The Endangered Karner Blue Butterfly (Lepidoptera: Lycaenidae): Biology, Management Considerations, and Data Gaps

Robert A. Haack[1]

Abstract: The Karner blue butterfly, *Lycaeides melissa samuelis* Nabokov, became federally listed as endangered in 1992 and is thus afforded protection under the Endangered Species Act of 1973. This insect has a very discontinuous range, with 1992 populations found in Minnesota, Wisconsin, Illinois, Indiana, Michigan, New York, and New Hampshire. Karner blue larvae feed exclusively on wild lupine, *Lupinus perennis* L., a disturbance-adapted plant common to oak savannas, pine barrens, and lake dune complexes. Historically, Karner blue sites have been maintained by fire. Besides lupine, the Karner blue requires nectar sources for adults and possibly ants for protection of the larvae. This paper provides current information on Karner blue distribution, taxonomy, general biology, habitat requirements, management practices, and data gaps.

INTRODUCTION

The Karner blue butterfly, *Lycaeides melissa samuelis* Nabokov (Lepidoptera: Lycaenidae), occurs primarily in oak savannas and pine barrens, and occasionally in lake dune complexes from Minnesota to New Hampshire. Over the past 100 years it is estimated that the Karner blue has declined by 99% in numbers (USFWS 1992). In December 1992 the Karner blue was federally listed as endangered (USFWS 1992), and therefore now receives protection under the Endangered Species Act of 1973 (Pyle et al. 1981, Rohlf 1989, Wilcove et al. 1993). Land managers with known Karner blue populations should follow management prescriptions to ensure its survival and recovery as stipulated in the Endangered Species Act. To assist managers, this paper summarizes much of what is known about Karner blue biology, habitat requirements, and management considerations.

DISTRIBUTION

The Karner blue is found in small pockets from Minnesota to New Hampshire, generally following the northern limits of the range of wild lupine, *Lupinus perennis* L., the insect's only larval food plant (Figure 1). Originally the Karner blue probably existed as several, large shifting clusters of populations, or metapopulations, waxing and waning as lupine first entered recently burned areas and then left when successional changes shaded out the plant (USFWS 1992, Schweitzer 1990). As of 1992, the Karner blue existed in Minnesota, Wisconsin, Illinois, Indiana, Michigan, New York, and New Hampshire (Table 1), with Michigan and Wisconsin appearing to have the most (but not the largest) discrete populations (USFWS 1992). In addition, this butterfly once existed in Massachusetts, Ohio, Pennsylvania, and Ontario (Figure 1, Table 1). In Illinois, 5 adults (3 males and 2 females) were reported in 1992, being the first confirmed occurrence of Karner blue in Illinois since about 1900 (S. Lauzon, pers. comm., Downey 1966). Because of some early confusion regarding these sightings in Illinois, 7 adults instead of 5 were reported in USFWS (1992).

[1]Research Entomologist, North Central Forest Experiment Station, USDA Forest Service, Insect Project, 1407 S. Harrison Rd., East Lansing, MI 48823.

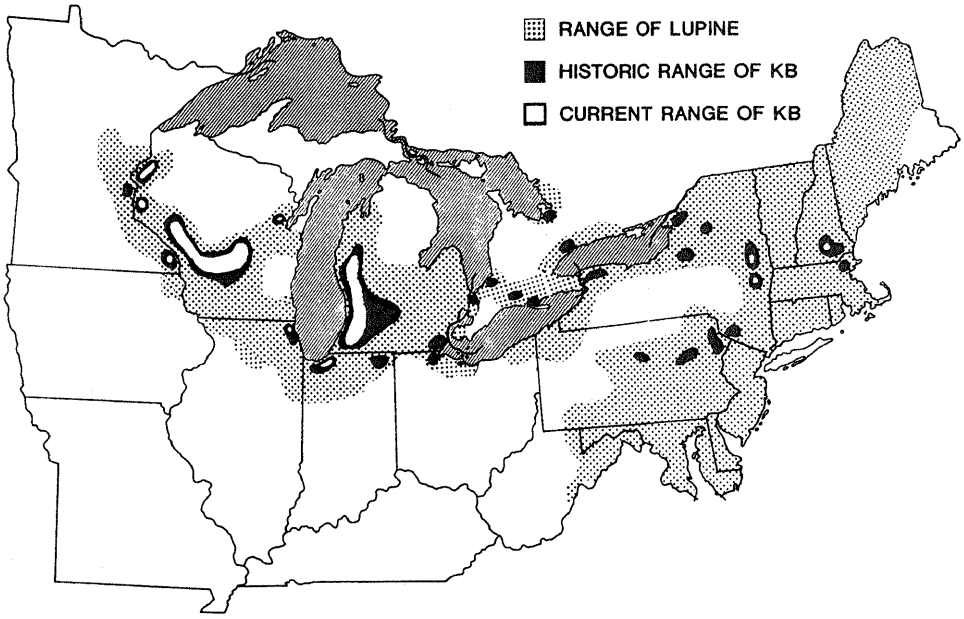

Figure 1.—Approximate range maps of wild lupine (incomplete, not showing extension southward to Florida), and the historic and current (1992) ranges of Karner blue (KB). The northern range of lupine was estimated from county records taken from over 30 books on the flora of individual states and regions (list of references available from the author), and from lupine survey records of the Wisconsin Department of Natural Resources. Karner blue sources include: Cryan and Dirig (1978); briefing material presented at the "Karner Blue Butterfly Population and Habitat Viability Assessment (PHVA) Workshop," April 22-24, 1992, Zanesville, OH; and comments from several reviewers (see acknowledgments).

ENDANGERED STATUS

Because of its dramatic rangewide decline, the Karner blue was proposed on January 21, 1992, for federal listing as "endangered" under the Endangered Species Act; this proposal became final on December 14, 1992 (USFWS 1992). The designation "endangered" signifies a species in danger of extinction throughout all or a significant part of its range (Haack 1992, Rohlf 1989, Wilcove et al. 1993). Having been afforded endangered species status, the Karner blue is protected from actions that could jeopardize either the insect itself or its "critical habitat." For example, gypsy moth control programs, using the lepidopteran-specific *Bacillus thuringiensis* (*Bt*) insecticide, could be banned from areas with known Karner blue populations because of the possible "non-target" effects of *Bt*. Although it is not yet known if Karner blue is sensitive to *Bt*, a "no-spray" policy would likely be taken as a precautionary step.

TAXONOMY

The Karner blue was originally described in 1861 under the name *Lycaeides scudderi* Edwards, being considered then the same species as the Scudder's blue. However, after a revision by Nabokov (1943) it was reclassified as a subspecies of the Melissa blue (*Lycaeides melissa melissa* Edwards), with the scientific name of *Lycaeides melissa samuelis* Nabokov. Although there is evidence that the Karner blue deserves full species status, no such change has yet been published (Schweitzer 1989, USFWS 1992). The type specimen of the Karner blue was collected near Karner, New York, from which its common name was derived.

