Hudsonian Emerald Dragonfly (*Somatochlora hudsonica*): A Technical Conservation Assessment

Prepared for the USDA Forest Service, Rocky Mountain Region, Species Conservation Project

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COVER PHOTO CREDIT

Hudsonian Emerald Dragonfly (*Somatochlora hudsonica*). Photograph by the author.

SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF THE HUDSONIAN EMERALD DRAGONFLY

Status

The Hudsonian emerald dragonfly (Somatochlora hudsonica) appears to be an uncommon species, both from the standpoint of its encounters with human beings as well as the number of specimens found in collections. Very little historical information or primary literature exists for this dragonfly, and it has never been studied in depth. Although the species is reported to be widely distributed across Canada (Dunkle 2000), the only records of its occurrence in the continental United States place it at seven locales in Colorado, possibly three in Wyoming, and one in Montana. Most records are over 30 years old, and little or no documented collecting has been done at these sites since the originals. The paucity of records for this species, which may be due to a lack of collecting in areas where the species may occur, makes it suspect as a species of special concern. At this time, however, there is limited scientific evidence that either alleviates or warrants concern for its viability. The Hudsonian emerald dragonfly is considered a sensitive species in the Rocky Mountain Region of the USDA Forest Service.

Primary Threats

As with other dragonflies, the main threat to the viability of this species would be the degradation of its aquatic habitat. Trees are an important component of areas surrounding the aquatic habitats of the Hudsonian emerald dragonfly since they provide areas for prey foraging by adults as well as shade that maintains lower water temperatures. Trees may also serve as mating areas. The loss of trees can occur through timber harvest, fuel reduction, or wildfires. Grazing by livestock may decrease perching or emergence vegetation for this species as well as degrade the aquatic habitat by increasing sedimentation. Sedimentation may also occur as a result of road construction or clear cutting. Tree harvest, grazing, and road construction can also help to produce nutrient runoff, increasing nutrient loads to the aquatic habitat, thus producing eutrophication. Use of pesticides, like piscicides and herbicides, can also serve to decrease population densities of the Hudsonian emerald dragonfly as well as populations of prey species when these chemicals enter the aquatic environment.

Primary Conservation Elements, Management Implications and Considerations

Since this species is known from only a few limited areas, those areas and nearby aquatic habitats should be protected from management practices that would adversely affect them until more information on this species is forthcoming. Since the largest proportion (possibly 80 percent or more) of this species' life cycle is spent as larvae in the water, these aquatic stages are the most important to preserve in order to produce reproducing populations. Land management practices done in or around the areas currently inhabited by this species must be done thoughtfully to have as little impact on the aquatic habitats as possible. Adaptive land management methodologies, such as adjusting livestock grazing regimes in riparian or wetland areas, creating alternative livestock watering sources, and leaving timber harvest and fuel reduction buffers around known aquatic habitats for this species may be warranted. The main conservation focus should be to keep the known aquatic habitats (given in this paper) in mind when proposing management of any kind in these areas.

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INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for the Rocky Mountain Region (Region 2), USDA Forest Service (USFS). The Hudsonian emerald dragonfly (*Somatochlora hudsonica*) is the focus of an assessment because it is considered a sensitive species in Region 2. Within the National Forest System, a sensitive species is a plant or animal whose population viability is identified as a concern by a Regional Forester because of significant current or predicted downward trends in its abundance and/or habitat capability that would reduce its distribution (FSM 2670.5 (19)). A sensitive species may require special management, so knowledge of its biology and ecology is critical.

This assessment addresses the biology of the Hudsonian emerald dragonfly throughout its range in Region 2. This introduction defines the goal of the assessment, outlines its scope, and describes the process used in its production.

Goal

Species assessments produced as part of the Species Conservation Project are designed to provide forest managers, research biologists, and the public with a thorough discussion of the biology, ecology, conservation status, and management of certain species based on available scientific knowledge. The assessment goals limit the scope of the work to critical summaries of scientific knowledge, discussion of broad implications of that knowledge, and outlines of information needs. The assessment does not seek to develop specific management recommendations. Rather, it provides the ecological background upon which management must be based and focuses on the consequences of changes in the environment that might result from management (i.e., management implications). This assessment was done to bring together the scientific knowledge on the Hudsonian emerald dragonfly. It is also meant to be a primer for this species, so that a researcher could use this assessment not only to identify the species, but also to easily pinpoint its historical habitat and to use the information needs stated here as a source for future research.

Scope

This assessment examines what is known about the biology, behavior, ecology, and management of the Hudsonian emerald dragonfly, with specific reference to the geographic and ecological characteristics of Region 2. Although some of the literature on the species may originate from field investigations outside the region, this document places that literature in the ecological and social context of the central Rocky Mountains. Similarly, this assessment is concerned with reproductive behavior, habitat requirements, and other characteristics of the Hudsonian emerald dragonfly in the context of the current environment rather than under historical conditions. The evolutionary environment of the species is considered in conducting the synthesis, but it is placed in a current context.

In producing the assessment, I reviewed refereed literature, non-refereed publications, research reports, and data accumulated by resource management agencies. It is possible that not all publications on this dragonfly are referenced in the assessment, nor are all published materials considered equally reliable. The assessment emphasizes refereed literature because this is the accepted standard in science. Non-refereed publications or reports were used when information was unavailable elsewhere, but these were regarded with greater skepticism. Unpublished data (e.g. personal communications from curators of insect collections and Natural Heritage Program records) were important in estimating the geographic distribution of this species. These data required special attention because of the diversity of persons and methods used in their collection.

Very little research has been done on the Hudsonian emerald dragonfly, owing, in part, to its seeming rarity. This may reflect the paucity of field work (i.e., collecting) and information available on dragonflies and damselflies (Order Odonata) in general. A large portion of the information contained herein was, as you will read, extrapolated from information about the Hine's emerald dragonfly (*Somatochlora hineana*; U.S. Fish and Wildlife Service 2001), an endangered species found in the Midwest. How similar these species are in life history, habitat, and behavior, remains to be seen as the Hine's emerald is a lowland species and the Hudsonian emerald is more of an alpine species.

Treatment of Uncertainty

Science represents a rigorous, systematic approach to obtaining knowledge. Competing ideas regarding how the world works are measured against observations. However, because our descriptions of the world are always incomplete and our observations are limited, science focuses on approaches to dealing with uncertainty. A commonly accepted approach to science is based on a progression of critical experiments to develop strong inference (Platt 1964). However, strong inference, as described by Platt, suggests that experiments will produce clean results (Hillborn and Mangel 1997), as may be observed in certain physical sciences. The geologist, T. C. Chamberlain (1897) suggested an alternative approach to science where multiple competing hypotheses are confronted with observation and data. Sorting among alternatives may be accomplished using a variety of scientific tools (experiments, modeling, logical inference). Ecological science is, in some ways, similar to geology because of the difficulty in conducting critical experiments and the reliance on observation, inference, good thinking, and models to guide understanding of the world (Hillborn and Mangel 1997). Uncertainty is especially relevevant when discussing life cycle models for this species. The lack of basic biological information for the Hudsonian emerald dragonfly makes it impossible to develop an accurate population model. As the basic demographic patterns are unknown for this species, mathematical simulation cannot be done at this time.

Confronting uncertainty, then, is not prescriptive. In this assessment, the strength of evidence for particular ideas is noted, and alternative explanations are described when appropriate. While well-executed experiments represent a strong approach to developing knowledge, alternative approaches such as modeling, critical assessment of observations, and inference are accepted as sound approaches to understanding and used in synthesis for this assessment. In order to decrease our uncertainty about the Hudsonian emerald dragonfly, additional studies have to include collection in areas of potential habitat for this species in order to understand populations of this species. As will become clear in this assessment, little can be said about the current status of this species until more study and collection of this taxon are done.

Application and Interpretation Limits

Application of ideas and recommendations in this document are the results of extrapolation from several sources, many of which do not apply directly to the Hudsonian emerald, but do apply to other dragonflies. The reason for this is the lack of strong scientific evidence about the Hudsonian dragonfly in particular and for dragonflies in general. Many of the statements included here are broad generalizations that would apply equally to all dragonflies, but there are always exceptions to the rule. The interpretation of data gleaned from the literature may be the correct interpretation, but there are always alternative interpretations that may turn out to be equally or more justifiably correct.

Publication of Assessment on the World Wide Web

To facilitate the use of species assessments in the Species Conservation Project, they are being published on the Region 2 World Wide Web site (http://www.fs.fed.us/r2/projects/scp/assessments/index.shtml). Placing the documents on the Web makes them available to agency biologists and the public more rapidly than publishing them as reports. More important, Web publication facilitates the revision of the assessments, which will be accomplished according to guidelines established by Region 2.

Peer Review of this Document

Assessments developed for the Species Conservation Project have been peer reviewed prior to their release on the Web. This report was reviewed through a process administered by the Society For Conservation Biology, which chose two recognized experts to provide critical input on the manuscript. Peer review was designed to improve the quality of communication and to increase the rigor of the assessment.

MANAGEMENT STATUS AND NATURAL HISTORY

Management Status

The Hudsonian emerald dragonfly has a global rank of G5 (http://www.natureserve.org, element code IIODO32120). It is not on the Federal threatened or endangered species list, nor is it a candidate for listing (http://endangered.fws.gov/wildlife.html). Within Region 2 of the USFS, however, the Hudsonian emerald dragonfly is considered a sensitive species.

Although the Hudsonian emerald may have a wide distribution in Canada, it is one of the species being tracked by the Natural Heritage Information Centre in Peterborough, Ontario (Catling and Brownell 2000). In the United States it is restricted to just four states: Alaska, Montana, Colorado, and Wyoming.

It has no status or designation in Alaska (see http://www.sf.adfg.state.ak.us/statewide/NGPlan/MSpecies.cfm), Wyoming (http://uwadmnweb.uwyo.edu/wyndd/), or Montana (http://fwp.state.mt.us/wildthings/concern/invertebrates.html). The Colorado Natural Heritage Program gives this species a rank of S2/S3 (http://www.cnhp.colostate.edu/list.html), meaning that it lies somewhere between S2 (imperiled in the state because of rarity [6 to 20 occurrences, 1,000 to 3,000 individuals] or because other factors demonstrably make it vulnerable to extinction throughout its range) and S3 (vulnerable throughout its range or found locally in a restricted range [21 to 100 occurrences, 3,000 to 10,000 individuals]).

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies.

Existing laws, regulations, and management plans appear to be adequate to conserve the species, if in fact through continued research the species is found to be in need of more focused conservation. Most of the threats to this species identified in this assessment refer to alterations of water quality and quantity, as these factors may be impacted by road maintenance and construction and the cutting of trees or fuel reduction. Federal, state, and private activities and permits should be reviewed for direct and indirect impacts on this species, such as section 404 Clean Water Act permits administered by the U.S. Army Corps of Engineers, as well as other roadway projects funded by the Federal Highway Administration. What is inadequate, at this time, is the knowledge to actually recommend conservation for this species. This assessment addresses that weakness, and without more data and evaluation, conservation strategies cannot be made. This does not preclude the fact that specific standards and directives for management activities could be designed at the forest level in known Hudsonian emerald habitats, promoting healthy aquatic communities.

Biology and Ecology

Systematics and general species description

Somatochlora hudsonica (Hagen)

The following is a typical taxonomic listing of citations and synonymy of *Somatochlora hudsonica* in the literature.

1871 *Epitheca hudsonica* Hagen *in* Selys, Bull. Acad. Belg., (2) 31: 301. (Reprint, p.67).

1878 *Somatochlora hudsonica*: de Selys, 2nd Add. Syn. Cord., pp. 205, 217 (subgenus of *Epitheca*).

1890 *Somatochlora hudsonica*: Kirby, Cat. Neur. Od., p. 49.

1906 *Somatochlora hudsonica*: Martin, Cordulines, p. 27 (Fig. of *sahlbergi*).

1925 *Somatochlora hudsonica*: Walker, N. Am. Species Somatochlora, p. 176.

1929 *Somatochlora hudsonica*: Needham & Heywood, Handb. Drag. N. Am., p. 190.

1955 *Somatochlora hudsonica*: Needham & Walker., Man. P. 400.

1975 *Somatochlora hudsonica*: Walker & Corbet, Odon. Of Can. & Alaska 3. P. 125.

1977 *Somatochlora hudsonica*: Cannings & Stuart. Odon. of B. C. P. 173.

1999 *Somatochlora hudsonica*: Corbet, Drag. Beh. Ecol. Od., p. 363.

2000 *Somatochlora hudsonica*: Needham et al., Drag. N. Am., p. 556.

2000 *Somatochlora hudsonica*: Dunkle, Drgfls. Through Binoculars, p. 151.

Somatochlora hudsonica (**Figure 1**) is known as the Hudsonian emerald dragonfly and is a member of the Family Corduliidae in the Order Odonata. The members of the Order Odonata (dragonflies and damselflies) are often placed under the Division Paleoptera together with the Order Ephemeroptera (mayflies). This grouping is due to the fact that adults in both orders lack the musculature and articulation to turn and fold their wings over their abdomens when not in use. Adults of both orders also have supernumerary veins (numerous cross veins found on their wings). The majority of the life cycle of species of Odonata is spent as aquatic immature forms or instars known as larvae (sometimes called nymphs or, more properly, called naiads, whereas the term larva is reserved for immature forms of species that include a pupal stage or complete metamorphosis in their life cycle). Dragonflies undergo incomplete metamorphosis, lacking a pupal stage. The adults can be found in a range of terrestrial habitats as well as proximity to an aquatic environment.

The insect order Odonata contains two suborders: the Anisoptera (dragonflies) and the Zygoptera (damselflies). These can be distinguished from each other in a number of ways. As adults, dragonflies at rest hold their wings outspread and perpendicular to the body while most damselflies hold their wings closely appressed above the body at rest. Dragonflies have the hind wings wider then the fore wings, particularly

Figure 1. Photograph of an adult male Hudsonian emerald dragonfly specimen (photograph by R.J. Packauskas).

at their base; both fore and hind wings are equally narrowed at their bases in damselflies. Dragonflies have a more stout body and beat both fore and hind wings in unison and are excellent fliers while damselflies have a more narrowed form to the body and beat their wings alternately and are poor fliers. The adults and larvae of both suborders are predaceous. The larvae of both groups possess an extensible labium, a piercing grabbing mouthpart that enables prey capture. Dragonfly larvae can be distinguished from damselfly larvae by their more robust body shape and the lack of external gill plates at the rear of the abdomen; damselfly larvae are slender-bodied and have three easily seen leaf-like external gill plates at the caudal or rear end.

