Appendix A. Karner Blue Butterfly Biology

The following summary of Karner blue butterfly biology and ecology is excerpted from the USFWS Final Karner Blue Butterfly Recovery Plan (USFWS 2003). For a complete copy of the Federal Recovery Plan, please go to the following USFWS website: http://www.fws.gov/midwest/endangered/insects/kbb/kbbRecPlan.html

Since this appendix consists of material excerpted from another document, some clarification is merited. The federal Recovery Plan was used as the source for this appendix because it includes the most succinct and current summary of Karner blue butterfly biology. References to "this recovery plan" found in this excerpt refer to the Karner Blue Butterfly Recovery Plan (USFWS 2003), *not* the Wisconsin Karner Blue Butterfly HCP (the HCP is not a federal recovery plan). Similarly, mention of appendices made in this excerpt refers to appendices of the Karner Blue Butterfly Recovery Plan (USFWS 2003), not material appended to the HCP. To reduce redundancy and costs, references cited in the excerpt are not included in the updated HCP. Readers should refer to the recovery plan for proper citations. However, table and figure references included here do refer to tables and figures in the excerpt.

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Reference

U.S. Fish and Wildlife Service. 2003. Final Recovery Plan for the Karner Blue Butterfly *(Lycaeides melissa samuelis*). U.S. Fish and Wildlife Service, Fort Snelling, Minnesota. 273 pp.

PART I. INTRODUCTION

The Karner blue butterfly (*Lycaeides melissa samuelis*) was proposed for Federal listing on January 21, 1992 [U.S. Fish and Wildlife Service (USFWS) 1992a], and on December 14, 1992 it was listed as federally endangered rangewide (USFWS 1992b). Historically, the Karner blue butterfly occurred in 12 states and at several sites in the province of Ontario. It is currently extant in seven states (New Hampshire, New York, Ohio, Indiana, Michigan, Wisconsin and Minnesota) with the greatest number of occurrences in the western part of its range (Michigan and Wisconsin). The Karner blue is considered extirpated from five states and the Canadian province of Ontario. Reintroductions are underway at three sites, Concord, New Hampshire, West Gary, Indiana, and in Ohio. The historic habitat of the butterfly was the savanna/barrens ecosystems. Much of these ecosystems has been destroyed by development, fragmented, or degraded by succession, and has not been replaced by other suitable habitat, especially in the eastern part, and along the margins of the butterfly's range. The loss of suitable habitat resulted in a decline in Karner blue locations and numbers, with some large populations lost, especially in the eastern and central portions of its range. Presently, the Karner blue butterfly occupies remnant savanna/barrens habitat and other sites that have historically supported these habitats, such as silvicultural tracts (e.g. young pine stands), rights-of-ways, airports, military bases, and utility corridors.

The ecology of the Karner blue butterfly is closely tied to its habitat which provides food resources and key subhabitats for the butterfly. The larvae feed only on one plant, wild lupine (*Lupinus perennis*). Adults require nectar sources to survive and lay sufficient eggs. Because these habitat components can be lost to succession, Karner blue butterfly persistence is dependent on disturbance and/or management to renew existing habitat or to create new habitats. The distribution and dynamics of these habitats in the establishment of viable metapopulation of this species forms the ecological basis for recovery planning.

TAXONOMY AND DESCRIPTION

Taxonomy

The taxonomy of the Karner blue *(Lycaeides melissa samuelis)* follows Lane and Weller (1994) who have conducted the most recent review of its taxonomy. The Karner blue is a member of the genus *Lycaeides* (Lepidoptera: Lycaenidae: Polyommatinae) (Elliot 1973, Nabokov 1943, 1949). In North America there are two species of *Lycaeides*, *L. idas* (formerly *L. argyrognomon*) and *L. melissa* (Higgins 1985, Lane and Weller 1994). *Lycaeides melissa* is comprised of six subspecies, *L. m. melissa*, *L. m. annetta*, *L. m. inyoensis*, *L. m. mexicana*, *L. m. pseudosamuelis*, and *L. m. samuelis* (Lane and Weller 1994). Vladimir Nabokov conducted the taxonomy for this group in the 1940s. Sometime after this work was published, Nabokov commented in private letters that the Karner blue should be classified as a distinct species (Nabokov 1952, 1975, 1989). Nabokov noted that the male genitalia of *L. m. melissa* were very variable geographically, but the male genitalia of *L. m. samuelis* were remarkably constant over the entire range of the subspecies. The wing shape of *L. m. samuelis* is rounder and less pointed than that of *L. m. melissa*, especially the female hingwing. Moreover, *L. m. samuelis* uses only one host plant throughout its geographic range, while *L. m. melissa* uses many species of host plant. The taxonomic work to elevate *L. m. samuelis* to the species level was never completed, and the currently accepted status of the Karner blue butterfly is subspecific (Miller and Brown 1983, Nabokov 1943, 1949, Opler 1992, Opler and Krizek 1984, Lane and Weller 1994). While other work has been done on the taxonomy of the Karner blue, the data thus far does not support a change in the classification of the butterfly.

Packer et al. (1998) described protein variation detected by starch gel electrophoresis in a study of 34 loci in two samples of the Karner blue (Wisconsin and New York) and one sample of the Melissa blue (Minnesota). Based on their application of a phylogenetic species concept criterion for species-level distinctness requiring fixed allele differences between the two supposed species, they concluded that the Karner blue and the Melissa blue are not distinct enough to be considered different species. They also reported that the genetic identity values between samples from the different subspecies (0.967 and 0.976) were less than between the two samples of Karner blue (0.989). They observed that these identity values were within the ranges of values reported for subspecies and intraspecific populations of other insects. Genetic data alone, according to their interpretation, is consistent with both population-level and subspecies-level divergence. The utility of these data for making inferences about taxonomy and population structure is limited by the small number of populations sampled and the small number of individuals (ranging from 3 to 17 individuals, depending on the population and locus) sampled. In addition, genetics data alone should not be used in making taxonomic decisions; it must be considered together with morphological, life history, and ecological data.

Nice et al. (2000) investigated the taxonomy of the genus using male genital morphology and variation in nuclear (microsatellite) and mitochondrial (mt) DNA, sampled from over 60 *Lycaeides* populations. The microsatellite DNA data support the treatment of the Karner blue as a distinct evolutionary unit (coherent taxon). Genetic distances based on DNA among taxa in this genus were small relative to the differentiation in morphological and ecological traits. Microsatellite allele frequency data indicate that the Karner blue population is a well defined, closely related group, distinct from other *Lycaeides* taxa. Indeed, microsatellite data indicate that the Karner blue is the most clearly defined of the North American *Lycaeides* taxa**.**

The morphology of *Lycaeides* male genitalia indicated that while other forms of *L. melissa* are more variable (as Nabokov noted), there was no diagnostic distinction between them and the Karner blue. These data support the treatment of *L. melissa* as a distinct taxonomic unit. They do not refute the indications of the microsatellite data that Karner blue is a clearly defined taxon, but they cannot be used to support the concept either.

In contrast, mtDNA variation found by Nice et al. (2000) was inconclusive. These data did not support the concept of *L. melissa* or the Karner blue as a coherent taxonomic unit, and cannot be used for inferences about the genetic distinctions among populations of the Karner blue butterfly. The Wisconsin and Minnesota Karner blue populations share mtDNA haplotypes with populations of *L. melissa* and *L. idas* in the western U.S. Two unique haplotypes were found in Karner blue populations east of Lake Michigan (i.e., Indiana, Michigan, New York, New Hampshire), but haplotypes associated with European species were also related to these eastern populations. The mtDNA haplotype data suggest that there may have been movement of haplotypes among *Lycaeides* species and among *L. melissa* subspecies (Nice et al. 2000). [However, use of these mtDNA data for making any taxonomic inferences, including inferences about gene movement is limited by the small sample size from some of the sites (one sample each from Minnesota and Michigan) and limited number of base pairs analyzed (Robert Zink, University of MN, pers.comm. 2002).]

Taken as a whole, the genetic, morphological, ecological, and life history data support treating the Karner blue as a coherent taxon, with taxonomic affinities to both the *L. melissa* and *L. idas* groups. Karner blue butterfly populations are distinct from other nearby *Lycaeides.* They are bivoltine, dependent on *Lupinus perennis* (wild lupine), and possess distinct wing pattern elements. In addition, there is no evidence of morphological intermediacy in the Karner blue populations sampled (Chris Nice, pers. comm. 2002).

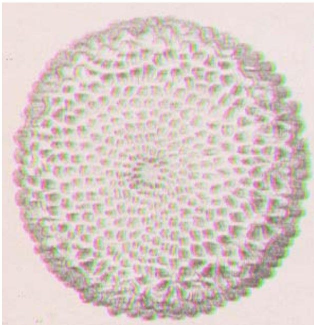
While additional genetics work, done with larger sample sizes, additional sample sites, and more analyses of nuclear and mtDNA may be helpful to further determine if *Lycaeides melissa samuelis* should be divided into two or more subspecies, such work is considered a low recovery priority for the reasons noted above.

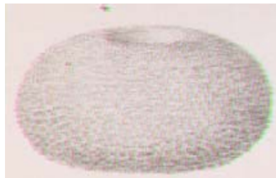
Description

Figure 1 depicts the various life stages of the Karner blue. Karner blue butterflies are small with a wingspan of about 2.5 cm. (one inch). The forewing length of adult Karner blues is 1.2 to 1.4 cm for males and 1.4 to 1.6 cm for females (Opler and Krizek 1984). The wing shape is rounded and less pointed than *L. m. melissa*, especially in the female hind wing (Nabokov 1949). The upper (dorsal) side of the male wing is a violet blue with a black margin and white-fringed edge. The female upper side ranges from dull violet to bright purplish blue near the body and central portions of the wings, and the remainder of the wing is a light or dark gray-brown, with marginal orange crescents typically restricted to the hind wing. Both sexes are a grayish fawn color on the ventral side. Near the margins of the underside of both wings are orange crescents and metallic spots. The black terminal line along the margin of the hind wing is usually continuous (Klots 1979, Nabokov 1944). Nobokov (1944, 1949) believed that male genitalia were the most reliable character for distinguishing adult *L. m. samuelis* from other subspecies (and species). The work of Nice et al. (2000) however, did not find the morphology of the male genitalia to be a good diagnostic characteristic.

The eggs of Karner blue are tiny and radially symmetric, about 0.7 mm in diameter, somewhat flattened, and pale greenish-white in color (Dirig 1994). The surface is deeply reticulated with a fine geometric pattern (Scudder 1889). Larvae are a pea-green color, pubescent and dorsally flattened, with a brown-black to black head capsule. The head is often not visible as it is tucked under the body. Older larvae have pale green (to white) lateral stripes, and a dark-green longitudinal stripe dorsally. In pre-pupal larvae, the lateral stripes become less distinct and the color becomes a duller green. Larvae have four instars (larval development stages) (Savignano 1990), and three glandular structures that are known to mediate interactions with ants in other species of Lycaenidae (Refer to PART I, LIFE HISTORY AND ECOLOGY, Associated Ants, and Savignano 1994a and references therein). Some of these glandular structures mediate interactions with ants in Karner blue, but it is not known what is secreted by any of the structures and if any of the structures are active throughout larval life.

Figure 1. Life stages of the Karner blue butterfly





Egg, top view
[-------------------------]
0.7mm

Egg, side view

Egg on lupine

Larva on lupine

Larva tended by ant
Larval feeding damage on lupine

Pupae on lupine

Adult Female

Adult Male

Photo credits. Drawings of eggs from Scudder (1889); Karner blue larvae tended by ant courtesy of the Wisconsin DNR, all other photos courtesy of Paul Labus, The Nature Conservancy, Whiting, Indiana (refer also to: http://nature.org/wherewework/northamerica/states/indiana/preserves/art9126.html for additional images).

Ants are known to tend larvae during their larval stage (Figure 1). Pupae are bright green and smooth, changing to a light tan with hints of purple shortly before emergence when the adult cuticle separates from the cuticle of the pupal case.

Distinguishing Karner blue from similar species

In the eastern United States, the Karner blue butterfly can be confused readily with the eastern-tailed blue (*Everes comyntas*) and less readily with the spring azure (*Celastrina argiolus*) complex (Opler 1992, Scott 1986). Eastern-tailed blues are on average smaller than Karner blue and they have black projections or "tails" on the outer angle of the hind wings (Opler 1992, Scott 1986). These tails may be broken off but usually leave some remnant indicating their former presence. On the underside of the wings, eastern-tailed blues lack orange crescents on the forewing, and four spots, two large and two small, are present on the hind wing (Opler 1992, Scott 1986). It may be difficult to distinguish a large male eastern-tailed blue from a small male Karner blue when they are in flight. Spring azures lack the orange crescents on the undersides of their wings (Opler 1992).

In the Midwest, Karner blue butterflies can be confused with Nabokov's blue (*L. idas nabokovi*), Melissa blue (*L. melissa melissa*), eastern- and western-tailed blues (*Everes comyntas* and *E. amyntula*), Reakirt's blue (*Hemiargus isola*), greenish blue (*Plebius saepiolus*), marine blue (*Leptotes marina*), acmon blue (*Icaricia acmon*), spring azure (*Celastrina argiolus*) complex, and silvery blue (*Glaucopsyche lygdamus*) (Opler 1992, Scott 1986). Species occurrence varies throughout the Midwest and to determine the species present locally, it is best to consult local guides and checklists. Eastern-tailed blue is the only species that is confused readily with Karner blue. Spring azure, silvery blue, Reakirt's blue, and marine blue lack the orange crescents on the under sides of their wings (Opler 1992, Opler and Krizek 1984, Scott 1986). Eastern- and western-tailed blues have tails (as described above), orange crescents are absent on the underside of the forewing, and there are, respectively, four or one orange spot(s) on the hind wing (fewer than Karner blue). The greenish blue has one or more orange marginal crescents, which are, however, much smaller in size than the spots on Karner blue. The marginal crescents on the dorsal side of the male acmon blue hind wing, tend to be more pink than orange (Opler 1992). Melissa blue can be distinguished from Karner blue by the orange banding on the upper (dorsal) side of the forewing (females only**),** genitalia differences and differential habitat use (Nabokov 1943, 1949, Scott 1986). Melissa blue larvae can feed on *Astragalus* sp., *Glycyrriza lepidota*, *Lupinus* sp., and several other species (Scott 1986). The occurrence of Melissa blue comes closest (30 miles) to Karner blue sites in southeastern Minnesota. The range of Nabokov's blue, *L. idas nabokovi*, overlaps with Karner blue in certain areas, but the Karner blue is typically found in oak and pine savanna/barrens, whereas Nabokov's blue is found primarily in forest clearings (Masters 1972). Also, the two species have different host plants. The Karner blue feeds exclusively on wild lupine (*Lupinus perennis*), and Nabokov's blue feeds on dwarf bilberry (*Vaccinium cespitosum*) (Nielsen and Ferge 1982). Although there are superficial differences in coloration between these two subspecies (Masters 1972), unequivocal identification would require dissection and examination of the male genitalia (Nabokov 1944). Interested readers should consult the cited references for more details.

DISTRIBUTION

Rangewide Distribution of Karner Blues

Historically, the Karner blue butterfly occurred in a geographic band between 41^o and 46^o North latitude extending from Minnesota to Maine (Dirig 1994) (refer to Figure B-1, APPENDIX B). The butterfly is commonly found on sandy soil types that have populations of *Lupinus perennis* (the only known larval food source), and often inhabits communities similar to oak and pine savanna/barrens communities. In this recovery plan, the term "lupine" will refer to *L. perennis* to the exclusion of all other species of *Lupinus*.

Dirig (1994) reviewed all of the locality records of the Karner blue he could find, whether or not they were confirmed with vouched specimens. His work is an exhaustive summary of the reports of Karner blue occurrence. To establish a definitive historic geographic range, this recovery plan only includes locality records with confirmed specimens. Additional information from Dr. Robert Dirig, requested by the Recovery Team, was especially critical for evaluating records from Pennsylvania, New Jersey, Maine, and Wisconsin. These findings are summarized here and presented in greater detail in APPENDIX B.

