Danaus plexippus

MONARCH BUTTERFLY MONITORING IN NORTH AMERICA: OVERVIEW OF INITIATIVES AND PROTOCOLS

This background paper was prepared for the Secretariat of the Commission for Environmental Cooperation (CEC) by Karen Oberhauser, Rebecca Batalden and Elizabeth Howard and does not necessarily reflect the views of the governments of Canada, Mexico or the United States of America.

Published by the Communications Department of the CEC Secretariat.

Publication details
Type: Background paper
Date: February 2009
Original language: English
Review and Quality Assurance Procedures
• Review by the Parties: September 2008

For more information, please consult the Introduction.

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ISBN 978-2-923358-56-7 (Electronic version)

Dépôt légal – Bibliothèque et Archives nationales
du Québec, 2009

Dépôt légal – Bibliothèque et Archives Canada, 2009

Printed in Canada

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1 INTRODUCTION

Background and Uses of this Overview[1]

A key objective of the North American Monarch Conservation Plan (NAMCP) is to "*monitor monarch baseline performance and habitat quality*" (CEC 2008). To address this objective, during the development of the NAMCP, a trinational multi-stakeholder group of experts recommended the development and dissemination of a monarch monitoring program as a complementary tool.

Monarchs are currently monitored in many locations, using many different methods.

Monarchs are currently monitored in many locations, using many different methods. Some monitoring programs assess local densities of breeding monarchs throughout their breeding range, numbers of individual butterflies passing through migratory stop-over sites, and areas occupied on the winter range. Other programs assess the timing and location of fall and spring migratory movement. The fact that monarchs are spread over such a large area for most of their annual migratory cycle makes their population dynamics difficult to assess, and integrating information from so many programs presents a scientific challenge that we are only beginning to address. However, without these programs, we would have no understanding of such basic questions as how and when monarchs use available habitat, how population numbers change within and between years, how environmental perturbations affect these changes, and how monarch populations are responding to conservation efforts.

This book is a trilateral resource that can be used in Mexico, the United States and Canada by anyone interested in monarch biology or conservation, including land managers, citizen scientists, and nature center personnel. Our goal is to facilitate the development of monarch monitoring programs throughout the monarch's annual cycle of breeding, migrating and overwintering in North America. Importantly, because many of the monitoring programs are currently focused on monarchs in Canada and the United States, a Spanish introduction to these programs will allow organizations and individuals in Mexico to choose monitoring protocols that are appropriate to their location and specific needs, contact leaders of existing programs, enter their data, and access the findings of monarch monitoring programs. In addition to contributing data that enhance our understanding of monarch biology, organizations and individuals will be able to assess habitat quality with respect to monarchs' biological needs during the breeding and migratory phases of the annual cycle. Local monitoring programs can also inform management strategies that will promote monarch long-term survival.

The program descriptions included here are not meant to include comprehensive directions for participation. Rather, they introduce the programs, giving enough background that organizations and individuals will be able to decide if a particular program is appropriate for their location. Detailed directions for programs that involve the public are included on the websites provided. Additionally, Spanish translations of the directions and datasheets for some programs are available as an annex to this document at: http://www.cec.org/monarch.

[1] Prepared by Karen Oberhauser, Rebecca Batalden and Elizabeth Howard.

Overall, this handbook seeks to support improved access to data and information from monarch monitoring programs in North America, whether carried out by governments, academic institutions, and nongovernmental or citizen science organizations. It is imperative, however, that scientific data are collected carefully and shared broadly. Keep clear and detailed records of the methods you use and the timing and location of your observations. If possible, take pictures to aid in record keeping. If you collect data for which there is no centralized repository, as is the case for some of the programs described here, it may be more difficult to disseminate your findings. If you are not associated with scientists who are familiar with the process of submitting research for scientific publication, contact a scientist or organization able to help you publish your research findings. This will allow everyone interested in monarch biology and conservation to learn from your work.

Citizen Science

Many of the programs described here are citizen science projects, projects that involve people who are not professionals in scientific research.

Many of the programs described here are citizen science projects, projects that involve people who are not professionals in scientific research. Ideally, these programs result in data that advance scientific understanding and can be applied to real-world problems. Unlike most scientific research, citizen science often combines research, education, community development, and conservation outcomes (Oberhauser and Prysby 2008).