The genus *Somatochlora* belongs to the Family Corduliidae (formerly a subfamily, Corduliinae, of the Family Libellulidae). Seven families of dragonflies (Anisoptera) are found in the United States (Borror et al. 1989). Characters included here are somewhat modified from Borror et al. (1989). The seven families of dragonflies in the United States can be split into two groups on the basis of mainly venational characters found on the wings of adults. Members of the Corduliidae, Libellulidae, and Macromiidae families have dissimilar basal triangles (formed by veins) in the fore and hind wings, with the fore triangle farther distad of arculus than the triangle in the hind wing (**Figure 2**); most of the cross veins in the costal and

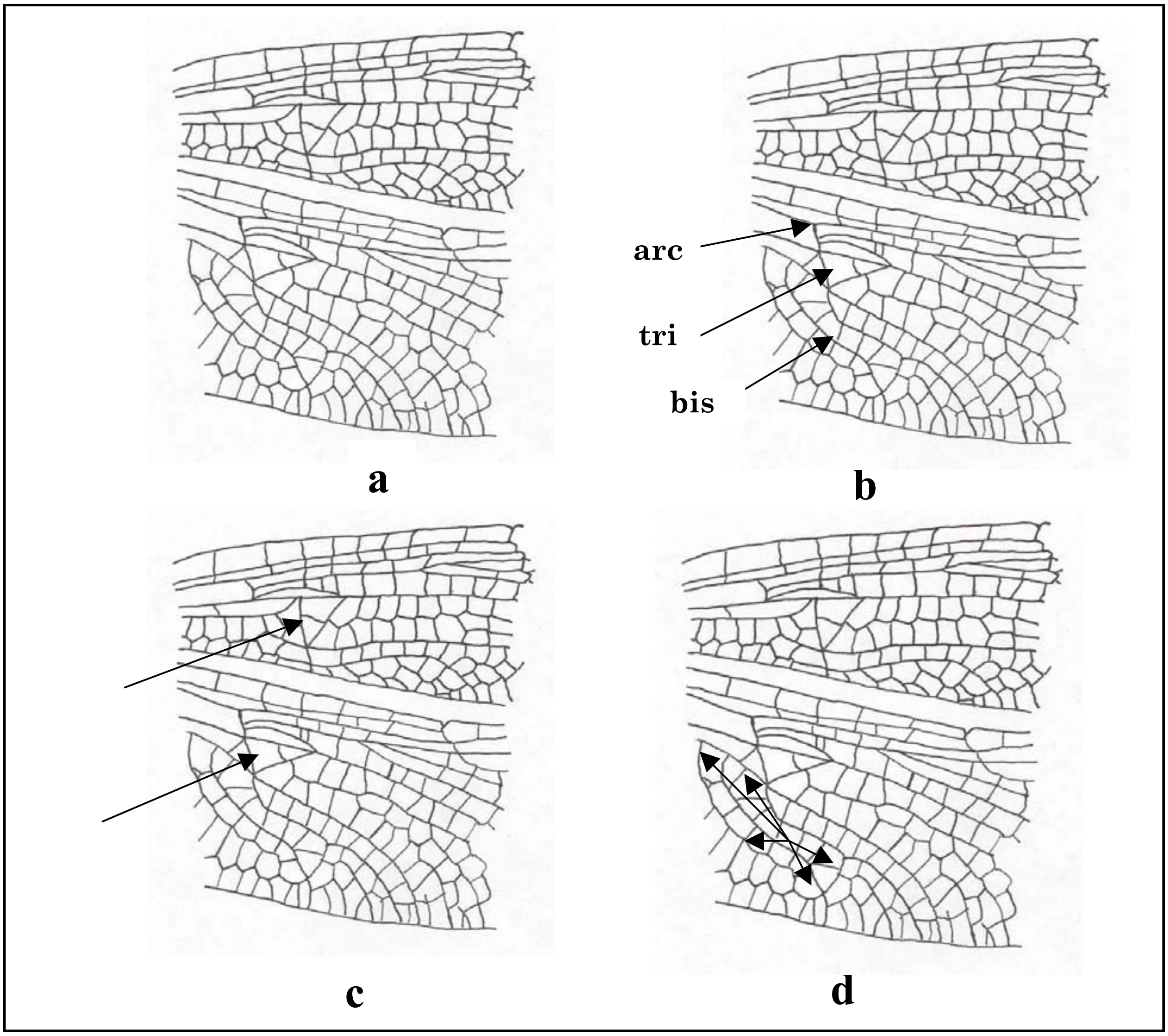

Figure 2a-d. Fore- and hindwing of Hudsonian emerald dragonfly. **Figure 2a**, showing unobstructed veins. **Figure 1b**, with arculus vein (arc), triangle (tri), and bisector vein (bis) labeled. **Figure 2c**, showing fore and hind triangles. **Figure 2d**, showing "foot" with little "toe" area (enclosing arrows), compare to **Figure 2a**. (Original drawings by author.)

subcostal areas in line and no brace vein at the proximal end of the stigma (a darker or pigmented area near the distal end of the leading edge of the fore and hind wings). The families Corduliidae and Macromiidae are separated from the Libellulidae by possession of the following characters: slight lobe on the hind margin of compound eye; inner margin of hind wing slightly notched; anal loop (basal area forming various shapes) rounded or elongate, but if foot-shaped, never having a well-developed "toe" (**Figure 2**); males with small lobe on each side of second abdominal segment (above genitalia). Members of the family Corduliidae can be separated from the Macromiidae on the basis of having the anal loop elongate with a bisector (**Figure 2**; rounded in Macromiidae, without a bisector) and triangle in hind wing opposite (or touching) arculus and one or two cu-a cross veins (in proximal area to left of the triangle, macromiid species have three or more). Members of the Family Corduliidae are known as the green-eyed skimmers, as most species have brilliant green eyes in life. Members of this family are generally black or metallic and usually without conspicuous light markings, but the Hudsonian emerald dragonfly has white rings found on each abdominal segment.

In distinguishing larvae, I have used characters somewhat modified from Westfall (1984). No larval picture for *Somatochlora hudsonica* could be found, but it is similar to the picture of *S. linearis*, which is an eastern American species, barely reaching eastern

Kansas in distribution (**Figure 3**). The larvae of dragonflies (Anisoptera) can be split into two groups based on the structure of the labium (mouthpart). The families Cordulegasteridae, Corduliidae, Libellulidae, and Macromiidae all have larvae that possess a spoon-shaped distal end of the labium (consisting of the palpal lobes and the prementum) with palpal setae present. The latter three families are further differentiated by having the distal end of the palpal lobes smooth or with small regular dentation (as opposed to irregular dentation in Cordulegasteridae). Larvae of the Corduliidae and Libellulidae are differentiated from the Macromiidae by the lack of a frontal horn on the head between the bases of the antennae and a more cylindrical shape than the depressed abdomen and circular shape of larvae of the Macromiidae. The Corduliidae larvae differ from those of the Libellulidae by having crenations (or rounded projections) on the distal (internal, at rest) margins of the palpal lobes separated by deep notches, so that these rounded projections are usually ¼ to ½ as high as they are broad; the cerci are usually more than ½ as long as the paraprocts and lateral spines on abdominal segment IX are usually longer than that segment's middorsal length. The species in this family are more common in northern parts of the United States and into Canada.

Genus *Somatochlora* — Striped emeralds: There are eight genera that occur in the United States found in the family Corduliidae, and the genus *Somatochlora* is the largest in the family (Borror et al. 1989). There are 40 species in the genus *Somatochlora* worldwide, mostly northern in distribution, and 26 of these occur in the United States. Adults: Characters included here are somewhat modified from Westfall (1984). Species in the genus *Somatochlora* can be differentiated from other genera by having the M_4 and Cu_1 veins converging toward the wing margin; wings lacking spots at the nodus (a slight angle in the front wing) and wing tip, perhaps a trace of color at the base of the hind wing; length of hind wing less than 38 mm (1.5 inches); body usually with a metallic blue or green sheen; mesotibiae of males lacking a keel; hind wing with second cubitoanal cross vein forming a subtriangle; inferior appendage of male usually triangular, rarely divided once.

Dunkle (2000) characterizes most species as possessing one or two pale lateral stripes or spots on the thorax and brilliant green eyes (can be red in juveniles); thorax often coated with metallic green wax; pale dorsally with a pale ring between S2 and S3.

Larvae: The larvae of *Somatochlora* can be differentiated from those of the other seven genera in that they may possess middorsal hooks; these may be absent or reduced to knobs (**Figure 3**). If absent or reduced to low knobs, then the sides of the thorax are also uniformly colored. If present and well-developed, the lateral spines are found on abdominal segments VIII and IX, which are equal in length or slightly longer on segment IX; spaces between crenations on the palpal lobes are not deeply cut or semicircular in shape.

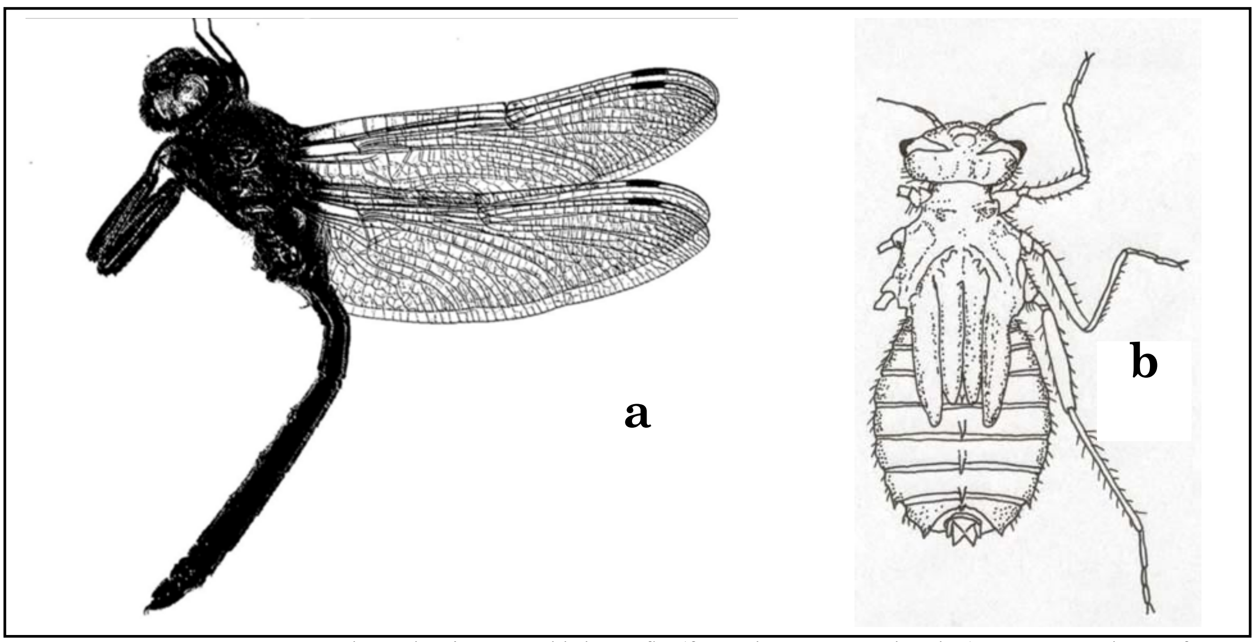

Figure 3a-b. Figure 3a, male Hudsonian emerald dragonfly (from photo, R.J. Packauskas). **Figure 3b**, larva of mocha emerald (*Somatochlora linearis*) (redrawn by author from Brigham et al., 1982).

Somatochlora hudsonica (Hagen): Only eight *Somatochlora* species are found in Region 2 (Bick and Mauffray 2003). Three of these species are restricted to eastern Kansas as to their most western distribution: *S. linearis* (Hagen), *S. ozarkensis* Bird, and *S. tenebrosa* (Say). The other five species may have some overlap in distribution, and these include *S. cingulata* (Selys) (WY), *S. ensigera* Martin (NE, SD, WY), *S. hudsonica* (Hagen in Selys) (CO, WY), *S. minor* Calvert (CO, SD, WY), *S. semicircularis* (Selys) (CO, WY). These distributions are from Bick and Mauffray (2003). Dunkle (2000) characterizes *S. hudsonica* as identical to the ringed emerald (*S. albicincta*) in having the thorax brassy green with a single anterior lateral stripe (short, white, diamond shaped); narrow white rings between all abdominal segments; S10 (10^{th} segment of abdomen) with pale spots at junctions of cerci, but it differs from *S. albicincta* in females having an ovipositor (**Figure 4**) while male cerci are bent-curled with large pointed ventral angles at midlength (**Figure 5**; these angles are lateral in *S. albicincta*).

Species diagnosis: In the genus *Somatochlora* there are only two adult species occurring in Region 2 that have narrow white rings between all abdominal segments: *S. cingulata* and *S. hudsonica*. The male cercus of *S. hudsonica* has a large pointed midventral angle (**Figure 5**) just distal of the middle; this is lacking in *S. cingulata*. Female *S. hudsonica* possess an ovipositor (**Figure 4**), also lacking in *S. cingulata*.

The keys found in **Appendix A** will help to separate *Somatochlora hudsonica* adults and larvae from the other four species.

Walker (1925) established species groups that he believed shared characteristics indicating close relationships. His *alpestris* group included *Somatochlora albicincta*, *S. alpestris*, *S. cingulata*, *S. hudsonica*, *S. sahlbergi*, *S. septentrionalis*, and *S. whitehousei*. *Somatochlora sahlbergi* is an Old World species, while the others are North American in distribution. Recent mtDNA cladistic analysis (Vogt

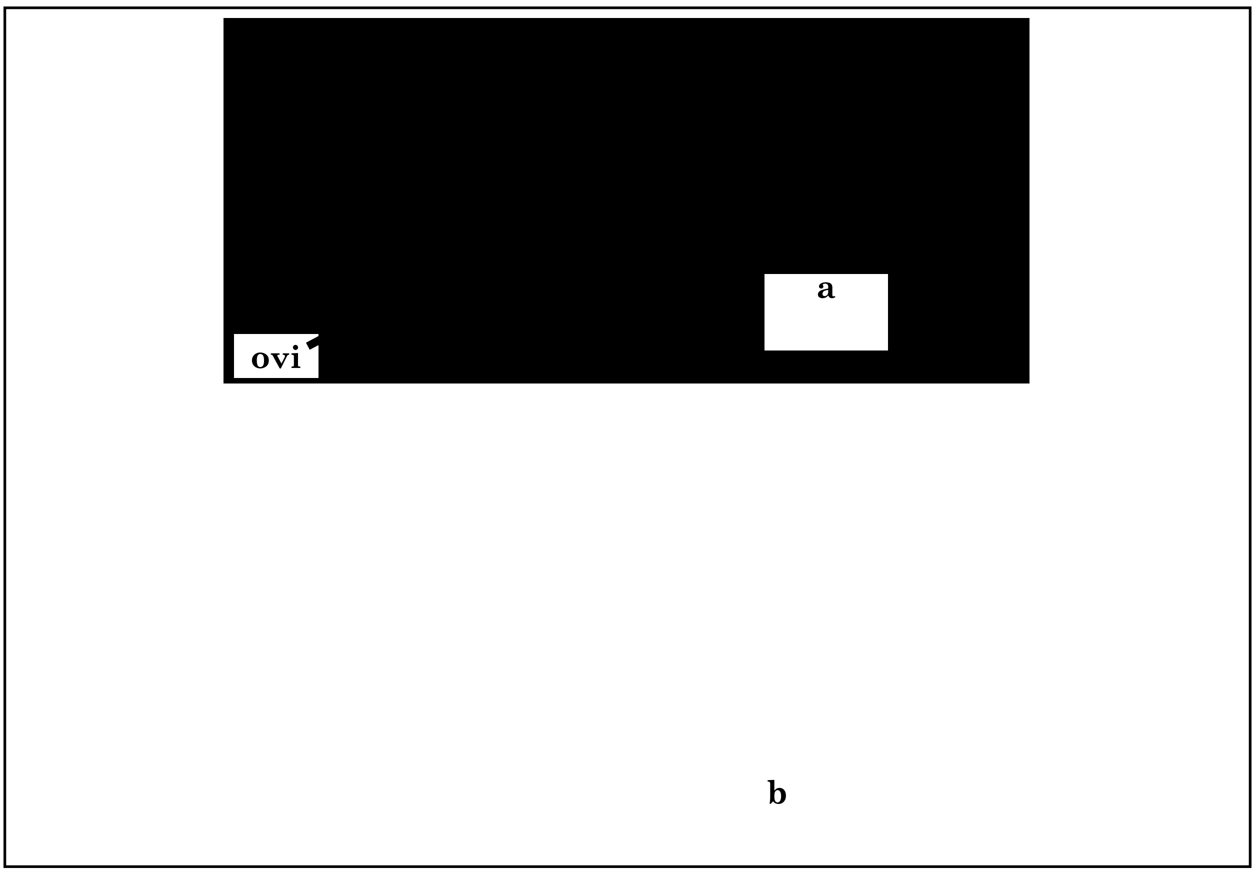

Figure 4a-b. Female terminal appendages of Hudsonian emerald dragonfly. **Figure 4a**, lateral view, with ovipositor (ovi) labeled. **Figure 4b**, ventral view. (Redrawn by author from Walker, 1825.)