The historic northern, eastern, and western limits of the butterfly correspond roughly with the distributional limits of lupine. In all three regions, the present distribution of the butterfly has contracted away from these limits, with extirpations of populations occurring in all three geographic directions. The northernmost population of the Karner blue occurs in the Superior Outwash Recovery Unit (RU) in Wisconsin, the westernmost population in the Paleozoic Plateau RU in Minnesota, and the easternmost population in the Merrimac/Nashua River System RU in New Hampshire (refer to APPENDIX B, Figures B2 and B4).

The historic southern limit of the butterfly did not correspond to the distribution of lupine, which occurred historically much further south than the butterfly. But even here the distribution of Karner blue has contracted away from the historic distribution. The southernmost population of Karner blue is now in the Indiana Dunes RU (refer to APPENDIX B, Figure B3).

As of Fall 2002, extant populations of the Karner blue occur in Indiana, Michigan, Minnesota, New Hampshire, New York, Wisconsin, and Ohio. Reintroductions are currently ongoing in Ohio, at Concord, New Hampshire, and in West Gary, Indiana. Almost all known extant populations occur on sandy soils associated with glacial outwash plains and terraces, glacial moraines, the shores and bottoms of glacial lakes, the glacial shores of existing lakes, and dissected sandstone outwashes (Andow et al. 1994 and references therein, APPENDIX B). Wisconsin and Michigan have the largest number of local populations with the greatest numbers of individuals; New York has one large population (Baker 1994). Many local populations of the butterfly appear extirpated, and the States of Iowa, Illinois, Pennsylvania, Massachusetts, Maine, and the Canadian province of Ontario no longer support populations of the butterfly (Baker 1994).

State Distribution of Karner Blues

This section briefly reviews survey efforts and the distribution of the Karner blue in each state where recovery units (RUs) have been established via this recovery planning process. Survey efforts to identify additional Karner blue sites are continuing in Wisconsin, Michigan and New York, with additional Karner blue butterfly localities identified in all three states since Federal listing of the species. Several of the survey efforts are a result of formal section 7 consultations with Federal agencies including the Department of Defense (Fort McCoy) in Wisconsin and the U.S. Forest Service in Michigan (for forest management activities on the Huron-Manistee National Forest [NF] and for gypsy moth control). For a glossary of terms used in this recovery plan (Plan) refer to APPENDIX A. For information and locations on the 13 RUs and six potential RUs established by this Plan refer to APPENDIX B.

<u>New Hampshire</u> (Merrimack/Nashua River System RU)

No native Karner blue populations remain in New England. The last native population occurred in the Concord Pine Barrens in Concord, New Hampshire, and was extirpated in 2000. That last population, which existed in a powerline right-of-way and the grassy safeways of the Concord Airport had declined from 3,700 estimated butterflies in 1983 (Schweitzer 1983, 1994), to 219 butterflies in 1991, and to less than 50 in 1994, making this site at extreme risk for extinction (Peteroy 1998). A reintroduction program was started in 2001 at Concord, with the donor population coming from the Saratoga Airport in New York (refer to PART I, Translocation/Reintroduction, <u>Captive rearing</u>)**.**

<u>New York</u> (Glacial Lake Albany RU)

The Karner blue butterfly was once common in New York (Cryan and Dirig 1978, Dirig 1994). In the Albany area alone, the Karner blue probably inhabited most of the 25,000 acres of the original Albany Pine Bush, the area from which Karner blues were first described. The Albany Pine Bush area once supported an estimated 17,500 butterflies in one 300 acre site during 1978 (Sommers and Nye 1994). By the mid-1980's, however, much of the Albany Pine Bush had been destroyed by development and degraded by introduction of non-Pine Bush species and natural succession. By 1988, only 2,500 acres of the original 25,000 acres remained (Givnish et al. 1988), and loss of habitat has continued. Current populations number only in the several hundreds (Schweitzer 1994a), and existing habitat continues to undergo succession and degradation.

Additional Karner blue butterfly sites occur in the Saratoga Sandplains and Saratoga West areas north of Albany. The majority of the sites in these areas support less than 100 butterflies. The largest population of the butterfly is at the Saratoga Airport, and is estimated to support 10,000 Karner blue butterflies.

Currently the New York Department of Environmental Conservation (NY DEC) has identified 70 Karner blue localities and 56 subpopulations (using the 200 meter separation criteria for subpopulations**,** refer to APPENDIX A) in the Glacial Lake Albany RU. Of those, 43 subpopulations are within the three recovery areas: 7 in the Albany Pine Bush, 27 in Saratoga Sandplains, and 9 in Saratoga West. Of these 43 subpopulations, only 15 are anticipated to have more than 10 butterflies in the annual index counts. Eight subpopulations are within the Queensbury Sandplains in Warren County, which is considered a location for recovery under the state's draft recovery plan. Five subpopulations are within Glacial Lake Albany RU, but are isolated from any expected interaction with the sites in the recovery areas. The NY DEC considers a site occupied until at least five years of adequate survey has failed to find the species. Some of the New York subpopulations are extremely small and vulnerable and will be considered extirpated if Karner blues are not found in the next year or two (Gerald Barnhart, NY DEC, in litt. 2002).

Michigan: (Ionia, Allegan, Newago and Muskegon RUs)

The Karner blue butterfly is currently found in 10 of the 11 Michigan counties in which it historically occurred. Early surveys by Wilsmann (1994) noted that the Karner blue populations were reduced and highly fragmented. The majority of the Karner blue sites occur on state land (Flat River and Allegan State Game Areas [SGAs]) in the Ionia and Allegan RUs, and on Federal lands (Huron-Manistee National Forest) in the Newaygo and Muskegon RUs.

Survey efforts during 1994-1996 by the Michigan Natural Features Inventory (NFI) of 65 areas within the Ionia RU on public and private lands revealed nine extant Karner blue sites, eight within the Flat River SGA; with the exception of one site, all supported low numbers of butterflies (Cuthrell and Rabe 1996). Based on data through 1998, eight subpopulations (defined as separated by 200 meters of unsuitable habitat) have been identified at the Flat River SGA and 23 at the Allegan SGA. In addition, two other subpopulations occur on private property; one near each of these state properties (Daria Hyde, Michigan NFI, pers. comm. 1998). The Ionia RU is the least well surveyed of all the Michigan RUs with much of the area outside of the Flat River SGA developed for agriculture and other uses (Baker 1994, Wilsmann 1994). The most sizable populations in the state occur at Allegan and Flat River SGAs and most likely on the Huron-Manistee NF (Jennifer Fettinger, pers. comm. 2002).

Many locations in the Newaygo and Muskegon RUs that supported Karner blue butterfly populations 35-40 years ago have been lost to succession, agricultural conversion, forestry, and residential and commercial developments (Wilsmann 1994). The majority of Karner blue sites in these two RUs occur on the Huron-Manistee NF. As of the fall of 2002, a total of 13,792 acres of the Huron-Manistee NF were surveyed for the Karner blue, with butterflies found on 2,026 acres in 267 locations. As of 2002, 78 subpopulations (using the 200 meter criteria) were reported on the Huron-Manistee NF; these includes seven along powerline ROWs (Jennifer Fettinger, MI NFI, pers. comm. 2002). In 2002, the Michigan NFI surveyed 58 sites on the Huron-Manistee NF and found the Karner blue at 40 of these sites. Surveys on private lands within the Manistee National Forest boundary have documented an additional 56 localities on about 440 acres (Joe Kelly, pers. comm. 1998, Jennifer Fettinger, pers.comm. 2002). Some utility companies (e.g., Consumers Energy and Wolverine Power Company) in Michigan are surveying their transmission line corridors for Karner blues.

As of the fall of 2002, Michigan, excluding the Allegan SGA, supported 158 subpopulations of Karner blues (based on a 200 meter separation criteria) (Jennifer Fettinger, Michigan NFI, pers. comm. 2002). As noted above, in 1998, Allegan SGA supported 23 subpopulations of Karner blues; this number is currently under revision to reflect 2002 numbers.

Indiana: (Indiana Dunes RU)

Historically, the Karner blue was reported from eight counties in Indiana. In 1990, Karner blue butterflies were identified at 10 sites out of 35 potential sites surveyed (Martin 1994). Two population clusters were identified within two counties (Lake and Porter), the majority of which was associated with medium to high quality Karner blue habitat (Martin 1994). The early surveys in Porter County (which includes the National Park Service's Indiana Dunes National Lakeshore [IDNL]) identified between 1,000 and 10,000 second brood Karner blue adults (Baker 1994). In Lake County, at the IDNL, several thousand second brood adults were estimated (Schweitzer 1992), and in other Lake County sites, the subpopulations likely number between 100-500 (John Shuey, The Nature Conservancy (TNC), pers. comm. 1998).

Currently it is estimated that 17 subpopulations of Karner blues (using the 200 meter separation criteria) occur at IDNL (Ralph Grundel and Noel Pavlovic, U.S. Geological Survey (USGS), pers. comm. 1998). In West Gary, about 21 tracts clustered into 11 individual preserves and management areas have been identified as potentially able to at least periodically support the Karner blue (Shuey, undated); these sites are associated with a remnant dune and swale complex. In 1998, four of these tracts supported Karner blues (John Shuey, pers. comm. 1998); however, by 2000, Karners were gone from all four sites. In 2001, a reintroduction project was started to restore Karner blues to West Gary (refer to PART I, Reintroduction/Translocation, Captive rearing)

Wisconsin: (Morainal Sands, Glacial Lake Wisconsin, West Central Driftless, Wisconsin Escarpment and Sandstone Plateau and Superior Outwash RUs)

The Wisconsin Department of Natural Resources (WDNR) began systematic statewide surveys for the Karner blue in 1990 including surveys of 33 of the 36 known historic butterfly sites. Initial surveys by Bleser (1993) reported that only 11 of the 33 historical sites supported Karner blues, and also identified 23 previously unknown sites. Additional survey efforts were subsequently conducted by the Wisconsin DNR, the U.S. Fish and Wildlife Service (Service) [Trick 1993, Necedah National Wildlife Refuge (NWR)], Fort McCoy (Leach 1993), and other biologists (Swengel 1994, Bidwell 1996). By 1993, an estimated 150 to 170 discrete Karner blue sites were documented in Wisconsin (Baker 1994). In recent years, additional surveying has been done by partners to the Wisconsin Statewide Habitat Conservation Plan for the Karner Blue Butterfly (HCP) including eight county forest departments, several private forest and utility companies, The Nature Conservancy, and the Wisconsin Department of Transportation. Partners to the HCP routinely survey for the butterfly prior to conducting management activities in an effort to avoid adverse impacts to the Karner blue. In addition, partners monitor for Karner blues annually as part of the HCP effectiveness monitoring program coordinated by the Wisconsin DNR.

Two separate but related sources of data on the Karner blue and its habitat in Wisconsin currently demonstrate that Karner blue butterfly populations in Wisconsin are numerous and widely distributed across the state. As of April 2002, Wisconsin DNR's Natural Heritage Inventory (NHI) database noted 311 Karner blue butterfly occurrences (using a one-half mile separation criteria) across 20 counties in Wisconsin. This reflects an 815 percent increase in recorded NHI Karner blue occurrences since listing. Similarly, the HCP annual monitoring program has documented 256 Karner blue occupied sites as of December 2002 on HCP partner lands, reflecting a 241 percent increase in Karner blue occupied sites on partner lands between 1998 and 2002 (Darrell Bazzell, WDNR, in litt. 2002). Most of the 256 Karner blue occurrences on partner lands are a subset of the NHI data (i.e. included in the 311 NHI occurrences), although further analyses is necessary to determine if some of these sites are new NHI occurrences (greater than 1/2 mile from an existing occurrence).

The number of known lupine sites on HCP partner lands in Wisconsin has also increased. About 252,299 acres of land (WDNR 2002a) are covered by the HCP, and partners implement measures that contribute to the conservation, and in some cases, recovery of the butterfly on these lands (WDNR 2000) (not all this acerage supports Karner blues). In 1998, there were 90 identified lupine sites on shifting mosaic (i.e. forestry) habitat that contained at least 25 plants or clumps of lupine at a density of 50 lupine plants/acre, or 25 lupine plants/200 meters for linear sites (e.g., rights-of-way). Annual HCP monitoring since 1998 has identified an additional 220 sites containing lupine, bringing the total to 310, an increase of 244 percent from 1998 to 2002. In addition, approximately 1,600 identified long-term habitat (e.g. barrens, rights-of-ways) sites in Wisconsin contain lupine.

Taken as a whole, the data demonstrate that of all the states, Wisconsin has the most numerous and widespread Karner blue occurrences, and that the butterfly is likely to be more stable in Wisconsin than previously believed (additional detailed review of HCP monitoring data is needed to further assess this possibility). In addition, there are many thousands of acres of suitable or potentially suitable habitat for the Karner blue in Wisconsin especially on HCP partner lands. The data strongly suggests that future monitoring will continue to identify new occupied Karner blue occurrences as well as additional suitable habitat in Wisconsin. For these reasons it appears appropriate for the Recovery Team to thoroughly review the data on the distribution, status, and threats to the butterfly in Wisconsin and to re-evaluate the recovery goals and criteria for the state, and if appropriate, to revise the goals as warranted. A recovery task has been added to this plan to that effect (refer to PART II, RECOVERY TASKS, Task 6.3).

Most of the Wisconsin subpopulations can be lumped into about 15 large population areas, many of which are found on sizable contiguous acreages in central and northwest Wisconsin (WDNR 2000). At least one sizable population occurs in each of the five Wisconsin recovery units (refer to APPENDIX B). Some of the largest Karner blue populations are found at Necedah NWR, Fort McCoy, Glacial Lake Grantsburg Work Unit [which includes Fish Lake and Crex Meadows State WAs], Eau Claire County Forest, Jackson County Forest, and Black River State Forest. Some larger populations occur on HCP partner lands.

Minnesota: (Paleozoic Plateau RU)

Karner blue butterflies currently only occur at the Whitewater Wildlife Management Area (WMA) in southeastern Minnesota. Two to possibly five small local populations are located in a 1770-acre expanse of poor to high quality oak savanna at the WMA. Translocation of butterflies into an unoccupied site was initiated in 1999 and was repeated in 2000 and 2002. Some success of this effort was evidenced by the discovery of butterflies during the first flight in 2001, thus indicating over-wintering survival (refer to PART I, CONSERVATION MEASURES, Reintroduction/Translocation).

Permanent transect counts conducted at two sites since 1992 (Cuthrell and Historic Sites) recorded peak second flight counts ranging from 0.63 to 4.00 butterflies per 1,000 square meters of transect (mean = 1.40) at the Cuthrell Site, and from 0 to 1.33 butterflies per 1,000 square meters of transect (mean = 0.60) at the Historic Site. These numbers represent relative abundance, and the relationship between numbers counted and total population size is unknown but is probably linear (Lane 1999a, Edwards 2002). Because other butterfly monitoring research has shown that only a portion of the butterflies in a sample area are counted and that in this case only a fraction of each site is surveyed, population numbers are considerably greater than the observed transect count numbers.

There are other locations in the southeastern and east-central part of the state that formerly supported lupine. The only other known location to have supported the Karner blue butterfly in Minnesota is the Cedar Creek Natural History Area (CCNHA). Surveys of 50 potentially suitable sites in Minnesota (oak savanna with sandy soil and lupine) revealed that many lupine sites were no longer present and that Karner blues had been extirpated from the CCNHA site (Lane and Dana 1994).

