PART I. INTRODUCTION

The Hine's emerald dragonfly, *Somatochlora hineana* Williamson, also known as Ohio emerald, Hine's bog skimmer, and hook-tipped emerald, is among the most endangered dragonflies in the United States (Bick 1983, Cashatt 1991). Hine's emerald dragonfly is currently known to occur in Illinois, Wisconsin, Michigan and Missouri. Historically, this species was known to occur in three areas of Ohio, and one site in Indiana. One specimen was collected in Alabama. Since 1961, Hine's emerald dragonfly has not been collected from Ohio or Indiana, and it is believed to be extirpated from these States.

Based on its limited distribution and need for protection, the Hine's emerald was proposed for Federal listing as endangered on October 4, 1993 (USFWS 1993a) and was listed as endangered under provisions of the Endangered Species Act of 1973 (ESA), as amended, on January 26, 1995 (USFWS 1995). Departments of Natural Resources in Illinois, Wisconsin, and Ohio list this species as state endangered (Herkert 1992, ODNR 1997, WDNR 1997). This species is proposed for listing as state endangered in Michigan. The International Union for the Conservation of Nature (IUCN) also lists Hine's emerald dragonfly as endangered (Moore 1997), and The Nature Conservancy lists this species as globally imperiled (USFWS 1995).

The Hine's emerald dragonfly is apparently restricted to wetland habitats characterized by thin soils over dolomite bedrock with marshes, seeps, and sedge meadows. Fragmentation and destruction of suitable habitat are believed to be the main reasons for this species' endangered status and continue to be the primary threats to its recovery. The known breeding sites in Illinois occur along the Des Plaines River floodplain, which has been fragmented by industrial and urban development (Cashatt 1991). In Wisconsin, land development for agriculture, light industry, and tourism are principal threats (Vogt and Cashatt 1990). Off-road vehicle use and possibly logging, creation of water impoundments, real estate development, road development and maintenance, pipeline construction, and changes in hydrology, are potential threats in Michigan (Steffens 1997). In addition, the species is vulnerable to loss of habitat caused by off-site hydrology alterations and groundwatershed development affecting the groundwater-fed seeps and springs.

TAXONOMY AND DESCRIPTION

Order Characteristics: Order Odonata (dragonflies and damselflies) is cosmopolitan and includes at least 5,309 species (Bridges 1994). Dragonflies and damselflies are characterized by two pairs of large membranous wings; large compound eyes; short, bristle-like antennae; chewing mouth parts; slender, elongate abdomens; and male secondary reproductive organs. Larvae (nymphs, naiads) are predominantly aquatic and characterized by tracheal gills and a large hinged labium (lower lip). *Somatochlora hineana* is in the Family Corduliidae ("emeralds") which includes 384 species. Of 39 described species of *Somatochlora*, 26 occur in North America (Bridges 1994).

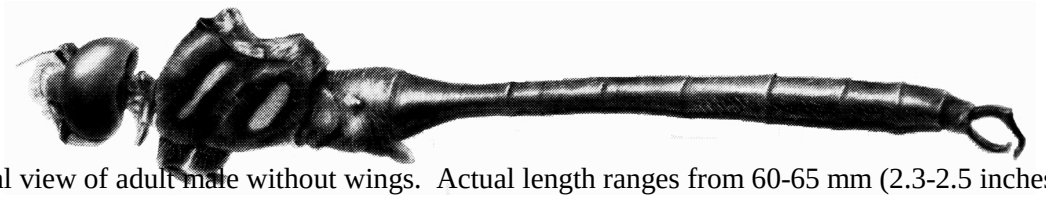
Adult Characteristics: Hine's emerald, like many other members of its family, has brilliant green eyes. It is distinguished from all other species of *Somatochlora* by its dark metallic green

thorax with two distinct creamy-yellow lateral lines, and distinctively-shaped male terminal appendages and female ovipositor (Figure 1) (Williamson 1931). Adults have a body length of 60-65 millimeters (mm) (2.3-2.5 inches) and a wingspan of 90-95 mm (3.5-3.7 inches). The wings are clear and may have an amber hue towards the base of the hind wings. Other species of *Somatochlora* that occur in the same range and may be confused with Hine's emerald dragonfly, *S. hineana*, include *S. linearis*, *S. tenebrosa*, *S. ensigera*, *S. elongata*, and *S. williamsoni* (Walker and Corbet 1975, Needham and Westfall 1954). However, distinctive shapes of terminal appendages and ovipositors separate adults of this species from all others (Figures 1B and 1C).

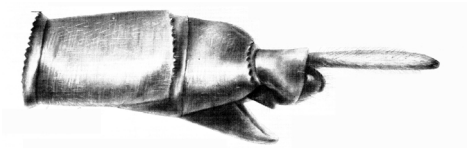
Two characteristics change with the age of the Hine's emerald dragonfly. After emerging as an adult, the eyes are initially brown and turn emerald green within 1 to 3 days. Toward the end of the adult life span, the wings may turn from clear to a slightly opaque, smokey color.

Larval Characteristics: No one character has been found that will easily and reliably differentiate larvae of Hine's emerald dragonfly (Figure 2) from the species listed above. Among the species with middorsal hooks, *S. elongata*, *S. linearis*, *S. minor*, and *S. tenebrosa* are often the most difficult to distinguish from *S. hineana*. Most *S. hineana* specimens may be distinguished from most other *Somatochlora* by the presence of a small middorsal hook on segment three. However, *S. minor* also has a middorsal hook on segment three, while *S. elongata*, *S. linearis*, and *S. tenebrosa* occasionally have a small or vestigial middorsal hook on this tergite. Other characters include head width, metatibial length, palpal crenulation setae, and total length. A detailed discussion is presented in Cashatt and Vogt (2001). Soluk *et al*. (1998) described the distinguishing features of *S. hineana* larvae from other larval dragonfly species in Door County, Wisconsin, as "the size of the dorsal hooks on the abdomen, general hairiness, shape of head, and lack of stripes on the legs." The earliest instars of *S. hineana* larvae have fewer dorsal hooks than later instars.

Figure 1. Adult Hine's emerald dragonfly (*Somatochlora hineana*). Images from Williamson (1931), courtesy of the University of Michigan Museum of Zoology.



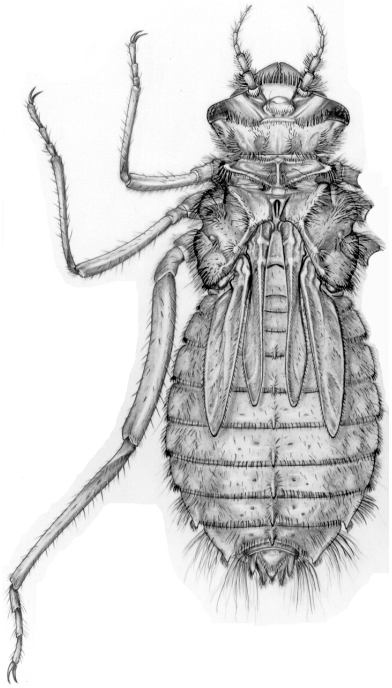
A. Lateral view of adult male without wings. Actual length ranges from 60-65 mm (2.3-2.5 inches).



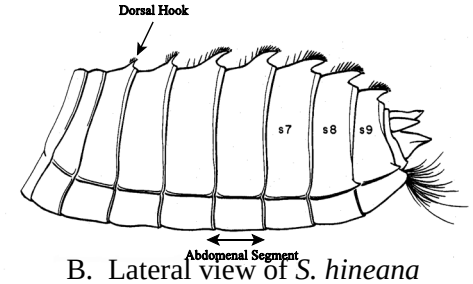
B. Lateral view of female abdominal tip.

C. Lateral view of male abdominal tip.

Figure 2. Larval Hine's emerald dragonfly. Illustrations by Julie Snider, courtesy of the Illinois State Museum.



A. Dorsal view of larval *S. hineana*. Actual size of final instar larva ranges from 23.5-25.0 mm (0.92-0.98 inches).



B. Lateral view of *S. hineana* larval abdomen.

PRESENT AND HISTORICAL DISTRIBUTION

Currently, populations of Hine's emerald dragonfly occur in Wisconsin, Illinois, Michigan, and Missouri (Figure 3). Appendix 2 provides a list of the sites surveyed for Hine's emerald dragonfly, the years visited, years when Hine's emerald dragonfly was observed, life stage, behavior, and sampling effort expended at each site.

Distribution by State and County:
Illinois: Nine sites in Will, Cook, and Du Page Counties
Wisconsin: Twenty sites in Door, Kewaunee and Ozaukee Counties
Michigan: Ten sites in Mackinac, Presque Isle, and Alpena Counties.
Missouri: Three sites in Reynolds and Iron Counties.
Ohio: Believed extirpated. Historically collected from Lucas, Logan, and Williams Counties.
Indiana: Believed extirpated. One specimen historically collected from Lake County in 1945.
Alabama: Believed extirpated. One specimen historically collected from Jackson County in 1978.

Present Distribution:
Illinois: Hine's emerald dragonfly inhabits nine sites in Will, Cook, and DuPage Counties, Illinois (Figure 3). Breeding behavior has been observed at five sites in Will County: Keepataw Forest Preserve, Lockport Prairie Nature Preserve, Long Run Seep Nature Preserve, Middle Parcel and River South Parcel in Yard 61 at Material Service Corporation, and at two sites in Cook County: Black Partridge Woods Nature Preserve and McMahon Woods. Two sites where Hine's emerald dragonfly adults have been observed foraging or in transient flight are Romeoville Prairie Nature Preserve in Will County and Waterfall Glen Forest Preserve in Du Page County. Figure 4 illustrates the relative location of the Illinois sites. All nine sites are within 20 kilometers (km) (about 12 miles) of each other, within 4 km (2.5 miles) of the Des Plaines River, and occur in the Des Plaines River watershed.

