Dragonfly migration in North America is an understudied phenomenon. Little is known about key overwintering locations, the southern extent of migration, triggers and pathways for migration, and the degree and causes of differences in the intensity and timing of migration—but the Migratory Dragonfly Partnership (MDP) is changing that. Since 2011, MDP has combined research, citizen science, education, and outreach to better understand North America’s migrating dragonflies, and to promote conservation of their wetland habitats. Our work is revealing more details of this amazing process, and raising awareness of freshwater habitats and their importance to humans and wildlife. The main migratory species in North America are wetland-dependent, and although these dragonflies are currently widespread and abundant, their habitats are among the most threatened on the continent. Ongoing surveys by citizen scientists across North America coordinated by MDP will also allow us to detect the first changes in range or status that may occur due to impacts from climate change and habitat loss, which will better enable us to work toward the conservation of these animals and their habitats.

**Accomplishments**

In a short span of years, MDP has moved from being an exciting concept to a successful, active collaboration. Working with volunteers and professionals from Saskatchewan, Canada to Tabasco, Mexico, we have increased awareness of issues in dragonfly migration and conservation among thousands of people, including the public and staff of federal, state, and regional natural resource agencies. We have created high-quality publications on dragonfly migration, life history, identification, and habitat needs that are both accessible to the public and useful for natural resource professionals. Most importantly, we have engaged hundreds of enthusiastic volunteers and dozens of natural resource organizations across North America in citizen scientist projects that have generated thousands of observations of migratory dragonfly species. This work has already led to insights into dragonfly migration. With an established and growing network of monitors throughout North America, and analysis of the first few years of monitoring data, we are poised to expand our work in the coming years, so that we can ultimately fully explain—and protect—this amazing phenomenon.
WHAT HAVE WE LEARNED?

Dragonfly Migration

By reviewing published and unpublished information on dragonfly migration, and working with hundreds of volunteer monitors across North America, we are gaining a better understanding of the flight paths of migratory dragonflies and the timing and intensity of their annual flights in different parts of the continent. Early results indicate that the timing and intensity of migration flights varies annually within and between species. Specific insights into the timing and location of migration and aspects of species’ life histories include:

Fall Migration

- Timing, intensity, and relative species composition of dragonfly migration varies annually, even among species known to be regular migrants. The earliest and latest reports of migratory flights differ between and within species and years by as much as one month.

- Migration activity/intensity peaks in September, though the peak week varies from year to year, and can continue in southeastern Mexico at low levels through mid-November.

- Migration begins several weeks earlier in the east than in the west; this appears to be the trend for spring migration as well but the pattern is less clear at this point.

- Common Green Darner (*Anax junius*) is the most frequently reported migrant in the eastern USA and Canada, but Wandering and Spot-winged Gliders (*Pantala flavescens* and *P. hymenaea*) comprise a greater proportion of migrants in southeastern Mexico. This may suggest that more Common Green Darners are overwintering in Florida, but additional research is needed.

- Swamp Darners (*Epiaeschna heros*) have a short localized burst of migration dispersal annually, as the first large fall flights reported in the northeastern USA include high proportions of this species (often in conjunction with a smaller number of Common Green Darners), but Swamp Darners are not reported later in the season or farther south.

- Large flights that follow the east or west coast or Great Lakes may assemble at staging areas located farther inland/upland.

- Time of year and apparently appropriate weather conditions are not a guarantee of migration activity, even in a locality where migration has been seen within recent days.

- Migrants in the east continue farther south than Veracruz, but the southern extent of this migration and the location of dragonfly overwintering grounds are unknown.
Spring Migration

- Movement to the north is governed by spring temperatures; as temperatures warm, migrants are seen soon after, especially in the east. Although a cold snap will halt their activity, movement north resumes almost immediately upon warming.

- Return of migrants to the north in spring is more diffuse in space and time than fall migration, but may occur at times in spring in large directed flights, as we have seen for Common Green Darner and Variegated Meadowhawk (*Sympetrum corruptum*).

- MDP analyzed first flight dates for Common Green Darner for 13 states in the USA (Connecticut, Georgia, Maine, Maryland, New Hampshire, New York, North Carolina, Ohio, Oklahoma, Vermont, and West Virginia), and determined latitude, longitude, and degree days for each month associated with each record. Findings from this work include:
  
  • First flight dates were strongly positively correlated with latitude and negatively correlated with degree days, confirming the strong influence of warming temperatures on movement.

  • Common Green Darners travel an average of 27.4 km per day (17.03 miles per day) during northbound migration, and advance their first flight date by four days for every additional degree day.