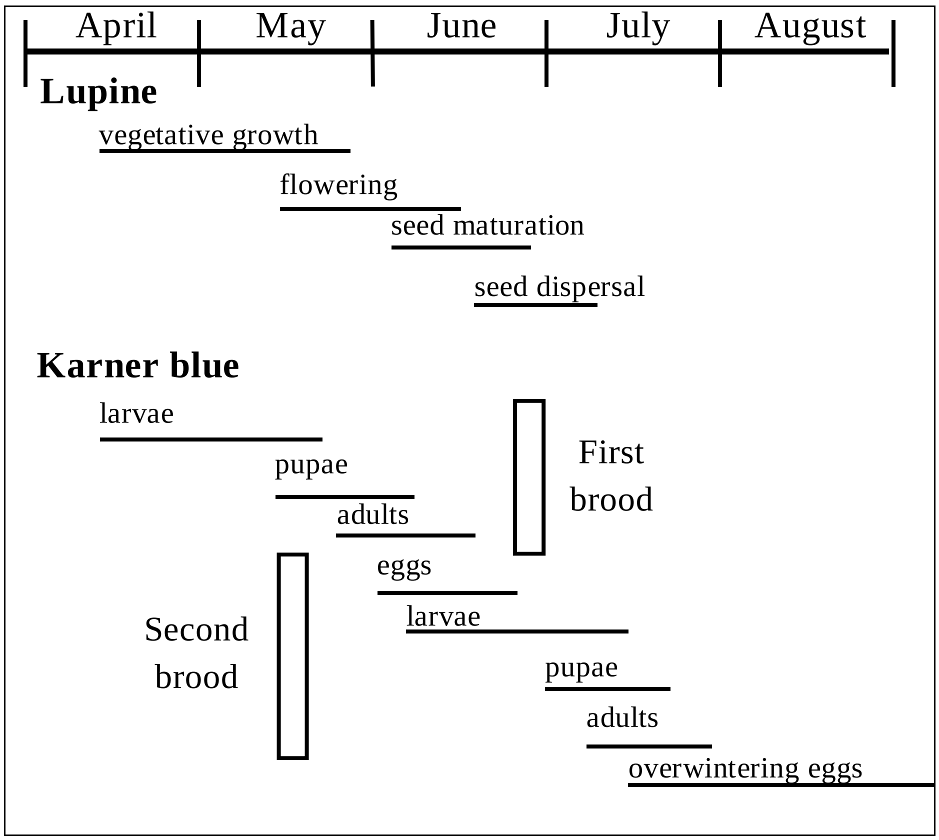
LIFE HISTORY AND ECOLOGY

Karner Blue Butterfly

The life history of the Karner blue butterfly has been studied by Scudder (1889), Dirig (1976, 1994), Cryan and Dirig (1978), Savignano (1990), Swengel (1995), Swengel and Swengel (1996, 1999, 2000), and Lane (1999b). The Karner blue butterfly is bivoltine, which means that it completes two generations per year (Figures 2 and 3). In typical years, first brood larvae (caterpillars) hatch from overwintered eggs in mid- to late April and begin feeding on wild lupine (*Lupinus perennis*), the only known larval food source (Figure 2). Larvae pass through four instars (developmental stages), between which the relatively soft larval exoskeleton is shed. Feeding by first and second instar larvae results in tiny circular holes in the lupine leaves while older larvae eat all but the upper or lower epidermis, creating a characteristic window-pane (Figure 1) appearance (e.g., Swengel 1995). Larvae feed for about three to four weeks and pupate (transform from larvae to adult) in late May to early June. Ants commonly tend larvae (refer to PART I, LIFE HISTORY AND ECOLOGY, Associated Ants). Mature larvae enter a wandering phase, after which the pre-pupal larvae attach themselves to various substrates with a silk thread. Karner blues are known to pupate in the leaf litter, on stems and twigs, and occasionally on lupine leaves (Dirig 1976, Cryan and Dirig 1978). Dirig (1976) reported that pupation generally lasted seven to eleven days in the field. Laboratory-reared pupae typically took seven to nine days, and sometimes up to eleven days before emerging as adults (Savignano 1990, Herms et al. 1996). First flight adults begin emerging in late May with the flight extending through late June (Swengel and Swengel 1996). At peak flight the sex ratio typically exceeds 50% males. The Swengels (1996) have reported 70 percent males at peak flight. The percent males decrease as the flight period progressess (Leach 1993, Swengel and Swengel 1996). Adults are believed to live an average of four to five days but can live as long as two to three weeks. First flight adult females lay their eggs primarily on lupine plants, often singly on leaves, petioles, or stems, or occasionally on other plants or leaf litter close to lupine plants.

Second brood eggs hatch in five to ten days, and larvae can be found feeding on wild lupine leaves and flowers from early June through late July. Typically, a larva can survive on one large lupine stem; however, the larva moves from leaf to leaf on the lupine stem, often returning to leaves fed on during earlier instars, and it may even move to other lupine stems (Lane 1999b). Larvae are found often on the lower parts of the stems and petioles. Ants also typically tend second brood larvae, but during midday on hot days tending may be reduced. Pupae are also frequently tended by ants (Cynthia Lane, pers. comm**.** 1997). Refer to Figure 1 which depicts the different life stages of the Karner blue.

Figure 2. Phenology of the Karner blue and lupine. In colder (warmer) areas and years phenologies will be delayed (advanced).



Second brood adults begin to appear in early to mid-July and fly until mid to late August, and in some years into early September (Swengel and Swengel 1996). Flight phenology may be delayed because of cool wet summers and result in an adult flight period lasting through late August (Cathy Bleser, pers. comm. 1995; Cynthia Lane, pers. comm. 1995). The peak flight period usually lasts one to two weeks. Generally, there are about three to four times as many adults in the second brood compared with the first brood (Schweitzer 1994b). Maxwell and Givnish (1994) surveyed Karner blue populations at 46 locations at Fort McCoy, Wisconsin, during 1993; they found that locations with high first flight butterfly counts also had high second flight counts ($r^2 = 0.674$) and that populations were three to four times as abundant during the second flight. However, the pattern is highly variable, and in some years, the second brood is not larger than the first brood (Swengel and Swengel 1996). The first brood is usually smaller most likely due to high overwintering mortality of eggs, the inability of larvae to find lupine in the spring, or greater oviposition success of first-flight females.

It is important to note that there is a significant amount of annual variation in adult abundance relative to peak flight date and in brood timing and length among years (Swengel and Swengel 1996, 1999). Based on extensive survey data, the Swengels (1999) suggest four kinds of variability to consider when assessing the butterfly's phenology: "1) inter-generational fluctuations in abundance, 2) phenological differences among years and 3) among sites, and 4) inter-annual variation in span between spring and summer generations."

Second flight females usually land on green non-senesced lupine, crawl down the stem, and lay eggs primarily on grasses and sedges, other plant species, leaf litter near lupine stems, and occasionally on lupine (Lane 1999b). In general, insects that overwinter in the egg stage often lay their eggs on various materials close to the ground because these sites afford better winter protection (Bernays and Chapman 1994). The eggs laid by second flight females are the overwintering stage (evidence summarized by Haack 1993), and studies by Spoor and Nickles (1994) and VanLuven (1993, 1994a) provide strong experimental evidence of this phenomena. Spoor and Nickles (1994) observed second brood eggs through November and determined hatching rates of these eggs the following spring. Researchers in New Hampshire and Wisconsin have successfully overwintered eggs for rearing experiments (VanLuven 1993, 1994a; Curt Meehl, University of Wisconsin-Stevens Point, pers. comm. 1997).

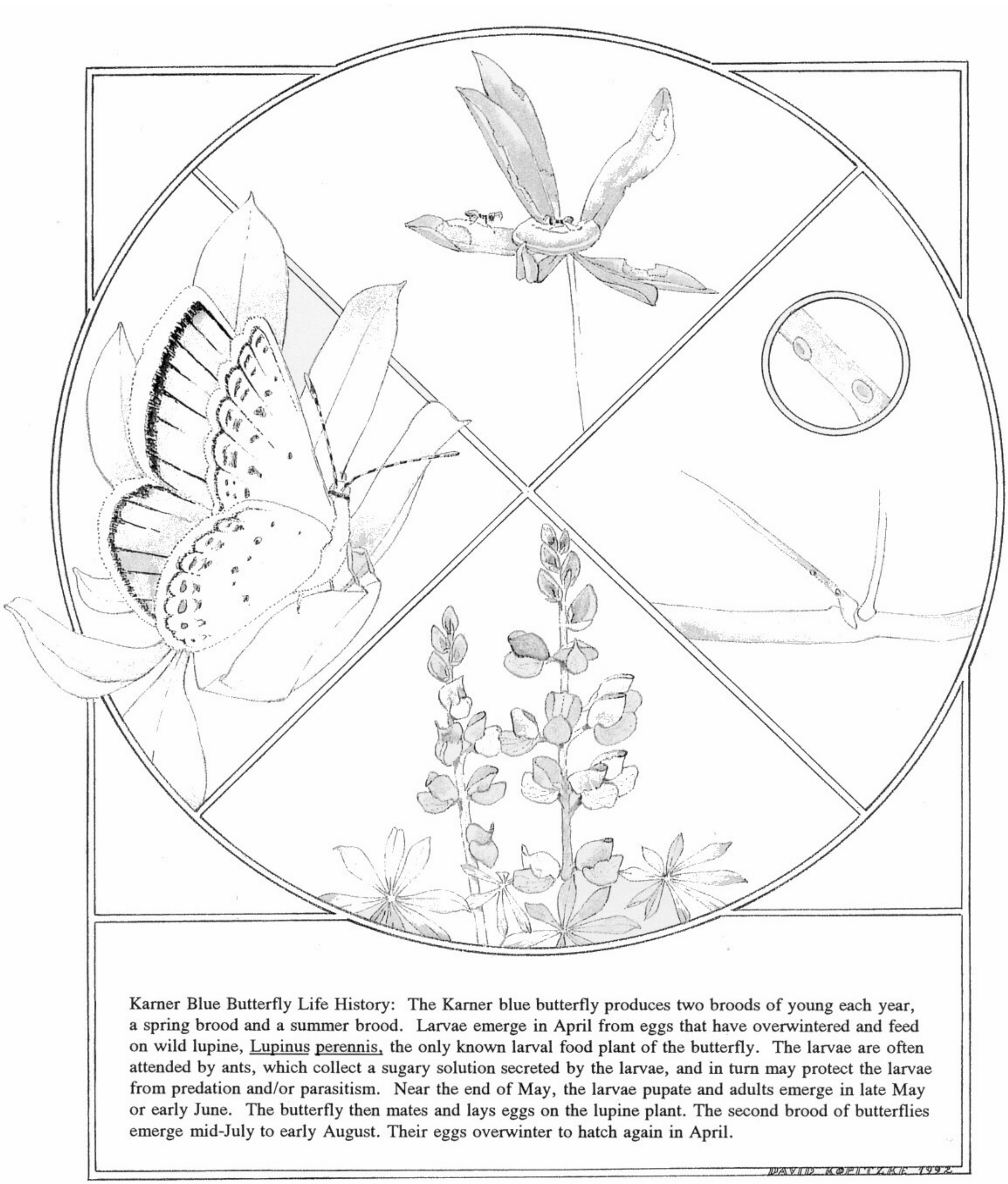
Karner blue adults are diurnal and initiate flight between 8:00-9:00 a.m. and continue until about 7:00 p.m. [although they have been observed flying as early as 6:51 a.m. by Swengel and Swengel (1996)], a longer flight period than most butterflies. Butterflies become more active with increasing temperature and/or sunshine (Swengel and Swengel 1998). Adult activity decreases at temperatures lower than 75^{o} F, and during heavy to moderate rains (Haack 1993).

Lupine Food Resource

Lupinus perennis is a member of the pea family (Fabaceae) and has the common names wild lupine and blue lupine. Lupine is the only known food plant of larval Karner blues and is an essential component of its habitat. Two varieties have been identified: *Lupinus perennis* var. *occidentalis* S. Wats. and *L. perennis* var. *perennis* L. (Ownby and Morley 1991). The varieties are morphologically similar except the former has spreading pilose hairs and the latter thinly pubescent hairs (Boyonoski 1992). The Karner blue may use both varieties, but the details of the interaction are not known. The inflorescence is a raceme of numerous small flowers which are two lipped, with the upper lip two-toothed and the lower lip unlobed. Flower color ranges from blue to violet and occasionally white or pink (Gleason and Cronquist 1991). Peak bloom typically occurs from mid-May to late June within the geographic range of the Karner blue, but varies depending upon weather, degree of shading, and geographic location in its range. Stem density and flowering is greatest in open- to partial-canopied areas (Boyonoski 1992), and in greenhouse studies lupine were larger in full light conditions (Greenfield 1997). However, areas receiving high solar radiation can have low lupine densities and may be less than ideal habitat (Boyonoski 1992). Plants in dense shade rarely flower.

Lupine distribution extends from Minnesota east to New England, then southward along the eastern Appalachian Mountains to southern Virginia and along the eastern coastal plain to Georgia wrapping around the Gulf coastal plain to Louisiana (Dirig 1994). Surveys of lupine throughout its northern range report populations to be declining and many sites have been extirpated (Cuthrell 1990, Boyonowski 1992, Grigore 1992). The primary cause of this decline appears to be loss of habitat from conversion to housing, retail, light industrial, and agricultural development, and degradation of habitat because of the deep shade that develops when disturbance is interrupted. *Lupinus perennis* is state-listed as threatened in New Hampshire.

Figure 3. Illustration of life history stages of the Karner blue.



Lupine abundance and Karner blue

Management for sufficient lupine is critically important for the Karner blue, because it is the only food plant for the larvae. Significant increases in the abundance of lupine will usually not be detrimental to the Karner blue, and may in many cases be beneficial. Lupine, however, is not the only factor limiting Karner blue butterfly subpopulations, and it is important to manage for additional factors important to the butterfly.

A positive association between lupine abundance and Karner blue abundance or persistence would indicate that lupine abundance could be a factor limiting Karner blue populations. Several researchers have found a positive correlation between lupine abundance and number of Karner blue butterfly adults in New York, Michigan, and Wisconsin (Savignano 1994b, Bidwell 1995, Herms 1996, Smallidge et al. 1996, Swengel and Swengel 1996, Lane 1999). In Wisconsin, lupine abundance and proximity to the middle of a large lupine population were correlated with adult Karner blue abundance (Swengel and Swengel 1996). Savignano (1994b) found a significant correlation between Karner blue numbers and the number of lupine rosettes in New York studies. At one site with abundant lupine but few butterflies, Savignano (1994b) suggested that a dearth of nectar plants limited the butterfly. Herms (1996) found a significant positive correlation between lupine density and Karner blue abundance at the Allegan SGA in Michigan.

The reproductive status of lupine was found to be a key in explaining butterfly numbers at Fort McCoy, Wisconsin, where Maxwell (1998) found significantly greater second brood larval densities in shady plots which had a higher proportion of non-reproductive lupine. Second brood adult abundance increased with the frequency of non-reproductive lupine plants, but declined with increasing cover of flowering plants. Maxwell (1998) also detected that lupine plants in open areas, which tended to be reproductive, senesced earlier than those in shaded areas and suggested that early senescence could result in larval starvation. However, the study year (1995) was particularly hot and studies by Lane (1999) suggest that in most years larvae are able to reach pupation before lupine senesces. In addition to the influence of lupine abundance on the Karner blue, it is important to consider lupine quality (refer to Lupine quality and the Karner blue below).

Lupine was not a good predictor of Karner blue abundance in Minnesota. Lane (1994a, 1999b) found that of her study sites, the site with the densest lupine did not support Karner blues; however, this site was over 2.5 kilometers (1.6 miles) from occupied habitat. Lawrence (1994) and Lane (1994a, 1999b) suggest that other factors, such as microhabitat might influence the butterfly's population dynamics.

Lupine abundance at a site may vary temporally within a year or between years. Late emergence or early senescence of lupine might result in larval starvation, although Swengel's (1995) field observations suggest that larval and lupine phenology are well synchronized even in years with delayed lupine appearance. The timing of lupine senescence varies with canopy cover and annual weather. Lane (1994b) observed that second brood larvae disappeared from lupine that senesced early. These individuals probably died because lupine density was low, and successful dispersal to another plant was improbable. Maxwell (1998) suggested that the shadiest lupine patches serve as "nurseries" for second brood larvae due the greater availability of non-reproductive lupine, which are not as susceptible to mildew and remain green throughout the larval stage.

