perception of insects in general is often negative, such that encounters with insects are likely to be viewed as unpleasant. This may be less the case in Hawaii, in part because of the year-around abundance of insects and because lepidopterans (moths and butterflies) are perhaps the insects most favorably viewed by the general public. Informational programs can present insects in general, and Blackburn's sphinx moth in particular, as beneficial and interesting living components of Hawaii's ecosystems. Visitor centers at State and National Parks, at U.S. Fish and Wildlife Service Refuges, or other State and Federal installations open to the public and on islands where Blackburn's sphinx moth occurs, can devote space for exhibits, prepare pamphlets and other informational materials, and inform people about this unique and spectacular, native Hawaiian insect. Additionally, 'moth walks' can be conducted, providing the public with an opportunity to observe and monitor Blackburn's sphinx moth or similar species in their natural setting. State and Federal agricultural and health agency staff working with the public would benefit from a program aiming to distribute information to the agricultural industry about Blackburn's sphinx moth, their status, and their potential benefits as pollinators of native Hawaiian plants.

7. Validate recovery objectives

The scientific validity of the recovery objectives should be reviewed and revised as appropriate as more information becomes available.

7.1 Refine/revise downlisting and delisting criteria as necessary

Based upon scientific information gathered during recovery efforts (*e.g.*, data on viable population sizes, longevity, etc.), recovery criteria for Blackburn's sphinx moth should be revised. Until this additional information is available, the

criteria presented in this recovery plan should be used as the basis for downlisting and delisting.

Table 10 provides a cross-reference of recovery actions and listing factors.

Table 10. Cross-reference of recovery actions and listing factors for Blackburn's sphinx moth.

LISTING FACTOR	THREAT	STILL A THREAT?	RECOVERY ACTION NUMBERS	RECOVERY CRITERIA
A	Destruction of habitat by feral animals	yes	1.3, 1.4.1, 1.4.2, 1.4.5, 2.1, 2.2, 3.2, 3.3, 3.6, 5.1, 6	*See pages 63-64 for downlisting and delisting criteria.
A	Invasion and competition of alien plants	yes	1.3, 1.4.3, 1.4.5, 3.1, 3.2, 3.3, 3.4, 3.5	
A	Development	yes	1.3, 1.4.7, 6	
A	Ranching	yes	1.3, 1.4.7, 6	
A	Agricultural development	yes	1.3, 1.4.3, 1.4.4, 1.4.6, 1.4.7, 6	
A	Wildfire	yes	1.3, 1.4.3, 1.4.4, 1.4.5, 2.1, 2.2, 3.3, 6	
B	Collection of specimens	yes	1.4.5, 6	
C	Parasitism/predation from alien species including ants, wasp, and flies	yes	1.4.6, 3.4, 3.5	
D	Inadequacy of federal regulations allowing introduction of alien biocontrol agents	yes	1.4.6	
E	Susceptibility to seasonal variations and weather fluctuations	yes	1.3, 1.4.4, 2.1, 2.2, 2.2, 3.2, 3.4, 5.1, 5.2, 5.3	

III. IMPLEMENTATION SCHEDULE

The Implementation Schedule that follows outlines actions and estimated cost for the Blackburn's sphinx moth recovery program, as set forth in this recovery plan. It is a guide for meeting the objectives discussed in Part II of this plan. This schedule indicates action priority, action numbers, action descriptions, duration of actions, the organizations involved and/or responsible for committing funds, and lastly, estimated costs. When more than one organization is listed as the responsible party, an asterisk is used to identify the lead entity.

The actions identified in the implementation schedule, when accomplished, should lead to a better understanding of the current distribution and status of Blackburn's sphinx moth, protect habitat for the species, stabilize the existing populations, and allow for an increase in population sizes and numbers. Monetary needs for all parties involved are identified to reach this point, whenever feasible.

Priorities in Column 1 of the following implementation schedule are 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 species' population/habitat quality, or some other significant negative impact short of extinction.
Priority 3	All other actions necessary to provide for full recovery of the species.

Key to acronyms used in the implementation schedule:

BRD	United States Geological Survey, Biological Resources Division
DOFAW	Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife
ES	U.S. Fish & Wildlife Service, Pacific Islands Fish and Wildlife Office, Honolulu, Hawaii