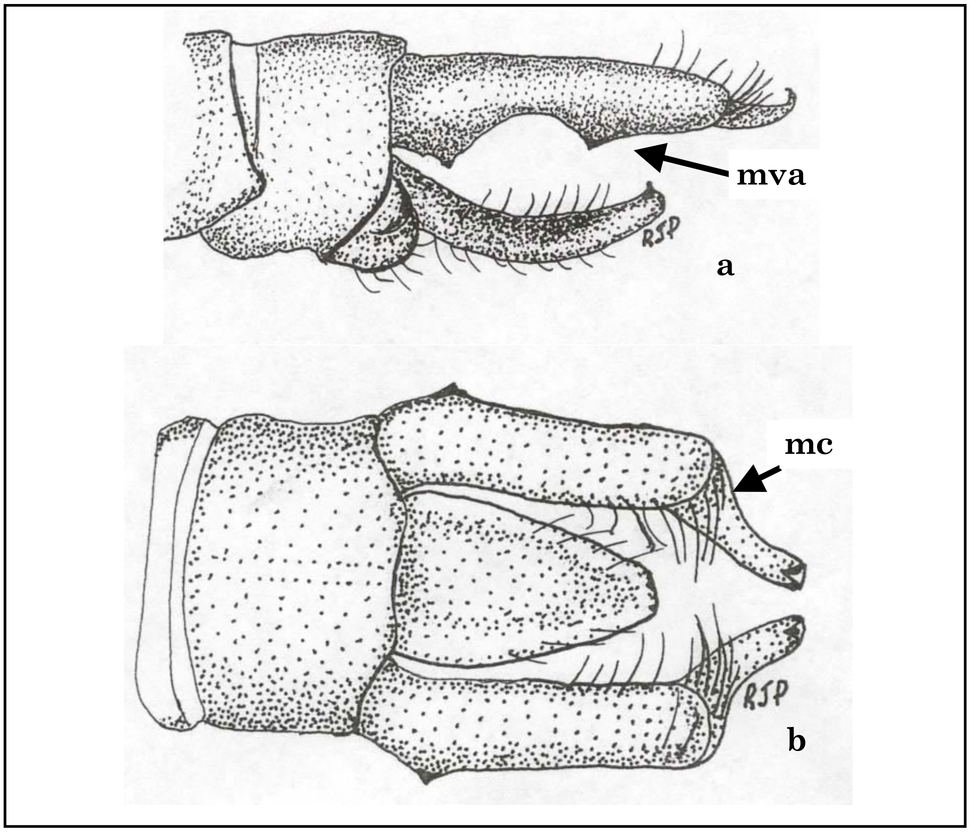

Figure 5a-b. Male terminal appendages of Hudsonian emerald dragonfly. **Figure 5a**, showing lateral view with median ventral angle (mva) labeled. **Figure 5b**, showing dorsal view, with male cercus (mc) labeled. (Redrawn and retouched from Walker, 1825, and from a male specimen.)

unpublished) has validated the grouping of these North American species as a clade.

Distribution and abundance

The Hudsonian emerald dragonfly can be found in the Hudsonian and Canadian zones from James Bay and northern Ontario to the Alberta Rocky Mountains, and southward along the mountains to southwestern Colorado (Walker 1925). It is common from Alaska to Hudson Bay, but local along the Rocky Mountains to Colorado (Dunkle 2000). Bick and Mauffray (2003) list the distribution as CANADA: AB, BC, MB, NT, ON, SK, YT; UNITED STATES: AK, **CO**, MT, and **WY** (Region 2 in bold). Walker (1925), giving no other statement as to why, said that members of the genus *Somatochlora* are "seldom abundant even in the immediate vicinity of their breeding places," calling them "shy denizens of the wilderness."

Distribution in Region 2

In Wyoming, the few records that exist are from two rather specific locales: (1) near Moran in Grand Teton National Park and (2) along the North Fork of the Little Laramie River in the Medicine Bow National Forest. A possible third locale listed as "Medicine Bow Mtns." could be close to the second locale stated above (see **Appendix B** for more specific collection data).

In Colorado, the distribution appears to be more localized at seven different locales. It may indicate that this taxon has been poorly collected in other possible habitats, and all seven sites occur within a roughly 40 mile radius of Boulder, CO. For specific collection data, refer to **Appendix B**. This does not preclude other similar habitats from investigation (see Information Needs section).

Population trend

Due to the lack of data in the scientific literature that would allow one to make any inferences, no statements can be made on the populations of Hudsonian emerald dragonflies. Few population studies have been done on other dragonflies. There is little historical data on the distribution of the Hudsonian emerald, and the few records that exist have not been reverified to show possible decline, nor have similar habitats been examined. Further investigation and observations on the species in one or more of its habitats is certainly needed in order to begin a discussion on population trends. All that being said, the fact remains that the species does not show up in collections, and there are few published reports of its presence in areas other than those noted in this document. This may indicate very small populations on the edge of extinction. However, these populations may just as well be thriving or expanding in numbers and distribution. This remains to be proven by further investigation.

Activity patterns and movements

Dragonflies are predators, and modes of feeding differ among species. The larvae of *Somatochlora* are considered to be "sprawlers" or sit-and-wait predators as described by Johnson (1991); they remain motionless until prey come within striking range. Dunkle (1977) noted that early instars (post-hatching) sprawled on the bottom of their aquatic habitats while later instars buried themselves during the day. In raising various *Somatochlora* nymphs, Walker (1925) observed that they are sluggish feeders, rarely making attempts to approach their prey from a distance, but rather relying on their prey to approach them. They often use their long, extended legs to support their body on or among a matrix made up of detritus or macrophytes (Corbet 1999). They may be more active at night as Hine's emerald dragonfly larvae have been observed nocturnally crawling about in streamlets (Mierzwa et al. 1999, U.S. Fish and Wildlife Service 2001). Dunkle (1977) also noted that nymphs were more active at night, when molting usually occurred. Hine's emerald larvae have also been shown to become less active during cooler water temperatures in late fall and early spring (Soluk et al. 1996, U.S. Fish and Wildlife Service 2001), but they have been found in crayfish burrows during this period (U.S. Fish and Wildlife Service 2001). During periods of drought, larvae of Hine's emerald dragonflies were found under discarded railroad ties in a dry streamlet channel in Illinois (Soluk et al. 1998) and in moist streamlets and hummocks with little or no surface water (Soluk et al. 1998).

Walker (1925) believed that the larval stages lasted at least two complete seasons (years), and if he was right about the eggs overwintering (see Life Cycle) then the entire life cycle could take three or more seasons. For dragonflies in general, larval development can be as short as 20 days (for some tropical species; Corbet 1999) or span a number of years. In Illinois, Soluk et al. (1996, 1998) stated that the larvae of Hine's emerald dragonfly may spend two to four years in small streamlets before molting to adult form. Walker (1925), estimated two years of larval development for Hudsonian emerald dragonfly.

Clusters of Hine's emerald dragonfly larvae have been found (Soluk et al. 1996, Mierzwa et al. 1998, Soluk et al. 1998). Single square-foot samples taken in aquatic habitats have yielded varying size-classes of Hine's emerald dragonfly individuals and as many as 28 first instar larvae, as well as single individuals (U.S. Fish and Wildlife Service 2001). However, the pattern of distribution within the aquatic medium remains unknown.

Adults have a much shorter life span. For the Hine's emerald dragonfly, the adult life span lasts at least 14 days (Soluk et al. 1996) and may last four to six weeks (Mierzwa et al. 1995). Walker (1925) estimated 1.5 to 2 months for Hudsonian emerald adults, which can be found in a range of terrestrial habitats as well as proximity to an aquatic environment.

Adult dragonflies generally exhibit three successive phases of adult life (Corbet 1999): a pre-reproductive period, a reproductive period, and a post-reproductive period. Corbet (1999) denotes the pre-reproductive phase (sometimes called the maturation phase) as that period of time preceding the onset of reproductive behavior and includes the teneral stage. The teneral stage of an adult is the period of time just after emergence from the larval form when hardening of the exoskeleton occurs as well as the onset of final color of the adult form. Corbet (1999) states that "the duration of the pre-reproductive phase must be known to interpret the dynamics of adult populations and to estimate the time available for reproductive activity" and also describes a method for doing so. During the pre-reproductive phase, adults may venture far from the aquatic emergence site and feed before returning to aquatic environments to establish breeding sites and territories, which are used to mate and oviposit. Walker (1925) noted that when *Somatochlora* individuals first emerge from larval forms, they generally leave their areas of emergence and breeding and can be found far from such areas. Having collected many species of *Somatochlora* himself, Walker characterized some of their favorite feeding haunts: sunny sheltered spots in woods, lumber roads, edges of clearing, and open spaces on wooded mountain slopes. They may fly at heights of 30 to 50 feet (9.14 to 15.24 m) or more and generally stay within an area with the same length and width (30 to 50 feet [9.14 to 15.24 m]) for long periods of time. They appear to be most active in the afternoon, and they may fly higher at sunset in order to stay within the sunlight. Walker caught a specimen in Banff, Alberta, Canada in July at 8 o'clock in the evening. Walker also indicated that most of the records of *Somatochlora* captures in the literature are from the month of July.

The duration of the pre-reproductive phase for the Hudsonian emeralds is unknown, but males of the Hine's emerald have been known to start patrolling aquatic territories approximately seven to ten days after emergence from larval form (U.S. Fish and Wildlife Service 2001).

In the reproductive phase, the territorial patrols of male Hudsonian emerald dragonflies may cover a range of 2 to 4 m (6.2 to 12.9 feet) at a height of 0.5 to 2 m (1.5 to 6.3 feet), darting throughout the areas (Cashatt and Vogt 1990, Vogt and Cashatt 1994). Territorial patrols for Hine's emerald males consisted of darting, hovering, and occasionally perching on cattails. These patrols were often over areas that were within small clearings of cattails or streamlets. The territorial areas were defended from intrusion by conspecific and non-conspecific dragonflies and damselflies.

Post-reproductive adults behave similarly to pre-reproductive adults in leaving the aquatic sites and are unlikely to be encountered; this phase appears to be of little biological significance (Corbet 1999).

Walker (1925) observed female Hudsonian emerald dragonflies in oviposition. Females fly over water or moss, striking the water or moss at short intervals with the end of the abdomen, releasing a large number of eggs with each strike. They may hover in one place, striking the water at intervals of two to three seconds, while frequently changing their position.

Habitat

The larvae of members of the genus *Somatochlora* are predators (engulfers) (Westfall 1984) and are found in habitats that are primarily lentic—littoral (bogs) and lotic—depositional (springs) as sprawlers.

Cashatt and Vogt (2001) characterized the aquatic habitat requirements for Hine's emerald dragonflies as being very narrow with some unifying features. These features include: "shallow, organic soils (muck) over dolomitic bedrock; calcareous water from intermittent seeps; shallow small channels and/or sheetflow." Many of these seepage marshes were dominated by graminoid plants such as cattail (*Typha* spp.; Vogt and Cashatt 1994, Cashatt and Vogt 2001), tussock sedge (*Carex stricta*; U.S. Fish and Wildlife Service 2001), or sweetflag (*Acorus calamus*; Cashatt and Vogt 2001). Nearly all of the wetlands in which Hine's larvae are found are spring fed, indicating that temperature fluctuations would be minor (U.S. Fish and Wildlife Service 2001). Cashatt and Vogt (2001) noted that many of the seepage wetlands often dried out for a few weeks during the summer, but otherwise had thermal regimes that were relatively moderate and warmer in winter as well as cooler during the summer.

Dunkle (2000) characterized the habitat of Hudsonian emerald dragonfly as being that of deep, sedge-bordered lakes and ponds, but also as ponds with lake inlets, boggy edges, and sedge marshes. They may also be found at boggy slow streams, ditches, and sloughs. The larvae are found mostly in "mucky" edges of woodland streams and bogs (Needham et al. 2000). Walker (1925) maintained that all *Somatochlora* species develop in water of a comparatively low summer temperature from 16 to 20 °C (60.8 to 68 °F). Larvae are usually not found in shallow stagnant ponds in open situations with the exception of areas with cool summer climate such as high altitudes or latitudes. Most individuals are found in well-aerated waters in boggy situations (upland bogs near sources of streams or small forest brooks). In Ontario, Catling and Brownell (2000) characterize the habitat as that of slow streams and bog-margined ponds.

Walker (1925) set up groups of species that he believed had shared characteristics that indicated close relationships. His *alpestris* group included the Hudsonian emerald dragonfly. Walker stated that the members of the *alpestris* group were mainly inhabitants of bogs or cold ponds and lakes and were all northern (Canadian) or alpine in range.

In examining the collection data (**Appendix B**), there appears to be an altitudinal aspect in that all specimens have been collected in areas over 5000 feet (1524 m) in elevation. This may indicate a thermal aspect necessary for its viability. Although evidence indicates that the Hudsonian emerald may prefer bog lake areas, Lavigne (personal communication, collector) characterized the North Fork of the Little Laramie, where he collected this species, as a small rushing mountain stream, and stated that he probably collected specimens over still pools occurring intermittently along the stream.

Trees near the aquatic habitat may be of some importance for adult dragonflies. Walker (1925) noted that many species appear to forage in open spaces of wooded areas. In England, the British Dragonfly Society (1993) has indicated that *Somatochlora arctica* requires trees within 200 m (656.2 feet) of its habitat and that the habitat of *S. metallica* is tree-lined. Cashatt and Vogt (2001) observed that for all extant sites for the Hine's emerald, there were forested areas and/or scattered shrubs close by. They also pointed out that shrubs/trees were likely important areas for roosting as well as for protection from inclement weather, such as thunderstorms and heat. Two important components of wetland seep/marsh areas have been noted for the Hine's emerald dragonfly (U.S. Fish and Wildlife Service 2001): 1) open, vegetated areas and 2) nearby or adjacent forest. Areas of open vegetation serve as forage sites while trees/shrubs provide protection, shade, and perch or roost sites.

Larvae of Hine's emerald dragonfly have primarily been found in good quality water, possibly indicating that this species may be sensitive to water quality degradation (U.S. Fish and Wildlife Service 2001). Larval habitat is an important aspect affecting the distribution and population size of Hine's and Hudsonian emeralds.

Food habits

While raising *Somatochlora kennedyi* nymphs in the lab, Walker (1925) found that the first instars or newly-hatched nymphs fed only on protistans, mainly *Euglena* species supplemented by *Paramecium* species and other ciliates. Second and third instar nymphs took ostracods (microcrustaceans) as food while fourth and fifth instars devoured *Cyclops* and *Daphnia* (both copepod crustaceans), as well as oligochaetes. Later instars moved on to larger creatures. Observations on larger instar nymphs of *S. forcipata* and *S. albicincta* showed that these readily preyed on mayflies and stoneflies, but they would eat any small arthropods such as black flies, amphipods, or cladocerans. Walker also fed a single *S. whitehousei* nymph small earthworms of an inch or less in length, but the nymph shunned larger sizes. Nearly all taxa of freshwater invertebrates, including gastropods, along with small fish and amphibians, serve as prey of dragonfly larvae, as do all other odonates, including conspecifics (Corbett 1999). Analysis of fecal pellets from Hine's emerald dragonfly larvae has shown that this species feeds on oligochaetes (Annelida), as well as mayflies and caddisflies, commonly found in its habitat (Soluk et al. 1998, U.S. Fish and Wildlife Service 2001).