It is unlikely that a single factor, such as the density of lupine, would account for variation in abundance of the Karner blue throughout its range. In places where it does, however, such as in the Glacial Lake Albany RU in New York, and at Fort McCoy, Wisconsin, it suggests that Karner blue populations might be enhanced by increasing the amount of lupine available. In localities where there is a poor correlation between lupine abundance and adult Karner blues, such as in the Paleozoic Plateau RU in Minnesota, and possibly, the Allegan SGA in Michigan, other factors may be important such as lupine quality, microhabitat, and distance from the nearest occupied site.

<u>Lupine quality and the Karner blue</u>

Variation in plant quality, as influenced by nutrient composition, secondary plant chemistry, morphology, and other factors can have significant effects on Lepidoptera (Bernays and Chapman 1994). *Lupinus* species have secondary plant compounds, typically alkaloids, that influence lupine's suitability as insect food. Levels of alkaloids in *Lupinus* species vary with plant part and are highest in reproductive parts and the epidermis (Bernays and Chapman 1994). In addition, habitat differences in sun and shade may affect host plant quality by influencing host plant nutrients, secondary plant compounds, phenological state, and/or physical condition (Mattson 1980, Waterman and Mole 1989, Dudt and Shure 1994, Ravenscroft 1994).

Laboratory and field feeding studies have shown that the quality of lupine as larval food is affected by growing conditions (Grundel et al. 1998a, Maxwell 1998, Lane 1999). Grundel et al. (1998a) tested the effects of nine types of lupine on larval growth and survival. Lupine type was based on several factors including: age, reproductive/phenological status (non-flowering, flowering, seed, and senesced), percent canopy cover where lupine was growing, water status, presence of powdery mildew, and soil type. These laboratory feeding studies demonstrated that larvae fed leaves from shade grown plants that had gone to seed grew faster than larvae fed leaves from sun grown plants that had gone to seed (Grundel et al. 1998a). Lane (1999) also conducted laboratory feeding studies, using six lupine types, and found that larvae fed sun grown lupine in seed had the lowest survival rates of the lupine types tested (Lane 1999). Results from these studies are significant because during the second brood larvae feed extensively on leaves from plants that have gone to seed.

Larvae fed wilted lupine took significantly more days to pupate than larvae fed all other lupine types (Lane 1999). Grundel et al. (1998a) found that water stressed lupine was one of four types of lupine that produced slow larval growth rates. Lane (1999) also observed a lower percent survival to pupation for larvae fed wilted leaves than for three of the six other lupine types tested.

Faster growth rates are often advantageous to immature stages as they are then vulnerable to parasitism and predation for a shorter period of time. For Karner blue larvae, faster growth rates for second brood larvae may offer the additional benefit of allowing larvae to complete their development before lupine plants senesce (Grundel et al. 1998a).

During field studies, Maxwell (1998) counted a greater number of larvae on non-flowering lupine than on reproductive lupine. In addition, summer brood adult abundance was positively associated with the frequency of non-flowering lupine and negatively with the frequency and density of reproductive lupine.

The quality of lupine as a larval food plant does not appear to be affected by whether the soil is predominately sand or one with an organic O and A horizon (Grundel et al. 1998a). However, because lupine abundance and reproduction on sandy soils can be low (N.B. Pavlovic and R. Grundel unpublished data), selecting sites where soils have greater organic content will be important if increasing lupine abundance is a primary management goal.

Studies have also examined the influence of powdery mildew, a common leaf disease, on lupine quality. Maxwell (1998) counted the number of lupines with larval feeding damage and found less larval feeding where the proportion of lupine infected with powdery mildew was the greatest. However, although feeding intensity may be lower in these areas, laboratory feeding studies by Grundel et al. (1998a) found that larvae grew faster when fed leaves with large scale infections of powdery mildew than similar plants without such an infection.

Fire may also influence lupine quality. Maxwell (1998) observed a fire-mediated improvement in lupine quality that was reflected in a significantly greater abundance of second brood larvae on burn plots.

In general, field and feeding studies suggest that lupine grown in partial to closed subhabitats provide a superior food source for Karner blue larvae, especially during the second annual brood of larvae. Female Karner blues have been observed ovipositing relatively more frequently in moderately shaded areas than in open areas where lupine is most abundant (Grundel et al. 1998b). The growth advantage of eating shade-grown lupine may explain this relative overuse of shaded areas by ovipositing females and larvae. Nonetheless, although lupine quality may be superior in areas with shade, the larger quantity of lupine in openings at some sites may result in a greater total number of butterflies produced from open subhabitats (Lane 1999). Therefore, a mixture of sun and shade across the landscape can increase the viability of Karner blue populations by providing for a tradeoff between lupine quality and quantity.

<u>Lupine growth, reproduction, dispersal, and propagation</u>

Lupine reproduces vegetatively and by seed. Seedpods have stiff hairs with an average of 4-9 seeds per pod (Boyonoski 1992). When seedpods are dry, they suddenly twist and pop open (dehisce), throwing seeds several feet. Dehsicing is the only known dispersal mechanism and Celebrezze (1996) suggests that lupine colonization would be very slow, about 0.5 to 2 meters (20 to 79 inches) per year. Alternatively, these results may imply that there is another unidentified dispersal agent. Seeds are known to remain viable for at least three years (Zaremba et. al. 1991), do not have a physiological dormancy, and will readily germinate if moisture and temperature conditions permit. The hard seed coat produces an effective dormancy, and germination is usually enhanced by scarification, stratification, and/or soaking in water (Boyonoski 1992, Zaremba and Pickering 1994) (Bob Welch, Waupaca Field Station, pers. comm. 1995).

Lupine also reproduces vegetatively by sending up new stems from rhizomatous buds. Usually, plants a few years old will form a clump of several stems and in areas with dense lupine, it is difficult to distinguish individual lupine plants. Established lupine plants do not grow every year. It is not known how long established plants can remain dormant.

Lupine can be propagated by planting seed or transplanting seedlings. Direct germination from seed appears to result in higher first-year survival than seedling transplants (VanLuven 1994b, Zaremba and Pickering 1994). Seedling establishment from seed in New Hampshire was between 3-43 percent in the first year, and survival of seedlings was about 50-60 percent per year (VanLuven 1994b). Large quantities of seed will be necessary to establish dense stands of lupine in this area. Welch (pers. comm. 1994) established lupine patches with over 5,000, 8,500, and 17,500 seedlings, two to four months old, and uncounted numbers of seeds near Waupaca, Wisconsin. The patches were established successfully, but no data are available on survival. Maxwell and Givnish (1994) established lupine by direct seeding in experimental plots in 1993. Although soil preparation was homogeneous, lupine establishment was better in the compacted subsided soils associated with an old trail. This area had less vegetative cover, and the lupine was growing in association with *Cycloloma atriplicifolium* (pigweed), which may have protected it from deer browsing. During the dry 1995 season, *C. atriplicifolium* was absent and lupine on this trail developed faster and senesced earlier than the surrounding lupine, and lupine cover was greater where the seeded perennial grasses had established the best (Maxwell and Givnish 1996). These observations suggest that nurse plants may be useful for establishing lupine.

<u>Renewal of lupine habitat</u>

Lupine is an early successional species adapted to survive on dry relatively infertile soils. Even the seedlings have long taproots that presumably allow the plant to reach soil moisture. It can grow on soils low in nitrogen because of its association with the nitrogen fixing bacterium *Rhizobium lupina*, and does not do well when grown without *R. lupina* (Zaremba and Pickering 1994). Similar to other legumes, it probably does best when growing on nitrogen-poor soils that have sufficient phosphorus. Lupine does not reproduce in dense shade. All available evidence suggests that lupine thrives on nitrogen-poor soils in partial- to open-canopied areas, and is suppressed by shade; it is possibly out-competed by other plants on nitrogen-rich and phosphorus-poor soils.

Based on Greenfield's (1997) work, lupine growing under trees may benefit from the lower pH levels caused by tree leaf litter. However, while lupine appears to benefit from association with trees (Boyonoski 1992, Greenfield 1997), without periodic disturbance to reduce tree cover, light levels under the canopy may become too low to support lupine growth.

Several species of pines, oaks, and shrubby vegetation are adapted to the same soils and habitat as lupine (Nuzzo 1986, Haney and Apfelbaum 1990), and without disturbance, these species will close the canopy, shading and suppressing lupine (Haney and Apfelbaum 1990, Apfelbaum and Haney 1991). The rate of closure will vary from locality to locality, based on edaphic and prevailing climatic conditions, and current and historic management practices. If the habitat supports high grass and sedge productivity, litter could build up and suppress lupine. Consequently, disturbances that reduce tree and shrub canopy cover are necessary for lupine to persist, and under some conditions, occasional disturbances that remove the litter layer are needed for lupine regeneration. Several disturbances have been suggested to be beneficial for renewing lupine habitat, including prescribed fire, mowing, tree removal, and a variety of methods to kill trees and shrubs such as girdling and brush-hogging (Swengel 1995, Swengel and Swengel 1996, Smallidge et al. 1996, Maxwell 1998). Frequency of management treatment to reduce woody cover is an important consideration. Smallidge et al. (1996) found that infrequent removal of woody stems often resulted in an increase in woody plant density and suggested the use of frequent mechanical treatment or a seasonally timed application of an appropriate herbicide (refer to APPENDIX G)

Other factors affecting lupine

Mechanical disturbance of the soil can affect lupine. Research at Fort McCoy has demonstrated that military training activities appear to be beneficial to the Karner blue (refer to PART I, HABITAT/ECOSYSTEM, Renewal of Habitat for the Karner blue, Other contemporary habitats).

Lupine is browsed by deer, woodchucks, and insects. The relationship between grazer density, grazing intensity, and Karner blue populations is largely unknown. If deer populations are too abundant in the spring and browse is scarce, excessive browsing could occur on lupine, with potential detrimental effects on the Karner blue (Schweitzer 1994a). Heavy spring flower browse by deer reduces the number of seedpods for that season's lupine (Straub 1994). Transplanted lupine may be less able to recover from being browsed than field sown plants (Zaremba and Pickering 1994). Herbivory by the painted lady butterfly (*Vanessa cardui*) has caused severe defoliation of lupine foliage (Cynthia Lane, pers. comm. 1996), but the potential detrimental effects on the Karner blue are not documented. Lupine species typically contain alkaloid compounds, which are hypothesized to serve as chemical defense mechanisms against herbivory (Dolinger et al. 1973), but the significance of these compounds in the ecology of the Karner blue is not known. Several diseases of lupine are known, but their effects on Karner blue or lupine populations are unknown.

Recolonization or regeneration of lupine to areas that have had closed canopy or little disturbance for long periods may be reduced or even absent after disturbance. Sferra et al. (1993) used cutting and burning to restore savanna structure in Michigan but did not see increases in lupine abundance possibly because no plants or seeds were present on the site to regenerate, and because lupine was not able to recolonize. Celebrezze (1996) found less lupine on cultivated/homesteaded sites than would be expected. Also, no long distance dispersal mechanism is known for lupine. Celebrezze's (1993) work suggests that lupine might only move 0.5 to 2 meters per year. Without active disturbance/seeding regimes, lupine could undergo gradual elimination due to very slow reinvasion following local extirpation. There is concern that lupine habitat lost due to maturation of red pine stands may not be able to regenerate after harvest [refer to Recovery Task 5.25(d)].

Nectar Food Resources

Adult Karner blue butterflies feed at flowers, sipping nectar and presumably obtaining nourishment; adult feeding increases longevity and fecundity in many Lepidopteran species, especially butterflies (Chew and Robbins 1989). Although increased longevity and fecundity have not been specifically demonstrated for the Karner blue butterfly, it is generally agreed that nectar is an essential adult resource. Adult Karner blue butterflies spend considerable time nectaring on a wide variety of plant species (refer to APPENDIX C). Adults have been observed during the first brood to feed on flowers of 39 species of herbaceous plants and 9 species of woody plants, and during the second brood, on flowers of 70 species of herbaceous plants and 2 species of woody plants. Indeed, nectar plant availability may be a key factor in determining habitat suitability (Fried 1987). Lawrence and Cook (1989) suggested that the lack of nectar sources may limit populations at the Allegan SGA in Michigan, and Packer (1994) implicated the dearth of nectar sources as one of the causes of the extirpation of populations in Ontario. Bidwell (1994) found a positive correlation between nectar plant abundance, specifically abundance of *Monarda punctata* (horsemint), and the number of Karner blue butterflies. Other researchers, Herms (1996), and Richard King (USFWS, pers. comm. 1996), did not find a correlation between adult butterfly numbers and nectar plant abundance. Herms (1996) suggested that the lack of correlation between Karner blue and nectar sources could also mean that the minimal requirement for nectar was met and that nectar was not limiting during the years of study. It is generally accepted that nectar plant phenology, presence, distribution, and abundance can vary from year to year on any given site. In addition, absence of correlation might also mean that other factors, such as larval density, are more directly determining adult population numbers.

Some plant species appear to be utilized more frequently than others (Fried 1987, Bleser 1993, Leach 1993, Bidwell 1994, Lane 1994a, Lawrence 1994, Herms 1996). The nectar plant used most frequently in the field may be the one that is spatially or temporally available or most abundant, and not the species that is preferred. Observations of nectaring frequency, however, can indicate the relative utility of the species as a nectar resource. For example, Herms (1996) found that *Asclepias tuberosa* was the most frequently used summer nectar sources two years in a row, but was consistently rare on all sites. Common nectar plant species used by first and second brood Karner blues in Minnesota, Michigan and Wisconsin are summarized in Table 1. A more comprehensive list of nectar plants used by the Karner blue can be found in APPENDIX C, Table C1.

Studies by Grundel et al. (2000) at IDNL suggest that the Karner blue is opportunistic in selecting nectar plants, choosing species with the greatest total number of flowers or flowering heads. However, the studies also showed that the Karner blue preferred certain select nectar species (Table 1) and nectar plants with yellow or white flowers.

In addition to nectaring, males and females sip at moist earth (mud-puddling) and human perspiration, and males sip at animal droppings (Swengel and Swengel 1993). Adults may be obtaining sodium or other substances from this behavior.

Subhabitats

Karner blue adults and larvae use a variety of subhabitats created by variation in tree canopy cover, topography, and soil moisture, and the population dynamics of the butterfly is probably influenced by these factors. Adult butterflies use open-canopied areas for nectaring, roosting, mate location, and oviposition (Packer 1987; Lawrence and Cook 1989; Lawrence

1994; Maxwell and Givnish 1994; Lane 1994a, 1994b, 1995, 1999b; Grundel et al. 1998b). The majority of Karner blue nectar plants require medium to high levels of sun to produce flowers and the adults nectar most frequently in open-canopied areas. The phenology of flower production also varies with subhabitats; therefore, subhabitat diversity may provide a more guaranteed source of nectar. For example, wetlands adjacent to suitable Karner blue habitat at IDNL or Necedah NWR may provide almost unlimited nectar resources. Extremely xeric sites, on the other hand, such as Allegan SGA, may have limited adult nectar resources, which could limit butterfly populations (Lawrence and Cook 1989).

Adults are commonly found in open-canopied areas. In Minnesota, Lane (1994a) classified habitats with lupine or adult butterflies, and showed that adults were found in areas with less than five percent canopy cover. In western Wisconsin, Maxwell and Givnish (1994) collected data on the physical structure of habitat and cover estimates of selected vegetation, and found a positive correlation between adult Karner blue butterfly abundance and grass cover. Because the grass was used as adult roosting sites, they suggested that this indicated the importance of roosting sites for healthy populations of Karner blue. Grass cover may also indicate open canopy on less xeric, slightly more fertile areas of savanna, which could be beneficial in other ways to Karner blue.