Wisconsin: Hine's emerald dragonfly inhabits 20 sites in Door, Kewaunee and Ozaukee Counties, Wisconsin (Figure 3). The dragonfly breeds at nine sites in Door County: Arbter Lake, Big Marsh (Washington Isalnd), Ephraim Swamp, Mud Lake "North" at Lime Kiln Road, Mud Lake "South," North Bay, The Ridges Sanctuary, Three Springs Creek, and the Upper Mink River. The dragonfly also breeds at one site in Ozaukee County: Cedarburg Bog (Vogt and Cashatt 1990, Kirk and Vogt 1995, Soluk *et al*. 1998a, Kathy Kirk, pers. comm. 2001, Dan Soluk, Illinois Natural History Survey, pers. comm. 2001, Gretchen Meyer, Cedarburg Bog Field Station, pers. comm. 2001). Breeding is also likely at the Kellner Fen in Door County (Mike Grimm, The Nature Conservancy, pers. comm. 2001) and the Black Ash Swamp in Kewaunee County (Kathy Kirk, pers. comm. 2001). Hine's emerald dragonfly adults have been recorded from eight additional Door County locations where they have been seen foraging, perching or in transient flight: Bailey's Harbor Township marsh, Bailey's Harbor Swamp, Mud Lake "North"at Pioneer Road, Mud Lake "North" near Grove Road, Piel Creek, Toft Point and near Spring Road (Soluk et al. 1998, Mike Grimm, pers. comm. 2001, Janice Stiefel, pers. comm. 2001). Roadkill specimens of the dragonfly have also been collected along County Q Road, State Highways 42 and 57 in Door County and County Road X in Kewaunee County (Soluk *et al*. 1998a, Paul Burton, pers. comm. 2000, Kathy Kirk, pers. comm. 2001).

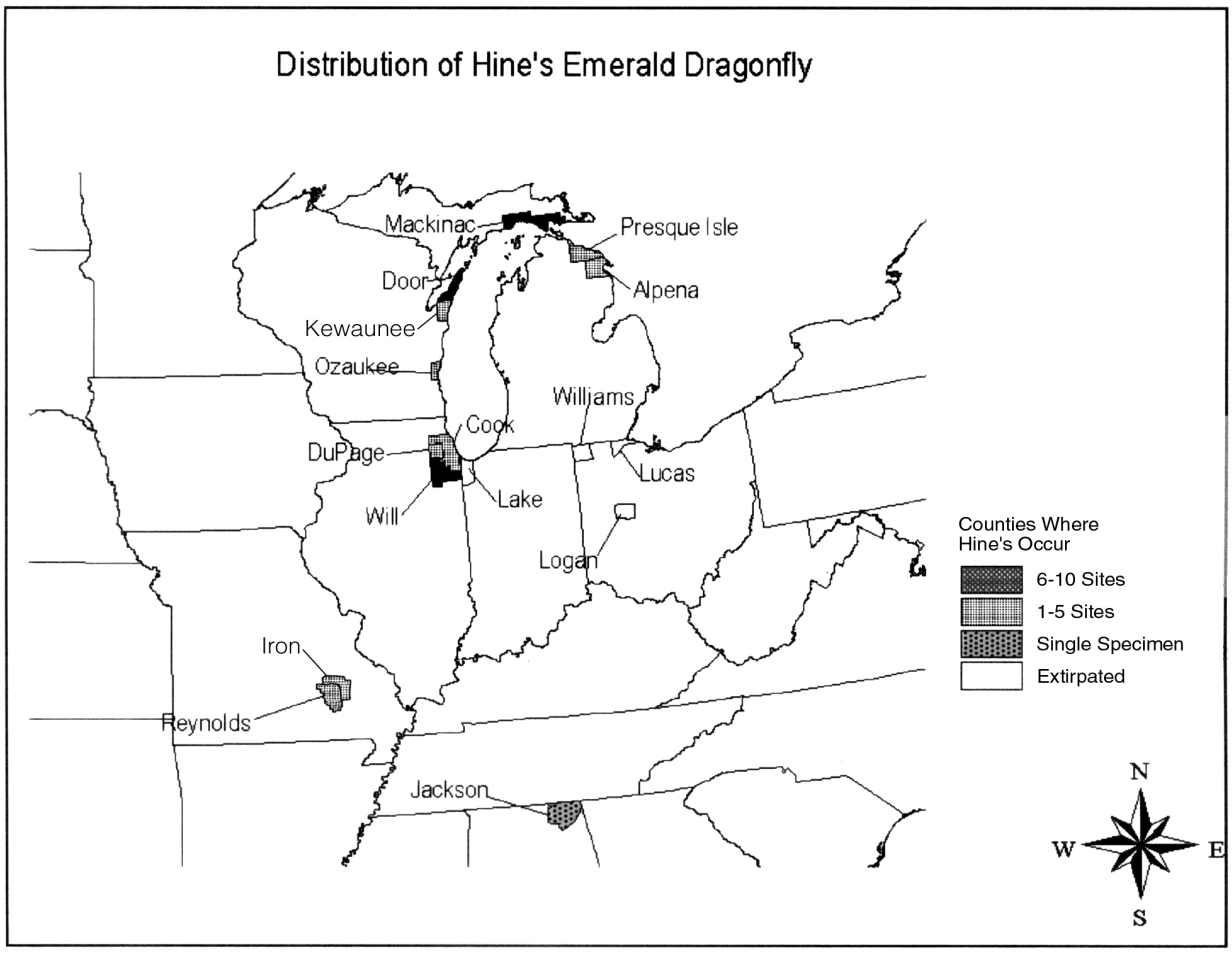


Figure 3. Present number of Hine's emerald dragonfly sites per county in the Great Lakes Region. All historic occurrences and single specimens collected are included in this map.

The Door County sites from Big Marsh (Washington Island) to Kellner Fen (near Sturgeon Bay) occur within a 69 km (43 mile) stretch in Door County. The furthest distance between two sites is approximately 20 km (12.5 miles), and the majority of the sites are within a 10 km (6.2 mile) radius. All of these areas are less than 6 km (4 miles) from the Lake Michigan shoreline. The Black Ash Swamp in Kewaunee County lies 18 km (11 miles) south of Kellner Fen, and the site furthest south in Wisconsin, Cedarburg Bog, is located 142 km (88 miles) south of Kellner Fen.

Michigan: Hine's emerald dragonfly inhabits a total of 10 sites in Michigan in Mackinac, Presque Isle, and Alpena counties (Figure 3). Seven of these sites occur in the Upper Peninsula in the Hiawatha National Forest, Mackinac County. These sites are Acklund Road, Brevort Lake Road, Horseshoe Bay, I-75 East, I-75 West, Martineau Creek SW, and Summerby Swamp (Steffens 1997, 1998). A roadkilled specimen was collected along Inglesbe Road north of Mackinac Trail and could represent either a new location or a wandering specimen (Steffens 1997). All areas within the National Forest are located within 12 km (7.4 mile) radius. During 1999 surveys, three new Hine's emerald sites were discovered: Snake Island Fens on Bois Blanc Island in Mackinac County, Loop 2 Fen at Thompson's Harbor State Park in Presque Isle County, and Misery Bay in Alpena County (Steffens 1999). These sites are approximately 37, 111, and 151 km (23, 69, and 94 miles), respectively, from the closest site in the Upper Peninsula (Steffens 1999).

Missouri: Hine’s emerald dragonfly inhabits three sites in Missouri, the Grasshopper Hollow Natural Area and Ruble Meadow in Reynolds County and Barton Fen in Iron County (L. Trial, Missouri Department of Conservation, pers. comm. September 2001).

Collection History and Historical Distribution:
Hine’s emerald dragonfly was first described in 1931 from specimens collected near Indian Lake in Logan County, Ohio, in 1929 and 1930 (Williamson 1931). Hine’s emerald dragonfly has also been collected in Ohio from Lucas County within the Maumee River watershed, and Williams County within the St. Joseph River watershed (Figure 3) (Price 1958, Glotzhober 1995). Numerous individuals were collected from the site in Lucas County between 1952 and 1961. Only a small number of individuals were collected at the other sites. Hine’s emerald dragonfly may have been extirpated from Ohio. The habitats at the Ohio sites have since been severely altered and Hine’s emerald dragonfly has not been found again at these sites (Glotzhober 1995, Moody 1995). Suitable habitat may still be found in northwest Ohio, northeastern Indiana, or southern Michigan (Moody 1994).

Only one Hine’s emerald dragonfly specimen has been recorded from Indiana, collected by William Kowlek from Gary, Lake County, in 1945 (Figure 3) (Montgomery 1953). Currently, this area is highly polluted from industry and steel mills, and if a viable population existed at this site, it is highly probable that it has been extirpated (Bick 1983). In 1995, visits to potential habitats in Lake County were unsuccessful in locating any Hine’s emerald dragonflies. A single adult male was collected in 1978 from Jackson County in northeastern Alabama (Vogt and Cashatt 1994).

Ronald J. Panzer collected the first Illinois specimen of Hine’s emerald dragonfly in 1983 during an insect survey at Lockport Prairie Nature Preserve. The specimen was identified as

this species by Tim E. Vogt in 1987. Hine's emerald dragonfly was first collected from Wisconsin in 1987 by William A. Smith near the Mink River in Door County (Vogt and Cashatt 1990). In 1997, Wayne Steffens collected the first Michigan specimen of this species during a Hine's emerald dragonfly status survey of the Upper Peninsula (Steffens 1997). This discovery extended the known range of Hine's emerald dragonfly approximately 200 km (124 miles) to the northeast from previously known locations in the Door Peninsula, Wisconsin. In 1999, Linden Trial collected an adult male Hine's emerald dragonfly from the Grasshopper Hollow Natural Area, in Reynolds County, Missouri. This specimen was sent to Tim Vogt for identification that same year. Grasshopper Hollow is approximately 603 km (375 miles) southwest of the Illinois site and almost as far northwest of the Alabama collection.

The full extent of the historical range of this species is unknown. Hine's emerald dragonfly had not been known to occur in Michigan prior to 1997, yet searches of potentially suitable habitat located a population in the Upper Peninsula of Michigan. It is important to identify a potential range for this species to guide searches for remaining undiscovered extant populations of Hine's emerald dragonflies. Information on the potential historical range of this species and guidelines for surveys are presented in Appendix 3.

STATUS OF EXTANT POPULATIONS

In order to describe the status of extant populations of Hine's emerald dragonfly, the following terminology will be used to distinguish between populations and subpopulations, and the sites at which these occur. A population is defined as a group of individuals of the same species, coexisting at the same time and in the same geographic area, and capable of interbreeding (Purves *et al*. 1998). For example, the Hine's emerald dragonfly individuals in the lower Des Plaines River valley, Illinois, would constitute a population, the individuals in Door County, Wisconsin, would constitute a second population, and the individuals in Mackinac County, Michigan, would constitute a third population. Populations are distinguished from each other by being separated by large distances (e.g., 50 km (31 miles) or more) and having a low probability of genetic exchange.

A subpopulation in most cases would be defined as a local population occurring at a specific geographic site (e.g. Lockport, The Ridges, etc.). A subpopulation would be relatively self-sustaining (Pulliam 1988; Pulliam and Danielson 1991). If a few individuals occur at a specific site primarily due to the immigration from a source population, that would not constitute a subpopulation. In addition, over the course of several years, the combination of birth and immigration minus death and emigration in a subpopulation should balance out to have a non-negative growth rate. In cases where larval habitat constitutes what appears to be separate subpopulations, but adult habitat is contiguous (e.g., Middle Parcel, River South, and Lockport), the geographic area used by the adults would define the edges of the subpopulation because it will be assumed that the adults are freely using the entire area and genetically mixing (Figure 4). Similarly, a road that cuts through an otherwise contiguous habitat would not create two subpopulations. These two areas would be considered one subpopulation.

