

610 m (2,000 ft), and is also restricted by rainfall, rarely being found in particularly dry (less than 35 to 50 cm (15 to 20 in) annually) or wet (more than 250 cm (100 in) annually) areas (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 on all the major Hawaiian Islands, including those currently inhabited by Blackburn's sphinx moth and is a direct threat to these populations (Neil Reimer, Hawaii Department of Agriculture (HDOA), pers. comm. 2001; Medeiros *et al.* 1993; Nishida 1997).

Several additional ant species threaten the conservation of Blackburn's sphinx moth. The Argentine ant (*Linepithema humilis*) has been reported on several islands, including Maui, Kahoolawe, and Hawaii (Adam Asquith, Service, pers. comm. 1998; A. Medeiros, pers. comm. 1998; Nishida 1997). The long-legged ant (*Anoplolepis longipes*) is reported on several islands, including Hawaii and Maui (Hardy 1979). At least two species of fire ants, *Solenopsis geminata* and *S. papuana*, are also important threats (Reagan 1986; Gillespie and Reimer 1993) and occur on many of the major islands (Reimer *et al.* 1990; Nishida 1997). *Ochetellus glaber*, a recently reported ant introduction, occurs on Maui, Hawaii, and Kahoolawe (A. Medeiros, pers. comm. 1998; N. Reimer, pers. comm. 2001; Nishida 1997).

Parasitic Wasps

Hawaii also has a limited fauna of native Hymenopteran wasp species, with only two native species in the family Braconidae (Beardsley 1961), neither of which is 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 nonnative 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 and have become the dominant larval parasitoids even in intact, high-elevation, native forest areas of the Hawaiian Islands (Zimmerman 1948, 1978; Funasaki *et al.* 1988; Howarth *et al.* 1994). 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*, is known to attack the tobacco hornworm and the related tomato hornworm in North America (Carlson 1979). This wasp is recorded from all of the main 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 moths, 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 (F. Howarth, pers. comm. 1994; Howarth 1983; Gagné and Howarth 1985; Howarth *et al.* 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 (John Beardsley, University of Hawaii, pers. comm. 1994; Nishida 1997). Several alien species are established in Hawaii (Nishida 1997), including *Trichogramma minutum*, which is known to attack the sweet potato hornworm in Hawaii (Fullaway and Krauss 1945). In 1929, the wasp *Trichogramma chilonis* was purposefully introduced into Hawaii as a biological control agent for the Asiatic rice borer (*Chilo suppressalis*). 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 *T. chilonis*. Over 80 percent of the eggs of the alien grasswebworm (*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 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

(Tothill *et al.* 1930; Howarth 1991; Nafus 1993b).

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, *C. monticola* is known to attack at least 36 species of Lepidoptera in eight families, including sphinx moths; *L. 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 (Tothill *et al.* 1930; Howarth 1991). Both of these species occur on Maui and Hawaii (Nishida 1997) and are direct threats to the Blackburn's sphinx moth.

Based on the findings discussed above, nonnative predatory and parasitic insects are considered important factors contributing to the reduction in range and abundance of the Blackburn's sphinx moth, and in combination with habitat loss and fragmentation, are a serious threat to its continued existence. Some of these nonnative species were intentionally introduced by HDOA or other agricultural agencies (Funasaki *et al.* 1988) and importations and augmentations of lepidopteran parasitoids continues. Although the State of Hawaii requires new introductions to be reviewed before release (HDOA 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 parasitoid is a potential threat to the conservation of the Blackburn's sphinx moth (Gagné and Howarth 1985; Simberloff 1992).

As Table 1 indicates, the assemblage of potential alien predators and parasites on each island may differ.