Table 1.—Status of the Karner blue throughout its current and historical rangeas of 1992

Location	Current status (Current and recent references)*
Minnesota	5 sites in 1 population cluster; ≤14 adults/site seen in 1991 (8 13 20)
Wisconsin	131 sites in 1991; ≤100 adults seen at 90% of sites (4, 20)
Illinois	Considered extirpated ca. 1900; 5 adults reported in 1992 (20, 22)
Indiana	10 discrete sites in 2 population clusters in 2 counties (20, 24)
Michigan	Minimum of 93 sites in 6 counties (1, 2, 9, 14, 20, 21, 23)
Ohio	Extirpated since 1988 (10, 15, 19, 20)
Pennsylvania	Extirpated since about 1900 (16, 20)
New York	About 50 small and 2 large (1500 and 14,000 adults) sites (6, 7, 18, 20)
New Hampshire	1 site on 2-3 acres; 400 adults estimated in 1991 (3, 11, 20)
Massachusetts	Extirpated possibly before 1900 (20)
Ontario	Extirpated since about 1989 (12, 17, 20)

*References: 1=Ballard and Sferra (1991), 2=Bess (1989), 3=Bidwell (1991), 4=Bleser (1992), Campbell et al. (1990). 6=Cryan (1980), 7=Cryan and Dirig (1978), 8=Cuthrell (1990), 9=Ewert and Ballard (1990), 10=Grigore (1992), 11=Helmboldt and Amaral (1992), 12=Konecny (1986), 13=Lane (1992), 14=Lawrence and Cook (1989), 15=Magdich (1989), 16=Opler (1985), 17=Packer (1990), 18=Schweitzer (1990), 19=Shuey et al. (1987), 20=USFWS (1992), 21=Wilsmann (1992), 22=S. Lauzon, personal communication, 23=M. Rabe personal communication, Michigan Natural Features Inventory, 24=M. Martin (1992).

DESCRIPTION

Karner blue adults are rather small butterflies with a wingspan between 2.2 and 3.2 cm (Opler and Krizek 1984, Scudder 1889, USFWS 1992). The dorsal or upper wing surface of males is purplish (or silvery) blue with a narrow black border and a white fringe. The dorsal wing surface of females is similar to that of males except there is more brown and the outer edge of the female's hind wings has a row of dark spots with orange crescents. The ventral or lower surface of the wings is similar in both males and females—slate gray with several rows of black and orange spots. High quality Karner blue photographs are given in Opler and Krizek (1984), Shull (1987), and several other butterfly guides.

Eggs are about 0.7 mm in diameter, pale green, and somewhat rounded (Dirig and Cryan 1976, Scudder 1889). The egg's surface is highly sculptured or reticulated, appearing as a raised network of fine lines.

Larvae are dorsally flattened and pubescent, with black head capsules and green bodies (Dirig and Cryan 1976, Scudder 1889). Older larvae have a dark-green median stripe along the upper surface of the abdomen and white stripes laterally. Karner blue larvae are well camouflaged for feeding on lupine leaves. There are four larval instars (Savignano 1990). Scudder (1889) reports that first instar larvae measure about 1.25 mm in length, while fourth instars measure 12.25 mm long. Pupae are smooth, pea-green, and about 9.5 mm long (Scudder 1889). Pupae turn blackish purple just prior to adult emergence (C. Bleser, pers. comm.).

Life Cycle

The Karner blue's life history is generally well documented, with the following details taken from Bleser (1992), Cryan (1980), Cryan and Dirig (1978), Dirig (1973, 1988), Lawrence and Cook (1989), Masters and Karpuleon (1975), Packer (1987, 1990), Savignano (1990), Shapiro (1974), Schweitzer (1989), Scudder (1888, 1889), and Shuey et al. (1987). It is a bivoltine insect, i.e., it completes two generations per year (Figure 2) with the egg being the overwintering stage. The exact timing of each life stage varies somewhat within the species' geographic range, and from year to year, depending on local weather conditions. First-generation larvae hatch from eggs in middle to late April, and immediately search out and feed on wild lupine, their sole host plant. While feeding, young larvae make pinprick-sized circular holes in leaves or they skeletonize the leaves, which results in a window-pane appearance. Older larvae feed primarily on foliage, but may feed on lupine buds, flowers, and developing fruit. Larvae feed for about 3 to 4 weeks. First-generation pupation occurs primarily in late May to early June and lasts for about 8-11 days. Pupae are usually found on lupine plants or in nearby litter. First-generation adults fly from late May through mid-June. Adults typically live for about 5 days, but may live as long as 2 weeks. Peak male flight typically precedes peak female flight by a few days, as is true in many Lepidoptera. First-generation adults lay eggs on lupine plants, often singly on leaves, petioles, or stems. The male:female ratio is about 1:1.

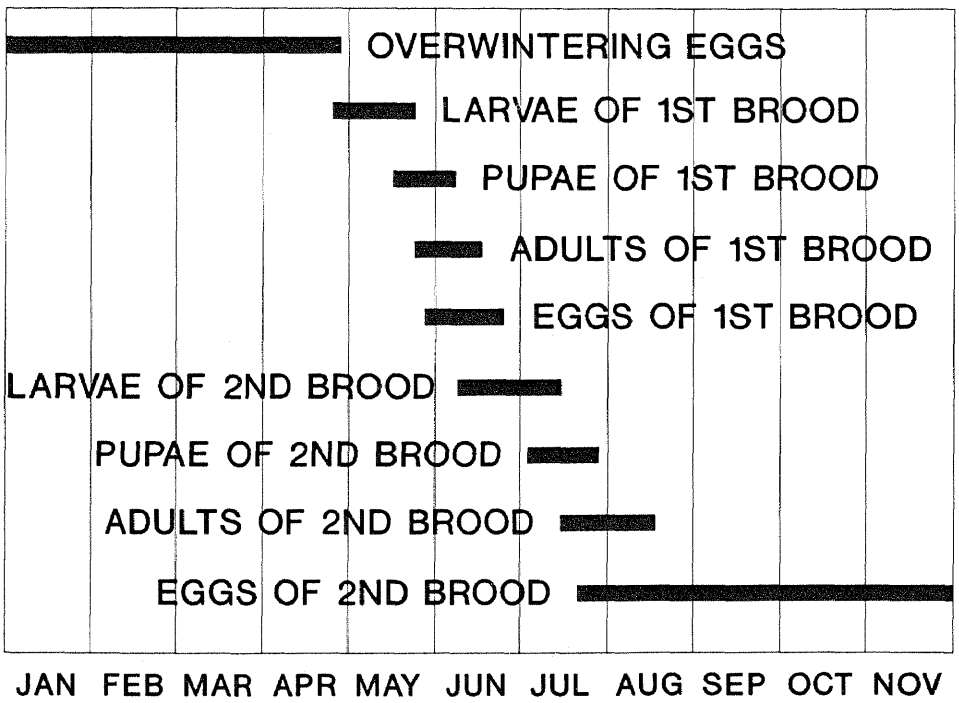

Figure 2.—Generalized occurrence of various Karner blue life stages through a typical year.

Larvae of the second generation can be found feeding on lupine from early June through late July. Second-generation adults typically fly from mid-July into early August. There are usually 3-4 times more individual adults in the second brood than in the first brood at a given locality. Second-generation adults lay eggs at or near the bases of lupine plants, on dry lupine pods, or low on the stems of surrounding vegetation. During the second-generation flight period, at which time lupine plants are senescing, adults do not appear to discriminate between dry and green plants for oviposition.

Adults initiate flight between 8-9 a.m. and continue to fly until about 7 p.m. Flight activity is greatly reduced below 75°F or during moderate to heavy rains. Adults tend to fly close to the ground. At night, they roost in open areas on grasses such as bluestem, *Schizachyrium* (=*Andropogon*). Adults can disperse at least as far as 1-1.5 km, which seemingly would help them search for new patches of lupine. However, in some populations (e.g., in New Hampshire), adults disperse very little (D. Schweitzer pers. comm.).