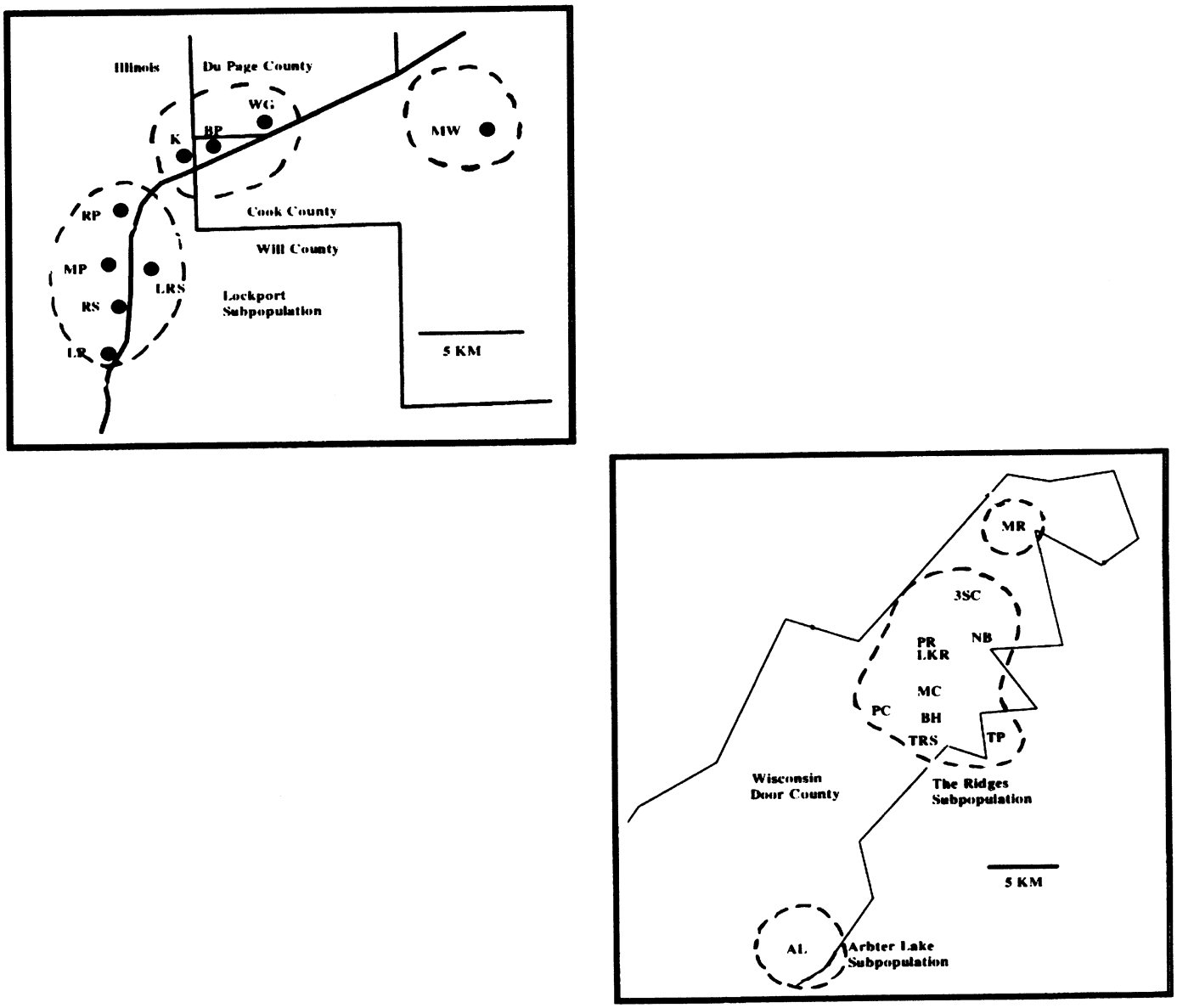


Figure 4. Hine's emerald dragonfly sites in Illinois and a subset of sites in Door County Wisconsin. Maps are different scales and illustrate relative locations of sites. Dashed circles illustrate potential subpopulation boundaries. Initial grouping are based on dispersal distance observations from mark-recapture studies. Nature and forest preserves are abbreviated NP and FP. Illinois abbreviations: BP - Black Partridge FP, K - Keepataw FP, LP - Lockport Prairie NP, LRS - Long Run Seep NP, MW - McMahon Woods, MP - Middle Parcel, RP - Romeoville Prairie Nature Preserve, RS - River South Parcel, and WG - Waterfall Glen FP. Wisconsin abbreviations: AL - Arbter Lake, BH - Bailey's Harbor, MR - Mink River, LKR - Mud Lake "North" (Lime Kiln Rd)., PR - Mud Lake "North" (Pioneer Rd.), MC - Mud Lake South (Mystery Creek), NB - North Bay marsh, PC - Piel Creek, 3SC - Three Springs Creek, TP - Toft Point, and TRS - The Ridges Sanctuary.

It is assumed that a sustainable subpopulation requires more than one breeding area and more than one seep head or spring located within the breeding area inhabited by the subpopulation. Breeding areas are important to the survival of this species and to the individual subpopulations the breeding areas support. Having at least two breeding areas would reduce the chances of losing an entire subpopulation if one of the breeding areas became unsuitable and unable to support reproduction. Male territorial patrols, oviposition, larvae, exuviae, or teneral adults, indicate that Hine's emerald dragonflies breed at a site.

Lack of sufficient information on demographics, dispersal, and status of populations has made it difficult to determine the population dynamics of Hine's emerald dragonfly. The patchy nature of habitat in Illinois and Wisconsin suggests a metapopulation structure, where there are groups of local breeding populations, each affected by some level of dispersal among these groups so that a metapopulation may be viewed as being composed of several smaller populations (Hanski and Simberloff 1997). Accordingly, metapopulation theory (Hanski and Gilpin 1997) has been used as a reference for establishing viability recovery criteria. The term "metapopulation" is not used in this plan to define units of Hine's emerald dragonfly populations because it is unclear how much migration and/or dispersal actually occurs among populations and subpopulations. It is assumed that dispersal between populations on the order of 10 km (6.2 miles) apart would be feasible for this species, but it is assumed that populations separated by distances of greater than 50 km (31 miles) would not have frequent exchange of individuals. It is not known, however, whether dispersal between subpopulations actually occurs or whether this species resembles a metapopulation solely due to habitat fragmentation. Subpopulations of species characterized by metapopulation dynamics are also assumed in many cases to have separate, independent fates. There is not yet enough information about the trends in each Hine's emerald dragonfly subpopulation to determine if this is the case.

Mierzwa *et al*. (1997) suggested that the mainland-island metapopulation model appears to fit the lower Des Plaines River valley population in Illinois the best. However, insufficient information on the Hine's emerald dragonfly's population dynamics, dispersal capabilities, and habitat stability do not allow researchers to confidently identify the importance or lack of importance of any of the sites. For example, in Illinois, the sites with the larger population sizes that could be identified as a mainland subpopulation occur within a relatively small groundwatershed, perhaps leaving this subpopulation at risk of extirpation from extreme drought or hydrologic changes due to development. If the larger subpopulation becomes extirpated or reduced in size, the sites with smaller Hine's emerald dragonfly population sizes may be critical to the survival of the lower Des Plaines River valley population as a whole if they serve as recruitment sources for the larger subpopulation. Until sufficient information is known about Hine's emerald dragonfly's population structure, sites with smaller population sizes should be considered important for the maintenance of the species.

Illinois:
The River South Parcel and Lockport Prairie Nature Preserve, located less than 1 km (0.62 miles) apart, support the greatest numbers of Hine's emerald dragonflies in Illinois (Mierzwa *et al*. 1995b, 1998). Population numbers at the remaining sites are relatively low.

Lockport Prairie Nature Preserve and River South Parcel support the largest and second largest number of larvae and exuviae (Table 1). One larva was found at Keepataw Forest Preserve, and exuviae were found at Middle Parcel (Cashatt *et al*. 1992, Soluk *et al*. 1996, 1998a, and Mierzwa *et al*. 1995b, 1998).

Wisconsin:
Three adult populations of the Hine's emerald dragonfly have been surveyed in Wisconsin to date, all in Door County. Of the three populations surveyed, the Ridges Sanctuary supported the largest population size (Vogt and Cashatt 1990, 1992; WDNR 1993). Mud Lake "North" and Three Springs Creek ranked second and third, respectively, in adult population size estimates (Table 2).

Mud Lake "North" had the highest density of Hine's emerald dragonfly larvae of the three sites sampled: Mud Lake "North," North Bay, and The Ridges Sanctuary (Table 1). The difficulty in locating larvae within the large area of potential larval habitat at The Ridges Sanctuary could explain why very few individuals have been collected from this site.

Since these studies, additional Hine's emerald dragonfly sites have been found that may support significant dragonfly populations including Cedarburg Bog (Ozaukee County), Black Ash Swamp (Kewaunee County) and Ephraim Swamp (Door County).

Michigan:
No attempt to determine population size has been made in Michigan. Steffens (1997, 1998) observed dragonfly breeding behavior, territorial patrol and oviposition, at four sites (Ackland Road, I-75 East, I-75 West, and Martineau Creek SW), and possible oviposition at two sites (Horseshoe Bay and Brevort Lake Road). The number of Hine's emerald dragonflies observed at each site ranged from one to four individuals. Steffens (1999) observed Hine's emerald dragonflies patrolling and feeding at Snake Island Fens, Loop 2 Fen, and Misery Bay. At least 15 adults were observed at the Snake Island Fens, the most ever observed at one time in Michigan (Steffens 1999). Surveys are being conducted to monitor the presence of Hine's emerald dragonfly at existing sites and *de novo* surveys are planned at sites with potential habitat. To date, no larval surveys have been conducted in Michigan.

Missouri:
No attempt to determine population size has been made in Missouri to date because new sites are being discovered. In 1999, Linden Trial collected an adult male Hine's emerald dragonfly from the Grasshopper Hollow Natural Area, in Reynolds County, Missouri. This specimen was sent to Tim Vogt for identification that same year. Two new sites were verified in Missouri in 2001, Ruble Meadow in Reynolds County and Barton Fen in Iron County. Reynolds County is approximately 603 km (375 miles) southwest of the Illinois sites and almost as far northwest of the Alabama collection.