Factors that influence foraging and feeding behavior or the predator-prey encounter rate of larvae include the temperature of the aquatic habitat, the density, activity, and microhabitat preferences of prey, as well as the presence of prey refuges (Corbett 1999).

Adults of *Somatochlora* presumably feed on midges, but they have not been observed feeding and probably do so in flight (Walker 1925). Walker also noted that they were attracted to a swarm of black flies encircling his head. Other biting insects, such as mosquitoes and deerflies, are likely taken as well. Like that of the larvae, the diet of most adult dragonflies can be taxonomically varied, but it is mainly made up of small insects, with the dominant prey species consisting of flies (Diptera) (Corbett 1999). However, Tsomides et al. (1982) found that Lepidoptera (moths and butterflies) were found in more than 50 percent of the gut contents of dragonflies in the Family Corduliidae (the family of *Somatochlora* spp.) in Maine.

Reports of dragonflies feeding on insects that are classified as pests by human standards are numerous (Corbett 1999), but little study has been done on how well such feeding suppresses populations of pest species.

Vogt and Cashatt (1994) observed the feeding behavior of Hine's emerald dragonflies in Illinois and Wisconsin and found that they foraged as early as 0700 hours when the maximal temperature for the day reached 35 to 38 °C (95 to 100.4 °F). Williamson (1922) observed foraging activity as early as 0500 to 0900 in Indiana for *Somatachlora linearis* and *S. ensigera* when daily maximums ranged from 30 to 38 °C (86 to 100.4 °F). Diurnal foraging was observed as well as crepuscular feeding. During these periods, Hine's emerald dragonflies often formed swarms of 30 to 70 individuals flying at 1 to 3 meters over sedge meadows, along shrubs, the forest edge, and over a gravel road (Vogt and Cashatt 1994).

Foraging flights occur in all phases (prereproductive, reproductive, and postreproductive) of adult life. Hine's emerald adults may be found 1 to 2 km (0.6 to 1.2 miles) from breeding sites. These flights may last anywhere from 15 to 30 minutes (U.S. Fish and Wildlife Service 2001).

Breeding biology

All dragonflies and damselflies are unique among insects in having male genitalia located at the anterior end of the abdomen on the ventral surface of the second abdominal segment. Males transfer sperm from a genital opening on the ninth segment of the abdomen to the genitalia by bending the abdomen down and forward. During courtship, males will grasp a female by the head with terminal abdominal structures called claspers. Once such an "embrace" occurs, the male-female pair will fly about together as copulation takes place. Such a pair is said to be flying in "tandem." Copulation takes place when the female bends her abdomen downward and forward, bringing her terminal genitalia into contact with the genitalia on the second segment of the male's abdomen. Although courtship has not been observed among *Somatochlora* species (Brigham et al. 1982), and copulation only rarely, Walker (1925) believed that August would be the prime month to observe breeding. Walker captured one copulating pair while at rest on a tree branch. Walker also observed several attempts at copulation in *S. linearis*, with males "pouncing" on females during flight, the pairs generally dropped to water and separated, except for one occasion where the female was captured and the pair flew into the forest. This may again underscore the importance of trees.

Further information on breeding behavior is needed. The assumption can be made that both males and females probably return to the immediate vicinity of the aquatic habitat from which they emerged to find mates. However, this does not preclude the idea that mating areas may be the same as foraging areas, which can be far from the sites of emergence, or even shrubs and trees. The information backing or repudiating this is unknown.

Vogt and Cashatt (1994) observed copulatory behavior for Hine's emerald dragonfly in Illinois and noted that in two instances of copulation in flight the pairs flew in tandem toward shrubs. In another instance the tandem pair flew to nearby trees. These trees and shrubs may be important mating areas for Hudsonian emeralds as well.

In many dragonfly species, males perform guarding behavior, protecting females when they oviposit; others fly in tandem while oviposition takes place. Walker (1925) makes no mention of either of these behaviors, but he does mention that females fly over water or moss, strike the water or moss at short intervals with the end of the abdomen, and release a large number of eggs with each strike. They may hover in one place, striking the water at intervals of two to three seconds, while frequently changing their orientation, which could indicate guarding behavior or lone oviposition. Vogt and Cashatt (1994) observed many Hine's emerald females with muck on abdominal segments 7 through 10, suggesting that oviposition took place in soft muck or shallow water. They also observed oviposition in water between sedge hummocks.

Life cycle

The life cycle of the Hudsonian emerald is, as in all dragonflies, comprised of the following stages: egg, numerous aquatic larval instars, and a terrestrial/flying adult.

A Hine's emerald female may lay up to 500 eggs during her life (U.S. Fish and Wildlife Service 2001). Dunkle (1977) found that eggs of *Somatochlora filosa* hatched 20 to 30 days after deposition while Walker (1925) stated (seemingly due to observations on *S. kennedyi* and *S. forcipata*) that hatching occurs the following spring. This would indicate that the egg stage overwinters.

The number of instars or immature stages of *Somatochlora* spp. is unknown, but Walker (1925), judging from laboratory rearing of *S. kennedyi*, expected there to be at least 13 or 14 instars, and this may even vary within species (Corbett 1999). From his observations in both the field and laboratory, Walker believed that the larval stages lasted at least two complete seasons (years), and if he is right about the eggs overwintering (see above), then the entire life cycle could take three seasons. It is not known which particular instars may overwinter. For Hine's emerald, it has been reported that larvae may spend from two to four years in small streamlets, foraging and molting as they grow (U.S. Fish and Wildlife Service 2001).

After development, larvae leave the water and molt to adults, leaving the cast skin (exuvium) behind. The latter will be referred to again later. The Hine's emerald may emerge as early as late May in Illinois, and late June in Wisconsin. In Region 2, the Hudsonian emerald would likely emerge as early as late June, temperature dependent, with continuing emergence throughout the summer.

Although little is known about Hudsonian emerald adult longevity, the Hine's emerald can live at least 14 days and possibly four to six months (U.S. Fish and Wildlife Service 2001).

The putative life cycle of the Hudsonian emerald dragonfly (after Caswell 2001) is shown in **Figure 6**. This diagram is tentative because several aspects of the life history of this species are not currently known. In particular, the number of instars is unknown (see

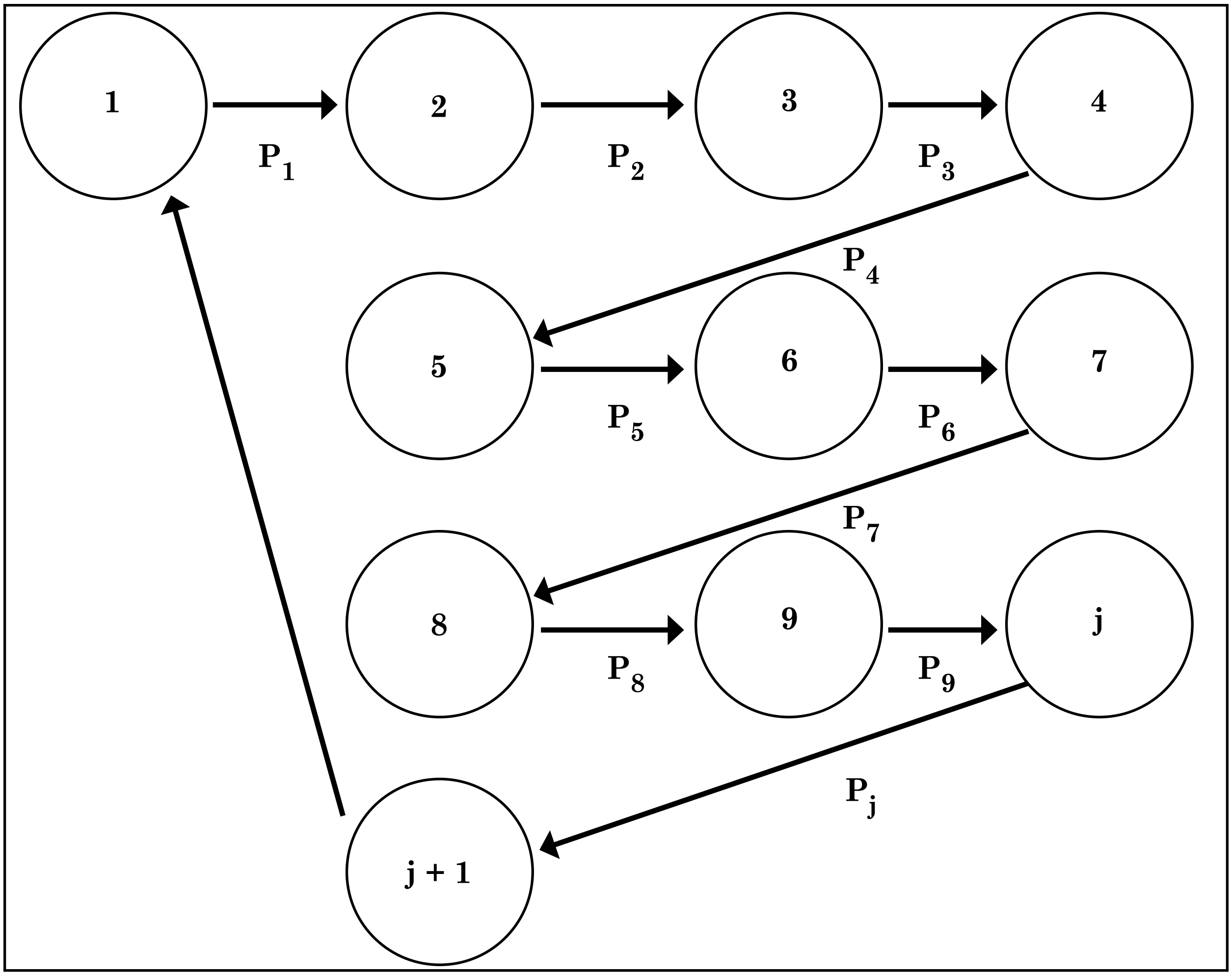

Figure 6. Putative life cycle of Hudsonian emerald dragonfly (after Caswell, 2001). Nodes represent stages: N1 = eggs, N2-Nj = larval (naiadal) instars. Nj = last instar (actual # unknown), Nj+1 = mature females. P1-Pj = probaility of surviving to next instar and F = fertility, production of new N1's (eggs).

above). The three stages of the life cycle shown in **Figure 6** are 1) eggs (N = 1), 2) immature instars (larval stages, N = 2 - j, j because the number of actual instars is unknown), and 3) reproductive females (N = j + 1). Variables are shown for the probability of successfully reaching each stage from the previous stage (P's) and fertility (F), the productivity of all females. When the probable number of instars and numerical data become known for survival and productivity of Hudsoninan emerald dragonflies, this diagram can serve as a starting point to construct a demographic model (after Caswell 2001).

Demography

Demography is defined as the study of populations, including, but not limited to, the size and distribution and including the number of births and deaths. In terms of the published literature on dragonflies, we are far from understanding how populations of even a single species are regulated. Particular factors influencing population sizes have not been studied well nor have population sizes themselves. There is a paucity of information on such aspects as dispersal, genetics, or life history characteristics. The degree to which geographically separate groups of individuals are demographically linked and how this affects population structure are also unknown.

The Rocky Mountain Hudsonian emerald populations could contain genetic units that are distinct from other parts of the species' range. Whether gene flow occurs among subpopulations or if there is a continuum of subpopulations across the Rockies is currently unknown. If there are isolated populations, then selection pressures may differ among populations, producing distinct genetic units. Such findings would stress the importance of maintaining populations of

Hudsonian emerald dragonflies to ensure genetic diversity. Six distinct haplotypes, different sets of maternal genes, have been found in Hine's emerald dragonfly populations in Illinois while populations in Wisconsin and Michigan have a seventh haplotype (U.S. Fish and Wildlife Service 2001). Analysis of haplotypes in other *S. linearis* species (*S. tenebrosa*, *S. linearis*, and *S. ensigera*) have revealed a similar pattern with even greater diversity (Purdue et al. 1999).

Captures of adult Hudsonian emerald dragonflies are rare, judging from the number of specimens in collections and, indeed, records throughout Region 2. The apparent skittish, shy behavior of *Somatochlora* species may contribute to the paucity of records for this particular species and may belie the fact that the population sizes could be quite large or small. The few known records and observations tell us little or nothing about population sizes.

Predation is probably the main cause of death among dragonflies in both larval and adult stages. In aquatic (larval) stages, fish are probably the main predators of dragonflies, if they are present. After fish, the next greatest level of predation would come from other dragonfly species, including conspecifics. The presence or absence of fish would certainly play an important part in regulating populations or allowing them to expand. When fish are absent, overcrowding or high population densities of other dragonflies in the aquatic habitat would be regulatory factors.

Population densities of adults obviously depend on population densities of the larvae and how many of these make it to the emergence of the terrrestrial adult stage. Larval densities may be at least two orders of magnitude larger than adult populations (Benke and Benke 1975, Ubukata 1981, Johnson 1986), and there can be overlapping generations (two to four year life cycle). As has already been noted, Walker (1925) estimated the larval stadia to add up to two seasons or two years, and this may be as long as four years, as shown by Hine's emeralds (U.S. Fish and Wildlife Service 2001). A stadium is the amount of time spent in each larval instar. The larvae can be negatively impacted by numerous abiotic factors in their aquatic habitat. Many of these show up in envirograms (**Figure 7**) later, but they are worth repeating in this section.

Flooding, whether by release from dams, storm precipitation, or quick snowmelt, can produce "scouring" of an aquatic system, washing larvae and/or prey out of their normal habitat.

Drought and high ambient temperatures can impact Hudsonian emerald survivorship by depressing water levels as well as increasing the water temperature to unfavorable levels. Solar radiation as well as high ambient temperatures can also increase water temperature. However, this can be negated by the presence of nearby trees or other factors providing shade to the aquatic habitat, therefore keeping temperatures at a lower, more compatible level. Dragonfly larvae have internal rectal gill areas for exchange of oxygen from the water. This gill utilization may be negatively impacted by higher temperatures that would reduce levels of dissolved oxygen in the water.

Community ecology

One of the more important community interactions found among dragonflies is the predator-prey relationship. Dragonflies are important predators in the aquatic ecosystem as well as the terrestrial surroundings. They may consume large numbers of pests as well as other flying insects. When they are abundant, their impacts on biting flies, such as mosquitoes, deerflies, and black flies, as well as pests of crops, can be substantial (Metcalf and Flint 1939, Stortenbacker 1967, Westfall 1984, Hilsenhoff 2001). Hilsenhoff (2001) considered the larvae to be apex predators in the invertebrate aquatic community because of their relatively large size. Their presence may lower the population density of many pests to humans as well as to livestock.

Larvae provide food for fish and various waterfowl species. They are also potentially useful indicators of water quality as well as habitat suitability in that their continuous presence or absence may be an indication of water quality, pollution, or degradation of the systems in question without resorting to detailed chemical analysis.