The first organized citizen science projects in the field of biology probably engaged citizens in collecting data on bird distribution and abundance (Droege 2007), but there is a long history of lay interest in butterflies. For example, the field notes and reports of many Victorian collectors comprise important contributions to our understanding of butterfly range, behavior and abundance. In fact, the first citizen science project designed to answer a specific research question (versus inventory and monitoring projects) probably involved monarch butterflies. Dr. Fred Urquhart's monarch tagging program throughout much of the twentieth century engaged hundreds of volunteers in a hunt for the winter destination of the Eastern North American migratory monarch butterfly population, a goal that they ultimately achieved in early 1975 (Urquhart 1976). Today, monarch citizen science programs are providing important information on the status of monarch populations, as well as engaging thousands of people in direct observations of monarch biology and engendering increased desire to promote monarch conservation.

Citizen science monitoring programs provide multiple values for land managers. They provide information on the status of the monarch population at a very local level, as well as contribute to continental-scale understanding. They provide an ideal way to engage visitors in conservation activities in federally managed parks, forests and refuges; state parks and forests; local parks and nature centers; and any other terrain visited by the public. Finally, they provide information that can be used in land assessment, or evaluation, and management.

Monarch butterflies are ideal candidates for citizen monitoring programs, for both practical and scientific reasons. From a practical perspective, they enjoy an almost iconic status with the public, and many people are willing to invest time to contribute to a better understanding of their biology and conservation needs. They are easy to recognize, and utilize habitats that are accessible to many people. From a scientific perspective, an understanding of monarch population dynamics requires long-term and large-scale monitoring. Monarchs utilize diverse habitats during their annual migratory cycle, and their populations fluctuate dramatically within and between years. Several overlapping breeding generations develop in milkweed patches across the United States and southern

Canada, then they migrate over a broad latitudinal range and overwinter in the mountains of central Mexico and coastal California. Throughout the course of this annual cycle, monarch distribution and abundance are affected by current environmental factors and conditions found in preceding habitats. For example, monarch abundance in June in the north central United States may be affected by storms in central Mexico in the preceding January, or dry conditions in Texas during April and May. The abundance of their host plants, competition from other milkweed-consuming herbivores, predators, land-use change, pesticide use, and human-induced climatic change also affect monarch abundance (Zalucki 1982; Malcolm et al. 1987; Zalucki and Rochester 1999, 2004; York and Oberhauser 2002; Oberhauser and Peterson 2003; Batalden et al. 2007). Understanding all of these factors would be difficult or impossible without the participation of citizen scientists throughout monarch habitats across North America.

2 MONARCH ANNUAL CYCLE

North America is home to two fairly well defined monarch populations, often referred to as the eastern and western migratory populations. The eastern population, found east of the Rocky Mountains, migrates to central Mexico, while the western population overwinters in coastal California. Recent work suggests that interchange between these populations could occur during the spring and fall migrations (Pyle 2000; Brower and Pyle 2004). Wayward migrants from the western population may follow the mountains from California through Nevada and Arizona, then into Mexico, and arrive at the eastern population's Mexican overwintering sites.

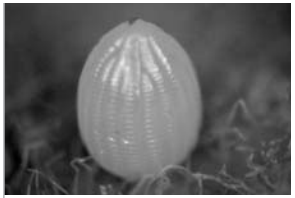
A non-migratory population lives along the gulf coast and southern Florida. This may not be a self-sustaining population; migrating monarchs, particularly those en route to Mexico from the eastern United States, could arrive in summer-like southern Florida, cease migrating, and become permanent residents.

Breeding Biology

Monarch butterflies breed throughout much of the United States and Mexico. The eastern migratory population breeds from the southern United States to southern Canada and from the Atlantic coast to the Rocky Mountains. The western population extends from the Rocky Mountains to the Pacific coast and from the Canadian border to the southern United States.

Three to four generations are produced in the United States and southern Canada each summer, and only the last of these migrates to wintering sites in Mexico or California. The number of generations and the development time between generations are dependent on latitude and climatic conditions. Under cool temperatures development can require more than 60 days, compared to fewer than 30 days under summer conditions (Cockrell et al. 1993).

Monarch reproduction is completely dependent on the presence of their larval host plants, primarily milkweeds in the genus ***Asclepias***[2] (Lynch and Martin 1993). Until recently, milkweeds were included in the family *Asclepiadaceae*, but the family is now treated as a subfamily in the dogbane family, *Apocynaceae*. Over 100 species of milkweed exist in North America (Woodson 1954), and monarchs will utilize most of these, although a small number of species probably host most individuals.