Nectar Sources

Karner blue adults obtain nectar from a wide variety of flowering plants, including both native and exotic species (Table 2). Lupine is used as a nectar source by first-generation adults, but few lupine plants are still flowering when second-generation adults fly. Although lupine is the sole larval host plant, it is not a favored nectar plant for adults (Leach 1993). Wide variation in the favored nectar plants occurs from state to state. However, New Jersey tea (*Ceanothus americanus*) is among the favorite nectar sources in Indiana, New Hampshire, New York, and Ontario (D. Schweitzer in press-b). A lack of nectaring plants, especially during the second-generation flight season, can render sites unsuitable for Karner blue even though lupine may abound (Bleser 1992, Leach 1993, Schweitzer 1989).

Association with Ants

Karner blue larvae, like many members of the family Lycaenidae, are associated with ants (Bleser 1992, Packer 1990, Savignano 1990, Scudder 1889). Reports from New York, Wisconsin, and Ontario have identified 27 species of ants that tend Karner blue caterpillars (Table 3). There is one report of ants tending a Karner blue pupa (Saunders 1878).

Lycaenid caterpillars and pupae have special glands that secrete juices high in sugars and amino acids that are harvested by ants (DeVries 1988, 1992, Maschwitz et al. 1975). In return for these nutritious secretions, ants protect lycaenid caterpillars and pupae from predation and parasitism (Atstatt 1981a, Jordano et al. 1992, Peterson 1993, Pierce and Easteal 1986). Savignano (1990) has reported lower predation of Karner blue larvae when tended by ants. Many lycaenid caterpillars, and perhaps Karner blue larvae as well, produce sounds that ants use to locate the larvae (Bleser 1992, DeVries 1988, 1989, 1992).

In addition, some lycaenids oviposit preferentially in habitats with ants (Atstatt 1981b, Pierce and Elgar 1985), which may help explain why lycaenid larvae are often found in close spatial proximity to ants (Jordano et al. 1992, Smiley et al. 1988). If these relationships hold true for the Karner blue, then it may be discovered that adults seek out and oviposit in habitats with both lupine and selected ant species. Packer (1987) suggested that a drastic decline in wood ant populations contributed to local declines of Karner blue in Ontario.

Table 2.—Nectaring sources for first-generation and second-generation Karner blue adults

Plant			
Scientific name	**Common name**	**Location**	**Reference**
First generation nectaring sources			
Achillea millefolium	Yarrow	WI	2 13
Amelanchier sp.	Juneberry	NY ONT	3 7
Anemone cylindrica	Thimbleweed	WI	13
Arabis lyrata	Lyre-leaved rock cress	IN ONT WI	2 7 12 13
Arenaria serpyllifolia	Thyme-leaved sandwort	ONT	7
Baptisia leucophaea	Wild indigo	WI	2
Berteroa incana	Hoary alyssum	WI	2 13
Ceanothus ovatus	Red root	WI	13
Ceanothus sp.	New Jersey tea	WI	2
Centaurea maculosa	Spotted knapweed	WI	13
Cerastium sp.	Chickweed	WI	13
Chrysanthemum leucanthemum	Daisy	WI	13
Comandra umbellata	Bastard toadflax	MI WI	2 10
Coreopsis lanceolata	Lance-leafed coreopsis	IN	12
Erigeron strigosus	Daisy fleabane	WI	13
Euphorbia esula	Leafy spurge	WI	13
Fragaria virginiana	Strawberry	NY WI	9 13
Gaylussacia baccata	Huckleberry	WI	2
Geranium maculatum	Wild geranium	ONT	7
Helianthemum canadense	Frostweed	NH	1 5
Hieracium aurantiacum	Orange hawkweed	WI	2 13
Hieracium sp.	Hawkweed	NH NY ONT	5 7 9
Houstonia longifolia	Long-leaved bluets	WI	2
Krigia biflora	Two-flowered cynthia	WI	2
Lithospermum caroliniense	Hairy puccoon	ONT WI	2 7
Lupinus perennis	Wild lupine	MI NH ONT WI	1 2 4 5 7 13
Medicago lupulina	Black medick	WI	2 13
Melilotus officinalis	Yellow sweet clover	IN WI	2 12 13
Pedicularis canadensis	Lousewort	WI	2
Phlox pilosa	Downy phlox	IN	12
Physocarpus opulifolius	Nine-bark	WI	13
Potentilla recta	Rough-fruited cinquefoil	WI	2
Potentilla simplex	Common cinquefoil	MI NY WI	2 8 10 13
Prunus sp.	Wild plum	NY	3 8
Rubus allegheniensis	Blackberry	MI	4 10
Rubus flagellaris	Dewberry	IN	12
Rubus sp.	Blackberry	IN NY WI	3 9 12 13
Rubus sp.	Dewberry	WI	13
Rumex acetosella	Sheep sorrel	WI	2
Salix humilis	Prairie willow	WI	2 13
Senecio pauperculus	Ragwort	WI	13
Senecio sp.	Ragwort	WI	2
Smilacina racemosa	False Solomon's seal	WI	2 13
Smilacina stellata	Starry false Solomon's seal	WI	2
Trifolium pratense	Red clover	WI	13
Trifolium repens	White clover	WI	13
Trifolium hybridum	Alsike clover	WI	2
Vaccinium sp.	Blueberry	NY	3 9
Vicia villosa	Vetch	WI	2
Viola pedata	Bird's-foot violet	WI	2
Zizia aurea	Golden alexanders	WI	2

Table 2. (Continued)