Many larval instars of dragonflies are often found with up to dozens of small, rounded, ectoparasitic, reddish water mites attached to the undersurface of the thorax or abdomen. When adult emergence takes place, the mites move onto the adult. The mites feed on the host body fluid, increasing in size, and they may remain on the dragonfly for two or three weeks, before dropping off. If these mites make it back to water, they develop into free-living, predaceous adults. Little damage appears to be done to the adult dragonfly (Borror et al. 1989), but some researchers have made the case for damage to flight muscles by mites found on the thorax of dragonflies and damselflies, thereby

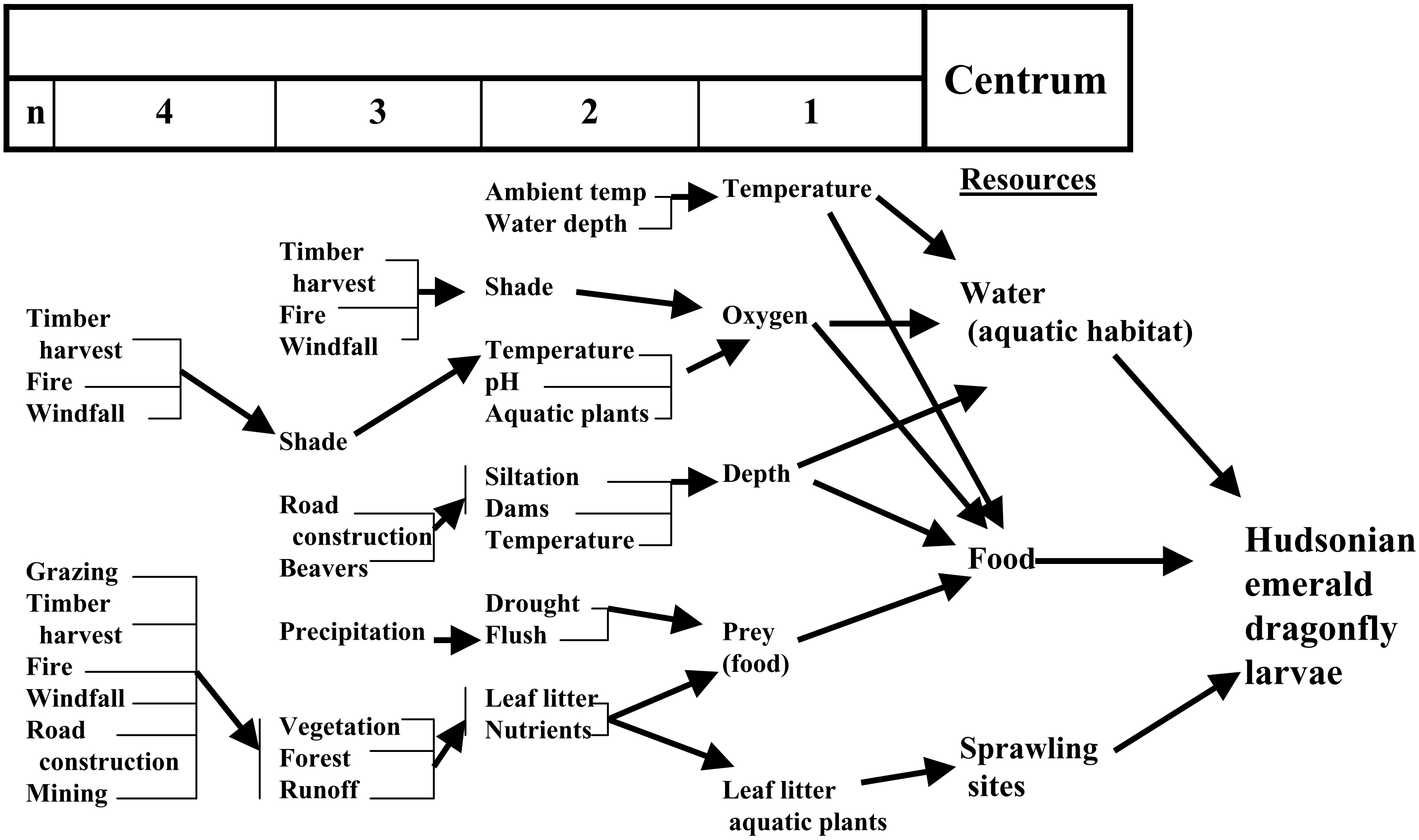

Figure 7a. Envirogram representing resources for Hudsonian emerald dragonfly larvae.

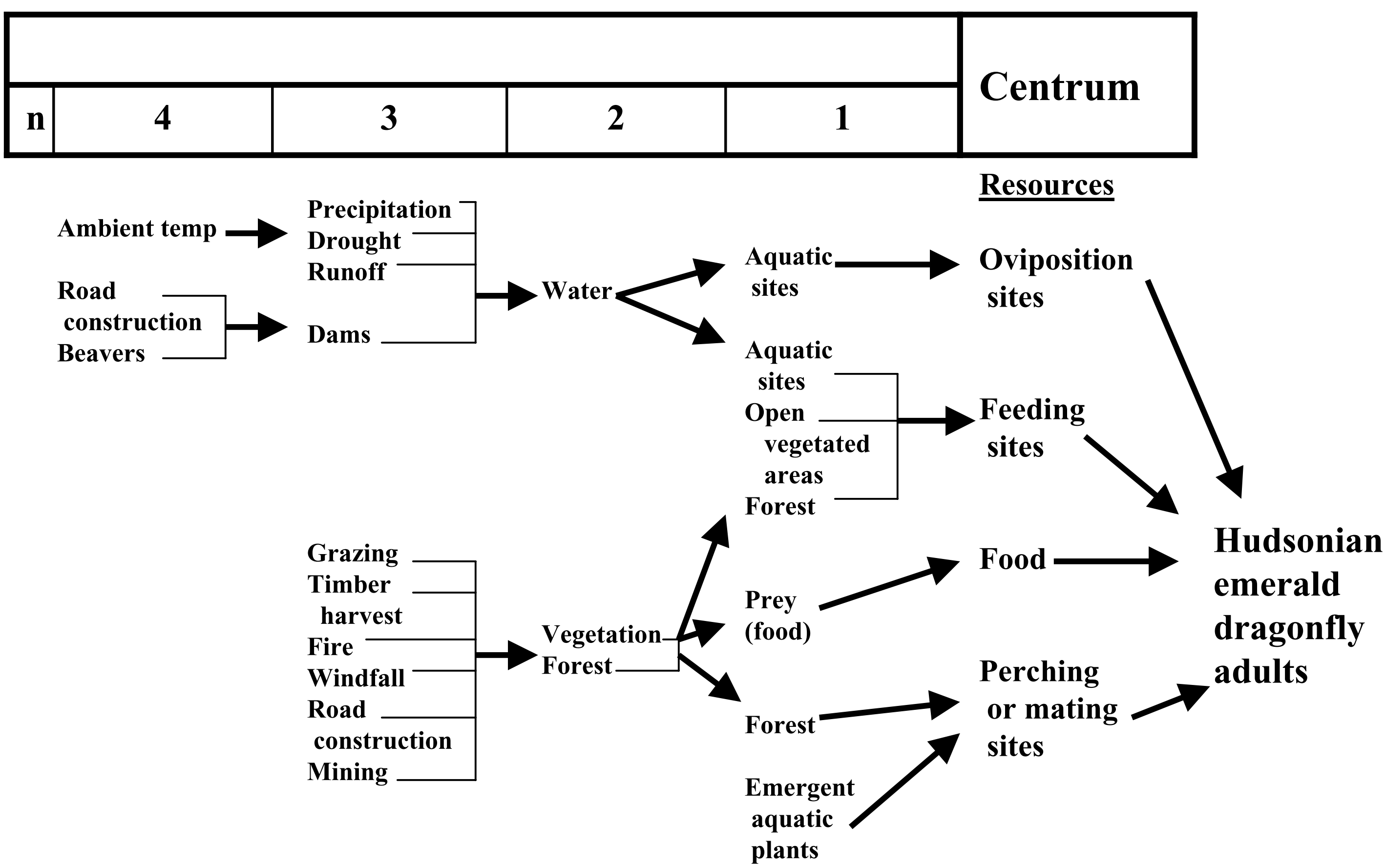

Figure 7b. Envirogram representing resources for Hudsonian emerald dragonfly adults.

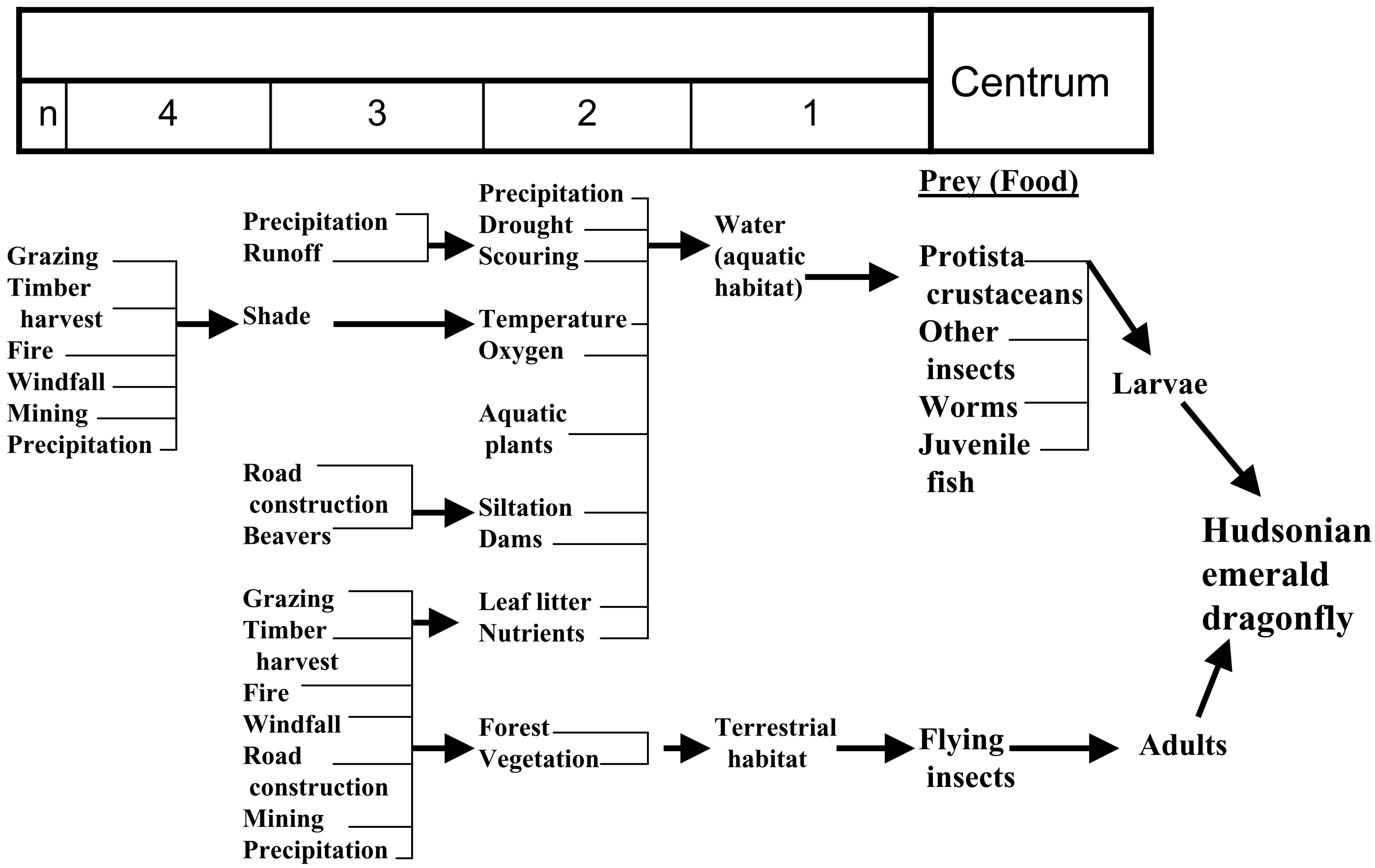

Figure 7c. Envirogram representing prey (food) for Hudsonian emerald dragonfly.

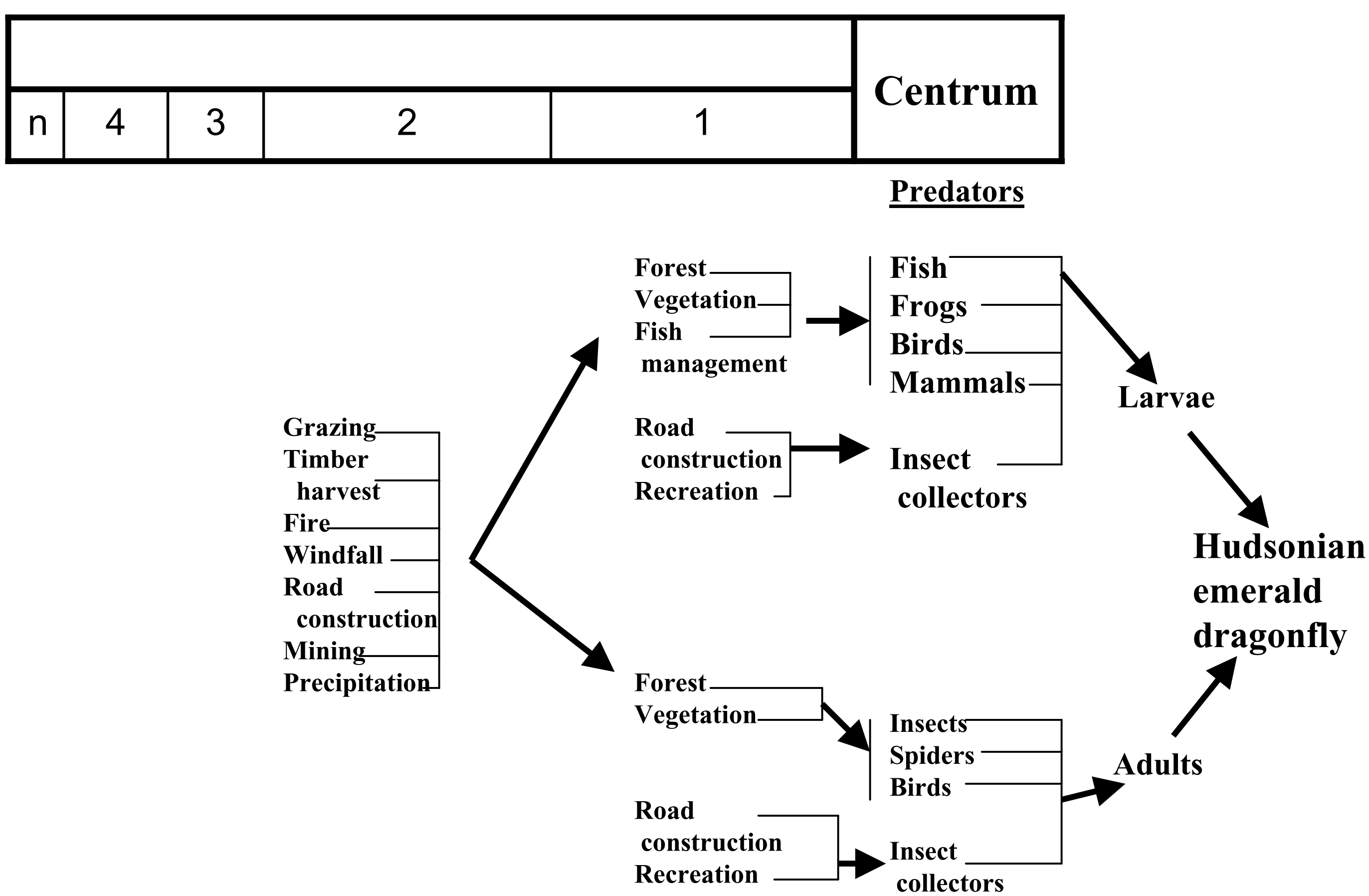

Figure 7d. Envirogram representing predators for Hudsonian emerald dragonfly.