Egg on Asclepias syriaca *(common milkweed)*

Eggs: Females lay eggs only on milkweed, ensuring that the **larvae** will have a ready supply of food upon hatching. Typically, a female lays one egg per milkweed plant, usually attached to the underside of the leaf. This placement probably provides added protection from predators or heavy rain. Monarch eggs are cream-colored, with a pointed tip and vertical ridges. Development rates at all stages vary with temperature—with development slower under cooler conditions—but typically eggs hatch four days after being laid.

Newly-hatched monarch first instar eating its chorion (egg shell). This caterpillar has not taken its first bite of milkweed, and thus does not have any stripes.

Individual females probably lay 300 to 400 eggs during their lifetime, but resources allocated to egg production are limited. Proteins, which are an important component of eggs, must either be derived from nutrients ingested during the larval stage or from the **spermatophore** obtained from males during mating (Boggs and Gilbert 1979; Oberhauser 1997). An individual monarch egg weighs about 0.460 milligrams (mg), about 1/100th the weight of the adult. Thus, females laying up to 400 eggs will lay more than their own weight in eggs in the course of their lifetimes!

Larvae: Monarchs complete almost all of their growth during the larval stage. They typically begin life by eating their eggshell (**chorion**), which provides a valuable first meal. A newly hatched monarch larva is greenish-gray in color, as it does not get its characteristic white, yellow and black stripes until after ingesting milkweed.

Characteristic eating patterns of monarch larvae.

To avoid becoming ensnared in milkweed latex, the sticky white sap from which milkweed gets its name, monarch caterpillars first bite through the leaf veins delivering the latex. If exposed to the latex, larvae risk gluing their **mandibles** together and starving (Zalucki et al. 2001). The characteristic half-moon-shaped eating pattern provides the small larvae with a safe meal. Larger caterpillars, with a larger appetite, cut off latex supply to the entire leaf by notching the petiole.

The larval stage lasts from 9 to 14 days. Larvae molt (shed their skin) as they grow, and the stages between larval molts are called instars. Monarchs go through five separate larval **instars**, which are distinguishable by the monarchs' head size and the presence and length of **filaments** on their **thorax** and **abdomen**. Although monarch larvae increase their body mass about 2000 times from hatching to **pupation**, size is not a good determinant of instar; caterpillars increase in size significantly between molts.

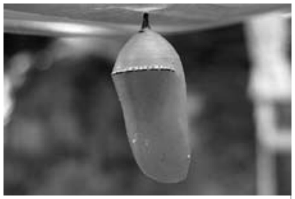
Five larval instars and egg

In parts of the southern United States, the range of the monarch butterfly overlaps with a close cousin, the queen butterfly (*Danaus gilippus*). While eggs of the two species are indistinguishable, queen larvae possess a third set of filaments in the middle of their abdomen.

Queen larva. Note the third pair of filaments in the middle of the abdomen.

Monarch eggs and larvae have a slim chance of reaching adulthood, with mortality rates of over 90% during the egg and larval stages (Borkin 1982; Zalucki and Kitching 1982; Oberhauser et al. 2001; Prysby 2004). **Abiotic** (nonliving) sources of mortality for eggs and larvae include environmental conditions such as pesticides and adverse weather. Eggs do not hatch in very dry conditions, and temperatures above 36°C can be lethal (Zalucki

[2] This and other bolded words are defined in a glossary at the end of the handbook.



Monarch pupa.

1982; Malcolm et al. 1987; York and Oberhauser 2002; Batalden personal observations). The effects of extreme temperatures on plants magnify the impact of these temperatures, since monarchs are indirectly affected by conditions that affect the health and survival of milkweed.

Biotic (living) factors that affect monarch survival include natural enemies and interactions with their milkweed hosts. Many monarchs are killed by invertebrate predators that eat the monarchs themselves, or by **parasitoids** whose larvae develop in and eventually kill the monarch host (Prysby 2004; Oberhauser et al. 2007). Diseases caused by bacteria, viruses, fungi, and other organisms are also significant sources of monarch mortality (Altizer 2001).

Pupae: Just before they pupate, monarch larvae spin a silk mat from which they hang upside down. After about a day, they shed their skin for the last time, and form the **pupa**, or chrysalis. The pupal stage, during which the transformation to the adult stage is completed, lasts about 9–15 days.