Specific adult behaviors are commonly seen in open-canopied areas. Adults have been observed roosting in open- to closed-canopied areas during the day on several woody and herbaceous plant species, but at night adults have been seen roosting in the open on grasses such as big bluestem (*Andropogon gerardii*) (Schweitzer 1989). Male Karner blue butterflies used open habitat areas for nearly 90 percent of their activities - primarily mating and nectaring activities (Grundel et al. 1998b). Males are commonly observed in open areas, and in studies on butterfly movement, Bidwell (1994) frequently observed males flying back and forth through open areas.

Female activity is more spread across subhabitat than male activity. Females have been observed ovipositing (laying eggs) in open- to closed-canopy areas and in a variety of slopes and aspects (Lane 1993, 1994c, 1999b; Grundel et al. 1998b; Maxwell 1998). Females may be ovipositing in open- and partial-canopied areas in response to the greater lupine, nectar plant, and male abundance in these subhabitats. In addition, during periods of cool weather, open and sunlit areas appear to enable butterflies to achieve threshold temperatures needed for flight activity (Lane 1994c, 1999b). Based on experiments that tested the minimum temperatures needed for Karner blue flight and measurements of temperatures in open- and closed-canopy areas, the average number of hours available for first flight females is 10.5 hours in the open versus one to two hours in partial to closed-canopy areas (Lane 1999b). In addition, observations of adult butterflies determined that a greater proportion of females occur in partial- and closed-canopied areas at higher temperatures. Studies also suggest that females were not moving into shaded areas to escape high temperatures (Lane 1999b).

In general, females tend to oviposit in partial to closed subhabitats (Lane 1999). Grundel et al. (1998b) measured an average canopy cover at oviposition sites of 54.8 percent. For spring flight females, a larger number of eggs were laid per lupine stem in partial and closed subhabitats than in open subhabitats (Lane 1999b). However, based on informal adult counts in New York, Karner blue adults did not appear to utilize lupine in heavily shaded areas (Dolores Savignano, pers. comm. 2002). Lupine quality in shaded subhabitats, direct benefits from shade, and avoiding male harassment are all factors thought to contribute to the observed oviposition patterns (Grundel et al. 1998b, Lane 1999). Lupine quality influences on larval growth and survival are reviewed above in the “Lupine quality and Karner blue” section.

The direct effects of shade have been shown to contribute to higher larval survival rates in field studies (Lane 1999b). In closed-canopied areas, larvae may be more protected from temperature extremes, wind and rain, and/or natural enemies. It may be that natural enemies do not inhabit these areas or are less efficient at searching these areas. Although the proportion of older larvae tended by ants has been found to be similar in open- and closed-canopy areas, early instar larvae have been found to be tended more in partial-canopy areas (Lane 1994b). Moreover, Lane (1999b) found tending ant species were different in different subhabitats.

At Fort McCoy during 1995, the summer drought conditions resulted in early senescence of lupine (Maxwell 1998). In open-canopied areas, late-maturing second brood larvae were often seen on completely senesced plants, while in shady areas senescence was delayed. Karner blue populations declined during this generation and were more abundant in the shade suggesting that early lupine senescence may have been the cause. Lupine quality has also been shown to be affected by shade (refer to Lupine quality and the Karner blue).

Another factor influencing oviposition site may be male harassment. Studies by Lane (1999b) indicated that a greater number of females were harassed by males in open- versus closed-canopy areas. The interruption of activity caused by harassment may encourage females to shift to partial- and closed-canopied areas during oviposition.

Egg deposition in a variety of subhabitats may also serve to mitigate physical or biological risks to immature stages (Bidwell 1994, Lane 1994c, 1999b). For example, several researchers have suggested that lupine senescence is earlier in xeric, open-canopied areas and may result in larval starvation, particularly during drought years.

Optimal subhabitat for larval stages contrasts with that used by adults (Savignano 1990; Lane 1994b, 1999b; Grundel et al. 1998a, 1998b; Maxwell 1998). Studies on larvae in Minnesota and Wisconsin found significant differences in larval survivorship between open-, partial-, and closed-canopy areas (Lane 1994b, 1999b). For second brood larvae, survival was highest in closed-canopied areas, intermediate in partial-canopied areas, and lowest in open-canopied and very xeric areas (Lane 1999b). The cause of higher mortality for larvae placed in the very xeric areas is uncertain. However, the lupine often were heavily infested with powdery mildew and the introduced predator, the seven spotted lady beetle (*Coccinella septempunctata*) (Schellhorn et al. unpublished), both of which may have contributed to observed mortality (Lane 1999b). Maxwell (1998) found lupine shaded by shrubs and dense herbaceous cover contributed to the larval survival and noted that removal of tree and shrub cover over a large area can be detrimental to the butterfly even when nectar and lupine resources are enhanced.

In summary, mating and adult feeding take place primarily in open-canopied areas. Oviposition occurs in many types of subhabitats, but larval growth and survival may be best in partial- to closed-canopy areas. Small-scale variation in topography and soil moisture could be

Table 1. Nectar plant species used commonly by first and second brood Karner blue butterflies. Percent of all nectaring observations at a locality for all plant species used by more than 10 percent of the observed butterflies.

Plant species — Percent of butterflies nectaring at plant species

First Brood	Locality MI[1]	WI[2]	WI[3]	WI[4]	WI[5 #]
* + *Arabis lyrata*			50		11
Hedyotis longifolia			14		
Hieracium aurantiacum				56	
Lupinus perennis				29	13
Melilotis offincionalis		16			
* *Potentilla simplex*					35
+ *Rubus flagellaris*	89	19			
Rubus sp.					20

Second Brood	MN[6]	MI[1]	MI[7]	MI[8]	MI[9]	WI[2]	WI[3]	WI[4]	WI[5]
Amorpha canescens						15	39	16	
* *Asclepias tuberosa*		66	40	22					
Asclepias verticillata							11		
Berteroa incana								23	
Centaurea biebersteinii				33	40				
* *Euphorbia corollata*				33					11
Euphorbia podperae						12			
Helianthus occidentalis									13
Liatris cylindracea				11					
*+ *Melilotus alba*						38			
* *Monarda punctata*	91	20	20		60	13	25	13	
Rudbeckia hirta								28	
* *Solidago speciosa*									17

References: 1 = Lawrence 1994, 2 = Leach 1993, 3 = Maxwell and Givnish 1994, 4 = Lane pers. comm. 1994, 5 = Swengel and Swengel 1993, 6 = Lane 1994a, 7 = Papp 1993, 8 = Sferra et al. 1993, Site 1, 9 = Sferra et al. 1993.

Notes: * Species most frequently chosen by Karner blues; also *Coreopsis lanceolata, Rubus spp. and Helianthus divaricatus.* (Grundel et al. 2000).

+ Nectar species preferred by Karner blues at IDNL; also *Coreopsis lanceolata.* (Grundel et al. 2000).

averages based on 4 years of data.

beneficial to Karner blue. A highly variable microtopography creates a highly variable thermal environment and a highly variable plant community and canopy structure. Variation in soil moisture will also contribute to variation in plant community and canopy structure. In addition. variation in plant community and canopy could be beneficial to Karner blue in the long-term. In hot dry years Karner blue can be found using shady moist subhabitats, while in cool years, they are more strongly associated with sunny and partially sunny subhabitats.

Given the different habitat requirements of adult and larval stages, and the relatively low within habitat mobility observed for the Karner blue, it is important that canopy cover subhabitat types be within close enough proximity for butterflies to move easily between them (Lane 1999b) (refer to Within-Habitat Movement and Between-Site dispersal, below).

Associated Ants

Immature stages (egg, larva and pupae) of the Karner blue butterfly have a mutualistic relationship with ants. Larvae tended by ants (Figure 1) have a higher survival rate than those not tended by ants (Savignano 1990, 1994a; Lane 1999b), presumably because the ants provide some protection from the natural enemies of larvae. In addition, laboratory feeding studies have demonstrated that larvae tended by ants grow relatively rapidly and gain weight more rapidly per amount of food eaten (Grundel et al. 1998a). Ants benefit from this relationship by using as food, a liquid secreted from specialized glands on the larvae that contains carbohydrates and possibly amino acids (Savignano 1990).

Tending levels for late instar larvae are close to 100 percent. The percentage of early instar tending varied between studies. Both Savignano (1990) and Lane (1999b) observed that a lower percentage of early instar larvae were tended by ants, while Herms (1996) found all instar age classes to be tended at similar proportions (88 to 92 percent). Herms (1996) suggested that early instar larvae in her studies may have been tended by different ant species than in other studies, and that some ant species may be more likely to tend early instars. Several ant species have been observed to tend Karner blue larvae (Table 2). Some species of ants appear to provide greater protection than other species. For example, larvae last tended by *Formica lasiodes* had significantly higher survival than those last tended by other ant species (Savignano 1990, 1994a).

During pupal survival studies, Lane (1999b) observed eight ant species to be associated with Karner blue pupae (Table 2). One species of ant built nests of dead vegetation around the pupae. Pupae within these nests were observed to emerge as adults, but how the ants influence pupal development or survival is not clear.

At the Crossgates Mall site in New York, Spoor (1993) observed ants (*Myrmica* sp.) removing eggs of Karner blue from lupine stems. Removal rates were sometimes exceedingly high (39 to 74 percent of eggs missing in one series of observations). Whether these eggs were killed or reared by the ants is unknown. A species of *Myrmica* in Europe carries larvae of the large blue butterfly (*Maculinea arion*) into its nests, where the butterfly larvae then feed on the ants' larvae (Thomas 1980). Spoor (1994, and pers. comm. 2002) also observed *Monomorium emarginatum* opening eggs and pulling larvae out whole or in two pieces.

Although ants appear to be important in the life cycle of the Karner blue, it is uncertain if it is necessary to manage habitat to ensure their presence. The interaction between Karner blue and ants appears to be facultative, and the ants appear to be opportunistic in tending, so that any species that is present might tend the larvae and pupae. In contrast, the apparent variation in protection provided by different ant species could influence Karner blue abundance and population dynamics, and therefore methods to manage the habitat to encourage more beneficial ant interactions may merit consideration.

Within-Habitat Movement and Between-Site Dispersal

Dispersal has not been carefully defined in the Karner blue literature. Dispersal usually refers both to the movement of individuals within and between suitable habitat sites. Because these two types of movements have different ecological implications, they will be separated in this discussion. The movement of individuals away from their natal site of suitable habitat, leaving the site and potentially finding another site will be referred to as dispersal between sites and will include dispersal from sites. Movement that remains in a habitat site (or within the local subpopulation) will be called within-habitat movement. Because suitable habitat sites vary in size, the frequency of these types of movement will vary from site to site. Dispersal from sites may lead to recolonization events, while movement within sites can result in greater use of the site, but will not contribute to recolonization. Karner blue butterfly movements range from relatively short within habitat movements to dispersal movements between sites greater than 1000 meters (1093 yards) apart that are separated by unsuitable habitat. Refer to APPENDIX G (Table G1) for a summary of the within-habitat movement and between-site dispersal studies discussed below.

<u>Within-habitat movement</u>

Nearly all researchers that have examined Karner blue dispersal concluded that Karner blue movements within sites are relatively low and short with nearly all movement less than 100 to 200 meters (110 to 220 yards) (Fried 1987, Givnish et al.1988, Lawrence and Cook 1989, Sferra et al. 1993, Welch 1993, Bidwell 1994, Lawrence 1994, Fuller 1998, King 1998, Knutson et al. 1999) (refer to APPENDIX G, Table G1). Knutson et al. (1999) found that 75 percent of the movements recorded were less than 100 meters (110 yards). The mean distance moved per day ranged from 32 meters (±3 meters) (Bidwell 1994) to 191 meters (±52.5 meters) (35 to 209 yards) (Lawrence and Cook 1989). Mean distance moved per day tended to be shorter at the relatively more closed IDNL sites, ranging from 46.4 to 55.0 meters (51 to 60 yards) (Knutson et al. 1999) than in the open landscape of Necedah, where dispersal ranged from 48.2 to 173.2 meters (53 to 189 yards) (King 1998). However, the distances reported by King (1998) are averages of within habitat movements and between site dispersal. Because he recorded many longer dispersal distances, averages are expected to be lower for within habitat movement alone.

Lane (1994a) measured within-habitat flight distances by following individuals and marking all landing points. The average flight distance between points was 4.99 meters (5.5 yards) for males and 1.49 meters (1.6 yards) for females, i.e. most within-habitat flights were short distances, but adults took many small flights in a day (Lane 1994a). The total distance traveled was also calculated from flight data on individuals (time per activity, and distance, angle, and direction of

Table 2. Ant species tending Karner blue butterfly larvae and pupae.

Ant Species Tending Larvae	Locality	Reference
Aphaenogaster rudis	Ont	Packer (1991)
Brachymyrmex debilis Emery	MN, WI	Lane (1999)
Camponotus americanus Mayr	NY	Savignano (1994a)
Camponotus ferrugineus	WI	Bleser (1992)
Camponotus novaeboracensis Fitch	NY	Savignano (1994a)
Camponotus pennsylvanicus	Ont	Packer (1991)
Crematogaster ashmeadi	WI	Bleser (1992)
Crematogaster cerasi Fitch	NY	Savignano (1994a)
Crematogaster lineolata (Say)	MI	Herms (1996)
Dolichonderus (Hypoclinea) plagiatus Mayr	NY, WI	Savignano (1994a), Lane (1999)
Dolichonderus mariae Forel	MI, WI	Herms (1996), Lane (1999)
Dolichonderus pustulatus Mayr	MI	Herms (1996),
Formica difficilis Emery	NY	Savignano (1994a)
Formica exsectoides	Ont	Packer (1991)
Formica fusca	WI	Bleser (1992)
Formica lasioides Emery	NY	Savignano (1994a)
Formica montana	WI	Bleser (1992)
Formica (Neoformica) incerta Emery	NY, MN, WI	Savignano (1994a), Lane (1999)
Formica (Neoformica) nitidventris Emery	NY	Savignano (1994a)
Formica (Neoformica) schaufussi Mayr	NY, MI	Savignano (1994a), Herms (1996)
Formica neogatates Emery	MI	Herms (1996)
Formica obscuripes Forel	WI, MI	Herms (1996), Lane (1999)
Formica obscuriventris Mayr	MI	Herms (1996)
Formica querquetulana Wheeler	NY	Savignano (1994a)
Formica schaufussi	WI	Bleser (1992)
Formica subnuda Emery	WI	Lane (1999)
Formica subsericea Say	NY, MI, WI	Savignano (1994a), Herms (1996), Lane (1999)
Lasius alienus Foerster	NY, MN, WI	Savignano (1994a), Lane (1999)
Lasius neoniger Emery	NY, MI	Savignano (1994a), Herms (1996)
Monomorium emarginatum DuBuois	NY	Savignano (1994a)
Monomorium pharaonis (L.)	MI	Herms (1996)
Myrmica americana Weber	NY, MI, MN, WI	Savignano (1994a), Herms (1996), Lane (1999)
Myrmica emeryana Forel	MN, WI	Lane (1999)
Myrmica fracticornis Emery	NY, MI	Savignano (1994a), Herms (1996)
Myrmica lobifrons	MN, WI	Lane (1999)
Myrmica punctiventris	Ont	Packer (1991)
Myrmica sculptilis	NY	Savignano (1990)
Paratrechina parvula Mayr	NY	Savignano (1994a)
Prenolepsis imparis (Mayr)	MN	Lane (1999)
Tapinoma sessile Say	NY, WI, MN	Bleser (1992), Savignano (1994a), Lane (1999)
Tetramorium caespitum	WI	Bleser (1992)

Ant Species Tending Pupae	Locality	Reference
Crematogaster lineolata (Say)	WI	Lane (1999)
Dolichonderus tashenbergi (Mayr)	WI	Lane (1999)
Formica obscuripes Forel	WI	Lane (1999)
Lasius alienus Foerster	WI	Lane (1999)
Lasius neoniger Emery	WI	Lane (1999)
Leptothorax sp.	WI	Lane (1999)
Myrmica emeryana Forel	WI	Lane (1999)
Tapinoma sessile Say	WI	Lane (1999)

flight) (Lane 1999b). Based on the average total square displacement per minute, after five days (the average life span of Karner blues), most of the butterflies would be expected to be within a 2.5 hectares area (6.2 acre). Individuals engaged in certain sets of behaviors (e.g., oviposition, roosting, testing for oviposition site) may be expected to move farther and be within a 32 hectare (79 acres) circular area after five days. Grundel et al. (1998b) also observed short movement distances, particularly for females. During one minute observation periods, only 8.4 percent of females moved greater than 10 meters (11 yards). The overall picture that emerges is that within-habitat movements of the Karner blues are short and frequent.