Table 1. Hine's emerald dragonfly larval abundance and sampling effort in Illinois and Wisconsin (Soluk *et al*. 1996, 1998, unpub. data, Mierzwa *et al*. 1998).

	No. Larva/No. Samples		
Location	1996	1997	1998
River South, IL	NSC	39/54	TBA
Lockport Prairie NP, IL	37/210	35/454	10/298
Long Run Seep NP, IL	NSC	0/28	0/11
Middle Parcel, IL	NSC	0/11	TBA
Waterfall Glen FP, IL	NSC	0/13	NSC
Keepataw FP, IL	0/33	1/27	0/25
The Ridges Sanctuary, WI	0/20	0/36	1/22
Mud Lake "North," WI	7/19	52/138	264/159
North Bay, WI	2/23	1/12	NSC

TBA=To be announced; NSC=No survey conducted

Table 2. Hine's emerald dragonfly adult population survey results. Adult population survey at three Hine's emerald dragonfly sites in Wisconsin and two sites in Illinois using a mark-resighting method (Kirk and Vogt 1995, Mierzwa *et al.* 1995a, Cashatt and Vogt 1996). Fisher-Ford trellis model was used to calculate population estimates. The total annual adult population size at each site may be estimated by multiplying the Average Daily Population Estimate by a factor of 30 (Gall 1984, Watt *et al.* 1977).

Location and State	Average Daily Pop. Estimate	Daily Population Estimate Range	No. of Individuals Marked	No. of Resightings
The Ridges Sanctuary, WI	2938	159-5607	635	28
Mud Lake "North," WI	1699	169-2276	240	12
Three Springs Creek, WI	141	25-374	62	6
Lockport Prairie, IL	57	15-329	71	17
River South Parcel, IL	100	15-209	110	11

Genetic Diversity:
The Illinois population of Hine's emerald dragonflies contains the highest genetic diversity, as measured by numbers of different sets of maternal genes, or haplotypes (Purdue *et al*.1996). Six different haplotypes occur in the Illinois population. Three of the Illinois haplotypes are found only at Lockport Prairie Nature Preserve, and two are found only at the River South Parcel. The Wisconsin and Michigan populations are composed entirely of a seventh haplotype, which is not found in Illinois (Purdue *et al*.1996, Illinois Natural History Survey (INHS), unpub. data) . This suggests that females do not disperse between Illinois and Wisconsin or Michigan. Because this genetic analysis is based on genetic material inherited from the mother, it offers no information about whether males are dispersing between Illinois and Wisconsin or Michigan.

Tests conducted on specimens collected in Ohio and Alabama revealed that the Alabama haplotype was indistinguishable from the Wisconsin and Michigan haplotype, indicating a link between the Alabama specimen and the Wisconsin and/or Michigan populations (Purdue *et al*.1996). Analyses of Ohio's specimens indicate a relatively high level of genetic diversity with haplotypes being shared with the Illinois, Wisconsin, and Michigan populations. Specimens collected in 1999 from a site in Missouri and a site in southern Wisconsin each represented an additional unique haplotype (J. Purdue, Illinois State Museum, pers. comm.).

Genetic analysis of haplotype distribution in related *Somatochlora* species, *S. tenebrosa*, *S. linearis* and *S. ensigera*, have revealed a pattern similar to *S. hineana*, with greater diversity occurring in the unglaciated southern portion of the species' range, and lower diversity, probably indicating some interaction of post glacial dispersal into these areas and genetic drift, in the northern glaciated portion (Purdue *et al*.1999).

LIFE HISTORY AND ECOLOGY

Life Cycle:
The life cycle of Hine's emerald dragonfly is similar to most dragonflies in that it is comprised of the following stages: aquatic egg, aquatic larva, and a terrestrial/aerial adult (Corbet 1962). A Hine's emerald dragonfly female will most likely lay more than 500 eggs during her life (D. Soluk, Illinois Natural History Survey, pers. comm. 1999). After an egg is hatched, the larvae may spend 2 to 4 years in small streamlets, foraging and molting as they grow (Soluk *et al*. 1996, 1998a). Upon completion of larval development, the larvae begin to emerge as adults, possibly as early as late May in Illinois and late June in Wisconsin and continue to emerge throughout the summer (Vogt and Cashatt 1994, Soluk et. al. 1996, Mierzwa *et al*. 1997). The first emergence date can be estimated using temperature and precipitation data (Mierzwa *et al*. 1995a). The Hine's emerald dragonfly's known flight season lasts up to early October in Illinois (Vogt and Cashatt 1994, Soluk *et al*. 1996) and to late August in Wisconsin (Vogt and Cashatt 1994). Fully adult Hine's emerald dragonflies can live at least 14 days (Soluk *et al*. 1996), and may live 4 to 6 weeks (Mierzwa *et al*. 1995b). As with most dragonflies, adult Hine's emerald dragonflies feed, establish territories, mate, and oviposit (lay eggs) (Corbet 1962). Most dragonfly adults are general predators throughout their entire life cycle, feeding primarily on insects they can capture while flying.

Larval Life History:
From lab observations of *Somatochlora williamsoni* and a small number of Hine's emerald dragonflies (D. Soluk, Illinois Natural History Survey, pers. comm.), Hine's emerald dragonfly is assumed to be a sit-and-wait predator as described in Johnson (1991), remaining motionless until a prey item comes within striking range. Analyses of larval behavior using time lapse video and infrared light indicate that Hine's emerald dragonfly larvae are much more active at night than during the day (Pintor and Soluk, INHS, unpub. data). Hine's emerald dragonfly larvae have also been observed crawling around in streamlets at night (Mierzwa *et al*. 1998). Mobility at night may reduce predation risks. It is also possible that Hine's emerald dragonfly is an active predator, and the observed larvae were in search of prey items.

Preliminary analyses of fecal pellets from Hine's emerald dragonfly larvae indicate this species feeds on oligochaetes and larval mayflies and caddisflies, which are common in its habitat (Soluk *et al*. 1998a). Direct observation of larvae in containers indicate that Hine's emerald dragonfly will attack and consume mayflies, isopods, and smaller larvae of a related species, *Somatochlora williamsoni* (Soluk, INHS, unpub. data). Dragonfly larvae commonly feed on smaller insect larvae, including mosquito and dragonfly larvae, worms, small fish, and snails (Pritchard 1964, Merrill and Johnson 1984, Ross and Mierzwa 1995). As larvae grow, it is likely their prey items or prey size change. It is probable that Hine's emerald dragonfly is an opportunistic predator and does not rely on certain prey items for its diet.

Hine's emerald dragonfly larvae can occur in small clusters within their habitat (Soluk *et al*. 1996, 1998a, Mierzwa *et al*. 1998). Sample sizes of 1 square-foot have yielded different-size classes of Hine's emerald dragonfly individuals and up to 28 newly-hatched larvae (Mierzwa *et al*. 1998, Soluk, INHS, unpub. data). Single individuals have also been collected from numerous 1 square-foot samples. The pattern of distribution is unknown; however, these data imply that Hine's emerald dragonfly can coexist in clusters or remain independent. The quality of substrate may influence larval distribution within a site (Soluk *et al*. 1996).

Hine's emerald dragonfly larvae may become less active and/or crawl into tight spaces during cooler water temperatures in the late fall to early spring (Soluk *et al*. 1998a). Collectors have generally been unsuccessful in finding any Hine's emerald dragonfly larvae in streamlets during this time, even in streamlets that previously contained larvae. Hine's emerald dragonfly larvae have been located during this season by pumping water out of crayfish burrows. A single burrow contained as many as 21 larvae (D. Soluk and L. Pintor, Illinois Natural History Survey, pers. comm. 1999). This overwintering behavior and possible shift in habitat is an important aspect of the larval life history that should be studied further.

Another interesting aspect of larval ecology is the ability to withstand drought conditions. Hine's emerald dragonfly larvae have been found under discarded rail road ties embedded in a dry streamlet channel in Illinois (Soluk *et al*. 1998a). In Wisconsin, Hine's emerald dragonfly larvae were collected from moist streamlets and hummocks that had little to no surface water (Soluk *et al*. 1998a). The larval habitat in both Illinois and Wisconsin has dried up in the summer months during different years, and rainfall amounts in both Will County, Illinois and

Door County, Wisconsin, show similar drought frequencies (Soluk *et al*. 1998a). Hine's emerald dragonfly larvae may be adapted to survive drought conditions (Soluk *et al*. 1998a).

Adult Life History:
Hine's emerald dragonfly goes through three adult phases: pre-reproductive, reproductive, and post-reproductive (Cashatt *et al*. 1991). Pre-reproductive adults may fly 1 to 3 kms (0.6-1.9 miles) from their emergence sites and take short feeding flights of 1 to 3 minutes. Reproductive adults establish breeding sites and territories, using these areas to mate and oviposit. Males start patrolling territories approximately 7 to 10 days after emergence. Foraging flights for reproductive adults may be 1 to 2 kms (0.6-1.2 miles) from breeding sites and can last 15 to 30 minutes. Post-reproductive adults behave similarly to pre-reproductive adults.

Adult Hine's emerald dragonflies capture aerial prey in flight and have been observed foraging on small dipterans (gnats and other two-winged flies) (Vogt and Cashatt 1994). Typically, flight courses are irregular and occur over herbaceous habitat, often near clusters of shrubs or the forest edge (Cashatt and Vogt 1990; Vogt and Cashatt 1990, 1994, Nuzzo 1995). They frequently fly over open fields at a height of 1 to 3 meters (3-10 feet). Adults feed any time during the day but are most active during the morning (Mierzwa *et al*. 1995b, Cashatt and Vogt 1996, Soluk *et al*. 1998a). Crepuscular and diurnal feeding swarms of Hine's emerald dragonflies have been observed in both Illinois and Wisconsin (Vogt and Cashatt 1994). Hine's emerald dragonflies forage over meadows, successional fields, narrow roads, and along Lake Michigan (Vogt and Cashatt 1994).

In contrast to feeding flights, male territorial patrols are concentrated near aquatic habitats. Territories typically encompass a range of 2-4 meters (m) (6-13 feet) in length with flight heights ranging between 0.5-2.0 m (2-6 feet) (Cashatt and Vogt 1990, Vogt and Cashatt 1994). Vogt and Cashatt (1994) described territorial patrols in the following text: "males darted rapidly throughout their territories. They frequently hovered and often pivoted while hovering. Males usually conducted territorial patrols within small clearings of cattails, just above lower emergent vegetation (*Sagittaria* sp.), or just above the cattails. Also, males often assumed territorial patrols over a streamlet and hovered within 0.3 m (1 foot) of the surface. Occasionally, they perched near the top of cattail floral spikes. Territories were defended from intrusion by conspecific and nonconspecific Anisoptera [dragonflies]." Hine's emerald dragonflies patrol above both more permanent waters (streamlets) and temporary waters (inundated forest edges) (Soluk *et al*. 1998a).