Plant			
Scientific name	**Common name**	**Location**	**Reference**
Second generation nectaring sources			
Achillea millefolium	Yarrow	IN WI	2 12 13
Amorpha canescens	Leadplant	NY WI	2 9 13
Apocynum androsaemifolium	Spreading dogbane	NH	1
Arabis lyrata	Lyre-leaved rock cress	IN WI	2 12 13
Asclepias syriaca	Common milkweed	WI	2 13
Asclepias tuberosa	Butterfly weed	IN MI ONT WI	2 4 7 12 13
Asclepias verticillata	Whorled milkweed	IN WI	2 12 13
Aster ptarmicoides	Upland white aster	WI	2
Aureolaria pedicularia	False foxglove	WI	2
Berteroa incana	Hoary alyssum	WI	2
Campanula rotundifolia	Bluebell	MN	6
Ceanothus americanus	New Jersey tea	IN NH NY ONT	1 5 7 9 12
Ceanothus herbaceus	New Jersey tea	ONT	7
Centaurea maculosa	Spotted knapweed	MI NY WI	2 4 9 10 13
Chrysanthemum leucanthemum	Daisy	WI	13
Coreopsis palmata	Coreopsis	WI	13
Coreopsis sp.	Coreopsis	WI	2
Erigeron sp.	Daisy fleabane	IN	12
Erigeron annuus	Daisy fleabane	MI	10
Erigeron strigosus	Daisy fleabane	MI WI	2 10 13
Euphorbia corollata	Flowering spurge	IN MI WI	2 4 10 12 13
Euphorbia esula	Leafy spurge	WI	2 13
Froelichia floridana	Cottonweed	WI	13
Galium sp.	Bedstraw	WI	2
Gerardia pedicularia	Fern-leaved false foxglove	WI	2
Gnaphalium obtusifolium	Sweet everlasting	MN	6
Helianthus divaricatus	Woodland sunflower	IN	12
Helianthus occidentalis	Western sunflower	WI	2 13
Hieracium aurantiacum	Orange hawkweed	WI	2 13
Houstonia longifolia	Long-leaved bluets	WI	2
Krigia biflora	Two-flowered cynthia	WI	2
Lespedeza capitata	Round-headed bush-clover	WI	2
Liatris aspera	Rough blazing-star	MI WI	4 13
Liatris cylindracea	Cylindric blazing-star	WI	2 13
Lilium philadelphicum	Wood lily	NH	1 5
Linaria vulgaris	Butter-and-eggs	WI	2
Lithospermum caroliniana	Hairy puccoon	WI	2
Lobelia spicata	Pale-spike lobelia	WI	13
Lotus corniculatus	Birdfoot trefoil	WI	2
Lupinus perennis	Wild lupine	WI	2
Lysimachia sp.	Loosestrife	WI	2
Medicago lupulina	Black medick	WI	13
Medicago sativa	Alfalfa	WI	2
Melilotus alba	White sweet clover	IN MI NY WI	9 11 12 13
Melilotus officinalis	Yellow sweet clover	WI	2 13
Monarda fistulosa	Wild bergamot	IN ONT	7 12
Monarda punctata	Horsemint	IN MI MN NY WI	2 3 4 6 12 13
Oenothera sp.	Evening primrose	WI	2
Petalostemum candidum	White prairie-clover	WI	2 13
Petalostemum purpureum	Purple prairie-clover	WI	2 13
Phlox pilosa	Downy phlox	IN	12

Table 2. (Continued)

Plant			
Scientific name	**Common name**	**Location**	**Reference**
Potentilla simplex	Old-field cinquefoil	WI	2
Polygala polygama	Racemed milkwort	WI	2
Polygonum sp.	Smartweed	WI	2
Rosa sp.	Rose	WI	2
Rudbeckia hirta	Black-eyed Susan	ONT WI	2 7 13
Saponaria officinalis	Bouncing bet	NY	8
Smilacina stellata	Starry false Solomon's seal	WI	2
Solidago graminifolia	Lance-leaved goldenrod	WI	2
Solidago speciosa	Showy goldenrod	WI	2
Solidago sp.	Goldenrod	IN NH	1 5 12
Spiraea alba	Narrowleaf meadowsweet	WI	2
Spiraea tomentosa	Steeplebush	WI	2
Talinum rugospermum	Fameflower	WI	2 13
Tephrosia virginiana	Goat's-rue	IN	12
Trifolium arvense	Rabbit's-foot clover	WI	2
Trifolium hybridum	Alsike clover	WI	2
Trifolium pratense	Red clover	WI	2 13
Trifolium repens	White clover	WI	2 13
Vicia villosa	Vetch	WI	2
Tephrosia virginiana	Goat's-rue	NY WI	2 3

*References: 1=Bidwell (1991), 2=Bleser (1990, 1992), 3=Cryan (1980), 4=Ewert and Ballard (1990), 5=Helmboldt and Amaral (1992), 6=Lane (1992), 7=Packer (1990), 8=Savignano (1987), 9=Schweitzer (1989), 10=Sferra and Darnell (1992), 11=Wilsmann (1992), 12=Martin (1992), 13=Leach (1993), 14=D. Schweitzer personal communication.

Predators and Parasites

Only a few Karner blue predators and parasites have been reported. Larval predators include spiders (Packer 1987), pentatomid stink bugs, *Polistes* wasps, and *Formica* ants (Savignano 1990). Similarly, adult predators include crab spiders, robber flies, ambush bugs, assassin bugs, and dragonflies (Bleser 1992, M. Leach pers. comm., Packer 1987, Savignano 1990 and unpub. data). Savignano (1990) reported four larval parasites of the Karner blue — the tachinid fly *Aplomya theclarum*, the braconid wasp *Apanteles* sp. (possibly *epinotiae*), and two ichneumonid wasps, *Neotypus nobilitator nobilitator* and *Parania geniculata*. Savignano (1990) reared the tachinid *Aplomya theclarum* from both first- and second-generation Karner blue larvae, suggesting that it may be a lycaenid specialist. In Stone et al. (1983), however, no host data are reported for this fly. Of the three parasitic wasps, Krombein et al. (1979) list several lepidopteran hosts (although none are lycaenids) for *A. epinotiae* and *P. geniculata*, whereas only one host is given for *N. nobilitator nobilitator*—the eastern tailed blue, *Everes comyntas* (Lycaenidae).

General Habitat

The Karner blue is primarily found in openings within habitats classified as oak savannas, pine-oak savannas, or pine barrens (Shuey in press). Such habitats have declined dramatically in acreage throughout North America. For example, Nuzzo (1986) estimates that only 0.02% of the presettlement acreage of oak savannas in the Midwest still existed as of 1985. In addition to savanna-type habitats, the Karner blue occasionally occurs in dry sand prairies and some lake shore dune complexes where lupine exists (Bess 1989, Martin 1992). Generally, the Karner blue is associated with areas of low canopy cover (<5% in Minnesota; Lane 1992), but at times this butterfly occurs under semi-closed canopy conditions as well (Leach 1993).

Table 3.—Ant species reported to tend Karner blue larvae

Ant species	Location	Reference
Aphaenogaster rudis	Ontario	Packer (1990)
Camponotus americanus	NY	Savignano (1990)
Camponotus ferrugineus	WI	Bleser (1992)
Camponotus novoboracensis	NY	Savignano (1990)
Camponotus pennsylvanicus	Ontario	Packer (1990)
Crematogaster ashmeadi	WI	Bleser (1992)
Crematogaster cerasi	NY	Savignano (1990)
Dolichonderus plagiatus	NY	Savignano (1990)
Formica exsectoides	Ontario	Packer (1990)
Formica fusca	WI	Bleser (1992)
Formica (Neoformica) incerta	NY	Savignano (1990)
Formica lasioides	NY	Savignano (1990)
Formica (Neoformica) nitidventris	NY	Savignano (1990)
Formica (Neoformica) schaufussi	NY	Savignano (1990)
Formica lasioides	NY	Savignano (1990)
Formica montana	WI	Bleser (1992)
Formica schaufussi	WI	Bleser (1992)
Formica subsericea	NY	Savignano (1990)
Lasius alienus	NY	Savignano (1990)
Lasius neoniger	NY	Savignano (1990)
Monomorium emarginatum	NY	Savignano (1990)
Myrmica americana	NY	Savignano (1990)
Myrmica punctiventris	Ontario	Packer (1990)
Myrmica sculptilis	NY	Savignano (1990)
Paratrechina parvula	NY	Savignano (1990)
Tapinoma sessile	NY, WI	Bleser (1992), Savignano (1990)
Tetramorium caespitum	WI	Bleser (1992)

Pitch pine, *Pinus rigida*, is the dominant pine species in the pine barrens of the eastern part of the Karner blue's range, while jack pine, *Pinus banksiana*, is the most common pine at the western end (i.e., in the Lake States). Similarly, scrub oak, *Quercus ilicifolia*, and dwarf chestnut oak, *Quercus prinoides*, prevail in the east, while northern pin oak, *Quercus ellipsoidalis*, white oak, *Quercus alba*, and black oak, *Quercus velutina*, are the common oaks in the western range of the Karner blue (Bess 1989, Cryan 1980, Cryan and Dirig 1978, Lane 1992, Masters and Karpuleon 1975, Savignano 1990). These habitats are typically dry and sandy, and historically have been maintained by fire (Nuzzo 1986, Shuey in press). Because lupine generally expands after a disturbance opens the canopy and the soil, fire or other disturbances are believed to be important in maintaining lupine in the landscape. Similarly, lupine and Karner blue are often found in disturbed areas such as along gas and powerline rights-of-way, sand pits, highway margins, edges of trails and dirt roads, and abandoned farm fields.