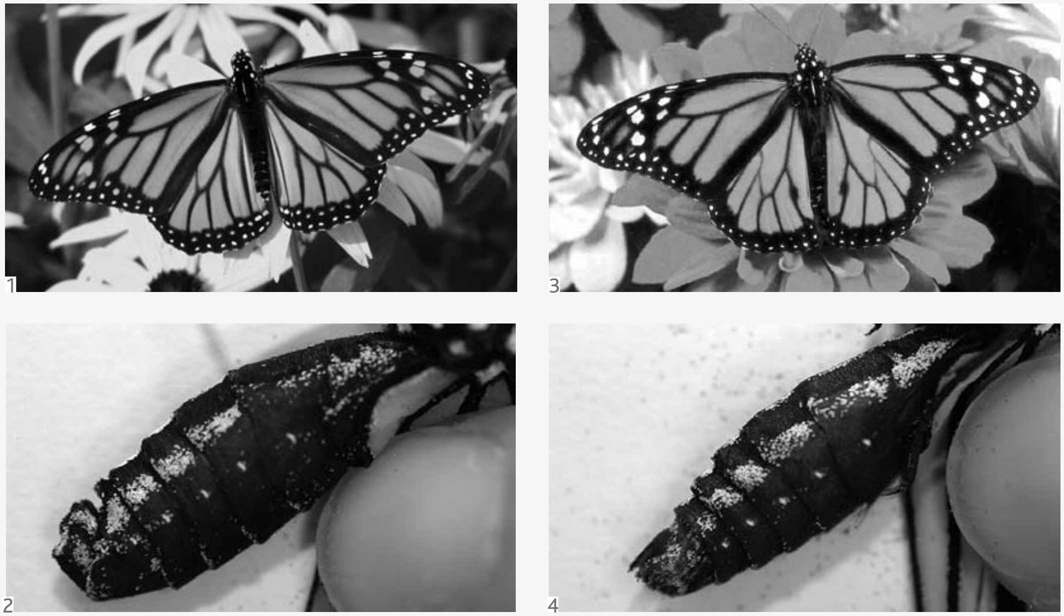
Most of the physiological and **morphological** changes that produce an adult monarch actually do not take place during the pupal stage. The wings and other adult organs develop from tiny clusters of cells already present in the larva, and by the time it pupates, the monarch has already begun the major changes to the adult form. As it forms the pupa, the antennae, **proboscis**, wings, and legs move to the surface, just inside the **exoskeleton**. Within the pupa, there is a major reorganization of the flight muscles in the thorax and, in males, sperm mature during the pupal stage. Eggs do not mature until after **eclosion**.

From the outside, few of these changes are visible until the last day. At this time, the scale pigmentation develops, and the black, orange, and white wing patterns can be seen. Until then, the pupae are green with gold flecks. It is difficult to find monarch pupae in the wild; their green color provides effective camouflage in a green world, and they appear to seek sheltered spots to undergo this transformation.

Adults: The primary goal during the adult stage is to reproduce—to mate and lay the eggs that will become the next generation. During the breeding season, adult monarchs live from two to five weeks. They first mate when they are three to eight days old (Oberhauser and Hampton 1995), and females begin laying eggs immediately after their first mating. When mating, the male and female stay coupled from one afternoon until early the next morning, sometimes up to 16 hours. The male uses this time to transfer the spermatophore to the female. Both sexes mate multiple times.

Since there is a delay between adult emergence and egg-laying and because monarch adults reproduce over a relatively long time, maximizing reproductive success requires being able to survive predators, environmental extremes, and other sources of mortality. The **aposematic**, or warning, coloration of the adult helps deter predators. The bright orange color on their wings tells predators that monarchs are distasteful or even poisonous to eat. Monarchs sequester a **cardenolide** toxin acquired as larvae from their milkweed host plant. This toxin makes them **unpalatable** as larvae and adults.

Male and female adults are distinguishable by the black dot on each hind wing that is not present on the female. These spots are made of specialized scales that produce a chemical used during courtship in many species of butterflies and moths, although such a chemical does not seem to be important in monarch courtship. The ends of the abdomens are also shaped differently in males and females, and females often look darker than males and appear to have wider veins on their wings.