Between-Site Dispersal

There is a fair amount of variation in dispersal tendency of Karner blues between habitat sites as demonstrated by various dispersal studies. Distances between populations that are likely to facilitate recolonization in a metapopulation most likely fall in the range of 0.5-2 kilometers (0.31-1.24 miles) and will depend on the nature of the habitat, especially canopy cover between habitat sites. For a detailed discussion of between-site dispersal refer to APPENDIX G, INCREASING THE COLONIZATION RATE OF SUBPOPULATIONS WITHIN A METAPOPULATION, Between-Site Dispersal and Table G1.

Dispersal barriers

Many factors have been suggested to be dispersal barriers for Karner blue butterflies. Anecdotal evidence has indicated that many geographic, vegetational, and human-constructed structures might act as dispersal barriers, including four-lane highways with heavy traffic in urban or semi-urban areas, steep embankments and cliffs, forested areas if no openings such as trails or roads are present, and residential and commercial areas (including paved parking lots and roads). Scientific evidence supporting any of these speculations is absent.

Dispersal corridors

Little data exists regarding dispersal corridors for Karner blues. It is widely believed that open-canopied areas through wooded landscapes provide the Karner blue with a dispersal corridor, but except for anecdotal observations, this hypothesis has remained unproven. Welch (1993) found that dispersing butterflies almost always followed canopy openings along fencerows, woodland trails, or small gaps in the canopy, stopping frequently to bask in the sun. During these between-site movements, open-canopied areas may be needed for thermoregulation (Lane 1994c), orientation (Welch 1993), or both. Based on observations of Karner blue movement patterns at IDNL (a more closed habitat area), Grundel et al. (1998b) suggest that patches of several 25 meter (27 yards) openings, positioned less than 300 meters (328) from a neighboring patch, will allow the butterfly to persist in the patch and disperse. Thus, dispersal corridors may be formed by a network of partially connected canopy gaps and trails (refer also to APPENDIX G**,** INCREASING THE COLONIZATION RATE OF SUBPOPULTAIONS WITHIN A METAPOPULATION, Facilitating Directed Dispersal Using Corridors, Corridors and Living Corridors).

HABITAT/ECOSYSTEM

Structure

The physical features that affect Karner blue butterfly habitat vary across its geographic distribution. The western part of the range is subject to greater continental effects, which include greater annual variation in temperature, lower precipitation, and greater year-to-year variation in precipitation. Average annual precipitation is higher in the eastern part of the range than in the western part of the range. Annual variation in precipitation is generally less than 10 percent of normal in the East, but more variable in the West at 15 percent of normal. In the East, the annual range in temperature is less than 28^{o}C, but in the West the annual range is greater than 28^{o}C. Thus, in the West, Karner blue habitat will be subjected more frequently to drought and temperature extremes, such as cool springs or hot summers, than in the East.

Throughout its range, the Karner blue butterfly was historically associated with native barrens and savanna ecosystems, but it is now associated with remnant barrens and savannas, highway and powerline right-of-ways, gaps within forest stands, young forest stands, forest roads and trails, airports, and military camps that occur on the landscapes previously occupied by native barrens and savannas. Almost all of these contemporary habitats can be described as having a broken or scattered tree canopy that varies within habitats from 0 to between 50 and 80 percent canopy cover, with grasses and forbs common in the openings. The habitats have lupine, the sole larval food source, nectar plants for adult feeding, critical microhabitats, and attendant ants. The stature and spacing of trees in native savannas is somewhat variable, reflecting differences in soils, topography and climate (Nuzzo 1986), and the distribution of trees in contemporary habitat is similarly diverse. Soils are typically well drained sandy soils which influence both plant growth and disturbance frequency. These conditions are generally wet enough to grow trees but dry enough to sustain periodic fires (Breining 1993). Topography is diverse and includes flat glacial lakebeds, dune and swale lakeshores, and steep dissected hills.

In order to restore viable metapopulations of Karner blues to the landscape, it will be important to establish and maintain the early successional habitat that the butterfly depends upon. This entails assuring that appropriate disturbance and/or management regimes (e.g., prescribed fire, mechanical management, etc.) necessary to renew existing habitat or to create new habitat are incorporated into management plans for the species.

Remnant native habitats

Barrens are often separated from savannas on the basis of soil type, plant species and form, fire frequency, etc.; however, the classification is not consistent among systems. For example in the Midwest Oak Ecosystems Recovery Plan (Leach and Ross 1995), barrens are considered to be a treeless type of savanna, and by this definition, most Karner blue habitat would be considered savanna, but not barrens. In other classification systems, savannas are wet/mesic habitats with burr oak and other mesic oak species, while barrens are xeric with 20-80 percent canopy cover on sandy soils. To further confuse this issue, Karner blue habitat in Minnesota is classified as dry oak savanna, barrens subtype (MNDNR 1993). Given the lack of a generally accepted classification system, in this document "oak and pine barrens and savanna" ("barrens and savanna" in short) will be used to describe the types of ecosystems providing habitat for the Karner blue.

Most of the eastern range of Karner blue habitat is dominated by pitch pine (*Pinus rigida*), scrub oak (*Quercus ilicifolia*), or both. This ecosystem has been referred to as the pitch pine barrens, Northeast pine barrens, or (Albany) pine bush (Dirig 1994, Schweitzer and Rawinski 1987). Karner blue habitat around Saratoga, New York, appears to resemble oak savanna (Schweitzer 1990).

In the Midwest, black oak (*Quercus velutina*), white oak (*Q. alba*), pin oak (*Q.ellipsoidalis*), bur oak (*Q. macrocarpa*), jack pine (*Pinus banksiana*), or any combination of these dominate suitable Karner blue habitat. Composition can vary from predominantly oak, especially black or pin, to mixtures of oak and jack pine, to predominantly jack pine. Black and pin oak dominated communities have been classified by Curtis (1959) as oak barrens. Those dominated by black oak, with or without white oak and jack pine, are referred to as oak barrens. Sites dominated by jack pine, such as portions of central and northwest Wisconsin where prescribed burns have not eliminated the pines, are called jack pine barrens.

Some of the common species found in the understory of these barrens and savanna habitats are big bluestem grass (*Andropogon gerardii*), blueberry (*Vaccinium angustifolium*), little bluestem (*Schizachrium scoparium*), Indian grass (*Sorghastrum nutans*), butterfly weed (*Asclepias tuberosa*), sweet fern (*Comptonia peregrina*), spotted knapweed (*Centaurea maculosa*), *Rubus* spp., soapwort (*Saponaria officinalis*), beebalm (*Monarda fistulosa*), bracken fern (*Pteridium aquilinum*), New Jersey tea (*Ceanothus americanus*), and goat's rue (*Tephrosia virginiana*).

Dune and swale habitats are one of the most biologically diverse in the Great Lakes Basin (Rankin and Crispin 1994), originally extending along the shore of Lake Michigan from southern Wisconsin through the Chicago and Gary metropolitan areas and north into southwestern Michigan. The dunes are in close proximity to the swales, creating an extreme diversity of regularly alternating subhabitats from xeric, sandy upland habitats to wetlands, and back to uplands and again to wetlands over distances of less than 50 meters. Karner blue populations can be found in the uplands, which are oak barrens habitats, but adults will forage on nectar-producing plants in the adjacent wetlands.

The spatial characteristics and arrangement of habitat patches also appears to be important for Karner blue butterfly populations (Greenfield 1997, Lane 1999). Habitat patches supporting the Karner blue in the Allegan SGA, Michigan, were found to have an edge density more than two times as large as patches without Karner blue butterflies (Greenfield 1997). Habitats with a large amount of edge would tend to have a high proportion of partial canopy subhabitat, one of the key habitats for Karner blue (refer to Subhabitats above). The arrangement of habitat patches, in particular distance between patches, has been correlated with the presence and abundance of Karner blue butterflies (Greenfield 1997, Lane 1999). Greenfield (1997) found that stands with Karner blue butterflies and lupine were significantly more concentrated, i.e. had a lower mean nearest neighbor distance [69.9 meters, (76.4 yards)]. Consistent with these findings are results from comparative studies between the densely populated habitats in Wisconsin and sparsely populated sites in Minnesota. In Wisconsin sites, habitat patches are essentially contiguous, whereas in Minnesota habitat is separated into many patches, often separated by more than 100 meters (110 yards) of dense oak woodland (Lane 1999).

<u>Other contemporary habitats</u>

Karner blues also occur in many other habitats managed for various purposes. These include powerline and highway rights-of-way, airport safeways, young managed forest stands, open areas within managed forest stands, along forest trails and roads, on military bases, and many other such areas. These areas all have soils that are suitable for lupine growth, an open canopy, and management that causes soil disturbance or suppression of perennial shrub and herbaceous vegetation (such as by mowing, brush-hogging, logging, chemical control, or prescribed fire). These habitats are very diverse vegetationally, and support herbaceous species that co-occur with lupine in the native remnant barrens and savanna habitats.

Renewal of Habitat for Karner Blues

Karner blue habitat is maintained in the balance between its decline from canopy closure and its renewal from external disturbance (Shuey 1997). Natural disturbances, such as fire (Chapman 1984) and large animal grazing (Hobbs and Huenneke 1992), that open canopy have decreased since the time of European settlement; thus, this balance is largely maintained by management activities (refer to APPENDIX G). These management activities intervene to influence the rates at which suitable habitat declines in quality and is renewed. Thus, an understanding of both natural factors and the interaction with management is essential to understanding the maintenance of Karner blue habitat. It is likely that the gradients in temperature and precipitation that occur from the eastern to western part of the range of Karner blue butterfly affect these rates. In the drier more variable climates of the western part of the range, it might be predicted that rates of canopy closure will be slower and rates of natural renewal, such as fire will be faster, which would result in a natural landscape with more early successional barrens and savanna and healthier Karner blue populations.

Many ecological processes act on Karner blue habitat to maintain populations of the butterfly. In the native barrens and savanna habitats, many factors, including deliberate fire, wildfire, disease, such as oak wilt, and herbivory, probably interacted to maintain the native vegetation and the associated Karner blue populations. In habitats dominated by anthropogenic activities, many management activities probably have been inadvertently beneficial to Karner blue butterfly. In general, the relation between specific management practices and Karner blue populations is not well characterized, yet the persistence of Karner blue on these managed ecosystems suggests a basic compatibility between Karner blue and alternate land uses that would merit additional study. For example, in New York, approximately half of the Karner blue subpopulations occur on powerline rights-of-way, and the largest subpopulation occurs on annually mowed airport lands (Smallidge et al. 1996). In Wisconsin, Karner blues persist on forested landscapes. Prescribed fire and targeted removal or suppression of trees and shrubs are methods commonly suggested for renewing Karner blue habitat, and are discussed in APPENDIX G and reviewed below. However, research to date has not identified a single management practice that correlated well with abundance of Karner blue or vegetation patterns (Smallidge et al. 1996, Swengel 1998, King 2000), which suggests that many management factors could be beneficial to the butterfly.

Remnant native habitats

The native barrens and savanna ecosystem and its unique combination of species developed from the interplay of natural disturbance processes, edaphic factors, climate, etc. (Forman 1979, Tester 1989, Faber-Langendoen 1991). Fire is recognized as the key element maintaining savanna vegetational structure and species composition (Tester 1989, Haney and Apfelbaum 1990, Faber-Langendoen 1991, Wovcha et al. 1995). Fire influences ecosystem dynamics by decreasing soil nitrogen and organic matter and raising pH (Tester 1989). It exposes mineral soils and reduces woody plant cover, conditions required by many savanna adapted species (Payne and Bryant 1994), and clears the understory but does not eliminate the adapted tree species. These trees survive by resisting fire with thick barks, by resprouting, or by germinating seeds after disturbance by fire. These setbacks of the woody vegetation maintain a mixture of open- to densely-canopied patches of habitat (Nuzzo 1986, Shuey undated). Fire suppression in recent history has resulted in succession of these barrens and savannas to woodlands.

Mammalian grazing, burrowing, trampling, etc., are considered by some to be a critical element in maintaining the oak savanna ecosystem (Hobbs and Huenneke 1992, Swengel 1994). Elk (*Cervus elapus*) and bison (*Bison bison*) are likely to have once grazed and browsed in Minnesota and Wisconsin (Hamilton and Whitaker 1979, Jackson 1961). During spring, elk feed extensively on grasses, sedges, and weeds. During summer, grasses, shrubs, and trees are eaten, and the diet shifts solely to shrubs and trees during fall. Bison feed on species similar to those consumed by domestic cattle, primarily grasses. Deer browse and occasionally graze on legumes and other selected plants. Deer are at very high population levels at some sites with Karner blue. For example, an average of 60-80 deer per square mile occur in the Whitewater WMA in Minnesota (Jon Cole, Whitewater WMA, pers. comm. 1996). Browsing by deer probably has helped to maintain the open canopy that is characteristic of savanna by killing or suppressing tree seedlings. In some areas browsing is so high on oak and jack pine seedlings and selected herbaceous species that several age classes of trees are missing (Cynthia Lane, pers. comm. 1995). If browsing by deer continues at these levels, regeneration of trees may be insufficient to maintain savanna. Similarly, deer grazing may reduce reproduction and survival of herbaceous plant species, such as lupine (Packer 1994, Straub 1994) (Dale Schweitzer, pers. comm. 1994**).**

It is possible that extirpation of bison and elk and increased numbers of deer have resulted in changes to the structure and species composition of the remnant barrens and savanna ecosystem. At the Whitewater WMA, grass litter has accumulated in open areas and certain age classes of trees are missing. In Ontario, extremely high deer populations consumed from 30 percent to 90 percent of the lupine plants in some areas, and probably contributed to the extirpation of the Karner blue butterfly (Boyonoski 1992, Packer 1994**,** Schweitzer 1994a).

Soil disturbances created by small mammals, such as plains pocket gopher (*Geomys bursarius*), can also affect the composition and abundance of oak savanna plant species (Reichman and Smith 1985, Davis et al. undated). For example, the savanna herb *Penstemon* *grandiflorus* (Scrophulariaceae) has increased growth rates and earlier reproduction when growing on areas disturbed by the northern plains gopher (Davis et al. undated). Lupine germination and growth on gopher mounds has not been studied; however, the early successional disturbance-associated niche of lupine suggests that it might benefit from gopher disturbances.

Insects and diseases that remove canopy trees have also contributed to the persistence of barrens and savannas in the central United States. Many remnants of high quality oak savanna are in areas where canopy trees have died as a result of oak wilt (*Ceratosystis fagacearum*). Two-lined chestnut borer (*Agrilus bilineatus* Weber), jack pine budworm (*Choristoneura pinus* Freeman), and gypsy moth (*Lymantria dispar* L.) are likely to reduce canopy cover in over-grown barrens areas (Coulson and Witter 1984).

Soil type and topography have contributed to the maintenance of barrens and savanna species composition and structure. The sandy well-drained soils characteristic of Karner blue habitat retain little moisture. These xeric conditions reduce growth of woody species (Burns and Honkala 1990) (Klaus Puettmann, UM-St. Paul, pers. comm. 1995), and only species tolerant of these conditions persist. In combination with soil type, many savanna species owe their persistence to topographic effects, especially in the unglaciated driftless regions in Wisconsin and Minnesota (Wilde et al. 1948, Lane 1994a). The steep slopes exhibit natural slumping, creating exposed mineral soil that favors early successional species. Many of these slopes are south and southwest in aspect, further enhancing their xeric quality and resulting in further suppression of woody plant species. In addition, during spring snowmelt and summer rain storms, several valleys experience erosion, exposing the mineral soils that benefits early successional species, such as lupine.