Lupine

The exclusive larval food plant of the Karner blue is wild lupine, a sun-loving, long-lived perennial legume, with a deep taproot (Boyonoski 1992, Grigore 1992). Lupine fixes nitrogen by means of the obligate bacterial symbiont *Rhizobium lupini*. The range of lupine extends from Minnesota to

Maine, through southern Ontario, and south along the Atlantic seaboard to the Gulf coast (Figure 1). In the northern portion of its range, lupine typically begins to grow in late March or early April, flowers during May and June, sets seed by mid-July, and senesces during late July and August (Dirig 1973, Grigore 1992). Lupine grows well in full sunlight as well as partial shade, but does not survive for very long in complete shade (Bess 1989, Smallidge and Leopold, in prep.). Leach (1993) reports that lupine appears to do best in areas with a mosaic of both sun and shade. Lupine is becoming rare in many parts of its range, reflecting in large part the decades of effective fire suppression and subsequent canopy closure (Shuey in press). Although fire is important in maintaining habitats suitable for lupine growth, fire can cause high mortality to lupine seed and seedlings (Boyonoski 1992, Grigore 1992).

Other Lupine Feeders

In addition to the Karner blue, there are two other local (and rare) lupine-feeding Lepidoptera: the frosted elfin, *Incisalia irus* (Lycaenidae), and the Persius dusky wing, *Erynnis persius* (Hesperiidae) (Shapiro 1974, Shuey et al. 1987). Ideally, the management practices selected to favor lupine and Karner blue should also benefit these other two lepidopterans (Campbell et al. 1990, Packer 1990, Schweitzer in press-a). Moreover, barrens and savanna communities are home to many other rare plants, invertebrates, and vertebrates, and probably all would be helped by efforts to restore and maintain these habitats. For example, Michigan Karner blue sites harbor many state-listed rare plants such as western silvery aster (*Aster sericeus*), side-oat grama (*Bouteloua curtipendula*), yellow flax (*Linum sulcatum*), Allegheny plum (*Prunus alleghaniensis*), and prairie smoke (*Geum triflorum*); rare invertebrates such as the dusted skipper (*Atrytonopsis hianna*, Persius dusky wing, Ottoe's skipper (*Hesperia ottoe*), frosted elfin, and regal fritillary (*Speyeria idalia*); and rare vertebrates like the eastern box turtle (*Terrapene carolina carolina*).

Minimum Habitat Requirements

Overall, the Karner blue appears to have two undisputed requirements: lupine for larvae and nectar sources for adults. Two other factors that may prove equally important are ants for protection of larvae and some source of shade (Leach 1993, Packer 1990). If any of these factors is lacking, the Karner blue could decline or perish at a given site.

A discussion about the acreage required to support Karner blue can be focused at the level of remnant demes as well as at the metapopulation level; see Schweitzer (in press-a,b) for a detailed discussion. Openings that support Karner blue do not need to be extremely large. For example, openings of even a single acre in size support Karner blue in New York (Schweitzer 1989), Wisconsin (Bleser 1992), and elsewhere. Nevertheless, if these small openings are isolated, resident Karner blue populations could easily be vulnerable to extinction. Therefore, small openings should not be considered as a management goal in themselves unless they are relatively close and possibly interconnected by way of dispersal corridors. In general, the smaller the opening the greater will be the required intensity of management to maintain conditions suitable for the Karner blue.

To sustain a viable metapopulation, such as the Albany Pine Bush area in New York, Givnish et al. (1988) and Schweitzer (1989, in press-a) suggest a minimum area of 2000 acres. In addition, Schweitzer (in press-a) suggests that a viable population in a pine barrens community should have a minimum of 1000 first-generation (3000-4000 second generation) Karner blue adults per deme, with at least 5 demes being present. Figures for minimum acreage and minimum population size have not yet been established for Karner blue metapopulations in oak savannas, but they are probably similar (Schweitzer in press-a). However, even populations of 1000 individuals or more are potentially at risk, as shown by the extinction of the Ontario population in 1989, which appeared linked to the drought of 1988 and the cool, wet spring of 1989 (Schweitzer in press-b, USFWS 1992).

Causes of the Rangewide Decline

Several causes have been proposed for the rangewide decline in Karner blue numbers (Packer 1987, 1990, Schweitzer 1989, 1990, in press-a, Shuey in press, USFWS 1992). Some of the principal and often interrelated causes suggested for the decline are (1) habitat loss or fragmentation, resulting from tree planting projects or through agricultural, residential, and commercial development, and (2) loss of lupine, resulting from vegetational succession due to fire suppression. In addition, often at a more local level, Karner blue populations may decline due to (3) lupine grazing by deer and other wildlife, and (4) loss of those ant species that tend and protect Karner blue larvae. Many of the above reasons have been put forward for the decline of other lupine-feeding insects (Campbell et al. 1990, Packer 1990, Shuey et al. 1987), as well as for other insects when considered in a more general sense (Greatorex-Davies et al. 1992, Murphy et al. 1990, Panzer 1988, Pyle et al. 1981). Saunders et al. (1991) review the major changes that occur in the physical environment as a result of habitat fragmentation.

As an example of habitat loss through reforestation, consider the history of establishing red pine, *Pinus resinosa*, plantations on Michigan state forest land in Region II (i.e., the upper half of Michigan's lower peninsula). During the years 1910 to 1979, an estimated 214,000 acres of state forest land were planted to red pine in Region II, with 59% of this acreage being planted between the years 1925-1940 (Haack and Mattson 1993). Much additional acreage was planted on federal lands and private lands in this area. Moreover, during these same years, thousands of additional acres were planted to jack pine and white pine, *Pinus strobus*. Practically all plantations were established on abandoned farmland and in fields and forest openings (Shuey in press). This was an especially common practice during the years of the Civilian Conservation Corps: 1933-1942 (Merrill 1981).

Several of Michigan's Karner blue sites are close to hundreds of acres of pine plantations on state and federal lands. It may be possible to log and burn selected areas in these pine plantations to create a network of sites and corridors that will subsequently be colonized by lupine, Karner blue, and other associated organisms. Restoring pine plantations to prairie or savanna with the selective use of logging and fire could serve to mimic the effects of a hot crown fire (D. Schweitzer pers. comm.).

Management Practices to Avoid

Even in areas with suitable habitat, Karner blue populations can be threatened by (1) applying herbicides that destroy lupine or nectar sources, (2) mowing during April through August, or (3) spraying insecticides that are harmful to Karner blue larvae, ants, or pollinators of the various nectar plants. In known Karner blue sites, managers should restrict the use of herbicides and insecticides along trails and roadsides.