Male and female adults

1 *Female on black-eyed susan*
2 *Female abdomen showing abdominal slit*
3 *Male on zinnias*
4 *Male abdomen showing claspers*

Fall Migration

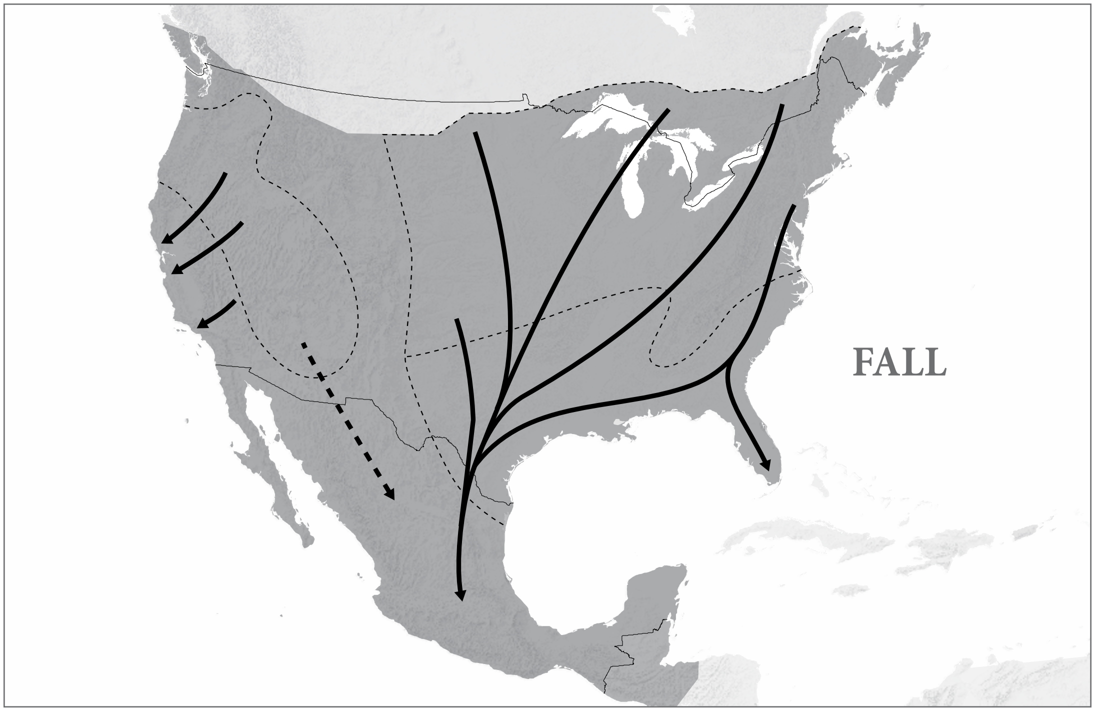
Monarchs are essentially a tropical species, and cannot survive freezing conditions. The incredible migration of the eastern population probably evolved with the northward expansion of milkweed after the melting of the last glaciers (Brower 1995). Monarchs followed their host plant, capitalizing on newly available habitat, but still need to move south for the winter. Every year they travel to the same mountainous location in central Mexico to winter in the protection of the **oyamel** fir trees.

While monarchs that develop during the summer are reproductive soon after eclosing, butterflies emerging in late summer or early fall delay reproduction. This period of reproductive arrest is termed **diapause**, and allows monarchs to use the energy that would have gone towards egg and spermatophore production for flying. In addition, the energy saved allows this migratory generation to live all winter, up to nine months. Monarch diapause is induced by decreasing day-length, fluctuating temperatures, and **senescing** milkweed (Goehring and Oberhauser 2002).

The monarch butterfly is the only butterfly to make such a long, two-way migration. The fall migration starts in late August and early September in the northern United States and southern Canada. Traveling between 80 and 160 kilometers (km) per day, these migrants are joined by additional monarchs along the way and reach the southern United States in late September and October. As they migrate, monarchs drink nectar to increase their **lipid** stores for the winter (Brower 1985; Gibo and McCurdy 1993; Borland et al. 2004). At night, hundreds or thousands of migrating butterflies roost in hanging clusters on trees. Some trees are used consistently year after year, probably chosen because they are sheltered from the wind.

Monarch butterfly habitat
Migration direction
Light migration
Population zones

Source: Maps based on research by Lincoln Brower, Sonia Altizer, Michelle Solensky and Karen Oberhauser, with reference to maps of Journey North and Texas Monarch Watch



The population west of the Rocky Mountains also migrates, but a much shorter distance. These monarchs overwinter along the coast of California, and then the population expands into nearby states in the Pacific Northwest for the summer.