Using Stable Isotope Technology to Understand the Movement and Life History of Migratory Species

Unlike other insect migrants such as the monarch butterfly, migratory dragonflies do not overwinter in dense groups. Their extreme mobility and difficulty of capture means that traditional mark-recapture studies are not possible. MDP is therefore using a different kind of mark to infer the movements of individual Common Green Darners: measuring the ratios of stable hydrogen isotopes in the adult wings and the cast-off skin (exuviae) of the final-stage nymph from which the adult emerged. These isotopes are present in the water where a dragonfly develops and remain locked in the wings and exuviae forever afterward. Examining stable hydrogen isotope ratios in exuviae helped us calibrate a latitudinal “isoscape” map, and assessing the ratio in the wings of captured adults allows us to infer the latitude at which the specimen developed and the direction and distance of its movement as an adult.

Because dragonfly wings cannot be repaired if they are damaged, older specimens as well as longer-distance migrants are expected to have a greater degree of wing
wear. Thus, the amount of wing wear on each specimen was also measured and is being assessed in combination with the stable isotope ratios to determine if there is a correlation between distance traveled from adult emergence site and the amount of damage to the wings.

This work demonstrated that Common Green Darner adults present in northern latitudes in the spring developed as nymphs in the south. Both resident and migrant individuals are present during the winter in the southern USA, indicating that not all migrants continue farther south into Mexico. The majority of migrant adults found in winter in the southern USA do not survive to make a return journey north but surprisingly, a few individuals may live through the winter and return north the following spring. Analysis of stable hydrogen isotope ratios in 1,000 wings and 300 exuviae of Common Green Darners collected in the eastern USA revealed the following:

- The strong positive relationship between isotope ratios in exuviae and wings of teneral (newly emerged) Common Green Darner adults and the known annual isotope ratios in water across eastern North America demonstrate that this is a valid way of determining emergence locality. In addition, specimen age does not affect isotope signature, allowing us to expand our dataset with material from museum specimens.
- Common Green Darners emerge locally in the southern USA (Florida, Georgia, and Alabama) for most of the year. Southbound migrants that originated in northern wetlands appear in August and September, and both residents and migrants are present in the southern USA in winter. Isotope patterns further indicate that most migrants do not survive the winter to return north. However, unexpectedly, it appears that a small number may overwinter and return north the following spring. A few of the Common Green Darners collected in Wisconsin, New York, and Vermont in April and May originated in the north; because it is still too early and cold at this time of year for resident nymphs in northern wetlands to have broken their winter diapause (dormancy) and completed development to adults, this raises the possibility that at least some could survive winter in the south and make a round-trip migration.
- Adult Common Green Darners collected in the far northern reaches of their range in early spring originated in the far south, meaning that they were migrant adults returning north to breed. Those collected in late summer in the same sites originated in the far north; this population represents the residents emerging locally.
- Collecting exuviae allows timing of adult emergence to be assessed. The appearance of exuviae at wetlands in the eastern USA echoes the pattern of adult movement. Exuviae appear in a south-to-north direction in spring and then are found in widely scattered locations in mid-summer. More exuviae appear in the north in late summer, and by late October exuviae records are present only in the southernmost states. This reflects the completion of development of overwintering resident nymphs beginning in the south in spring and continuing north as temperatures rise, and development and emergence of both residents and migrants in the summer. Nymphs hatched from eggs laid by returned migrants in the north in early spring develop rapidly and emerge in late summer as adults that will then migrate south. Both residents and migrants reproduce in winter in Florida, and at least some of the migrants’ offspring return north in the spring.

WHO HAVE WE REACHED?

We have reached thousands of people through our citizen science network, outreach and education events, publications and resources, our website, and social and traditional media, such as newspaper articles and radio interviews. Our message across all venues and media is that dragonflies are an important part of terrestrial and aquatic ecosystems, they can help control pest insects, and their habitat is vital not only for their survival but for the conservation of myriad other species, including migratory birds and waterfowl.

Citizen Science

- Participation in MDP citizen science programs has increased steadily since their inception in 2012; hundreds of volunteers are now participating in Migration Monitoring and Pond Watch projects throughout North America.
- By the end of 2014, 747 registered users had reported 5,800 Pond Watch and Migration observations on the MDP website—an increase of 340% in registered users and 800% in reporting from 2012.
- Because volunteers expressed a strong desire to report data in real time using mobile devices, we are working with David Bell (Birds in the Hand) to develop apps on iOS and Android platforms for identifying dragonflies and reporting observations (http://tinyurl.com/pkxbtkt). The identification app will be released first, and is being beta tested in spring 2015. Funding to support app development was obtained from outside sources, includ-
ing two private individuals who supported half the cost, and the Dragonfly Society of the Americas.