Management Practices to Encourage

Besides the minimum acreage issues discussed above, other practices to consider in managing Karner blue preserves include: (1) establishing dispersal corridors for adults, (2) creating openings (of various configurations with islands of trees remaining to provide some shade) to promote lupine and nectaring sources, (3) converting pine plantations to prairie, (4) propagating and planting lupine and nectaring sources as needed, (5) introducing or reintroducing Karner blues and/or ants as needed, (6) using fire and/or mowing to maintain or promote lupine growth (see below), and (7)

monitoring regularly populations of Karner blue, lupine, ants, and other associated sensitive species to assess the effectiveness of management treatments. In addition, private land owners should be informed about the Karner blue's presence on their properties, and they should be educated about practices that will favor the insect. Schweitzer (in press-b) provides guidelines on how to prioritize sites for protection activities. He advocates focusing on sites with more than 1000 second-generation adults per deme; where demes are or can be connected by way of foot-paths, dirt roads, or utility lines; and where a barrens/savanna community can be restored and maintained.

Fire and Mowing

Given the Karner blue's endangered status, managers will need to consult frequently with state and federal biologists and obtain necessary permits before conducting prescribed burns because such actions could result in a "take" of the species. When considering fire as a management tool, note that all life stages of the Karner blue are vulnerable to mortality from fire. Even though fast moving, patchy fires should spare some individuals, Bleser (1992) reported that Karner blue egg and larval mortality were high in spring- or fall-burned sites. It is important, states Panzer (1988), to use fire cautiously when dealing with isolated pockets of rare invertebrates.

Fire can be used both to maintain sites in early successional stages that support lupine or to restore other sites back to such a successional stage (e.g., logging followed by burning). Preserves should be divided into several fire-management units, and only one or a few burned during any single year (Lawrence and Cook 1989). Schweitzer (in press-a) advocates using fire only in sites that can be divided into three or more burn units. If possible, only a portion of each opening should be burned, with emphasis placed on areas near to active Karner blue patches but not the occupied habitat itself. Such practices will reduce Karner blue mortality within any particular site as well as reduce the flight distance required for recolonization. In Wisconsin, first-generation Karner blue adults were seen on some sites that had been burned in spring of the same year, while most burned sites were recolonized to some level during the second-generation flight (Bleser 1992). Nevertheless, several years may be needed before some burned sites are recolonized.

Prescribed burns are usually done in early spring (before mid-April) or fall (after September) when most Karner blue individuals are eggs. However, Bleser (1992) suggests that burning in August may be useful because it (1) can occur during or soon after an assessment is made of Karner blue population size and location, and (2) could allow some adults to escape the fire and oviposit elsewhere. Although true, good burning conditions are rare in August because sites are typically too moist and green. Prescribed burns would also be useful in areas that are near Karner blue sites but that do not currently support these insects. Overall, prescribed burns should be conducted in concert with Karner blue population monitoring. In isolated areas with relatively small (<100) Karner blue populations, burning should not be practiced (Schweitzer 1990, in press-a). Moreover, all proposed management plans should be reviewed by the United States Fish and Wildlife Service pursuant to Section 7 of the Endangered Species Act.

Mowing should be considered in areas that are too small for burning, where burning is difficult to accomplish, or where Karner blue populations are small and isolated. Mowing has been effective in maintaining prairie habitats (Hover and Bragg 1981, Opler 1981), and in fact, the site of the world's largest Karner blue population (at the Saratoga County Airport, New York) has been maintained entirely through mowing for the past 15 years. Schweitzer (1990, in press-a) recommends mowing from August 15 through April 15, with a minimum blade height of 4 inches and allowing the clipped vegetation to fall in place because it may contain Karner blue eggs. Waiting until late September to mow may be better, especially in cool years when development is slowed and thus oviposition is delayed.

Data Gaps

Although much is known about the Karner blue, there are still many gaps in our understanding of this insect (see Bleser 1992, Givnish et al. 1988, Packer 1990, Schweitzer 1990, in press-a,b). For example, further research is needed on:

Interaction studies

1. Karner blue performance (e.g., larval growth rate, adult fecundity) on older versus younger plants, on new versus older foliage, on fertilized versus unfertilized plants, on shaded versus open-grown plants, on plants with and without *Rhizobium lupini*, etc.);
2. Karner blue-ant interactions, the extent to which larvae need ants, which ant species best protect larvae, whether adult females oviposit preferentially in habitats occupied by certain ant species, the impact of burning on ants, and how best to promote and manage ant populations;
3. The impact of natural enemies and disease organisms on Karner blue dynamics;
4. The positive and negative aspects of gypsy moth defoliation on Karner blue and lupine dynamics;
5. The amount of canopy cover where Karner blue, lupine, and nectaring plants drop out of oak savanna, pine barrens, and other communities;
6. Identification of those habitat attributes that best predict Karner blue occupancy and reproductive success;
7. The relations between lupine, Karner blue, and various ant species with soil, weather, and landform gradients;
8. A landscape-level analysis of Karner blue and lupine sites, using GIS and various ecological classification systems;

Karner blue issues

9. Development of Karner blue life tables for different habitat types;
10. Dispersal and recolonization capabilities of Karner blue adults and barriers to their dispersal (see Givnish et al. 1988);
11. Methods to propagate, transport, and introduce Karner blue life stages into the field;
12. Whether any cluster of Karner blue populations is still behaving as a metapopulation;
13. The optimal size, spatial configuration, and juxtaposition of Karner blue sites to best promote a functioning metapopulation;
14. Fine-tuning of techniques to estimate Karner blue population size, including follow-up monitoring after initial surveys are conducted;
15. What constitutes the minimum viable population size (including population viability analysis; Boyce 1985), minimum habitat area, and critical habitat;
16. The susceptibility of Karner blue to *Bt* insecticidal sprays;
17. Historical studies that document long-term Karner blue population fluctuations in relation to weather and management practices.

Lupine issues

18. The life cycle and requirements of lupine and its associated *Rhizobium*, how long lupine lives and how seeds are dispersed, when to burn/mow to best promote lupine, how to best propagate and seed lupine, and what other herbivores feed on lupine;

Other biological and managerial issues

19. The genetic structure of Karner blue, lupine, and *Rhizobium lupini* populations; and
20. Setting specific guidelines as to which sites to burn, mow, or conduct other management practices, when to do these activities, and how often to repeat them to enhance survival and recovery of Karner blue and other associated sensitive species;

ACKNOWLEDGMENTS

The author thanks Michael Amaral, Cathy Bleser, Rex Ennis, Bill Gabbert, Michelle Grigore, Joe Kelly, Susan Lauzon, Mark Leach, Deborah McCullough, Paul Opler, Laurence Packer, Cathy Papp, Mary Rabe, Don Riemenschneider, Dolores Savignano, Nancy Sferra, Dale Schweitzer, and Leni Wilsmann for their critical reviews of an earlier draft of this manuscript; and Cathy Bleser, George Heaton, Judith Maxwell, and Brent Sieling for compiling much of the lupine range data.

LITERATURE CITED

Atstatt, P.R. 1981a. Lycaenid butterflies and ants: selection for enemy-free space. Amer. Nat. 118:638-654.

Atstatt, P.R. 1981b. Ant-dependent food plant selection by the mistletoe butterfly *Ogyris amaryllis* (Lycaenidae). Oecologia 48:60-63.