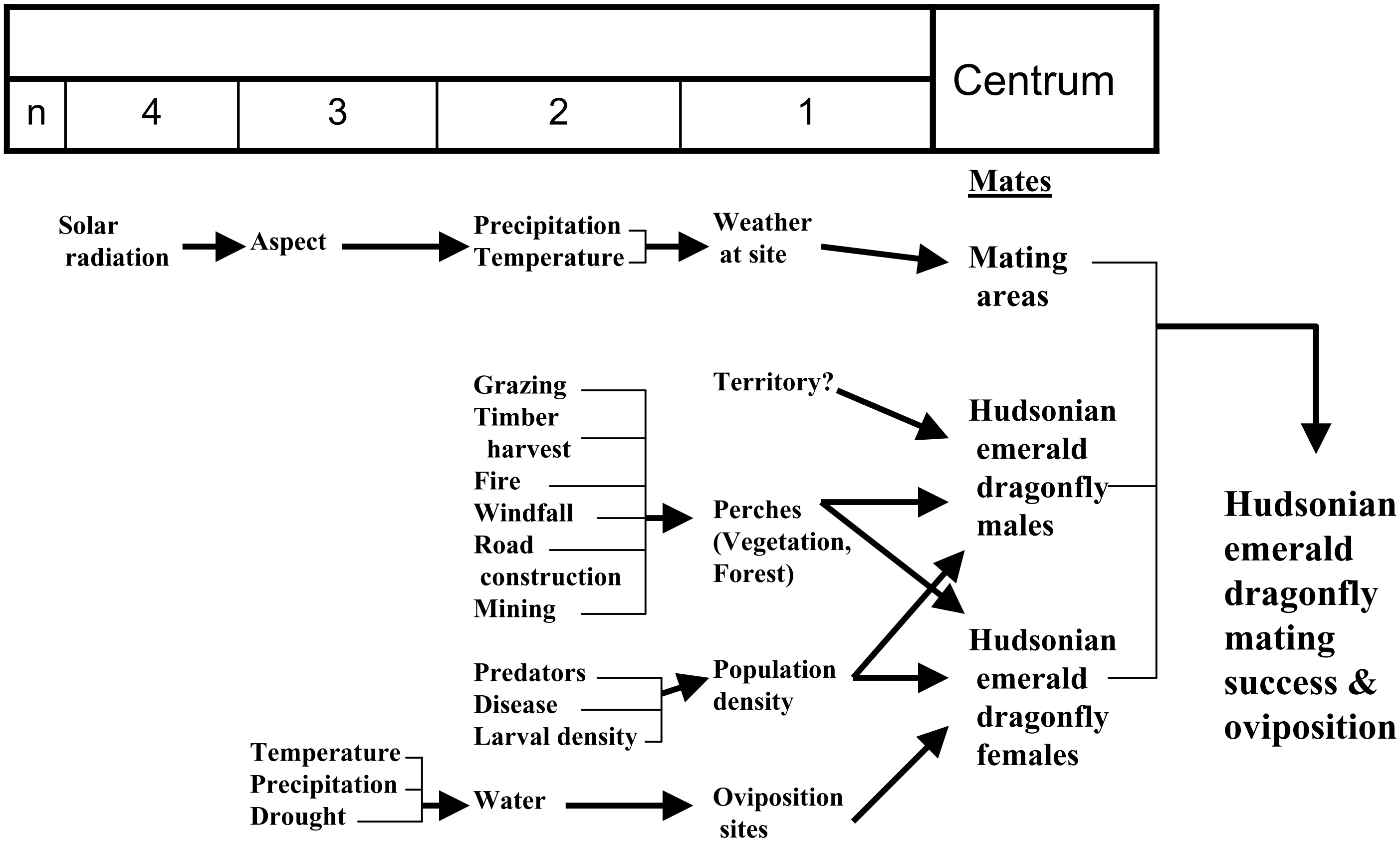

Figure 7e. Envirogram representing mating for Hudsonian emerald dragonfly.

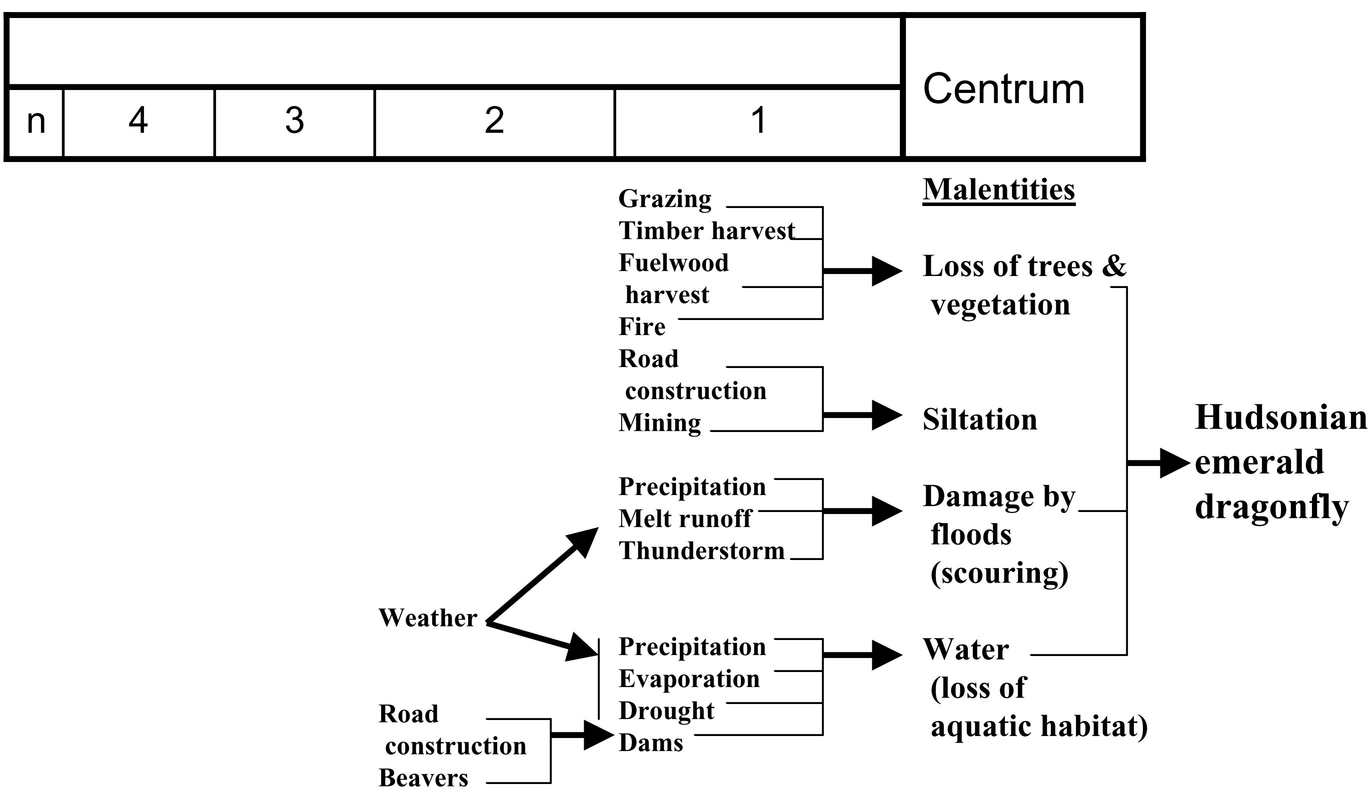

Figure 7f. Envirogram representing malentities for Hudsonian emerald dragonfly.

reducing flight capability (Pflugfelder 1970, Abro 1984). Mite-infested males were found to be attacked more often by members of their own species than to be doing the attacking; such males were also found to be less likely to form tandem flight and were rejected more often by females (Corbet 1999).

Other ectoparasites found on adult dragonflies are the biting midges (female flies of the Family Ceratopogonidae) that attach to the bases of the wings, where they may suck hemolymph (Downes 1958).

Internally, dragonflies are hosts to a long list of endoparasites including, but probably not limited to, gregarines (single-celled parasites of insects in the Kingdom Protista), immature forms of flukes and tapeworms (with the dragonflies serving as intermediate hosts for the definitive hosts of fish, amphibians, birds, and mammals), horsehair worms (arhropod parasites in the Phylum Nematomorpha), and roundworms (Phylum Nematoda) (Corbet 1999).

A number of commensals may live externally on dragonfly larvae including diatoms, rotifers, molluscs, and other insects (Corbet 1999).

Little is known about the pathogens of dragonflies, and much more study is needed before mortality roles of pathogens are elucidated. At least one virus has been found in dragonflies (Corbet 1999).

Dunkle (2000) also notes that the Hudsonian emerald is often found in such habitats along with the ringed emerald (*Somatochlora albicincta*) although this species is not known to occur in Region 2. Information on other aquatic invertebrate taxa in which Hudsonian emerald occurs as part of a larger species assemblage is not known.

Envirograms

Envirograms (**Figure 7**) are graphical representations of components or factors within the environment that either directly or indirectly affect an organism's chances for survival and reproduction (see Andrewartha and Birch 1984). They encompass three major propositions. In the first proposition the environment is made up of a "centrum" of directly acting components. The second proposition is that there is a "web" of indirectly acting components, linked as a chain with each link representing living organisms, their artifacts or residue, inorganic material, or energy. The third proposition is that the centrum is divided into four components called resources, predators, malentities, and mates (Andrewartha and Birch 1984).

Resources are separated for both larvae (**Figure 7a**), which are aquatic, and adults (**Figure 7b**), which are terrestrial, as obviously these are in differing habitats. I have also added an envirogram (**Figure 7c**) for prey of both aquatic (larval) and terrestrial (adult) stages.

The six diagrams in **Figure 7** can be viewed as a single envirogram for the Hudsonian emerald dragonfly. The figures represent the Andrewartha and Birch (1984) four divisions (resources, including an expansion of prey (food) to its own envirogram, predators, malentities, and mates) for the Hudsonian emerald. Management activities and events such as timber harvest, road building, fire, and others have been included in the webs of envirograms since these may have direct (in the case of malentities) or indirect effects on Hudsonian emeralds. Every attempt was made to include all components that are known or suspected of having effects on Hudsonian emeralds in Region 2. A brief description of each of the envirograms follows.

Figure 7a shows resource needs for Hudsonian emerald larvae. Water, food, and sprawling sites were deemed to be the most direct needs. Management activities and natural events are illustrated to show how they affect each of these needs.

Figure 7b shows resource needs for Hudsonian emerald adults. These differ significantly from those of the larva and include food, feeding sites, oviposition sites, as well as perching or mating sites. Oviposition sites are aquatic, and one can go back to the envirogram on the resources for larvae (**Figure 7a**) to examine other influences on water, which are also pertinent to the display shown here. The presence of trees may be more important than has been shown in this envirogram, serving not only as feeding sites and necessary components for production of prey (other insects), but also as mating sites.

Figure 7c shows factors that affect the food of both larvae and adults of the Hudsonian emerald, including some of the prey items possible for larvae. This may not be as important as the other envirograms, but if prey is lacking so is the Hudsonian emerald.

Figure 7d shows factors that affect the predators of Hudsonian emerald, including the main predators for both adults and larvae as well as insect collectors for both. Again, management processes that may influence both are included in the envirogram.

Figure 7e shows the factors important for mating among Hudsonian emeralds. Included are males and females as well as their mating sites. Males may be territorial, but this has yet to be observed among *Somatochlora* species. Other aspects are extrapolations from other dragonfly data. Perching areas may differ from mating areas, or, indeed, be the same. Oviposition sites are aquatic, and some of the same factors affecting water from **Figure 7a** (resources for larvae) can come into play in this diagram.

Figure 7f shows the malentities for the Hudsonian emeralds. Malentities can be considered as unfortunate consequences or damage, accidents, or artifacts of some management practices that may negatively affect Hudsonian emeralds. Included are mainly aquatic malentities that would affect the larvae, but also could threaten forage, mating, and oviposition sites for adults as well as degrade habitat for the next generation. The loss of trees and vegetation would more likely have an effect on the adults as to suitability of habitat, but also indirectly affects the aquatic habitat.

Conservation

Threats

Bick (1983) produced a list of 32 dragonfly species at risk in the United States. If he would have been aware of the paucity of specimens and locality data of *Somatochlora hudsonica*, there would have been little doubt that it would have been included on his list. Of these 32 species, 82 percent are associated with lotic systems. He stated that the most significant factor threatening dragonflies in North America is the loss of high quality, undammed, and entirely undisturbed streams, especially the larger ones. Threats to the aquatic habitat of immature Hudsonian emeralds are of key importance. Changes to the landscapes surrounding this aquatic habitat impact the aquatic environment severely. Road building, timber harvesting, wildfires or burning procedures, grazing practices, and mining all can negatively impact the aquatic ecosystem in which the Hudsonian emerald is found.

The loss of trees and the subsequent loss of shade surrounding the aquatic habitat (whether these trees are found upstream or in the immediate areas of residence) may profoundly affect the diversity of organisms found in the aquatic medium by raising the water temperature. High water temperature would not only aid evaporation, causing stagnation and concentration of nutrients within the water, but, in addition, higher temperatures themselves have an effect on the entire aquatic community.

Temperature is of primary importance to virtually all functions within an ecosystem. Temperature may directly affect organisms in an ecosystem, as well as produce secondary effects on production or composition of physical aspects of an aquatic ecosystem. Changes in temperature occur in lotic systems from loss or gain of cover, from an increase or decrease in sediments, changes in substrate, as well as changes in water depth. Such changes may occur as a consequence of urbanization or forestry practices (vegetative management). Greater tolerance to high temperatures has been shown for some species of Odonata that live in stagnant waters than for others living in streams, but odonates living in streams and lakes receiving cooling water were more heat tolerant than those from unaffected streams (Garten and Gentry 1976). Critical or lethal temperatures around 40 °C (104 °F) have been shown for some Odonata (Garten and Gentry 1976, Cherry et al. 1979). In response by communities, any temperature above 30 °C (86 °F) may cause a reduction in species numbers, abundance, biomass, and production (Dusage and Wisniewski 1976); prey would therefore be limited for odonates. Sublethal effects may be of more importance than critical or lethal temperatures that macroinvertebrates may undergo (Resh and Rosenberg 1984). Dragonflies may exhibit shorter developmental times or disruption of seasonal emergence. Niebeker (1971) has shown that high water temperatures in winter caused early emergence and greater lag time between emergence of males and females. High water temperatures also lead to less oxygen available in the water column producing anoxic levels that cause mortality of both Hudsonian emerald dragonflies and their prey. Low ambient temperatures could result in early death and no mating if lag times occur between male and female emergence.

Livestock grazing could impact the aquatic habitat by changing channel form and negatively affecting stream temperature. Grazing may also decrease aquatic vegetation, perching, emergence, or mating sites for adult dragonflies. Trees appear to be a necessary component surrounding the aquatic habitat of *Somatochlora* species (Walker 1925, British Dragonfly Society 1993, Vogt and Cashatt 1994, Cashatt and Vogt 2001). They may also be necessary as mating sites. Both trees and vegetation where prey may feed, perch, or otherwise be attracted to, serve as foraging areas for Hudsonian emerald adults.

Channelization, soil erosion, runoff, and increases in nutrients along with sedimentation, all threats to the habitat, can also occur as a result of road construction, creation of water diversion and impoundments, or due to beaver presence (dam building). Drought-reduced water quality, eutrophication, and algal bloom would decrease feeding success of predatory nymphs (or larvae) (Heliövaara and Väisänen 1993). Eutrophication as a result of discharge of nutrients from agricultural areas, sewage effluent, as well as other sources has been shown to threaten many dragonfly species in central Europe (Heliövaara and Väisänen 1993). Eutrophication and algal blooms are often due to the addition of nutrients to the aquatic medium. The cutting or burning of trees may cause soil erosion and runoff, which can also add soil components and nutrients to the aquatic habitats. Studies of streams where clear cutting occurred have shown increases of all nutrients in the water. Changes in channel form can cause sedimentation as well.