Overwintering

Two overwintering colonies exist in North America: in central Mexico and in coastal California (Brower 1995). Monarchs also inhabit southern Florida and other parts of the Gulf Coast during the winter. The Florida population breeds all year, and probably receives yearly influxes of migrating monarchs from the eastern population (Knight et al. 1999; Altizer 2001).

Whether spending the winter in the mountains of Mexico or coastal California, monarchs migrate to specific locations. They require particular environmental characteristics to survive throughout the winter. If conditions are too hot, they will deplete their lipid reserves and not survive until spring. Warm weather could also stimulate reproductive behavior, causing them to leave the overwintering areas while it is still too cold in their breeding habitats. If it is too cold or wet, monarchs could freeze to death (Anderson and Brower 1996).

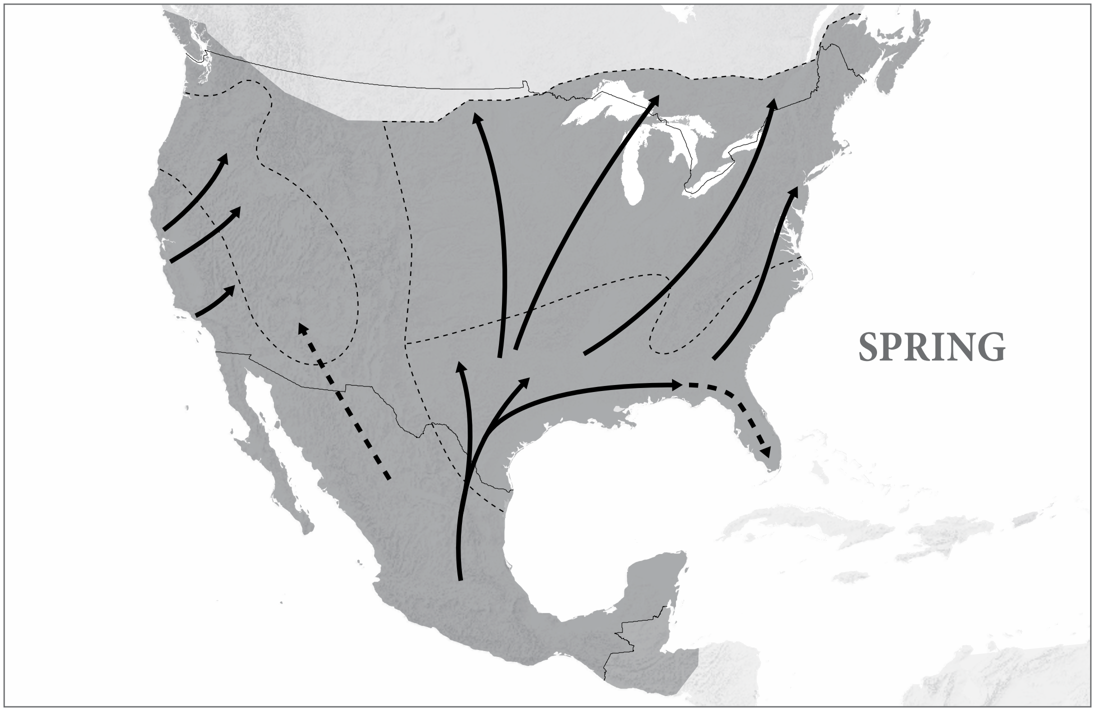
Oyamel fir forests in the mountains of central Mexico provide the required climate for the eastern migratory population. The high altitude, around 3000 meters (m), keeps temperatures from becoming too warm. The forest also acts like a blanket, protecting the monarchs from the wind and from becoming too cold. Logging provides an immediate threat to these overwintering sites, and it is possible that climate change will render these sites unsuitable in the next 50 years (Brower et al. 2002; Oberhauser and Peterson 2003).

In California, monarchs roost in wooded areas dominated by eucalyptus trees, Monterey pines, and Monterey cypresses. Again, monarchs seek sites with specific microclimate conditions, and are most often found in sheltered bays or inland areas. More than 300 different overwintering colonies have been reported (Frey and Schaffner 2004; Leong et al. 2004).

Mexico overwintering site.