<u>Other contemporary habitats</u>

The maintenance of Karner blues in contempory habitats such as on forest lands, right-of-way corridors, military lands, or airports, requires the maintenance of the early successional habitat required by the Karner blue.

Silvicultural practices can have beneficial or detrimental effects on Karner blue, many of which are summarized in Lane (1997). For example, in some parts of Jackson, Juneau, Wood, and Burnett counties in Wisconsin, summer harvest, road building and maintenance, site preparation, tree planting, slash burning, and other activities appear beneficial to lupine and the Karner blue**.** Within this complexity of management activity, however, it is important to focus on how various practices affect the balance between local extirpation of butterflies in a stand and recolonization of stands by butterflies. Forestry practices disturb habitat and butterflies in ways that can be related to the type of disturbance (mechanical, chemical, or prescribed fire), its spatial extent (area affected), its intensity (direct effect on the soil, lupine, and Karner blue), and seasonal timing. The effects of these management practices will be quite diverse, but these effects can be categorized as direct effects on populations of the butterfly, effects on important plant species, such as lupine, nectar plants, and competing plants, and effects on the soil that influences these plant responses. All of these effects will depend on many habitat characteristics, such as the spatial distribution and abundance of plant resources, site quality and topography, the previous history of the site, and the recent history of management. Because there is little scientific information for using silvicultural practices to enhance Karner blue butterfly, management planning should take an adaptive management approach.

Because silvicultural practices are implemented to achieve multiple management goals, there will be inevitable tradeoffs between achieving the various goals. For example, at a particular site, a manager may desire maximum immediate financial returns, minimal risk on investment, maximum sustained yields, optimal wildlife game animal production, and increased Karner blue butterfly populations. In most cases, it will not be possible to optimize simultaneously all economic and wildlife goals. Instead, it will be necessary to understand which silvicultural practices are compatible with each of these many possible goals and which practices create trade-offs among them. For some managers, such compatible practices may be those that, for example, enable sufficient financial return while supporting sufficient butterflies. Forest management activities vary considerably, and a better understanding of the complexities of management and their consequences for the Karner blue butterfly in the working landscapes is needed.

Silvicultural practices continually evolve as demand and technology changes. For example, because red pine fiber is now preferred to jack pine fiber in pulp processing, there has been a shift to replacing jack pine plantations with red pine plantations in many commercial forests. The effect of this shift on the Karner blue is not known, but because red pine has a denser canopy at similar stand densities and is grown on a longer rotation than jack pine, this shift may result in declines of the butterfly over the long term.

The monitoring program of the Wisconsin Statewide HCP in Wisconsin is providing insight into the effects of siliviculture on the Karner blue. Information from Plum Creek Timber Company (Lorin Hicks, in litt. 2002) notes that 54 percent of their young red pine plantations had lupine present, and 25 percent of the stands with lupine supported Karner blues. Their data also shows that prior to harvest, 28 percent of mixed oak/jack pine stands had lupine present prior with 25 percent of the stands supporting Karner blues. This information supports the existence of Karner blue on young red pine stands and to a lesser extent in older mixed stands; however, it will be important to learn how Karner blues persist on forest lands dominated by red pine stands as the stands age and whether lupine and nectar plants would regenerate after harvest of mature stands [refer to Recovery Task 5.25 (d)]. Measures should be considered on forest lands that maintain early successional habitat, dispersal corridors, and forest openings; these measures include less dense plantings and creation of wider roads, trails, and landing sites that can serve as habitat and dispersal corridors for the butterfly (Lane 1997). The effects of silvicultural practices on Karner blue should be evaluated carefully through an adaptive management process.

Information from the Wisconsin DNR's HCP compliance audit program is showing that shifting mosaic habitat patterns occur on HCP forest partner lands due to the spatial arrangements of age classes and harvest rotations. These habitat patterns are likely responsible for the persistence of Karner blues on these lands (refer to PART I, DISTRIBUTION, Rangewide Distribution of Karner Blues, Wisconsin). About 227,191 acres are currently managed in Wisconsin with the goal of maintaining a shifting mosaic of habitat on HCP partner lands. It is anticipated that many non-partner lands have been and will continue to be managed in this manner into the future. The Wisconsin DNR believes that the demand for forest products over the next century or more is expected to perpetuate Karner blue habitats in Wisconsin, much as it has in the past (Darrell Bazzell, in litt. 2002). The HCP monitoring data is and will continue to be valuable in furthering our understanding of the ability of forest lands to support viable populations of Karner blues [refer to PART II, RECOVERY TASKS, Task 5.25(e)]

Understory legumes, such as lupine, can raise soil nitrogen levels, improve rates of mineral cycling, reduce surface runoff and soil erosion, and may improve soil organic matter content, soil structure, and cation exchange capacity, and inhibit soil-borne pathogens (Turvey and Smethurst 1983, Smethurst et al. 1986). Many of these effects could benefit forestry production. Although a potential cost might be competition between lupine and the establishing of trees, in many situations it may aid production goals to encourage the growth of existing lupine and associated Karner blue butterflies, as long as it is not necessary to plant lupine.

Military training appears beneficial to the Karner blue when managed appropriately. The Fort McCoy Military Reservation contains some of the largest populations of Karner blues in Wisconsin (Leach 1993, Bleser 1994), with over 93 percent of the lupine patches occupied by the butterfly (Wilder 1998). It appears that military training activities, particularly inadvertent fires caused by artillery and mechanical disturbance by tracked vehicles, have created a mosaic of successional states similar to those in native habitats. Several studies have examined the effects of tank traffic on Karner blue butterflies and/or their habitat (Bidwell 1994, Maxwell and Givnish 1996, Maxwell 1998, Smith et al. 2002). Comparative studies relating the intensity of training activities to the density of butterflies suggest that these activities have been beneficial to the Karner blue (Bidwell 1994, Smith et al. 2002). Maxwell and Givnish (1996) and Smith et al. (2002) evaluated the effect of tank traffic on plots of established lupine at Fort McCoy, Wisconsin. In both cases greater lupine abundance was associated with areas where track vehicles had traveled as compared with areas where no tracked vehicles had traveled. Maxwell and Givnish (1996) suggested that this kind of traffic causes greater soil disturbance than ORV traffic, and could be comparable to some of the traffic during site preparation and harvest of commercial forest stands. They found that tank traffic crushed emerging lupine plants. Yet, within several weeks, seedling germination was observed on the disturbed soil, and the crushed plants re-grew with a three-week delay in developmental phenology. In the following year, plants on the disturbed areas developed about two weeks faster than the surrounding plants. Smith et al. (2002) measured the greatest lupine abundance in the median strip between vehicle ruts, although lupine regrowth was observed in the ruts and on eroded margins of the tracked vehicle trails. Maxwell and Givnish (1996) concluded that mechanical disturbance could create greater heterogeneity in lupine development. However, Smith et al. (2002) cautioned that repeated disturbance by tracked vehicles might have a negative effect on lupine because of repeated disturbance/damage to lupine roots and/or repeated duff removal.

Areas disturbed by tracked vehicles also had higher nectar plant abundance and lower shrub cover as compared with areas unaffected by tracked vehicles (Smith et al. 2002). However, because of experimental design constraints, it was not possible to determine if tracked vehicle traffic contributed to the reduction of shrub cover or if areas with low shrub cover were preferentially selected as easy routes.

Historical disturbances were also responsible for the pattern and abundance of Karner blue habitat at Fort McCoy (Bidwell 1995, Maxwell 1998). Maxwell (1998) found lupine frequency to be significantly higher in areas of military disturbance. Military caused fire may be one of the primary factors influencing Karner blue habitat and abundance at Fort McCoy (Smith et al. 2002). Some of the largest lupine patches occur in the ordnance impact area, a portion of which is burned each year by military activities.

Although Maxwell's (1998) study plots were monitored to assess the effects of prescribed burns, they were often subjected to light military traffic with untracked vehicles which resulted in an immediate flush of new seedlings in closed canopied plots. Her research indicates that the efforts to regenerate lupine in late successional sites may benefit from disturbance to soils to reactivate the seed bank.

Maintenance of suitable Karner blue butterfly habitat on rights-of-way and near airport runways in New York has been studied by Smallidge et al. (1996). The effects of eight management methods and two management modes (broadcast or selective mechanical and/or herbicide treatments) on Karner blue abundance and several habitat characteristics were examined. No clear pattern was detected between management scheme and vegetation patterns. However, both Karner blue and lupine abundance were greater at sites that had been more recently managed. Broad-scale applications of broad-spectrum herbicides can be detrimental to existing lupine in these habitats, but could be beneficial if they suppress lupine competitors and enable lupine to establish. Smallidge et al. (1996) suggest that frequent mechanical treatments or applications of herbicides (using the appropriate type, methods and timing) will be effective in maintaining suitable Karner blue habitat**.** Disturbance activities related to building, mowing, and grading activities in rights-of-way possibly can have beneficial effects on lupine and butterflies, but the magnitude and direction of the effects may depend on the scale and timing of the activity. Refer to APPENDIX G, REDUCING LOCAL EXTIRPATION RATES, Improving and Maintaining Karner Blue Habitat). Much work has been done by utility companies and highway departments (partners to the HCP) in Wisconsin to alter the timing of mowing in order to minimize the take of the butterfly, while still promoting habitat conditions that favor the butterfly (Darrell Bazzell, in litt. 2002)

Prescribed fire

Fire has been widely regarded as an effective means of maintaining an early successional habitat suitable for growth of lupine in native barrens/savanna ecosystems (Payne and Bryant 1994). Fire influences savanna/barrens structure and composition in many ways including reducing woody plant cover, increasing the abundance of some species while decreasing the abundance of others, and exposing mineral soil. Fire also volatilizes nitrogen (returning it to the atmosphere) while leaving much phosphorus behind in ash; together with opening the canopy, these two processes should strongly favor plants associated with nitrogen fixing bacteria, such as lupine.

When using fire as a management tool, it is important to recognize the balance between Karner blue (and other insect) mortality in the short term, and improvement in the quality of their savanna/barren habitats in the long term (Givnish et al. 1988, Andow et al. 1994, Maxwell and Givnish 1996, Swengel and Swengel 1997, Schultz and Crone 1998). In addition, the use of prescribed burn for habitat restoration will require different considerations than when fire is used for habitat maintenance. Some of the key factors to consider in developing habitat restoration and maintenance plans that include prescribed fire as a tool are: 1) site history and current condition, 2) amount of direct Karner blue mortality likely to occur during the fire, 3) potential for Karner blues to reoccupy the site, 4) characteristics of prescribed fire, 5) response of lupine and nectar plants to fire, and 6) other habitat responses. Because each recovery unit presents a unique combination of many of these key factors, it is important to develop site specific fire management plans for each Karner blue population. Refer to Appendix G for a review of each of the key factors noted above, background research relative to these factors, and recommendations regarding the use of fire.

<u>Removal and suppression of trees and shrubs</u>

Tree and shrub removal and suppression via mechanical means (mowing, brush-hogging and tree girdling), or with herbicides, can be effective ways of reducing canopy cover when timed and conducted in ways to minimize harm to the Karner blue, lupine, and nectar plants. Tree harvesting operations that remove canopy and disturb soil can have beneficial effects on lupine and Karner blue. Smallidge et al. (1995) recorded a greater percent of lupine cover on sites managed with herbicides. An Arsenal-Accord mix has been used to reduce woody cover in rights-of-way management in New York, and observations suggested that the response was positive for lupine (Scott Shupe, Niagara Mohawk, pers. comm. 2002). Infrequent mechanical removal may actually increase woody plant density because of re-sprouting after herbicide application or cutting (Smallidge et al. 1996). Karner blue sites mowed in late summer in Wisconsin were found to support an abundance of larvae the following spring (Swengel 1995). In general, many of the methods for removing and suppressing tree and shrub canopy can have a net positive effect on lupine and the Karner blue and should be timed and carried out in ways that minimize harm to the butterfly and its food resources (lupine and nectar plants). The effects of these management practices should continue to be documented in a wide range of Karner blue habitat types. Refer to APPENDIX G, for further information and guidance on use of these management tools.

Associated Species

Remnant native Karner blue habitats are home to an impressive variety of additional rare and imperiled plants and animals, but the healthy communities once associated with barrens and savanna habitats have declined dramatically because of habitat conversion, fragmentation, and disruption of disturbance regimes. The unique ecological conditions created by the xeric sandy soils, drought-like conditions, and frequent fire disturbances produced a suite of species that, because of their specialized adaptations, rarely occur outside of barrens and savanna habitats. Thus, although the Karner blue butterfly is perhaps the most frequently referenced member of this highly specialized community, many other regionally and globally rare species also depend on these same habitats. Because barrens and savannas are rare habitats in many of the states that have Karner blues, many of the species restricted to these habitats are regionally imperiled. The ecologies of many of these species are not well enough understood to know how adapted these species are to other contemporary anthropogenic habitats. APPENDIX D provides state lists of Federal and state imperiled species and species of concern known to be associated with savanna and barrens communities in states with designated recovery units for the Karner blue. These lists were compiled by the state agencies responsible for rare species. Consequently, not all of the species listed will be found in occupied or occupiable Karner blue habitat, and not all of the species that are rare in Karner blue habitat will be listed. These listings indicate that restoring, preserving, and managing these dynamic barrens and savanna habitats is anticipated to benefit not only the Karner blue, but other rare species associated with them (Table 3*).* Management plans for the Karner blue should include management strategies that are compatible with other rare species that share its habitat (refer to APPENDIX G).

The Kirtland's warbler, *Dendroica kirtlandii* in Wisconsin is the only federally-listed endangered species included in these lists. The bald eagle, *Haliaeetus leucocephalus* in Michigan, and prairie bush clover, *Lespedeza leptostachya* in Wisconsin are federally-listed as threatened.

Table 3. Number of designated state endangered, threatened, or special concern species potentially associated with Karner blue habitats (for each state with extant Karner blue populations). The number of species that are listed as Federal endangered, threatened, or species of concern is in parentheses. The number of invertebrates does not include the Karner blue, and not all federally-listed species are listed by each state.

State	Vertebrates	Invertebrates	Plants
New Hampshire	0 (0)	3 (0)	3 (0)
New York	6 (0)	0 (1)	3 (1)
Michigan	11 (3)	14 (2)	50 (4)
Indiana	8 (3)	2 (1)	24 (2)
Wisconsin	26 (5)	41 (5)	50 (5)
Minnesota	2 (1)	3 (0)	7 (0)

In Wisconsin, Kirk (1996) conducted a thorough review of the rare species associated with dry prairie, barrens, and savannas in Wisconsin. Forty-one species were identified as associated with Karner blue habitat in the known range of the butterfly, of which 24 were further reviewed. Ten of the species (seven butterflies, two tiger beetles and the sharp-tailed grouse) were considered to have a high Karner blue association. Kirk (1996) discusses the taxonomy, range, habitat, life history, and management concerns for all 24 species. A companion document by Borth (1997) provides further information including management recommendations for 10 of the rare butterfly species discussed in Kirk (1996).

THREATS TO SURVIVAL

The most important threats to the Karner blue range wide are habitat loss, which has been accompanied by increased fragmentation of the remaining suitable habitat, and habitat alteration primarily resulting from vegetational succession. Related to these is the threat of incompatible management stemming from conflicting and potentially conflicting management objectives. Large-scale disturbances, such as large wildfire and unusual weather, are also threats to Karner blue populations. More detailed discussion of the threats to Karner blues in each recovery unit is provided in APPENDIX B. Threats in Wisconsin are not as imminent as in some other portions of the range because implementation of the Wisconsin Statewide HCP by its 26 partners plays a significant role in the conservation of the butterfly. Overall, the partners have committed to implementation of the HCP's conservation program on about 252,299 acres of land in Wisconsin (WDNR 2000, WDNR 2002a).