Ballard, H., and N. Sferra. 1991. Distribution and management of an indicator species of oak savannas, the Karner blue butterfly (*Lycaeides melissa samuelis*): Post-treatment population studies. Unpublished report, The Nature Conservancy, East Lansing, MI. 9p. + tables.

Bess, J.A. 1989. Status of the Karner blue butterfly, *Lycaeides melissa samuelis* Nabokov, in the Manistee National Forest. Unpublished report, Michigan Natural Features Inventory, Lansing, MI. 20p.

Bidwell, A.D. 1991. A habitat-based preserve plan for the Karner blue butterfly (*Lycaeides melissa samuelis*) in Concord, New Hampshire. Unpublished report, The Nature Conservancy, New Hampshire Field Office. 37p.

Bleser, C.A. 1990. The Wisconsin 1990 status survey for the Karner blue butterfly (*Lycaeides melissa samuelis*). Unpublished report, Wisconsin Department of Natural Resources, Bureau of Endangered Resources, Madison, WI. 27p.

Bleser, C.A. 1992. Status survey, management and monitoring activities for the Karner blue butterfly (*Lycaeides melissa samuelis*) in Wisconsin, 1990-1992. Unpublished report, Wisconsin Department of Natural Resources, Bureau of Endangered Resources, Madison, WI. 88p. + appendices.

Boyce, M.S. 1992. Population viability analysis. Annu. Rev. Ecol. Syst. 23:481-506.

Boyonoski, A.M. 1992. Factors affecting the establishment and maintenance of *Lupinus perennis* (wild lupine). M.S. thesis, University of Guelph. Guelph, Ontario.

Campbell, C.A., D.P. Coulson, and A.A. Bryant. 1990. Status, distribution and life history characteristics of some butterflies at risk in th Carolinian forest zone of Ontario. In G.M. Allen, P.F.J. Eagles, and S.D. Price (eds.), Conserving Carolinian Canada, p. 207-252. Waterloo, Ontario: Univ. Waterloo Press.

Cryan, J.F. 1980. The Karner blue butterfly (*Lycaeides melissa samuelis* Nabokov) in Hudson Valley sand belt of New York State. Part II. An annotated list of Hudson Valley sand belt populations and their status. Unpublished report, New York State Department of Environmental Conservation, Endangered Species Unit. 31p.

Cryan, J.F., and R. Dirig. 1978. A report on the status of the Karner blue butterfly (*Lycaeides melissa samuelis* Nabokov) in New York State. Unpublished report, New York State Department of Environmental Conservation. 18p.

Cuthrell, D.L. 1990. Status of the Karner blue butterfly, *Lycaeides melissa samuelis* Nabokov, in Minnesota, 1990. Unpublished report, Minnesota Department of Natural Resources, Nongame Wildlife Program. 44p.

DeVries, P.J. 1988. The larval ant-organ of *Thisbe irenea* (Lepidoptera: Riodinidae) and their effects upon attending ants. Zool. J. Linnean Soc. 94:379-393.

DeVries, P.J. 1989. Detecting and recording the calls produced by butterfly caterpillars and ants. J. Res. Lepid. 28:258-262.

DeVries, P.J. 1992. Singing caterpillars, ants and symbiosis. Sci. Amer. 267(October):76-82.

Dirig, R. 1973. The endangered Karner blue. The Conservationist 28:6,47.

Dirig, R. 1988. Nabokov's blue snowflakes. Nat. Hist. 97:68-69.

Dirig, R., and J.F. Cryan. 1976. The Karner Blue Project: January 1973 to December 1976. Atala 4:22-26.

Downey, J.C. 1966. Distribution of Lycaenidae (Lepidoptera) in Illinois. Illinois Acad. Sci. Trans. 59:163-168.

Ewert, D.N., and H.E. Ballard, Jr. 1990. Distribution and management of an indicator species of oak savannas, the Karner blue butterfly (*Lycaeides melissa samuelis*): Preburn population studies. Unpublished report, The Nature Conservancy, East Lansing, MI. 10p.

Givnish, T.J., E.S. Menges, and D.F. Schweitzer. 1988. Minimum area requirements for long-term conservation of the Albany Pine Bush and Karner blue butterfly: an assessment. Unpublished report to the City of Albany from Malcolm Pirnie, Inc. Albany, NY. 95p. + figures.

Greatorex-Davies, J.N., M.L. Hall, and R.H. Marrs. 1992. The conservation of thepearl-bordered fritillary butterfly (*Boloria euphosyne* L.): preliminary studies on the creation and management of glades in conifer plantations.

Grigore, M. 1992. The short-term effect of fire on wild lupine (*Lupinus perennis* L.). M.S. thesis, University of Toledo. Toledo, Ohio. 73p.

Haack, R.A. 1992. Endangered and threatened insects in the United States and Michigan. Newsletter Mich. Entomol. Soc. 37(2&3):1-8.

Haack, R.A. and W.J. Mattson. 1993. Life history patterns of North American tree-feeding sawflies. In M.R. Wagner and K.F. Raffa (eds.), Sawfly Life History Adaptations to Woody Plants, p. 503-545. Orlando, FL: Academic Press.

Helmboldt, K.M. and M. Amaral. 1992. Status of the Karner blue butterfly in New Hampshire. Unpublished report, The Nature Conservancy, New Hampshire Field Office, Concord, NH and U.S. Fish and Wildlife Service, New England Field Office, Concord, NH. 7p.

Hover, E.I., and T.B. Bragg. 1981. Effect of season of burning and mowing on aneastern Nebraska *Stipa-Andropogon* prairie. Amer. Midl. Nat. 105(1):13-18.

Jordano, D., J. Rodriquez, C.D. Thomas, and J. Fernandez Haeger. 1992. The distribution and density of a lycaenid butterfly in relation to *Lasius* ants. Oecologia 91:439-446.

Konecny, A. 1986. A Status Report on the Karner Blue Butterfly (Lycaeides melissa samuelis Nabokov) in Canada. Unpublished report to the Ontario Ministry of Natural Resources. 48p.

Krombein, K.V., P.D. Hurd, D.R. Smith, and B.D. Burks (Eds.). 1979. Catalog of Hymenoptera in America North of Mexico, Vol. 1, p. 246, 541, 619-620. Smithsonian Institution Press, Washington, D.C.

Lane, C.P. 1992. The status of the Karner blue butterfly (*Lycaeides melissa samuelis*: Lycaenidae) and associated plant resources in Minnesota, 1991. Unpublished report, Minnesota Department of Natural Resources, Nongame Wildlife Program. 36p.

Lawrence, W.S., and A.C. Cook. 1989. The status and management of Karner blue (Lycaeides melissa samuelis) populations in the Allegany State Game Area, Michigan. Unpublished report, Nature Conservancy, Michigan Field Office, East Lansing, MI. 65p.

Leach, M. 1993. Status and distribution of the Karner blue butterfly at Fort McCoy, Wisconsin: Final report on a two-year study. Unpublished report prepared for the Natural Resources Management Division, Fort McCoy Military Reservation, U.S. Army. The Nature Conservancy, Wisconsin Chapter. 50p. + 27p appendix.

Magdich, M.L. 1989. A survey of Karner blue (*Lycaeides melissa samuelis* (Nabokov) populations in the oak openings of northwestern Ohio. Unpublished report, Ohio Department of Natural Resources, Columbus, OH. 47p.