Dispersal between sites and within sites in Illinois was documented during a 1995 mark-resighting study (Mierzwa *et al*. 1995a, Cashatt and Vogt 1996). From 180 marked Hine's emerald dragonflies, 4 out of a total of 48 resighted individuals were observed on a different site from which they were captured. Dispersal occurred from River South to Lockport Prairie Nature Preserve twice, Lockport Prairie Nature Preserve to River South, and Middle Parcel to Lockport Prairie Nature Preserve. The distances these four individuals traveled ranged from 3.3 km (2 miles) to at least 5.4 km (3.4 miles). Within River South Parcel, one male was documented traveling about 800 m (875 yards) in approximately 2.5 hours. The Des Plaines River and its riparian zone may be an important dispersal corridor (Cashatt and Vogt 1996).

Although dispersal between sites was not documented in Wisconsin, the extensive wetland system between the known sites in Door County may facilitate the dispersal of Hine's emerald dragonfly (Kirk & Vogt 1995).

Copulating pairs have been observed from early June (Vogt and Cashatt 1994) to late August (Vogt and Cashatt 1997) in Illinois and from early July to late July in Wisconsin (Vogt and Cashatt 1992). Males have been observed intercepting females within their territory, flying off in tandem with a female, and copulating while perched in shrubs (Vogt and Cashatt 1994). Females have also been observed flying over to males, which resulted in copulation (Soluk *et al*. 1996). These females were flying in a regular pattern approximately 0.5 m (1.6 feet) above the cattails. Occasionally, the females would chase nearby dragonflies, and on three occasions, these confrontations led to copulation. This female behavior is considered atypical for the genus *Somatochlora* and for other dragonfly species (E. Cashatt, Illinois State Museum, pers. comm. 1999).

Hine's emerald dragonfly females oviposit by repeatedly dipping their abdomens up to 200 times in shallow water. Observations of oviposition in Illinois range from late June to late August (Vogt and Cashatt 1997), and from early to late July in Wisconsin. Females have been observed with muck or mud on their abdomens, suggesting these females had oviposited in soft muck and/or shallow water. Females with muck on abdominal segments 7-10 have been observed as early as 6 June. Females oviposit in cattail seepage marshes, seepage sedge meadows, sedge hummocks near a marshy stream edge, near the edge of a swale, in muck in sluggish water at the margin of a spring run, in small puddles, in streamlets, and in small marl/muck bottomed pools (Vogt and Cashatt 1994, Soluk *et al*. 1996, 1998a, Steffens, pers. comm. 1998). Numerous females have been observed ovipositing between hummocks in shallow water with sheet flow in seepage sedge meadows (Vogt and Cashatt 1997, 1999). In cattail seepage marshes, females have been observed flying slowly into dense cattail stands. Occasionally, they fly just above cattails and then drop down into small clearings within the seepage marsh. Females will also fly slowly over small, shallow channels approximately 0.2 m (8 inches) above the water's surface within seepage marshes. These flights may be pre-ovipositional (Vogt and Cashatt 1994). All observations of oviposition by Soluk *et al*. (1998a) occurred in more permanent waters (streamlet and cattail/meadow borders).

HABITAT/ECOSYSTEM REQUIREMENTS

Hine's emerald dragonfly lives in wetlands dominated by grass (graminoid) or grass-like plants and fed primarily by water from a mineral source, or fens (Swink and Wilhelm 1994). Two important characteristics common to wetlands inhabited by Hine's emerald dragonfly appear to be groundwater fed, shallow water slowly flowing through vegetation, and underlying dolomitic bedrock or calcareous limestone. The flowing water can range from barely detectable sheet flow to deeper, well-defined streamlet channels. Parts of the streamlet channels are usually covered by vegetation such as cattails or sedges. These slow-moving aquatic systems provide appropriate habitat for larval development. Soil types of these aquatic systems can range from organic muck to mineral soils like marl. Two other important components of these wetland

complexes are open, vegetated areas and nearby or adjacent forest edge. Areas of open vegetation serve as places to forage. Forests, trees, or shrubs provide protected, shaded areas for Hine's emerald dragonfly to perch and roost.

Nearby or adjacent forested areas in Illinois are mainly floodplain deciduous forests. In Wisconsin and Michigan conifer swamps and forests are common. In Michigan, marl is a common substrate type, and in Illinois and Wisconsin, muck is the predominant substrate.

Habitat descriptions, community types, the physical aspects of Hine's emerald dragonfly sites, and a map of surface dolomite deposits are provided in Appendix 3. A list of dragonfly and damselfly species that often occur in Hine's emerald dragonfly habitat is also provided in Appendix 3.

Habitat descriptions from historic sites in Ohio include "a small, densely vegetated stream," "a bog meadow," "a shallow water (5-8 centimeters (cm) (2-3 inches) deep) bog densely vegetated with tall grasses and sedges," "a shallow pond," and "pond and streamlet" (Price 1958). Williamson (1931) further described one site as having a small stream with shallow water winding through brush, open areas, and through lizard tail. Trees were also present at this site.

Larval habitat may be an important factor affecting the distribution and population size of this species. Hine's emerald dragonfly larvae are usually found in small flowing streamlets within cattail marshes, sedge meadows, and hummocks (Cashatt *et al*. 1992, Vogt and Cashatt 1994, Soluk *et al*. 1996,1998a, Mierzwa *et al*. 1998). The marsh streamlet microhabitat in Illinois has "dead, coarse, cattail thatch which accumulates at constrictions in the channel" (Soluk *et al*. 1996). The majority of Hine's emerald dragonfly larvae in Illinois are collected in marsh streamlets with firm, intact cattail and sedge thatch. Prescribed burns may influence the amount and consistency of thatch in the streamlets. In Wisconsin, Soluk *et al*. (1998a) collected most larvae from small streamlet channels or from the water that flows between hummocks. The highest density of larvae came from distinct flowing channels that had silt, leaf litter, and decaying grasses for substrate. Larvae were also collected "among hummocks, which featured a braided network of pools between tussock sedges connected with narrow channels between the hummocks."

The hydrology of these wetlands may be one of the most critical components of the larval habitat. As previously stated, sheet flow through vegetation and/or slow-flowing streamlet channels within vegetation appear to be common characteristics of the Hine's emerald dragonfly larval habitat. Most of the larval habitat is believed to be fed by groundwater from seeps and springs. Some of the Hine's emerald dragonfly sites have experienced periods of drought and inundation. Natural hydrologic cycles including periods of drought may be an important aspect of the larval ecology.

Water quality may be another important component of larval habitat. Seeps occur at many of the Hine's emerald dragonfly sites. Water chemistry at known sites in Illinois and Wisconsin are consistent with the presence of dolomitic bedrock at or near the surface. The pH at these sites ranges from neutral to slightly alkaline (Vogt and Cashatt 1994, Midwest Environmental

Services 1995). A water quality study conducted in 1995 suggested the waters at the two Illinois sites with the largest Hine's emerald dragonfly population sizes were being enriched with nitrogen and phosphorous from fertilizers most likely used in agriculture (Midwest Environmental Services 1995). No pesticide or PCB residues were detected in this study. Appendix 4 presents a table of water chemistry for known and potential larval habitat at Hine's emerald dragonfly sites in Illinois and Wisconsin as reported in Soluk *et al*. (1998a). These data illustrate the wide range of chemical values of the known and potential aquatic Hine's emerald dragonfly larval habitat. A more in-depth study comparing water chemistry in areas with and without Hine's emerald dragonfly larvae may help in defining the water chemistry needs for this species. Appendix 4 provides a list of reports that provide water quality data at known Hine's emerald dragonfly locations. A summary and analysis of water quality results from past studies was conducted by Mierzwa *et al*. (1995b). None of the studies have found unique water chemistry parameters for the Hine's emerald dragonfly sites. Due to the fact that the larvae are found in water with good water quality, it is believed that this species may be sensitive to water quality degradation. Habitats occupied by Hine's emerald dragonfly frequently support other rare species of plants and animals as well (Appendix 5). Conservation of the Hine's emerald dragonfly is also expected to benefit these species as well.

Habitat Description by State:

Illinois: All sites in Illinois are wetland complexes consisting of several natural communities such as marsh, sedge meadow, dolomite prairie, spring, seep, and pond (Mierzwa *et al*. 1995a, Cashatt and Vogt 1996, Soluk *et al*. 1996, 1998a, Steffens 1997, 1998). Marshes are dominated by cattails (*Typha* spp.) and sedge meadows by tussock sedge (*Carex stricta*). Both of these communities can be broadly defined as fen (any minerotrophic peatland or mire) or fen-like. Shallow soils, including muck (Wascher *et al*. 1962, Link *et al*. 1978, Mapes 1979), overlie dolomitic bedrock (Niagaran limestone; Bretz 1939). Bedrock is occasionally exposed at the surface. Because these wetlands are spring-fed, water temperature fluctuations are minor. Forest communities are dominated by deciduous trees that are mainly floodplain forests. A beaver impoundment occurs at one of the Illinois locations.

Nuzzo (1995) and Mierzwa *et al*. (1998) sampled the structure and floral composition of the Hine's emerald dragonfly larval and adult foraging habitats at Lockport Prairie Nature Preserve, River South Parcel and Middle Parcel in Illinois. It was suggested that the presence of water, emergent vegetation, and percent of exposed surface water could be the critical components of the larval habitat, and that the type of emergent vegetation may not be as important. Oviposition occurred in marsh and sedge meadow communities with flowing water that averaged 0.7-13.5 cm (0.3-5.3 inches) in depth with a preferred water depth of 1.6-6.6 cm (0.6-2.6 inches) (Nuzzo 1995). As of 1995, oviposition had been observed at the following habitat types: "1. Channels within cattail marsh, with and without flow, 2. Channels within sedge meadow, 3. Shallow, wet depressions in sedge meadow with slow sheet flow, where water is at the surface for much of the year, 4. Seep heads on lower bluff faces" (Ross and Mierzwa 1995). Nuzzo (1995) found that Hine's emerald dragonfly preferred to forage in areas with a patchy habitat that occurred near areas with short and tall vegetation. High use foraging areas were located near larval habitats. Hine's emerald dragonflies also appeared to prefer patchy areas for breeding activities.