**Audiences and Communications Media**

- From 2012 through 2014, we reached at least 1,200 people directly through 35 workshops and presentations given across the USA and in Canada. These events were attended by the public, members of environmental education programs (Master Naturalist, Master Gardener), and staff of federal, state, and regional natural resource agencies.

- We reached thousands more through online and hard-copy distribution of MDP Dragonfly Habitat Guidelines and Pond Watch postcards, and by registering MDP volunteer projects on CitSci.org and Scistarter.org. In 2014, Scistarter.org named Pond Watch as one of the 10 top “Citizen Science in the Classroom” projects (of 800 projects registered on their site).

- The mailing list for MDP’s monthly e-newsletter has over 2,752 recipients, many of whom share each newsletter on their own Facebook feeds.

- The Hawk Migration Association of North America publishes an annual article written by MDP on the season’s migration data and the role of Hawk Watch observatories in its newsletter.

- The MDP Facebook page (https://www.facebook.com/MigratoryDragonflyPartnership) is nearing 1,000 “likes”, with steady growth since the page’s launch in 2012. The current demographic of our Facebook fans breaks down as 62% female and 36% male representing 39 countries, the top 10 being the USA, Canada, Mexico, Indonesia, Italy, and a tie among Costa Rica, Egypt, Colombia, Sweden, and Brazil.

- MDP’s Twitter account (@Dragonfly_MDP) has 80 followers; MDP posts are re-tweeted by at least two followers.

- MDP’s YouTube channel (https://www.youtube.com/user/MigratoryDragonfly) was launched in 2011, and the training and presentation videos available there have been viewed over 400 times.

- Scientific audiences:
  - We reached more than 200 people via presentations at conferences such as Dragonfly Society of the Americas, Society for Freshwater Science, and Hawk Migration Association of America.
  - To frame the work of MDP as the partnership was launched, MDP steering committee member Dr. Mike May wrote a comprehensive review of the current state of our knowledge.
about dragonfly migration in North America. This review was published in Journal of Insect Conservation, a core peer-reviewed journal in the field of conservation science with international scope and audience (February 2013, Vol. 17, issue 1, pp. 1–15; article cited 5 times in 2014), and has reached larger scientific audiences because Dr. May exercised the option to publish the paper as Open Access.

Spanish speakers:
- We translated the MDP field guide to migratory dragonflies into Spanish.
- We delivered two workshops in Tabasco in Spanish.
- We began developing Spanish-language sections of the MDP website.

Partners
We have engaged a variety of partners to help implement our successful programs. These include organizations and individuals from Mexico, the USA, and Canada.

- Two years of capacity-building through MDP empowered Pronatura Veracruz staff to conduct dragonfly migration monitoring full-time during their Rio de Rapaces (the annual fall raptor migration, which they have monitored for many years and during which they have regularly seen dragonfly migrations), incorporate dragonflies into local environmental education activities, and begin work on a guide to the most common odonates of southern Veracruz to share with visitors to their observatories.

- Through a partnership with Espacios Naturales y Desarrollo Sustentable (ENDESU) and Pronatura Veracruz, we taught two Spanish-language workshops in Tabasco at La Reserva de la Biosfera Pantanos de Centla.

- The Hawk Migration Association of North America board voted in 2013 to incorporate dragonfly monitoring formally into their Hawk Watch database; by the end of 2014, 18 observatories had contributed over 1,300 observations to MDP. The number of participating observatories is expanding, and several are now continuing dragonfly monitoring during their spring counting seasons as well.

- At the invitation of Dr. Leslie Ries (National Socio-Environmental Synthesis Center; SESYNC), we have joined the working group of her multi-year NSF-funded project addressing challenges and methods for analyzing data collected from a variety of invertebrate-focused citizen science projects.

- State-level Master Naturalist organizations have embraced the education and volunteer opportunities offered though MDP workshops and citizen science projects, and members of many programs, especially in Texas and Minnesota, have become active volunteers and agents of further outreach.
Dragonfly Society of the Americas provided partial financial support for development and maintenance of the new mobile apps.

The Minnesota Dragonfly Society, a newly formed nonprofit organization created by individuals who participated in the statewide dragonfly census several years ago, is an active proponent of MDP; they have incorporated information about migration and MDP projects in the many educational events they conduct around the state, and are investigating additional regionally focused projects as opportunities for partnerships with MDP.