Maschwitz, U., M. Wust, and K. Schurian. 1975. Blues' larvae as sugar suppliers for ants. Oecologia 18:17-21. (in German)

Martin, M.L. 1992. Karner blue butterfly (*Lycaeides melissa samuelis*) in Indiana: 1990 status report. Unpublished report, Indiana Department of Natural Resources, Indianapolis, IN. 13p.

Masters, J.H., and F.H. Karpuleon. 1975. Records of *Lycaeides melissa samuelis* (Lycaenidae) from Wisconsin. J. Lepid. Soc. 29:31.

Merrill, P.H. 1981. Roosevelt's Forest Army: A History of the Civilian Conservation Corps, 1933-1942. Montpelier, VT: published by the author.

Murphy, D.D., K.E. Freas, and S.B. Weiss. 1990. An environment-metapopulation approach to population viability analysis for a threatened invertebrate. Conservation Biol. 4:41-51.

Nabokov, V. 1943. The Nearctic forms of *Lycaeides* Hub. (Lycaenidae, Lepidoptera). Psyche 50:87-99.

Nuzzo, V.A. 1986. Extent and status of midwest oak savanna: presettlement and 1985. Natural Areas J. 6(2):6-36

Opler, P.A. 1981. Management of prairie habitats for insect conservation. J. Natural Areas Assoc. 1(4):3-6

Opler, P.A. 1985. Extirpated Karner blue butterfly. In H.H. Genoways and F.J. Brenner (eds.), Species of Special Concern in Pennsylvania, Special Publ. 11, p. 162-163. Pittsburgh, PA: Carnegie Museum of Natural History.

Opler, P.A. and G.O. Krizek. 1984. Butterflies East of the Great Plains, p. 120-121. Baltimore, MD: John Hopkins Univ. Press.

Packer, L. 1987. Status report on the Karner blue butterfly, *Lycaeides melissa samuelis* Nabokov, in Canada. Unpublished report for the World Wildlife Fund and the Ontario Ministry of Natural Resources, Wildlife Branch, Nongame Program. 66p.

Packer, L. 1990. The status of two butterflies, Karner blue (*Lycaeides melissa samuelis*) and frosted elfin (*Incisalia irus*), restricted to oak savanna in Ontario. In G.M. Allen, P.F.J. Eagles, and S.D. Price (eds.), Conserving Carolinian Canada, p. 253-271. Waterloo, Ontario: Univ. Waterloo Press.

Panzer, R. 1988. Managing prairie remnants for insect conservation. Natural Areas J. 8:83-90.

Peterson, M.A. 1993. The nature of ant attendance and the survival of larval *Icaricia acmon* (Lycaenidae). J. Lepid. Soc. 47:8-16.

Pierce, N.E. and S. Easteal. 1986. The selective advantage of attendant ants for the larvae of a lycaenid butterfly, *Glaucopsyche lygdamus*. J. Anim. Ecol. 55:451-462.

Pierce, N.E. and M.A. Elgar. 1985. The influence of ants on host plant selection by *Jalmenus evagoras*, a myrmecophilous lycaenid butterfly. Behav. Ecol. Sociobiol. 16:209-222.

Pyle, R., M. Bentzien, and P. Opler. 1981. Insect conservation. Annu. Rev. Entomol. 26:233-258.

Rohlf, D.J. 1989. The Endangered Species Act. Stanford Law School, Stanford, CA.

Saunders, D.A., R.J. Hobbs, and C.R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biol. 5(1):18-32.

Saunders, W. 1878. Notes on the larva of *Lycaena scudderi*. Can. Entomol. 10:14-15.

Savignano, D.A. 1990. Field investigations of a facultative mutualism between *Lycaeides melissa samuelis* Nabokov (Lycaenidae), the Karner blue butterfly, and attendant ants. Ph.D. Dissertation. Univ. Texas, Austin. 120p.

Schweitzer, D.F. 1989. Fact sheet for the Karner blue butterfly with special reference to New York. Unpublished report, The Nature Conservancy. 7p.

Schweitzer, D.F. 1990. The 1990 status of selected Karner blue remnants in Saratoga and Albany counties, New York with a discussion of monitoring methods. Unpublished report, New York Department of Environmental Conservation, Endangered Species Unit. 23p.

Schweitzer, D.F. 1993a. Recovery goals and methods for Karner blue populations. In D.A. Andow, R.J. Baker, and C.P. Lane (eds). Karner Blue Butterfly: a symbol of a vanishing landscape, 22-24 April 1992, Zanesville, OH. University of Minnesota Agricultural Experiment Station, St. Paul, MN. (In press)

Schweitzer, D.F. 1993b. Prioritizing Karner blue (*Lycaeides melissa samuelis* Nabokov) habitats for protection activities. In D.A. Andow, R.J. Baker, and C.P. Lane (eds). Karner Blue Butterfly: a symbol of a vanishing landscape, 22-24 April 1992, Zanesville, OH. University of Minnesota Agricultural Experiment Station, St. Paul, MN. (In press)

Scudder, S.H. 1888. Feeding habits of a lycaenid caterpillar. Psyche 5:13.

Scudder, S.H. 1889. The Butterflies of Eastern United States and Canada with special reference to New England. Cambridge, MA. pp. 964-969.

Sferra, N.J. and T. Darnell. 1992. Distribution and management of the Karner blue butterfly (*Lycaeides melissa samuelis*) in Newaygo and Muskegon Counties, Michigan. Unpublished report, The Nature Conservancy, Michigan Field Office, East Lansing, MI. 17p.

Shapiro, A.M. 1974. Partitioning of resources among lupine-feeding Lepidoptera. Am. Mid. Nat. 91:243-248.

Shuey, J.A. In press. Dancing with fire: Ecosystem dynamics, management, and the Karner blue (*Lycaeides melissa samuelis* Nabokov). In Proceedings of the midwest oak savanna conference, 20 February 1993, Chicago, IL. U.S. Environmental Protection Agency, Chicago.

Shuey, J.A., J.V. Calhoun, and D.C. Iftner. 1987. Butterflies that are endangered, threatened, and of special concern in Ohio. Ohio J. Sci. 87(4):98-106.

Shull, E.M. 1987. The Butterflies of Indiana, p. 163-164. Bloomington & Indianapolis, IN: Indiana Press.

Smallidge, P.J. and D.J. Leopold. Environmental factors and critical for *Lycaeides melissa samuelis* along transmission line rights-of-way in east-central New York, USA. In preparation.

Smiley, J.T., P.R. Atstatt, and N.E. Pierce. 1988. Local distribution of the lycaenid butterfly, *Jalmenus evagoras*, in response to host ants and plants. Oecologia 76:416-422.

Stone, A., C.W. Sabrosky, W.W. Wirth, R.H. Foote, and J.R. Coulson (Eds.). 1983. A Catalog of the Diptera of America North of Mexico, p. 1098. Washington, D.C.: Smithsonian Institution Press.

USFWS (United States Fish and Wildlife Service). 1992. Endangered and threatened wildlife and plants; determination of endangered status for the Karner blue butterfly. Federal Register (December 14, 1992). 57(240):59236-59244.

Wilcove, D.S., M. McMillan, and K.C. Winston. 1993. What exactly is an endangered species? An analysis of the U.S. endangered species list: 1985-1991. Conservation Biol. 7(1):87-93.

Wilsmann, L. 1992. Karner blue. *Lycaeides melissa samuelis* Nabokov. Unpublished draft report, Michigan Department of Natural Resources, Wildlife Division. 7p.