Wisconsin: The Wisconsin sites are described from wetland complexes with marsh, sedge meadow, small creek, pond, and spring communities (Vogt and Cashatt 1990, Kirk and Vogt 1995, Soluk *et al*. 1996, 1998a). Small, calcareous, marshy streams appear to be common at all Wisconsin sites. Marshes are dominated by cattails (*Typha* spp.), and sedge meadows are dominated by sedges (*Carex* spp.). Ridge-swale, river estuary, cedar swamps, low-gradient first and second order streams are habitat types that Hine's emerald dragonfly inhabits in Wisconsin. There appears to be a strong correlation between the distribution of Hine's emerald dragonfly and outcrops of Niagaran dolomite (Vogt and Cashatt 1990). Bedrock is exposed at the surface of some of the sites. Stream substrates are primarily muck and peat with some sand. Surrounding habitats include cedar swamps dominated by white cedar (*Thuja occidentalis*), wet-mesic upland forests, and old field communities. Tamarack (*Larix laricina*), black ash (*Fraxinus nigra*), and eastern white pine (*Pinus strobus*) are tree species that are present in this area. Beaver impoundments are known to occur at some locations.

Michigan: Similar to the Hine's emerald sites in Illinois and Wisconsin, Michigan sites with Hine's emerald dragonfly were underlain by shallow dolomite and were identified as calcareous or northern fens. These sites were described as "thinly treed, alkaline peatlands (Penskar and Albert 1988)." Sedges and cattails are present at the Michigan sites. Communities present at these sites included rich conifer swamps, northern fens, marl fens, and coastal fens with seeps, marl pools, hummocks, shallow pools, small creeks, and "small marly seeps and creeks." Northern fens are dominated by sedges and rushes and are commonly surrounded by white cedars. Very high microsite diversity was documented for several of the sites. One site had both minerotrophic and ombrotrophic wetland plant species. Surrounding habitat of some of the sites included white cedar swamps with scattered small fens. Most sites had Markey and Carbondale soil types that are partly defined as "very poorly drained organic soils (mucks and mucks over sand) on glacial lake beds and outwash plains (Natural Resources Conservation Service 1995)." Seeps were documented at five of the seven sites, and most of the sites were believed to be spring-fed. Characteristics of all Michigan Hine's emerald sites have been described in Steffens (1997, 1998, 1999).

Missouri: Grasshopper Hollow Natural Area contains a variety of habitats including fens, upland and bottomland forests, and pasture and old fields. Nigh (1992) identified four fens, a forested fen, ten deep muck fens, and one prairie fen. He considers the prairie fen to be the best of its known type in Missouri based on size and natural quality. The first Hine's emerald dragonflies collected in Missouri were taken as they flew over this prairie fen. Grasshopper Hollow is in an area that is moderately dissected with broad to narrow ridgetops, gentle to steep sideslopes, and narrow stream valleys. The watershed that includes the natural area is approximately 2000 acres of surface area. Eminence Dolomite underlies the valley bottom, Gasconade Dolomite underlies the uplands, and Roubidoux Sandstone/Dolomite occurs on the ridges and upper slopes (Nigh 1992).

In addition to the prairie fen at Grasshopper Hollow, the Hine's emerald dragonfly has also been collected at two deep muck fens in Missouri, Ruble Meadow and Barton Fen. Ruble Meadow is a privately owned site that is 3.4 acres in size and is considered an excellent example of a deep muck fen with deep peaty sedge-shrubs in diverse plant communities. Barton Fen, managed by

the U.S. Forest Service, is a high quality deep muck fen that is two acres in size (Janet Sternburg, Missouri Department of Conservation, pers. comm. 2001).

THREATS TO THE EXISTENCE OF THE SPECIES

The significant threats to the existence of this species have been identified as habitat destruction/alteration and contamination. The other threats described in this section are considered potential concerns but are not considered significant threats to the existence of this species.

Significant threats to the existence of Hine's emerald dragonfly:

Habitat Destruction/Alteration: Destruction or alteration of Hine's emerald dragonfly habitat is one of the main threats to its survival. Developing commercial and residential areas, quarrying, creating landfills, constructing pipelines, and filling of wetlands could decrease the area of suitable habitat available to the Hine's emerald dragonfly and fragment populations. Direct loss of breeding and/or foraging habitat could potentially reduce both adult and larval population sizes. A reduction in foraging habitat has the potential to reduce the fitness of the adults, which may result in females laying fewer eggs. Hine's emerald dragonfly habitat is closely associated with surface dolomite deposits, an extractable resource that is often quarried. River South Parcel and Middle Parcel in Illinois and Mud Lake "South" in Wisconsin occur near quarries. Mineral mining rights are owned under a portion of Grasshopper Hollow. Mining for lead is expected to continue in this area, but may not occur under the natural area.

Changes in surface and sub-surface hydrology could be detrimental to the Hine's emerald dragonfly. Alteration of water regimes could potentially affect surface water flow patterns, cause loss of seep heads, and reduce existing or potential larval habitat. Permanent loss of appropriate hydrology also has the potential to reduce the amount of suitable breeding and larval habitat. Road construction, channelization, and alteration of water impoundments, temperature, discharge quantity, water quality, and lake levels have the potential to affect important hydrologic characteristics of Hine's emerald dragonfly larval habitat that could be necessary for the survival of this species. A study to predict hydrologic changes to a spring near Black Partridge Creek from a proposed interstate highway suggested that an 8 to 35 percent reduction in spring discharge may occur after the construction of the highway (Hensel *et al*. 1993). Hensel *et al*. (1993) suggested that the highway could cause a loss of recharge water for the spring and lower the water table, reducing the discharge of the spring. Pumping of groundwater for industrial and agricultural use also has the potential to lower the water table and change the hydrology, which may affect larval habitat. Dye-tracing indicates the fens at Grasshopper Hollow are fed by springs originating south of the natural area in the Logan Creek valley (Aley and Adel 1991). These results were not anticipated when setting the natural area boundaries and a portion of the recharge area is not on public lands.

Loss of important habitat types within suitable wetland systems may also threaten this species. Wetland systems with wet prairie, sedge meadow, cattail marsh and/or hummock habitat,

interspersed with native shrubs, appear to be an important part of the overall habitat requirements of the Hine's emerald. The balance of these habitat types within the wetland systems may be important to the survival of this species. Woody vegetation may replace open wetland habitats through succession. Woody vegetation creates shade that can change plant community composition. Invading non-native species such as purple loosestrife could alter the wetland communities and decrease the amount of wet prairie, sedge meadow, and/or cattail marsh. Habitat changes can also be human-induced, caused by overuse from scientific studies and recreation and outreach activities. Management techniques for natural areas, such as prescribed burns and brush control, should be evaluated to determine how the Hine's emerald dragonfly is affected by habitat alterations.

Contamination: Contamination from landfills and past/present applications of habitat-altering chemicals may be harmful to this species. Due to its long aquatic larval stage, contamination of groundwater and surface water are primary threats to this species. Because groundwater moves relatively slowly through sediments, contaminated water may remain toxic for long periods of time and may be difficult or impossible to treat.

The larvae of this species live in streamlets fed by groundwater, and contamination of this source of water could have serious detrimental impacts on the survival of this species. High water quality may be a critical component of this species' habitat; the level of poor water quality that Hine's emerald larvae can tolerate is unknown. Hine's emerald dragonfly's reactions to toxic chemicals are unknown, and any contaminant introduced into its system may cause detrimental effects including mortality. It is possible that contaminated water could decrease or eliminate the number of larvae able to survive in the contaminated system.

Leaching may be one source of contamination of Hine's emerald habitat. Landfills may leach contaminants into the surrounding aquatic system, decreasing the water quality. Acidic water leaching from a sawdust pile at the Missouri site impacts the water chemistry of fens and stream reaches nearest this pile. Extensive data were collected in 1991 and a few readings made in 1996. The Nature Conservancy has water chemistry data on file in their Van Buren office (Blane Heumann, The Nature Conservancy, pers. comm. 1999). Data were collected to measure the impact from water leaching from a sawdust pile into nearby fens, deep muck fens, and small streams. An increase in acidity was noticeable in water near the sawdust pile. The impact appeared to be confined to areas near the sawdust pile. The sawdust pile started to burn in 1999 and has been much reduced in size. If it continues to burn, the water chemistry impacts should lessen. Winter winds can blow dust from lead mine tailings onto the northen end of Grasshopper Hollow Natural Area. Because this is an active lead mine and mill, tailings can be expected to be added to existing settling basins. Lead and arsenic are residues that may remain within watersheds from past orchard industry practices, which may be of concern in Door County, Wisconsin. During 1995, the Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) conducted a pesticide risk assessment of five Door County Hine's emerald dragonfly sites. Potential pesticide risks to Hine's emerald habitat included cherry and apple orchard operations (Three Springs Creek, Mud Lake "North"), plant nursery development (Mud Lake "North") and use of pesticides by the Town of Liberty Grove in roadside spraying (Mink River) (USDA 1995). Other potentially toxic chemicals include

insecticides, herbicides, and fertilizers from agriculture and recreation purposes (golf course development and maintenance). Gypsy moth and mosquito control may be detrimental to Hine's emerald dragonfly. It is unknown how insecticides would affect Hine's emerald adults and larvae if applied near their habitat. Indirect effects from chemicals such as fertilizers can include habitat alteration (eutrophication of aquatic systems).

Inadequate Regulatory Protection: Because habitat alteration and degradation are factors affecting the existence of this species, regulatory protection is important. The regulatory protections that pertain to the Hine's emerald dragonfly are described in the Conservation Measures section. The recovery of the species will depend on ensuring adequate suitable habitat and protection of that habitat.

Potential Concerns:

Environmental Extremes: Natural catastrophes and environmental extremes such as floods, drought, and/or severe freezing have the potential to reduce population sizes or cause extirpation of populations. Due to the relatively close proximity of the sites inhabited by Hine's emerald dragonfly, a natural catastrophe has the potential to impact all of the subpopulations within an area. The vulnerability of Hine's emerald dragonfly populations to extirpation from environmental extremes may be increased by the habitat alteration and fragmentation caused by human development, such as the alteration of hydrology. Impoundments built by beavers can also modify the hydrology of a system.

Transportation: Adult mortality from direct impacts with vehicles or trains may reduce Hine's emerald dragonfly population sizes (Steffens 1997, 1998, Soluk *et al*. 1998a). Because Hine's emerald dragonflies are known to be killed by vehicles and they have been observed flying over railroad tracks, it is believed that high speed trains may also have the potential to serve as a source of mortality for this species (Soluk *et al*. 1998b). However, the extent to which Hine's emerald dragonfly populations are affected by roadway or railway mortality needs to be determined. The ability to link the mortality of adult individuals to a reduction in population size and/or a loss in genetic diversity is difficult due to the complex population dynamics and life cycle of this species.