Through a partnership with Dr. Karen Oberhauser at the University of Minnesota, MDP is providing input on the new dragonfly curriculum for elementary school and middle school students that her lab is developing, and we will work with her to train teachers in its use once it is completed.

LESSONS LEARNED AND KEY NEXT STEPS

We have used adaptive management in data collection and analysis and in our volunteer management practices. We strive constantly to retain and work productively with current volunteers and partners while gaining new partners and project participants. With a large enough number of records from a sufficiently broad geographic scope, we are also learning more about how best to visualize and analyze the data, and dealing with the challenges inherent in the range of resolution and information content in volunteer-generated observations. Specific lessons learned and subsequent next steps include:

Migration

- Data gaps exist for the local phenology (life history) of migratory species.
  - Next steps: Incorporate a study on the local phenology of migrants by creating a field guide to exuviae and incorporating monitoring of exuviae, with an initial focus on Common Green Darner, into Pond Watch.

- Relationships between and presence of overwintering resident versus migrants in southern locations of the USA are not clear.
  - Next steps: Develop and implement targeted studies in southern California, Arizona, Texas, and Florida, making observations throughout the year at a limited number of selected sites.

- The level of information in migration reports varies greatly, including whether individual species and/or their abundances are reported, and there is some overlap between Migration and Pond Watch reports, especially in the spring.
  - Next steps: Work with a biostatistician to formulate data analysis methods and identify and address any gaps or issues in the way we are currently collecting data.

Conservation

- The main migratory dragonfly species are not currently rare or endangered, but multiple other North American dragonfly species are at risk, and even common species may become rarer as their habitats are lost and global climate change impacts occur.
  - Next steps: Work with NatureServe to revise their current odonate species accounts and statuses; work with state fish and game agencies in the USA to accurately represent odonates in their State Wildlife Action Plans.

Citizen Science

- Two-way communication is key in recruiting and maintaining volunteers. To foster this, we issue an annual survey to participants to gain insights into volunteer attitudes and needs, and we added a member list and shared localities option to the MDP website to make it easier for members to interact with each other.
  - Next steps: We are exploring ways to make the website more interactive and encourage more cross-member conversations among Facebook fans and website users. We will continue to share data and findings with the public and scientific audiences, including practitioners of citizen science, via newsletters and journal publications. MDP steering committee member Dr. Mike May is currently collaborating with other researchers outside of MDP on a new publication tentatively titled “Emergence phenology of *Anax junius* in North America".
Materials and workshops in Spanish have been well received, and having resources available in Spanish has made it easier for additional volunteers and partners to participate.

- Next steps: Additional Spanish-language resources are needed. A field guide for Mexico has long been critically needed but does not currently exist, so MDP may need to create identification resources in Spanish on the MDP website.

Our network of monitors has grown steadily, but gaps in data reporting still exist in northern Canada, much of Mexico, and parts of southeastern and west-central USA.

- Next steps: Continue to expand network of monitors across North America, with an emphasis on expanding our partners and monitoring networks in Mexico and providing more Spanish-language resources; continue to engage the public, schools, Master Naturalist programs, federal and state agency staff and others about the importance of dragonflies, their habitat and how they can engage in citizen science.

### Continuing the Migratory Dragonfly Partnership

MDP has been successful in advancing our understanding of dragonfly migration and in engaging a constituency that is actively collecting the data we need and becoming more aware of the landscapes these animals inhabit and how to protect them. In just a few years, we created an effective network of partners and volunteers, supported by our high-quality resources in education, outreach, and identification. We have engaged thousands of enthusiastic participants across North America whose efforts have already given us insights into dragonfly migration and life history. The educational materials that accompany participation in MDP projects have raised awareness not only about migration but also about the threats and conservation needs of this remarkable group of insects. We have established systems that will help us engage larger numbers of people in these efforts at an overall lower cost. With a state of the art citizen science website, training materials in two languages and externally-funded mobile apps that will allow easier access to our identification materials and facilitate reporting, we have set the stage the next phase of this project. As our work expands in the coming years, we will be able to fully explain the process of dragonfly migration in North America, and implement more conservation actions to protect dragonflies and conserve and restore the habitat they need to survive.

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**Photographs**

*Front:* A Common Green Darner lays eggs (Photograph by Walter Chadwick, citizen science volunteer).


*Back:* A pond in a suburban backyard supports dragonflies.

All photographs taken by Xerces Society staff, except where indicated.