Livestock grazing and watering can add to both sedimentation and nutrient loading. Grazing animals may also add to the eutrophication of the systems by defecation in the surrounding area.

The lowering of water depth, whether by drought, ambient temperature increases, loss of shade, water withdrawals (for both human consumption and agriculture), or other factors, can affect the microhabitat of larvae. This concentrates individuals, exposing them to more predation by fish, other dragonfly nymphs, or larger members of their own species (cannibalism does occur among dragonflies). Increases in water depth can have an inverse negative effect by not concentrating (dispersing) their prey. Both effects could be caused by creation of dams by beavers or humans. Flooding, whether by heavy precipitation, heavy snowmelt, or release from dams, can produce flushing of the larvae from their typical habitats. The release of water from dams could also negatively affect the aquatic areas by decreasing water amounts leading to temperature increases in the habitat, concentrating nutrients in the water and negatively impacting prey species. Release of water from dams can produce negative effects by scouring habitats. Higher levels of water negatively impact aquatic vegetation, as well as emergent vegetation. Dragonfly larvae are sprawlers, striking passing prey from good vantage points. They require particular substrates of detritus, leaf litter, and vegetation, on which to sprawl. Adults also require emergent vegetation as platforms for undergoing their final molts (from larva to flying adult).

Flow or seepage from springs at shallow depths may be as important for Hudsonian emerald dragonflies as it is for Hine's emerald dragonflies. Beaver dams, impoundments, or diversions could therefore negatively impact Hudsonian emerald habitats.

The use of pesticides in other countries has been shown to affect dragonflies. In Zimbabwe the use of delmethrin to control tsetse flies caused a catastrophic drift (floating dead) among members of the family Gomphidae (Clubtail dragonflies; Grant 1989) while the use of pyrethroid applications markedly affected both dragonflies and damselflies in Nigeria (Smies et al. 1980). Wayland and Boag (1990) examined carbofuran (2,3-dihydro2-2 dimethyl-7-benzofuranyl methylcarbamate), one of the most widely used carbamate insecticides on the Canadian prairies, in terms of its effects on macroinvertebrates known for their importance as waterfowl food. They confined insects in small cages in prairie ponds that were subsequently treated with carbofuran. They found lower survival in *Enallagma* damselflies in treated ponds where concentrations were 9 and 32 µg/l, respectively. Other carbamates, such as fenoxycarb, an insect growth regulator, have induced varying degrees of morphogenetic aberrations in nontarget species. Miura and Takahashi (1987) found morphogenetic aberrations in dragonflies and damselflies (*Anax junius*, *Pantala hymenea*, and *Enallagma civile*) with treatment of 34 g a.i. per hectare for mosquitoes.

Piscicides could impact populations of the Hudsonian emerald, but no study has been done in this area.

Herbicides, in direct application to water for the destruction of undesirable plants as well as clearance of vegetation in waterways, have been also found to negatively affect dragonflies. Smith and Isom (1967) found that epiphytic insects, including dragonflies, disappeared after treatment with 2,4-D to control water milfoil in Tennessee.

Mining often produces compounds that produce acids when mixed with water. Acidification of waters may have a strong effect on Odonata. Bradt and Berg (1987) compared the benthos in three lakes in Pennsylvania with varying sensitivities of acidification and found higher biomass of Odonata in the circumneutral lake than in the more or less acidic lakes.

Chlorination of water can affect dragonflies as well. Discharge of chlorinated effluents from sewage or other treated runoff, containing high levels of humic material, can result in the formation of TCA (trichloroacetic acid) and other chlorinated products (Heliövaara and Väisänen 1993). Such compounds were found to increase oxygen consumption in dragonfly larvae (*Aeshna umbrosa*) at concentrations of 100 to 1000 µl/l (Dmoski and Karolewski 1979, Calbrese et al. 1987).

The introduction of insectivorous fish by fish managers or illegal stocking may influence Hudsonian emerald populations; if their habitats previously lacked these predators, the numbers of larvae may decline precipitously. Many fish are important predators of dragonfly larvae.

Conservation Status of the Hudsonian Emerald Dragonfly in Region 2

Currently, the Hudsonian emerald dragonfly is poorly understood in relation to its population numbers, demography, life history, ecology, mating habits, as well as characterization of its habitat. What we have is a species that is known from a limited number of sites across Region 2, according to actual collection data. Less than 40 specimen records exist for Region 2 as well as the rest of the continental United States. Whether these collections are indicative of limited distribution is open to debate. Most of the collection sites are reported here for the first time. None of the sites (with the possible exception of the Medicine Bow Mountain area in Wyoming) have been revisited, or if they have, no records of such revisits exist. This state of affairs warrants further study of former habitats by actual collection in these areas as well as other potential sites nearby. Until such studies of this taxon are completed, its rank of S2/S3 in Colorado is warranted, and this ranking should probably be given to the species in Wyoming as well.

Few management practices would directly affect the adult stage insects, with the possible exception of loss of trees and vegetation around aquatic habitats. Adult terrestrial stages, however, are only a fraction (<20 percent) of the entire life cycle. Management practices that directly impact the aquatic ecosystem in which the Hudsonian emerald resides would be of more importance to examine critically. These may include timber or fuel harvest too near to water resources. The loss of trees can subsequently produce fine sediment, excess nutrient loadings, and increase eutrophication of the aquatic medium. Further complications would be the loss of shade that could lead to temperature increase in the water and the negative effects of such temperature rises on both larvae and prey. The importance of trees/shrubs has previously been discussed, and these can be impacted by cutting of trees, fuel harvest, fires, and road building. The grazing of animals near water also produces direct impacts, by aiding sedimentation, destroying emergent vegetation, and increasing eutrophication of the water body as well. Mining operations leaching their tailings into the water column would have devastating impacts by increasing acidity, or adding toxins to the water environment.

Currently, the simplest path toward preservation of this species is that of preserving its aquatic or larval habitat. This may have other benefits as well. Habitats of the Hine's emerald dragonfly have been noted to support other rare species of plant and animals (U.S. Fish and Wildlife Service 2001). Benefits to similar species, if they are present, would accrue from conservation of Hudsonian emerald habitats.

A more accurate status of the Hudsonian emerald can only be assessed by more intensive study of this species to determine its true distribution and population size, and to characterize its habitat. At this time, there is no information on any of these parameters. Such study is further addressed in the Information Needs section. It is beneficial, however, to assume low populations currently, until evidence shows otherwise, than to look back in hindsight at the disappearance of this species.

Potential Management of the Hudsonian Emerald Dragonfly in Region 2

Implications and potential conservation elements

This species is known from only a few limited areas. Those areas and their nearby aquatic habitats must be protected from management practices that would adversely affect Hudsonian emerald habitat until more information on this species is forthcoming. The largest proportion of the life cycle is spent as larvae in the water (encompassing 80 percent or more of its life cycle), so these aquatic stages are the most important to preserve in order to produce reproducing populations. Threats or factors that would affect aquatic habitats were noted above.

Walker (1925) stated: "In the Transition and Upper austral zones the species of *Somatochlora* are ecologically unimportant elements of the odonate fauna.

They are all more or less rare and local and are found only where the original conditions of the environment have been little disturbed. When the forests are cleared and the streams dry up, or flow becomes irregular and water turbid or polluted, they soon disappear. Hence they are seldom found except in the wilder districts and even here they tend to occupy out-of-the-way places, where other dragonflies are few both in species and individuals. They are therefore seldom taken by the general collector and are among the rarer insects in collections." Walker made that statement for all species in the genus, but it certainly pertains to the Hudsonian emerald. If Walker is correct in his assessment, then management should be geared toward maintaining forested areas around this species' habitat, and every effort should be made to maintain the integrity of the aquatic systems in which they are found. The apparent rarity of Hudsonian emerald dragonfly encounters may be a function of the scarcity of high quality habitats in the region.

The Hine's emerald dragonfly was listed as federally endangered in January 1995, and there is a recovery plan for this species in USFS Region 3 (www.museum.state.il.us/research/entomology/hedplan.pdf; U.S. Fish and Wildlife Service 2001). The Hine's emerald dragonfly also appears to require nearby or adjacent forest or shrub areas, as noted previously and for other species of *Somatochlora*. This leads to the conclusion, unless further research shows otherwise, that the forest or shrub areas surrounding the aquatic habitats of Hudsonian emerald dragonfly may be critical to its survival and should be maintained. Therefore, management of forested areas around the identified sites of collection of this species appears to be crucial.

Timber harvest, fuel reduction, and fire management could severely negate the forest needed in the surrounding area of aquatic ecosystems. These trees may be necessary for production of insects that make up prey for dragonflies. In addition to foraging, they may also serve as mating areas, as well as produce shade that may lower the effect of solar radiation on the aquatic habitat itself, decreasing possibility of raising temperatures in the water column. Areas adjacent to Hudsonian emerald habitat sites could be left uncut as buffer zones to mitigate any effects tree loss would produce.

Other management practices that could severely impact population sizes of Hudsonian emerald dragonflies include grazing by livestock, impoundments, diversions, and road building. Such practices may negatively affect the aquatic habitat by altering channel form or stability of shoreline, and by increasing sedimentation, thereby increasing temperature and decreasing water clarity and/or depth. Livestock may also increase eutrophication of limited aquatic areas through defecation in the surrounding terrain. Excessive livestock grazing could also negatively impact riparian or emergent vegetation (important perching or final molting sites for dragonflies) that provide aquatic habitat stability. Where these problems occur, adjusting grazing systems, or providing for alternative water locations may be needed.

Mining and the building and maintaining of roads could also negatively impact habitats by increasing fine sediment within the aquatic environment. Such practices could also dam water that normally flows into the aquatic habitats. Changes in pH (acidity) as a result of runoff from mines or other mining practices in combination with acidified rainfall could kill off prey as well. Managers should carefully examine such practices near Hudsonian emerald habitat

Natural events, such as heavy rainfall or heavy snowmelt, could produce scouring effects. Droughts can cause changes in temperatures as well as nutrient concentrations. High ambient temperatures leading to drought increase water temperature, which leads to decreased levels of oxygen in the aquatic medium that could produce negative effects on the Hudsonian emerald as well as its prey. Extreme cold temperatures during the winter may cause the aquatic environment to completely freeze, killing all life as well as producing scouring effects by moving ice.

As discussed in the Demography section of this assessment, genetic diversity of subpopulations or disparate populations may harbor unique genetic components that must be preserved for genetic diversity and viability of the species.

Tools and practices

Inventory and monitoring populations and habitats

Moore (1991) has said of dragonflies that conservation depends on accurate knowledge of the current distribution of each species and that such information indicates whether measures should be taken to conserve a particular species. Very few specimens of Hudsonian emerald dragonfly are in collections, and those that are may reflect hurdles to its study. The first of these may be that its rarity is tied to its behavior of often flying at heights of 30 to 50 feet (9 to 15 m), thus not allowing easy capture. In addition, Walker (1925) said that species of *Somatochlora* "are seldom abundant even in the immediate vicinity of the breeding places," and called them "shy denisens of the wilderness" emphasizing the "remote nature of their habitats" that has impeded their capture and, thus, our knowledge of their life history. Secondly, the collection data may actually be an artifact reflecting proximity of localities to major universities. In Colorado, all sites of collection are fairly close to both the University of Colorado and Colorado State University, and in Wyoming, one site is fairly close to the University of Wyoming while the other is close to Yellowstone National Park (near Moran Junction). This may reflect easy accessibility (i.e., near roads, major trails). Other habitats in which these species may be found have likely not been examined as a result of little visitation by collectors or accessibility. Thirdly, it may very well be that little dragonfly collecting has been done in the Rocky Mountains, and thus species occurrence in other habitats is poorly understood. Of top priority would be the return to habitats that are known from the collection data listed in **Appendix B** and establishing the current presence or absence of this species at those habitats as well as further collecting at similar habitats.

Returning to historical areas where this species has been found will be necessary to characterize the aquatic habitats that occur there as we know so little about physical parameters of the habitat of this species. Conservation also depends upon sound knowledge of the habitat requirements of each species (Moore 1991). It is known that water is necessary for its developmental stages as an immature larva, but more specific information is needed:

- ❖ are these bodies of water permanent or semi-permanent?
- ❖ are they bogs?
- ❖ are they deep or shallow?
- ❖ are they spring-fed, glacial, or snow melts?
- ❖ what are the yearly temperatures of these waters?
- ❖ what of their pH, dissolved oxygen, or ion concentrations?
- ❖ are these bodies of water in open areas or associated with woodlands?
- ❖ what of the soils that characterize these areas?
- ❖ what of associations with other animals or plants?
- ❖ is there a preferred microhabitat for the immatures (e.g., particular plant, substrate, depositional quality)?
- ❖ on what do the immatures feed?
- ❖ what prey species occur in the aquatic habitat?
- ❖ are there fish or other potential predators present?
- ❖ are there preferred communities or animal or plant assemblages?
- ❖ are there plants or animals that are unique to these habitats and that may be indicators of potential or existing habitat for this species?

Along with the physical parameters, there is a need to examine the behavior of this species:

- ❖ what are its mating habits?
- ❖ is there territorial defense of mating areas?
- ❖ do males establish territories?
- ❖ are other dragonflies found in concert with Hudsonian emeralds?
- ❖ are there preferred oviposition sites?
- ❖ do they forage for food as adults in the same general areas where the immature forms are found?
- ❖ on what do the adults feed?

These questions can only be answered by direct observation of the species.

As a minimum, historical (collection data) sites need to be revisited and the presence or absence of this species needs to be established. Reasonable assessments of the types of habitat need to be made, and similar habitats need to be explored for presence or absence before further conservation measures can be explored.

Population or habitat management approaches

Any management practices done in or around the areas inhabited by this species must be done thoughtfully to have as little impact on the aquatic habitats as possible. Adaptive land management methodologies, such as adjusting livestock grazing regimes in riparian or wetland areas, creating alternative livestock watering sources, and leaving timber harvest and fuel reduction buffers around known aquatic habitats for this species may be warranted. Until proven otherwise, trees appear to be necessary in rather close proximity to larval aquatic habitat of Hudsonian emeralds. Fish managers should be made aware of Hudsonian emerald dragonfly sites when making decisions to stock areas that overlap the species' habitat and that were previously lacking in fish populations. At a minimum, the known aquatic habitats (**Appendix B**) must be kept in mind when proposing management of any kind in these areas.

Information Needs

As has been stated continuously in this document, very little pertinent information exists in the scientific literature for the Hudsonian emerald dragonfly. Indeed, there is very little information of use for conservation of dragonflies in general. There is an obvious gap in our understanding of dragonfly populations, their densities, habitat requirements, as well as basic life history data. Such understanding is crucial to the process of making decisions about management strategies that can address the well-being and viability of populations of the Hudsonian emerald. This leads to the question of what do we need to know?

There is an immediate specific need to conduct research that would involve collection visits to the known collection sites. It is possible that the species is even more limited in its distribution than this assessment reports as many of the specimen collections were taken nearly 30 years ago in Wyoming. While in Colorado, with the exception of four specimens taken in 2003 from a previously unknown site, all specimens were collected over 50 years ago (see **Appendix B**).