In Illinois, roadways with the most potential to serve as sources of vehicle-related mortality for Hine's emerald dragonfly adults are Highway 53, Route 7, and New Avenue. An interstate is proposed to be built through and near Hine's emerald dragonfly habitat in Illinois, which could possibly reduce the population size and/or decrease dispersal between subpopulations. Railways are a concern in Illinois because active railroads pass through and near the habitat of three of the sites with the largest population sizes. At two of these sites, railway speed is reduced to 4 to 6 miles per hour during the Hine's emerald dragonfly flight season. These trains probably do not kill adult dragonflies from direct impacts (Mierzwa *et al*. 1998). High speed trains run near the third site, and a high speed railway system is being proposed in this area. A preliminary assessment of the effects from a high speed train on the Hine's emerald dragonfly indicated that the high speed of these trains has the potential to be a source of mortality for this species (Soluk *et al*. 1998b).

In Door County, Wisconsin, roadways shown to serve as sources of vehicle-related mortality for the Hine's emerald dragonfly are State Highways 42 and 57, County Route Q, and Ridges Road. In Kewaunee and Ozaukee Counties, County Route X and Blue Gooose Road, respectfully, appear to be sources of vehicle related mortality. It is possible that some of the roads in Door County may be expanded in the future to accommodate tourist traffic. Traffic increases during tourist season, which correlates with the flight season of the adults. Railways are not currently a problem in Door County, Wisconsin.

Several of the Michigan sites are located near roadways, and it is believed vehicles may serve as a source of mortality in these areas (Steffens 1997, 1998). Interstate 75, a busy four-lane divided highway, and Mackinac Trail run near several of the sites. Currently, there are no railroads near the Hine's emerald dragonfly sites in Michigan.

Transportation corridors such as roads and railroads may also impact the Hine's emerald dragonfly habitat. The creation of impoundments from road and railroad development could change appropriate hydrology which could decrease or alter suitable larval habitat. Maintenance of roads and railroads could also be detrimental to this species. Salt spray from roads and creosote from railroad ties may leach into its aquatic habitat. This may create a toxic environment for the Hine's emerald larvae and decrease population size. Discharge from the Chicago Sanitary and Ship Canal is also a potential threat to larval habitat in Illinois.

Demographic and Genetic Stochasticity: The vulnerability of Hine's emerald dragonfly to effects from demographic and genetic stochasticity (Schaffer 1981) may be increased by habitat fragmentation and small population sizes. Demographic stochasticity is the random outcome of deaths, births, sex ratio, and other demographic variables within a population. Demographic stochasticity can cause small populations, like the Illinois and Michigan populations, to vary widely in size. A drastic reduction in population size can lead to the further decline of a population to extirpation, or can exacerbate the effects of genetic stochasticity. As a population loses individuals, it may lose genetic variation, which may reduce the species' fitness or ability to cope with environmental change. The Wisconsin population has little genetic variation, and the Illinois population has the most genetic diversity. This indicates the importance of the Illinois population to the survival of the Hine's emerald dragonfly.

Disease or Predation: The vulnerability of Hine's emerald dragonfly to effects of predation may be increased by habitat fragmentation and small population sizes. Dragonfly larvae can be consumed by wading birds, puddle ducks, shorebirds, fish (mud minnows and sunfish), turtles, amphibians, crayfish, and other aquatic invertebrates, including other dragonflies, or vertebrates larger than the larvae. Adults may fall prey to spiders, frogs, birds, and other invertebrates including large dragonflies.

It is probable there are pathogens, diseases, fungi and/or parasites that could kill or decrease the fitness of the Hine's emerald dragonfly; however, no pathogens are known to affect this species. Parasitic mites are known to attach to odonates (Smith 1988, Forbes and Baker 1990, 1991, Forbes 1991); however, their impact on dragonflies is poorly understood. Little information is known about insect pathogens affecting dragonflies in general. If a disease outbreak occurred, it

would be difficult, if not impossible, to determine and correct the cause. Insect populations have been known to be reduced to low levels due to insect pathogens (S. Kohler, pers. comm. 1999). A fatal outbreak could be especially detrimental to the Hine's emerald dragonfly given its relatively small population size.

Overutilization for Commercial, Recreational, Scientific, or Educational Purposes: Collection of Hine's emerald dragonfly individuals for commercial, recreation, science, or educational purposes is not considered a significant threat to this species. It is estimated that the number of individuals collected for scientific purposes would be relatively low. Of that number, the majority would most likely be males. Before the inadvertent collection of Hine's emerald dragonfly during a general insect survey in Illinois, this species was believed to be extinct. Knowledge of Hine's emerald dragonfly individuals inadvertently taken would be beneficial in locating new areas inhabited by this species. To avoid violation of the ESA through inadvertent collection of Hine's emerald dragonfly, dragonfly surveyors should obtain a section 10 research permit from USFWS if they propose to collect from potential Hine's emerald habitat areas.

CONSERVATION MEASURES

Endangered Species Act Protections:

The Federal Endangered Species Act of 1973, as amended (ESA) contains protection and recovery provisions for federally listed threatened and endangered species. Recognition through listing encourages and results in conservation actions by Federal, State, and private agencies, groups, and individuals. The ESA provides for cooperation with the States, including possible land acquisition, and requires that recovery and conservation actions be carried out for all listed species.

"Take" Prohibitions:

Section 9 of the ESA prohibits any person subject to the jurisdiction of the United States from taking listed wildlife species. The term "take" is defined to include harassing, harming, pursuing, hunting, shooting, wounding, killing, trapping, capturing, or collecting. It is also unlawful to attempt such acts, solicit another to commit such acts, or cause such acts to be committed. Regulations implementing the ESA (50 CFR 17.3) further define "harm" to include significant habitat modification or degradation that results in killing or injury of listed wildlife species by significantly impairing essential behavioral patterns including breeding, feeding, or sheltering. "Harass" means an intentional or negligent act or omission which creates the likelihood if injury to listed wildlife species by annoying it to such an extent as to significantly disrupt normal behavioral patterns which include, but are not limited to, breeding, feeding, or sheltering.

Federal Permits:

Section 10 of the ESA provides for the issuance of two types of permits that may be granted to authorize activities prohibited under section 9:

Section 10(a)(1)(A): permits for scientific purposes or to enhance the propagation or survival of a listed species;

Because very little was known about the biology and ecology of the Hine's emerald at the time of listing, section 10(a)(1)(A) permits were granted for several research projects conducted to gather more information that contributed to the understanding and recovery of this species. The USFWS funded population and habitat monitoring studies for Illinois populations (Cashatt and Vogt 1996), genetic studies (Purdue *et al*. 1996), population surveys (Moody 1994, Steffens 1997, 1998), population monitoring and dispersal studies in Wisconsin with the cooperation of The Nature Conservancy (TNC) and Wisconsin DNR (Kirk & Vogt 1995), and population, behavior, and life history studies on larvae and adults in Illinois and Wisconsin (Soluk *et al*. 1998a). Section 10 permits have also been granted for research projects funded by Illinois Department of Natural Resources, Illinois Department of Transportation, Commonwealth Edison, and Material Service Corporation. These projects have included studies on Hine's emerald dragonfly annual population and habitat use (Mierzwa 1995, Mierzwa *et al*. 1995b, Soluk *et al*. 1996, Mierzwa *et al*. 1997, TAMS 1997, Vogt & Cashatt 1997), site hydrology, water quality monitoring, genetics (Purdue *et al*. 1996), adult flight behavior near roadways, larval population, and life history in Wisconsin and Illinois (Soluk and Swisher 1995, Soluk *et al*. 1996, 1998a).

Research has provided valuable information toward the recovery of the Hine's emerald dragonfly. Population surveys have provided population size estimates for sites in Illinois and Wisconsin. These surveys have been useful in locating sites where Hine's emerald dragonflies are breeding. These studies have also provided evidence of dispersal between several of the Illinois sites, which has been useful in evaluating the Illinois' population structure. Genetic research has been useful in identifying 1) the genetic diversity of the past and present populations, 2) Illinois as the most genetically diverse extant population, 3) the lack of genetic diversity in the Wisconsin population, 4) the genetic links between the populations and sites, and 5) closely related species. Adult and larval ecology and life history studies have provided valuable information on adult habitat preference, larval habitat characteristics, length of larval period, phenology, and potential interspecific species interactions. Information on Hine's emerald dragonfly ecology has and will improve the recovery and management recommendations for this species. Water quality monitoring has provided important information on Hine's emerald larval habitat requirements and is important to the management of this species.

A Safe Harbor Policy has been established by the USFWS and the National Marine Fisheries Service (USFWS 1999). This policy encourages non-Federal landowners to voluntarily conserve threatened and endangered species. Under a Safe Harbor agreement, a private landowner would agree to create, restore or maintain habitats, and/or manage their lands so that listed species will benefit. In return, the USFWS provides assurances that future landowner activities above baseline conditions will be exempt of additional future regulatory restrictions. The USFWS issues section 10 (a)(1)(A) permits to cover non-Federal landowner agreements under the Safe Harbor Policy.

Section 10(a)(1)(B): permits for "take" that is "incidental to, and not the purpose of, carrying out an otherwise lawful activity."

Section 10(a)(1)(B) of the ESA allows permits to be issued for take that is "incidental to, and not the purpose of, carrying out an otherwise lawful activity" if the intent is not for research or recovery activities, and the activity occurs on non-Federal land where no Federal action is involved. An applicant for an incidental take permit must prepare a habitat conservation plan that specifies the impacts of the take, steps the applicant will take to minimize and mitigate the impacts, funding that will be available to implement these steps, alternative actions to the "take" that the applicant considered, and the reasons why such alternatives are not being utilized. No section 10(a)(1)(B) permits have been issued for the dragonfly.

Section 7 Consultations: Section 7(a)(2) of the ESA requires Federal agencies to consult with the USFWS prior to authorizing, funding, or carrying out activities that may affect listed species. Section 7(a)(1) also requires that these agencies use their authorities to further the conservation of federally listed species. This consultation process promotes interagency cooperation in finding ways to avoid or minimize adverse effects to listed species. Several section 7 consultations have been conducted for actions in the rapidly developing lower Des Plaines River valley in Illinois. Such actions have included expansion of a commuter airport, expansion of a quarrying operation, extension of a highway, building of a bridge, and upgrading of a railroad. Because the Hine's emerald dragonfly depends on a wetland habitat, most of these consultations have involved the U.S. Army Corps of Engineers, pertaining to their Clean Water Act section 404 permits for wetland filling. Most of these consultations resulted in no project modifications or blockages, while related studies contributed information important to the recovery of the species. For a railroad upgrade project, Commonwealth Edison took an innovative approach by using steel railroad ties as an alternative to creosote-treated ties that could potentially contaminate the wetlands used by the dragonfly. An offshoot of the railroad upgrade consultation was the formation of a Right-of-Way Management Team, composed of Federal, state, and county natural resource agencies, Commonwealth Edison, Material Service Corporation, and the EJ & E Railroad Company. This Right-of-Way Management Team meets at least quarterly to review progress and results of studies and to make recommendations for implementing compatible right-of-way activities and Hine's emerald dragonfly habitat management.