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

As noted above, the most significant threat to the Karner blue range wide is habitat loss, alteration, and destruction. Habitat loss has resulted in a reduction in the number of Karner blue subpopulations, habitat fragmentation, and smaller-sized occupied sites. Habitat alteration has reduced the abundance and quality of the Karner blue's food resources (lupine and nectar plants) and subhabitat diversity. Non-management of habitat has resulted in habitat loss over time due to ecological succession. Loss to commercial, industrial, and residential development is more a threat in areas where Karner blue populations are in close proximity to cities or desirable recreational lands (e.g. West Gary, Indiana, the Glacial Lake Albany Recovery Unit in NY, and Concord, New Hampshire, and the Morainal Sands Recovery Unit in Wisconsin).

<u>Loss and alteration of native habitat</u>

The major threat to native habitats is conversion to alternate uses, such as agriculture, forestry, industrial, residential and commercial development, and road construction. Originally, barrens and savanna were widespread in the central United States but rare in the eastern United States. In both regions, there has been a precipitous decline in these habitats. Remaining barrens and savanna usually consist of isolated patches that persist because of droughty soils, insects and disease, and human disturbance such as mowing, light grazing, and intermittent prescribed or wild fires.

The major threat to the survival of the Karner blue butterfly in native habitats is habitat alteration resulting from vegetation succession from barrens and savanna habitat to woodlands and forests. Other threats include incompatible management actions for other wildlife and natural areas goals that do not take into account the needs of the butterfly, such as restoration and maintenance of native vegetation, encouragement of game animals, and recreational use (refer to <u>Types of incompatible management</u>, below). Human use of these native habitats and adjacent developed habitats has often resulted in suppression of disturbance and decline of Karner blue butterfly populations. Although wildlife and other management goals are often compatible with enhancement for Karner blues, too vigorous a pursuit of these other goals can be detrimental to the butterfly.

<u>Loss and alteration of other contemporary habitats</u>

The Karner blue butterfly inhabits several non-native habitats, including some silvicultural habitats, mowed rights-of-way, and roadside edges. Some of these habitats are being lost to commercial and residential development. Agricultural impacts that could pose threats include use of pesticides near Karner blue sites, conversion of large acres (e.g., in Wisconsin) to cropland (e.g., potato fields), cranberry beds, or hog farms. However, agriculture in sandy soil areas favored by the Karner blue may diminish in Wisconsin over time as it is becoming increasingly costly, and therefore less profitable to support agriculture on sandy soils.

Global warming is expected to reduce agriculture on these more arid soils over the next century (Darrell Bazzell, in litt. 2002).

Some silvicultural habitats that are suitable for Karner blues are being converted to residential and commercial uses, and others to intensive forestry practices that may affect the ability of these lands to support Karner blues. Conversion of former jack pine plantations to red pine could result in a loss of Karner blue habitat because red pine canopy is thicker and closes more rapidly. In addition, it is questionable whether lupine will regenerate after harvest of mature stands, but this requires confirmation (refer to PART I, HABITAT/ECOSYSTEM, Renewal of Habitat for Karner Blue, Other contemporary habitats).

Silvicultural habitats that are suitable Karner blue habitats degrade as the trees mature and the canopy closes. This is a natural part of the production cycle, and as long as other silvicultural habitat is opened up within dispersal distances of extant Karner blue butterfly subpopulations, such as by harvesting (creating a shifting mosaic of habitat), a metapopulation may remain at viable levels. Silvicultural habitats supporting Karner blues can degrade in more subtle ways, such as by changing the management objective for land that was previously suitable for the butterfly. Shifting objectives can change the balance between the duration of a Karner blue subpopulation on a site and the proportion of total area that is suitable for the butterfly. For example, suppose a particular silvicultural objective results in canopy closure occurring ten years after planting, and maturation and harvest in year 40. If a Karner blue subpopulation occupies a site for those 10 years before canopy closure, then 25 percent of the land managed for that objective (10 out of 40 acres) could support habitat suitable for the Karner blue butterfly. If the land is managed for a different objective, so that canopy closure occurs faster and subpopulations can only persist for 6 years, and stand maturation takes 60 years, then only 10 percent of the land managed for this objective could have habitat suitable for Karner blue. The exact percentage will vary from year to year depending on the proportion of the land harvested, variation in growth among sites, and changes in management objectives for a particular site. The longer the subpopulation can persist at higher population numbers, in general, the better for the butterfly**.** Currently in Wisconsin, the HCP monitoring program is demonstrating that Karner blues are persisting on forested landscapes, however questions remain as to the impact of various forest operations on the butterfly (refer to PART II, RECOVERY TASKS, Task 5.25)

The Karner blue butterfly also inhabits power line and railroad rights-of-way (Smallidge et al. 1996, WDNR 2000). If these are managed with herbicides or mowing during the late spring to the early summer, lupine and nectar plants would be suppressed, reducing habitat quality for the Karner blue butterfly as well as butterfly numbers. On some roadside corridors, native vegetation is being replaced by more uniform, exotic vegetation. On other corridors, ORV use is degrading habitat. It has been suggested that development of dedicated ORV trail systems may alleviate this problem (Scott Shupe, Niagara Mohawk, in litt. 2002).

Types of incompatible management

Incompatible management practices threaten some populations of Karner blues and can occur when land managers have several management goals and they either are unaware how pursuit of these other goals could have detrimental effects on the Karner blue or they judge the trade-off with its detrimental effect on the butterflies to be acceptable. Incompatible management practices can occur as described below:

1. Pesticide Use

Poorly timed or poorly located use of herbicides can have a negative effect on Karner blue butterflies, by killing or suppressing lupine or important nectar plants. Application of herbicides in Karner blue butterfly occupied areas is best done after lupine and nectar plants senesce.

Most insecticides are not target-specific and can kill most insects in the treated area including the Karner blue butterfly. In laboratory tests, even the relatively specific insecticide, *Bacillus thuringiensis kurstaki* (*Btk*), used to control the gypsy moth killed about 80 percent of the Karner blue larvae fed Btk treated lupine leaves (Herms 1997). Because the timing of Btk applications for gypsy moth control typically coincides with the larval stage of the Karner blue, application of this insecticide results in Karner blue mortality (Herms 1997). Individuals and agencies (e.g. U.S. Forest Service) wishing to use Btk for gypsy moth suppression are encouraged by the Service to use alternative, non-lethal control methods in Karner blue butterfly areas. Miller (1990) found that *Btk* reduced the number of non-target Lepidoptera species and suggested that if any of the species had been limited in its distribution, it would have been at high risk of becoming extirpated. The effect of biological control agents on non-target insects is poorly documented. Analysis of the effects of releases of the biological control agent *Trichogramma nubilale* (an egg parasitoid) (Andow et al. 1995) showed the risk to be small. An examination of the introduced insect predator *Coccinella septempunctata* (seven-spotted ladybird beetle) in Karner blue habitat (N.A. Shellhorn, UW-Madison, pers. comm. 1997**)** suggests that the risk could vary with predator density, prey density, and microhabitat. The direct or indirect effects of fungicide applications on the Karner blue butterfly is not known. Refer also to APPENDIX G, REDUCING LOCAL EXTIRPATION RATES, Improving and Maintaining Karner Blue Habitat, Pesticides.

2. Mowing

While mowing can be an effective management tool (Swengel 1995), some precautions are warranted. Mowing between late spring and early summer is anticipated to have detrimental effects on Karner blue populations. Mowing can damage lupine, eliminating food for larvae. Although mowing may reduce shade and competition, it could also favor plant species not used by the Karner blue (Givnish et al. 1988). Mowing during adult nectaring periods can greatly reduce flower number and nectar availability. Mowing of lupine and nectar plants before seeds mature and disperse could reduce reproduction of these food plants, and have a long-term detrimental effect on Karner blues. In addition, mowing can kill larvae that are present, and may crush eggs laid on lupine plants. Refer to APPENDIX G, Alternatives to fire management for more information and guidance regarding mowing.

3. Prescribed fire

Fire is being used as a management and restoration tool (sometimes in conjunction with mechanical management) on several Karner blue sites e.g., the Albany Pine Bush Preserve (Albany, New York), Necedah NWR (Wisconsin), and at several Wisconsin DNR properties with positive effects for the Karner blue. Fifty years of fire and mechanical management on the Crex Meadows and Fish Lake WAs in Wisconsin have produced 12,000 acres of quality barrens habitat and monitoring has demonstrated the maintenance of a Karner blue population on the property. Necedah NWR currently manages about 500 acres of savanna habitat for the butterfly, mostly through a prescribed burning program.

While prescribed fire is a very useful management and restoration tool, it may threaten Karner blue populations e.g., if the burning is conducted on the majority of the habitat at one time, and if high intensity fires are used at frequent intervals. For a review of the effects of fire on the Karner blue and its food resources and for guidance on use of fire in Karner blue butterfly habitat refer to APPENDIX G.

4. Deer and grouse management

High deer densities can devastate Karner blue butterfly habitat and cause direct mortality by ingestion of larvae (Packer 1994, Schweitzer 1994a). Schweitzer recommends that deer populations be managed to levels where no more than 15 percent of lupine flowers are consumed (Schweitzer 1994a), but this recommendation has not been rigorously tested. Fencing may be useful in some situations to exclude deer from habitat areas. New economic solar powered electric fencing is currently available (David Wagner, University of Connecticut, in litt. 2002). Ruffed grouse habitat does not support lupine, because the dense, shrub vegetation favored by these game birds casts too much shade to allow lupine to thrive. Because Karner blues can occur on lands managed for sharptail grouse, burn management should be designed to promote conservation of the butterfly as well as grouse. Currently brush prairies that support sharptail grouse at Crex Meadows WA also provide the best habitat for Karner blues (Paul Kooiker, WDNR, pers. comm. 1997).

Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

Collection of the Karner blue butterfly has occurred in the past (USFWS 1992a and 1992b), but is not considered a significant factor in population decline. In the parts of its range where only a few small populations remain, however, extensive collections could have a detrimental effect. Although it has been suggested that collecting of three Karner blue butterflies in Illinois in the Kenosha Potential RU (refer to APPENDIX B) may have contributed to the extirpation of the butterfly in this RU, it is highly unlikely that this could have been the main cause of extirpation.

Disease or Predation

Very little research has been conducted on the natural enemies of the Karner blue butterfly, so the significance of these biotic factors as threats to the butterfly cannot be definitively stated. Similar to most other insects, the mortality of Karner blue immature life stages is very high (Savignano 1990, Lane 1994b). Part of this mortality is caused by predators, parasitoids, or pathogens (Savignano 1990). Larval predators include pentatomid stink bugs (*Podisus maculiventris*), wasps (*Polistes fuscatus* and *P. metricus*), ants (*Formica schaufussi* and *F. incerta*) (Savignano 1990, 1994a), spiders (Packer 1987), and ladybird beetles (*Coccinella septempunctata*) (Schellhorn et al. unpublished data). Four larval parasitoids have been reared from field collected larvae: a tachinid fly (*Aplomya theclarum*), a braconid wasp (*Apanteles* sp.), and two ichneumonid wasps (*Neotypus nobilitator nobilitator* and *Paranoia geniculate*) (Savignano 1990). Several insect predators have been observed attacking adults, including spiders, robber flies, ambush bugs, assassin bugs, and dragonflies (Packer 1987, Bleser 1993). Disease pathogens of the Karner blue butterfly have not been identified, but probably exist.

It is unknown whether birds or mammals cause significant mortality at any life stage of the Karner blue. Bird beak-marks are occasionally observed on adult wings. Direct mortality to Karner blue larvae by deer browse can have a detrimental effect on the butterfly (Schweitzer 1994a).

Plant diseases of lupine could reduce its food quality or render it unsuitable, resulting in larvae mortality or reduced adult fecundity. Lupine leaves are attacked by both powdery mildew (*Erysiphe polygoni*) and a leaf rust (*Puccinia andropogonis*). Research on the effect of powdery mildew on Karner blue butterfly host plant quality is inconclusive. Maxwell (1998) found lower densities of larvae in areas where the proportion of lupine with mildew was the greatest. However, Grundel et al. (1998a) fed mildew infected leaves to larvae in laboratory feeding studies and measured more rapid larval development on post-flowering mildewed leaves than on comparable uninfected lupine.

Of particular interest is how fragmentation and degradation of habitat influences the population dynamics of natural enemies and competitors of the Karner blue butterfly and lupine, and the ultimate effect on Karner blue metapopulations. For example, the abundance of predators and parasitoids varies with tree canopy cover and therefore some subhabitats may provide refuges for Karner blue (Lane 1994b, Schellhorn et al. unpublished data).

Inadequate Regulatory Mechanism

While most states still supporting butterfly populations have legislation that protects the butterfly (refer to PART I, CONSERVATION MEASURES, State Protection), provisions for protection and management of the habitat are incomplete to non-existent (USFWS 1992a and 1992b). This is an important gap in that loss and degradation of suitable habitat are primary reasons for population extirpation and decline in numbers, and recovery of the species will depend on ensuring an adequate base of suitable habitat. Implementation of management agreements, development of conservation easements, and outright land purchase could be used to ensure the habitat base. Other, more flexible regulatory mechanisms could be developed to ensure this habitat base.

Populations of Karner blues that occur on Federal and state lands are protected from destruction, but Federal and state land managers might not manage actively for appropriate savanna or barrens habitat. Developing streamlined procedures for incorporating concerns for Karner blue butterflies into current management plans is recommended in this plan.

Other Natural or Man-made Factors Affecting Its Continued Existence

Stochastic events, such as unusual weather, can detrimentally affect Karner blue populations. Spring and summer drought can stress lupine and may reduce larval populations, and reduce flowering of nectar plants (Cynthia Lane, pers. comm. 1996) which may result in greater adult mortality. Cool springs can delay lupine emergence until after egg hatch (Lane, unpublished data). Cold, wet weather during the flight periods reduces the time available for oviposition and could increase adult mortality. A combination of summer drought and cool, wet springs is one of the suspected causes of population extirpation in Ontario (Packer 1994, Schweitzer 1994b) although habitat damage also contributed to extirpation. In particular home building in some key lupine areas at the Port Franks Estate site and logging at the Port Franks Bowl site were detrimental. The greatest impact of the logging was thought to be the removal of one large shade tree in the center of the most suitable habitat area at the Port Franks Bowl site. The reduction in shade increased light levels which may have made the site more susceptible to drought (Packer 1994).

Heavy browse by mammals (e.g., deer, rabbit, woodchuck), or insect herbivores on lupine in Karner blue areas can also have a detrimental effect. Larvae may starve if lupine is severely defoliated. Browse or herbivory on the flowers or fruits can reduce lupine seed and possibly affect the long-term survival of the lupine population (Straub 1994). Insect herbivores, such as painted lady larvae *(Vanessa cardui)* and blister beetles, can defoliate high percentages of the lupine in an area, which may result in larval starvation.

Large-scale wildfire could destroy a large metapopulation. These events are infrequent, but potentially devastating. Although these rare events would have large detrimental effects that last for several years, it is possible that the metapopulation could recover if enough healthy unburned populations existed nearby or if the fire left patches of unburned refuge areas.

Aggressive exotic (non-native) plant species may pose a threat by out-competing other plant species required by the Karner blue butterfly. Orange hawkweed (*Hieracium aurantiacum*), leafy spurge *(Euphorbia esula*), crown vetch *(Coronilla varia),* white sweet clover *(Melilotus alba),* and Pennsylvania sedge (*Carex pennsylvanicus*) can dominate some Karner blue habitats and reduce lupine and the diversity and abundance of nectar plants available to the Karner blue adults. Spotted knapweed (*Centaurea maculosa*) is used as a nectar plant, but its dominance can reduce the diversity of nectar plants, increasing the risk of extirpation of the subpopulation. In the absence of management, dense cover of buckthorn (*Rhamnus catharticus*), American hazelnut (*Corylus americana*), black locust *(Robinia pseudoacacia),* or other woody shrubs will eventually eliminate lupine.

Global warming may also pose a threat to the Karner blue. A hotter longer growing season may cause a reduction in the habitat quality of some areas by causing early senesce of lupine. Recovering Karner blues in the more northern recovery units of its existing range should help address this concern.