Such visits would reveal the presence or absence of Hudsonian emeralds. This can be done by searching for exuvia (cast skins of the last larval instar) on cattails or other emergent vegetation along the aquatic sites. These can be identified and are the preferred instar stage for using the only key to larvae of *Somatochlora* (Cashatt and Vogt 2001; **Appendix A**). Counts of these exuvia over a season can produce an estimate of the size of adult populations at historical sites. If they are no longer present in historically known sites, any management practices (i.e., grazing, road construction, timber harvest) that may have taken place at those sites should be noted as well as current aquatic conditions and absence or presence of trees. The prime survey period indicated by Walker (1925) would be during the month of July for aerial adults, while August would be the best month for observation of breeding. This would garner scientific fodder and make the case for restricting or allowing certain management practices to occur in areas where this species is present. Such a study could be done in a single season.

As a researcher visits these sites and collects adult dragonflies by aerial nets, larvae by aquatic dip nets, and exuvia on emergent vegetation, other pertinent data can be acquired. Characterizations of the aquatic habitat sites can be done. Such characterizations would give us an idea of whether or not the Hudsonian emerald is restricted to particular aquatic sites by answering key questions, such as:

- ❖ are they of a particular type, i.e. lotic or lentic?
- ❖ are such sites spring-fed, glacial melt areas, or impoundments?
- ❖ what is the size of the aquatic habitat (measurements made directly or by utilizing Global Information Systems [GIS] methods?
- ❖ do the larvae prefer slow moving or fast water?
- ❖ are they found in temporary waters?
- ❖ what is the importance of riparian and coniferous trees?

The Hine's emerald dragonfly, which is currently endangered in the Midwest, has been known to inhabit crayfish burrows when surface water is not abundant (Cashatt and Vogt 2001); is this also true of the Hudsonian emerald?

Other habitat inquiries should include a survey of prey found (both vertebrates and invertebrates) and note whether predators, particularly fish, are presently found. Once known for various sites, such information can be used to make correlations or comparisons among sites for prey, predators, or other variables such as associations of emergent vegetation, presence/absence of trees, shrubs, or meadows, and their proximity to the aquatic sites. This would help to explain why similar sites or former historical sites no longer have viable populations of Hudsonian emerald larvae.

If there are nearby aquatic habitats that are similar to historically known sites, adult collection visits to these areas could reveal more on the distribution of this species and answer the question of how widespread the species may be. However, presence of the larvae would be more indicative of a utilized aquatic habitat than presence of the adults that may forage there unless mating at the site can be observed. This can be revealed by a search for exuviae on emergent vegetation in such areas. The records already noted may be wanderers that are only foragers. If the habitats are similar to those of the Hine's emerald dragonfly (i.e., circumneutral to alkaline fens with groundwater seeps or springs), then these could be targeted as potential new habitat sites for the Hudsonian emerald dragonfly.

Another important area of research would be to work out the basic life history of the Hudsonian emerald. Laboratory raising of individuals would be necessary to establish numbers of instars (immature stages) as well as their sizes. Such research would help to establish if the Hudsonian emerald has a 2, 3, or even a 4-year life cycle from egg to adult dragonfly. This could be done by graphing numbers of immature individuals of particular instars (once established by size and wingpad length) of larvae present at habitat sites at various times over a number of seasons in at least two locales. This would show proportions of particular instars at various times over a succession of seasons (years) and would reveal recruitment (hatchlings) as well as overwintering stages and proportions of ultimate juvenile instars (stage prior to the adult stage).

In addition, mark and recapture methods such as The Schnabel Method or "multiple census" modified by Schumacher (Ricker 1958) or sequential sampling of Hutchinson (1994) could be used to estimate population densities of adults and/or larvae.

Other research could garner information on basic behavior of the Hudsonian emerald:

- ❖ are they extremely skittish; do the leave the area when disturbed?
- ❖ are males territorial?
- ❖ what are the mating and ovipositional behaviors?
- ❖ are there particular oviposition sites, or do they scatter eggs over the water or lay them in muck?

Such studies help to formulate the basic ecology of this species. The basic information outlined above is necessary before one can honestly assess the current status of this dragonfly as well as make judgements as to its viability as a species.

DEFINITIONS

Acidification – turning more acidic; a lowering of the pH

Cercus – paired lateral terminal appendages found at the end of the abdomen of male dragonflies (see **Figure 5**)

Chlorination – disinfection of water by the addition of small amounts of chlorine or chlorine compounds

Ciliates – single-celled organisms bearing cilia (small hair-like structures used for locomotion and food gathering) in the Kingdom Protista

Clade – a grouping for monophyletic (descended from a common ancestor) organisms

Conspecific – belonging to the same species

Crenation – rounded toothlike structure

Cu_1 vein – cubitus one vein in the wings of insects from a common system of naming and numbering veins of insects

Ectoparasite – external parasite

Endoparasite – internal parasite of the gut or hemolymph

Engulfers – characterization of species eating whole prey (carnivores)

Eutrophication – too many nutrients causing increases in photosynthetic organisms (e.g., algal blooms), subsequently causing decreases in oxygen levels

Exuvium (plural, -via) – the cast skin of an arthropod

Instar – general term for any particular stage (i.e., naidal, nymphal, larval, or pupal in insects)

Labium – the most ventral mouthpart or lower lip; in dragonfly larvae this is extensible and used to capture prey; it is folded upon itself at midlength and turned backward beneath the front legs

Larva (plural, –vae) – term used by Odonatologists for immature stages of dragonflies

Larval – of, or pertaining to the larva, but more properly used for insects that undergo complete metamorphosis (i.e., possess a pupal stage)

M_4 vein – median four vein in the wings of insects from a common system of naming and numbering veins of insects

Metamorphosis – the transformation of immature stages to the adult stage

Midges – flies that usually have an aquatic immature stage and may be biting (Family Ceratopogonidae) or non-biting (Family Chironomidae)

Molting – the act of ecysis; shedding of the previous cuticular exoskeleton

Morphogenetic aberrations – changes in form during development that are not normal for the species

Naiad – term for aquatic immature stages of insects that undergo incomplete metamorphosis

Oviposition – egg laying

Palpal lobes – lobe-like structures (quite variable) articulating at corners of the prementum

Palpal setae – setae found on the dorsal surface of the palpal lobes

Piscicide – chemical treatment that is often used to kill non-desirable fish in an aquatic system

Predaceous – feeding on other animals

Prementum – the most anterior segment of the labium

Pupa – stage in metamorphosis or development of an insect from immature to adult typical of complete metamorphosis in which development of wings is internal (often in cocoons) during which the insects rarely feeds; formerly thought of as a resting stage

Seta (plural, -ae) – a sclerotized (hardened cuticular) hairlike projection

Sprawlers – one of the designations of microhabitat found in dragonflies based on the way the legs are used to secure a larva's normal resting position; sprawlers use long, laterally extended legs to support the body on or among a matrix, usually of detritus or leaf litter; other designations may include claspers, hiders, burrowers, climbers, and crawlers

Stadium – amount of time spent in an instar.

Supernumerary veins – numerous cross veins found in the wings of insects typical of the paleopteran insects (e.g., mayflies, dragonflies, and damselflies)

Tagma – specialized region of the body in insects made up of segments a unit (i.e. head, thorax, abdomen)

Taxon – a group at any taxonomic rank (e.g., species, genus, family)

Thorax – the second tagma in insects; the locomotory region to which legs and wings are attached

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APPENDIX A

Key to adult species of *Somatachlora* in USDA Forest Service Region 2 (modified from Walker 1925)

Adult males:
1a. Apices of superior appendages bifid with a dorsocaudal and a ventral tooth .... *S. ensigera*
1b. Apices of superior appendages without a ventral tooth 2
2a. Apices of superior appendages slender and recurved 3
2b. Apices of superior appendages not recurved .... *S. semicircularis*
3a. Abdomen distinctly shorter than hind wing, widest as distal end of segment V, the width of which is about equal to it length .... *S. minor*
3b. Abdomen as long as hind wing, broadest at distal end of segment VI, distal width of segment V much less than its length.. 4
4a. Inferior appendage bifurcate; superior appendages with a prominent sub-basal external tooth and an ante-apical external prominence.. *S. cingulata*
4b. Inferior appendage triangular.. *S. hudsonica*

Adult females:
1a. Vulvar lamina erect or suberect, more or less compressed, triangular in profile, as long as lateral margin of segment IX, not longer.. 2
1b. Vulvar lamina usually horizontal or inclined, when erect shorter than lateral margin of IX, not or but little compressed... 3
2a. Labrum at least partly yellow, postclypeus wholly yellow .... *S. ensigera*
2b. Labrum wholly black, postclypeus or its median part black .... *S. minor*
3a. Thorax with 2 lateral yellow spots, the mesepimeral well defined, ovate, the metepimeral much smaller sometimes rather obscure; vulvar lamina half as long as sternum of IX, apically notched.................. *S. semicircularis*
3b. Thorax without a metepimeral yellow spot, the anterior spot small or wanting.. 4
4a. Vulvar lamina more than half as long as sternum of 9, entire or but, slightly emarginated, often projecting .... *S. hudsonica*
4b. Vulvar lamina a third as long as sternum of 9, not projecting .... *S. cingulata*

Key to larvae of *Somatachlora* in USDA Forest Service Region 2 (modified from Cashatt and Vogt 2001)

1a. Middorsal hooks present on S3-9, middorsal hook length on S3 greater than 1/8 middorsal length of S3.. *S. minor*
1b. Middorsal hooks present on S4-9, S5-9, or S6-9; middorsal hook on S3, if present then less than 1/8 middorsal length.. 2
2a. S9 with lateral spines at least 3/5 as wide as long... *S. ensigera*
2b. S9 with lateral spines less that 3/5 as wide as long.. 3
3a. Lateral spines distinct on S8 and 9.. 4
3b. Lateral spines absent or only on S9, may be minute, best observed from ventral view .... *S. hudsonica*
4a. Low, broad dorsal prominences on S4-9 (lateral view); metatibia length8.5-9.1; lateral margins of male epiproct with prominent tubercles.. *S. cingulata*
4b. No middorsal prominences on S4-9 (lateral view); metatibial length 6.7-8.5; lateral margin of male epiproct without tubercles .... *S. semicircularis*

Diagnosis: there are only two adult species in Region 2 which have narrow white rings between all abdominal segments: *S. cingulata* and *S. hudsonica*. The male cercus of *S. hudsonica* has a large pointed ventral angle at midlength, lacking in *S. cingulata*, while *S. hudsonica* females have an ovipositor, lacking in *S. cingulata*.

APPENDIX B

Published and unpublished (New) records for *Somatochlora hudsonica* in USDA Forest Service Region 2.

The following records are from label data on specimens of *Somatochlora hudsonica*. The additional coordinates in bold and in parentheses are approximate and revealed from maptech.com, UTM coordinates are for Zone 14.

Published *Somatochlora hudsonica* records:

Walker (1925): COLORADO: GILPIN Co.: **South Boulder Park (UTM: northing: 44 17 305 N, easting: 4 49 074 E; DMS: latitude: 39° 54' 26" N, longitude: 105° 35' 41" W):** 23. VI. 1914, 2 ♂ 1 ♀; 7. VII. 1914, 1 ♂; 10. VIII. 1914, 1 ♂; BOULDER Co.: **Teller Lakes (UTM: northing: 44 29 987 N easting: 4 87 244 E; DMS: latitude: 40° 01' 19" N longitude: 105° 08' 58" W)**, 1. VII. 1914, 1 ♀, with exuvium; 9. VIII. 1914, 1 ♂; 6. VII. 1915, 1 ♂ with exuvium. **Eldora Lakes (UTM: northing: 44 21 054 N easting: 4 51 680 E; DMS: latitude: 39° 56' 07" N longitude: 105° 35' 14" W)**, 11 VIII. 1914, 1 ♀. Also 2 ♀ with exuviae from Colorado without data (G. S. Dodds). *Nymphs*: Teller Lakes (See above for coordinates) 1. VII. 1914, 2 exuvium, with ♂ and ♀ adults; 6 VII 1915, 1 exuvium. with ♂ adult; and 2 exuvium. with ♀ adults from same general locality.

Bick and Hornuff (1972): (state records, 4 collections) WYOMING: TETON Co.(all), Moran Junction **(UTM: northing: 48 53 813 N easting: 5 39 210 E; DMS: latitude: 43° 50' 17" N longitude: 110° 30' 44" W):** 7.9 mi. S., VII-7-71, 1 ♂; 22.3 mi. E., VII-19-71, 3 ♂; 12.6 mi. E., VII-24-71, 1 ♂; 27.3 mi. N. W., VII-25-71, 2♂. All were taken at elevations of 6,600 to 8,500 feet, the first three collections at bog ponds, and the last along a creek fed by hot springs. **Note:** Bick and Hornuff (1972) considered their records to be "too limited seasonally and geographically to yield a comprehensive state list or to permit analysis of distribution within the state." They considered their collections of *Somatochlora hudsonica* filling a gap in the distribution of *S. hudsonica*.

Molnar and Lavigne (1979): WYOMING: ALBANY Co., (1 spec.) Medicine Bow Mtns., 19 July 1937. For TETON Co., they repeat Bick and Hornuff's records above.

Unpublished (new) *Somatochlora hudsonica* records:

COLORADO: LARIMER Co.: Bierstadt Lake **(UTM: northing: 44 64 043 N, easting: 4 47 131 E; DMS: latitude: 40 19' 37" N, longitude: 105 37' 20" W, ca. 7 mi SW of Estes Park)**, Rocky Mountain National Park, 28 July 1954 Caswell (coll.), (no determiner's name on determination label); BOULDER Co. 10,000ft; Gentian Lake near Science Lodge, 13 July 1939 URL Lanham (coll.), Determined: MA Evans 1986; BOULDER Co., 10,000ft, Science Lodge, 31 July 1939, URL Lanham (coll.), Determined MA Evans 1986; BOULDER Co., 9,200ft, Red Rock Lake **(UTM: northing: 44 36 849 N easting: 4 53 916 E; DMS: latitude: 40° 04' 57" N longitude: 105° 32' 26" W)** near Ward, 10 July 1939 HG Rodeck (coll.), Determined: MA Evan 1986. (personal communication, Virginia Scott, Collections Manager, Entomology Section, CU Museum). BOULDER Co., 4 specimens: Rainbow Lakes **(UTM: northing: 44 29 110 N easting: 4 50 012 E;DMS: latitude: 40° 00' 45" N longitude: 105° 35' 07" W)**, 10 August 2003, elevation: 10,200, lake in coniferous area with peat bogs, Air Temp 70°, H_2O Temp Lake 1 (lower): 78°, H_2O Temp Lake 2: 72°, Collected a short time after a rain and hail storm, Lake 1, collected 1 male *S. hudsonica* and 1 male *Somatochlora semicircularis*, Lake 2, collected 1 pair S. hudsonica and 1 male *S. hudsonica*. (Personal communication, Boris Kondratieff, Director, C. P. Gillette Arthropod Biodiversity Museum, Dept. of Entomology, Colorado State University).

WYOMING: ALBANY Co., 4 specimens: Snowy Range Mountains, North Fork, Little Laramie River **(UTM: northing: 44 67 955 N, easting: 4 07 707 E, DMS: latitude: 41° 15' 34" N, longitude: 106° 06' 05" W)**, September 4, 1978, R. Lavigne, coll. (Personal communication, Scott Shaw, Insect Museum Curator, Rocky Mountain Systematic Entomology Lab, University of Wyoming, Laramie, WY). With regard to these specimens, it's hard not to believe that these were plentiful at this site, as the collector collected four at once and anyone who has collected dragonflies knows it's hard to collect four of any dragonfly taxon during a collecting trip to a site. Robert Lavigne (the collector, personal communication) gave me that thought.