Other Federal Protection:
Wetland habitat loss through the discharge of fill material is regulated under section 404 of the Clean Water Act by the U.S. Army Corps of Engineers and may provide protection for Hine's emerald dragonfly habitat. The U.S. Environmental Protection Agency provides guidance and some funding for groundwater protection. In September 1994, 14 Federal agencies, including the USFWS, National Park Service, U.S. Army Corps of Engineers, Federal Highway Administration, and Department of Defense signed a Memorandum of Understanding (MOU) affirming their commitments to carry out programs for the conservation of federally listed species and the ecosystems on which they depend including cooperation in the implementation of recovery plans.

State Protection:
Illinois: The Hine's emerald dragonfly is listed as endangered by the Illinois Endangered Species Protection Board and is protected from take by the Illinois Endangered Species

Protection Act. The Illinois Endangered Species Protection Act also requires consultation with the Illinois Department of Natural Resources (Illinois DNR) for actions authorized, funded, or carried out by any agency of state and local governments to ensure that state-listed species are not negatively affected by the action. Due to the complexity of most development projects within the lower Des Plaines River valley, there is often state, local, and Federal involvement. In such cases, state and Federal consultations are conducted in coordination with each other.

Under the Illinois Natural Areas Preservation Act, dedicated nature preserves are afforded the maximum legal protection against future changes in land use. Three of the Hine's emerald dragonfly sites occur within Illinois nature preserves. The Illinois Nature Preserves Commission coordinates with the USFWS in consultations on actions involving these nature preserves and requires permits for research and other activities conducted within the preserves.

The Will County and Du Page County Forest Preserve Districts and the Illinois DNR have carried out habitat management measures, such as prescribed burns, brush clearing, and non-native vegetation control, on their lands to benefit the Hine's emerald dragonfly, as well as other federally and state listed species and rare and unique wetland plant communities. Material Service Corporation has also conducted a controlled burn at a Hine's emerald dragonfly site on their property. As part of a mitigation requirement for a Clean Water Act permit for filling wetlands, another quarrying operation funded extensive brush clearing at an Illinois site supporting the Hine's emerald dragonfly, which may provide additional potential breeding habitat. As part of another wetland mitigation requirement for a highway extension, the Illinois State Toll Highway Authority implemented a project to restore historic hydrologic conditions at an Illinois Hine's emerald dragonfly site that had been altered in the past by a railroad and by ditching.

Wisconsin: The Hine's emerald dragonfly was listed as endangered by the Wisconsin Department of Natural Resources in 1997. The Wisconsin statutes require that a state agency must consult with the Wisconsin DNR if an activity that it funds, conducts, or approves may affect a listed species. The statutes allow for the issuance of permits for incidental take of listed species if an appropriate conservation plan that minimizes and mitigates for the take is submitted by the applicant.

Currently, The Nature Conservancy has project areas in Door County, Wisconsin, that encompass several Hine's emerald dragonfly sites. The Nature Conservancy is interested in providing long-term protection of the project areas by purchasing important habitat, working with other organizations (e.g., The Ridges Sanctuary, Inc. and the Door County Land Trust) to purchase and obtain conservation easements for important habitat, contacting landowners to provide information on ways to conserve the Hine's emerald dragonfly, and conducting public outreach to the outlying community.

Michigan: The Hine's emerald dragonfly is proposed for listing as state endangered under the Endangered Species Protection section of the Natural Resources and Environmental Protection Act (Part 365 of Public Act 451 of 1994). Part 303 of Public Act 451 also provides for the preservation, management, protection, and use of certain wetland habitats. The law lists habitat

for threatened and endangered wildlife species as a criterion to be considered in the administration of the Public Act. The Michigan Department of Environmental Quality is responsible for regulating the discharge of pollutants into surface waters, including wetlands. Since most known Hine's emerald dragonfly sites occur within the Hiawatha National Forest, which is managed by the U.S. Forest Service, the U.S. Forest Service would conduct biological evaluations for projects that may affect the Hine's emerald dragonfly sites and would consult with the USFWS regarding potential impacts. Most of the Hine's emerald dragonfly sites occur in wilderness or research natural areas, which are considered protected areas.

Missouri: The Hine's emerald dragonfly will be listed as endangered in Missouri. This species will be included in the 2001 Wildlife Code.

Ohio: The Hine's emerald dragonfly has also been listed as state endangered by the Ohio Division of Wildlife. The Ohio statute restricts the taking or possession of native wildlife, or any eggs or offspring thereof, that is threatened with statewide extinction.

Outreach:
Education and outreach can be important tools for recovery, especially for little-known invertebrate species such as the Hine's emerald dragonfly. Internet web sites with information on the Hine's emerald dragonfly, including images of adults, larvae, and habitat, can be found at the following addresses USFWS Endangered Species program, http://endangered.fws.gov; Illinois Natural History Survey's Center for Aquatic Ecology, http://www.inhs.uiuc.edu/cae/; Daniel Soluk's personal page, http://www.inhs.uiuc.edu/cae/staff/~dsoluklab/hines.htm; and Illinois State Museum, museum.state.il.us/research/entomology/hines/mainpage. Guest lectures on the Hine's emerald dragonfly and other listed species have been provided to high schools, universities, a college, an environmental education center, and Cub Scouts. A Recovery Team member has given a presentation to a mosquito abatement district on the status and protection needs of the Hine's emerald dragonfly. Recovery Team members and research personnel from the Illinois State Museum and the Illinois Natural History Survey presented four research presentations on the Hine's emerald dragonfly at the annual meeting of the North American Benthological Society in San Marcos, Texas, in May 1997. Recovery Team members also presented papers about the Hine's emerald dragonfly at the 1999 International Congress of Odonatology at Colgate University, Hamilton, New York, in July 1999. Other outreach by Recovery Team members include alerting people nationwide to the plight of this species and the need for more research.

RECOVERY STRATEGY

Due to the limited numbers and small sizes of extant Hine's emerald dragonfly populations, the overriding priority for recovery of this species is to protect and maintain the known populations and their associated terrestrial and aquatic habitat. A second component will be to survey for additional populations and to monitor known populations to detect population trends. To achieve recovery, it may be necessary to establish populations at appropriate places within the historic range of the species. Because so little is known about the biology and population

dynamics of Hine's emerald dragonfly, research is an important supporting component of the recovery strategy to guide these efforts.

The recovery criteria are based upon conservation biology and metapopulation theory. It is assumed that a metapopulation structure (with most populations made up of several subpopulations) provides a stable system for long term viability. Though much is unknown about the population dynamics of Hine's emerald dragonfly (*e.g.*, fecundity and dispersal), the basic metapopulation structure increases the potential for the species to survive chance events that might lead to extinction of a single population, and increases the potential of a rescue effect, or recolonization of extirpated populations by individuals from remaining populations (Brown and Kodric-Brown 1977). The criteria to reclassify from endangered to threatened status include an alternative population size requirement that relies on the existence of additional numbers of small populations rather than on the metapopulation structure. The subpopulation size criterion is based on data from an adult Hine's emerald dragonfly mark-recapture study (Mierzwa *et al*. 1995) and Hine's emerald dragonfly larval studies (Soluk *et al*. 1996, 1998a), and on the conservation biology literature. New information on adult dispersal patterns and modeling of alternative population distributions may identify additional arrangements that provide long-term viability for recovery (see task 2.1.3).

A population size of 500 adults would not be considered very large for an invertebrate (insect) population. For comparison, Mace and Lande (1991) assessed differences between threatened and endangered vertebrate species. They proposed three different categories of threat: *critical* for any species with 250 individuals and two or fewer populations, *endangered* for any species with 2500 individuals and five or fewer populations, and *vulnerable* for any species with fewer than 10,000 individuals and five or fewer populations. Criteria for insect populations could be even an order of magnitude larger in size given the potential for large fluctuations in population size. The criteria for delisting the Hine's emerald dragonfly are six populations and 9000 individuals.

A minimum viable population (MVP) as defined by Schaffer (1981) is "the smallest isolated population having a 99 percent chance of remaining extant for 1000 years despite the foreseeable effects of demographic, environmental, and genetic stochasticity and natural catastrophes." MVPs may be defined according to different survival probabilities and time periods, but a given probability of a population's survival over a given time period will depend on a minimum population size. An effective population size of 500 was frequently cited in the early 1980's as a guideline for MVPs (Franklin 1980, Frankel and Soulé 1981), but this value was based solely on genetics (Menges 1992). Genetics is only one of the four factors considered in a population viability analysis, and populations can spiral downward at an even faster rate than expected if these factors (e.g., genetics and demographics) interact (Gilpin and Soulé 1986). In addition, it is rarely easy to estimate effective population size. Because most populations do not behave as ideal populations, effective population size is generally smaller than actual population size. This difference is caused by unequal sex ratios, unequal reproductive success among individuals, and variation in population sizes over time.

A population viability analysis of the Hine's emerald dragonfly has yet to be conducted. The recovery criterion for minimum population size is based upon current census values for existing

population sizes of Hine's emerald dragonfly, and the following assumptions: 1) larval populations of dragonflies are generally at least two orders of magnitude larger than adult populations (Benke and Benke 1975, Ubukata 1981, Johnson 1986), 2) mean reproductive output per female could easily be over 500 eggs per life span, and 3) a 3 year life cycle (overlapping generations). The 10 year criterion requires monitoring over several generations to ensure that population trends are discerned. Given the potentially large natural fluctuations in insect populations among years and the overlapping of three separate generations, this would provide a minimum amount of data with which to discern a trend.

The two recovery units (Figure 5) are broadly based upon Bailey's ecoregions (*e.g.*, Eastern Broadleaf Forest Province and Laurentian Mixed Forest Province) and as modified by Keys *et al.* (1995), so that local recovery planning can be coordinated among populations within more similar habitats with like management concerns.

Figure 5. Hine's emerald dragonfly Recovery Units. The Recovery Units (RU) are based on ecoregions from Bailey (1995) and as modified by Keys *et al.* (1995). The two divisions used from Bailey's (1995) ecoregions were the Warm and Hot Continental Divisions. See Appendix 3 for details.