HHP	Hawaiian Natural Heritage Program
HDOA	Hawaii Department of Agriculture

Recovery Plan Implementation Schedule for Blackburn's sphinx moth

Priority #	Action #	Action Description	Action Duration	Responsible Parties	Total Cost[a]	Costs Estimates ($1,000s)					
						FY 1	FY 2	FY 3	FY 4	FY 5	FY 6
1	1.1	Identify and map significant, wild *Nothocestrum* spp. host plant populations	2	*ES BRD DOFAW HHP	15 15 15 30	10 10 10 20	5 5 5 10				
1	1.2	Finalize delineation of recovery and management units	1	ES	20	20					
1	1.3	Ensure long-term protection of habitat	6	*ES DOFAW	60 60	10 10	10 10	10 10	10 10	10 10	10 10
1	1.4	Identify and control threats to Blackburn's sphinx moth and their host plants	6	ES *BRD DOFAW	60 60 60	10 10 10	10 10 10	10 10 10	10 10 10	10 10 10	10 10 10
1	1.4.1	Construct and maintain fencing around those areas containing *Nothocestrum* spp. host plants within the Blackburn's sphinx moth management units; remove ungulates	ongoing	*ES DOFAW	1,100 1,100	300 300	300 300	300 300	25 25	25 25	25 25
1	1.4.2	Conduct alien weed control	ongoing	*ES DOFAW	400 400	60 60	60 60	60 60	60 60	60 60	60 60
1	1.4.3	Provide necessary wildfire protection	ongoing	*ES DOFAW	120 120	20 20	20 20	20 20	15 15	15 15	15 15
1	1.4.4	Propagate and maintain *Nothocestrum* spp. host plant genetic stock *ex situ*	ongoing	ES *BRD DOFAW	210 210 210		30 30 30	30 30 30	30 30 30	30 30 30	30 30 30
1	1.4.5	Protect management units from human disturbance	ongoing	*ES DOFAW	30 30	5 5	5 5	5 5	3 3	3 3	3 3

Recovery Plan Implementation Schedule for Blackburn's sphinx moth

Priority #	Action #	Action Description	Action Duration	Responsible Parties	Total Cost[a]	Costs Estimates ($1,000s)					
						FY 1	FY 2	FY 3	FY 4	FY 5	FY 6
1	1.4.6	Control and manage purposeful and accidental introduction of potential predators and parasites	1	ES DOFAW *HDOA	10 10 10	10 10 10					
1	1.4.7	Control other threats as appropriate	6	ES	60	10	10	10	10	10	10
1	2.1	Select populations for expansion or sites for new populations	2	*ES BRD DOFAW	10 10 10		5 5 5	5 5 5			
1	2.2	Prepare sites within management units and out-plant species of *Nothocestrum* known to be larval host plants	5	*ES DOFAW	150 150		30 30	30 30	30 30	30 30	30 30
1	4	Develop and implement a detailed monitoring plan for Blackburn's sphinx moth	2	*ES BRD	200 200	100 100	100 100				
2	3.1	Conduct research to confirm or discount *Nothocestrum longifolium* and *Nothocestrum peltatum* as suitable larval host plants	2	ES *BRD	10 10		5 5	5 5			
2	3.2	Determine adult Blackburn's sphinx moth host plant associations and potential limiting factors	2	ES *BRD	10 10		5 5	5 5			
2	3.3	Study the natural recruitment and fecundity of larval host plants (*Nothocestrum* spp.)	6	ES *BRD	30 30	5 5	5 5	5 5	5 5	5 5	5 5

Recovery Plan Implementation Schedule for Blackburn's sphinx moth

Priority #	Action #	Action Description	Action Duration	Responsible Parties	Total Cost[a]	Costs Estimates ($1,000s)					
						FY 1	FY 2	FY 3	FY 4	FY 5	FY 6
2	3.4	Determine annual Blackburn's sphinx moth life history cycle; investigate impacts of non-native predators and parasites	2	ES *BRD	10 10		5 5	5 5			
2	3.5	Conduct studies on the demography, dispersal, and genetics of Blackburn's sphinx moth	6	ES *BRD	30 30	5 5	5 5	5 5	5 5	5 5	5 5
2	3.6	Evaluate research results and implement adaptive management as necessary	1	ES DOFAW *BRD	5 5 5	5 5 5					
2	5.1	Investigate feasibility and desirability of Blackburn's sphinx moth translocation	2	ES *BRD	30 30		15 15	15 15			
2	5.2	Develop and implement specific plans for Blackburn's sphinx moth translocation	2	ES *BRD	30 30		15 15	15 15			
2	5.3	If necessary for translocation, develop methods for laboratory-rearing of Blackburn's sphinx moth	2	ES *BRD	30 30		15 15	15 15			
3	6	Develop and initiate a public information program for Blackburn's sphinx moth	6	ES	24	15	5	1	1	1	1
3	7.1	Refine/revise downlisting and delisting criteria as necessary	6	ES	30	5	5	5	5	5	5
TOTAL NEED 7					**30**	**5**	**5**	**5**	**5**	**5**	**5**
TOTAL ESTIMATED COST					**5,574**	**1,185**	**1,370**	**1,141**	**442**	**442**	**442**

[a]In some cases the total cost for a given action in this table may exceed the action sum for FY 1 through FY 6 if the action is ongoing.

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