Spring Migration

In early March, temperatures warm in the overwintering sites, the monarchs become more active, and some break diapause and begin to mate. Soon, the colonies will disappear as the monarchs migrate back to their breeding habitat. The spring migration is markedly different from the fall, as the monarchs are mating and laying eggs as they fly. Monarchs in the eastern population lay their eggs in the southern United States. These eggs will become the first summer generation, completing the migration as they disperse throughout eastern North America as milkweed becomes available. Monarchs reach the northern limit of their habitat in early to mid-June.



Monarch butterfly habitat
Migration direction
Light migration
Population zones

Source: Maps based on research by Lincoln Brower, Sonia Altizer, Michelle Solensky and Karen Oberhauser, with reference to maps of Journey North and Texas Monarch Watch

3 OVERVIEW OF MONITORING PROGRAMS

Monitoring opportunities exist during all stages of the monarch annual cycle, and can be tailored to meet the needs of individuals and organizations throughout North America.

Monitoring opportunities exist during all stages of the monarch annual cycle, and can be tailored to meet the needs of individuals and organizations throughout North America. Table 1 summarizes monarch monitoring programs described in this book; we suggest skimming their descriptions before choosing one or more programs for your site.

The first four columns after the program names in Table 1 refer to the four stages in the monarch annual cycle of ***breeding, migrating south, overwintering*** and ***migrating north***. A check in one of these columns means that the program can be conducted during that stage of the annual cycle. The fall and spring migration maps (see pp. 10 and 11) illustrate monarch migration ranges, and monarchs breed throughout their entire range. Thus, you can monitor monarchs throughout much of North America. Programs with a ***centralized data repository*** tend to cover entire states or provinces, or the entire monarch breeding or migratory range. These programs are centrally run, with prescribed protocols, and often make their data available to participants and the scientific community. Programs that are run at a ***single site*** have usually been developed to address a biological phenomenon that occurs at one location, such as a migratory **stopover site**. Programs that do not have a check in either the centralized data repository or single site column (flight vectors, habitat assessment and vital statistics) address data needs for which centralized data bases have not yet been developed. If you are interested in carrying out one of the programs without a centralized database, we suggest using the protocols described here, and then using your data to inform your own site development. It is also important to share the data with the public and with monarch scientists; feel free to contact the authors of this book for information on contacting appropriate scientists.

Some monitoring programs are not associated with a particular season or stage of the annual cycle of breeding, migrating and overwintering. For example, in Project MonarchHealth, volunteers sample the abdomen of wild-caught monarchs for a parasitic spore. This can be done during any stage of the annual cycle. Habitat assessments can also be done at any time, as can butterfly censuses. Other programs may have their primary focus on a particular stage, such as the Monarch Larva Monitoring Project (breeding stage) or Journey North (spring migration), but because different stages of the annual cycle often overlap and vary in timing throughout the monarchs' North American range, the programs may be conducted across different stages.

In some programs, monitoring involves capturing monarch butterflies to assess their condition or to place a tag on their wing. This is true for Project MonarchHealth and Monarch Watch. Wildlife protection laws in Mexico include the monarch butterfly as a protected species, and volunteers may not collect butterflies. Individuals in Mexico interested in either of these projects would need to contact a multidisciplinary scientific group, led by Profepa. The group includes representatives of Mexico's National Commission of Protected Natural Areas (***Comisión Nacional de Áreas Naturales Protegidas***, Conanp-RBMM), university groups from the National Autonomous University of Mexico (***Universidad Nacional Autónoma de México***, UNAM) and the ***Instituto Politécnico Nacional*** (National Polytechnic Institute, IPN) and nongovernmental organizations like the World Wildlife Fund (WWF).

Table 1. Monarch Butterfly Monitoring Programs in which Interested Individuals and Organizations can Participate.

	PROGRAM OR PROGRAM CATEGORY	STAGE IN ANNUAL LIFE CYCLE				CENTRAL-IZED DATA REPOSI-TORY?	SINGLE SITE?**	WEB ADDRESS
		SUMMER BREEDING	FALL MIGRATION SOUTH	OVER WINTERING	SPRING MIGRATION NORTH			
HABITAT ASSESSMENTS	Milkweed (p. 14)	x	x	x	x			none
	Nectar Sources (p. 22)	x	x	x	x			none
BREEDING POPULATION MONITORING	Monarch Larva Monitoring Project (MLMP) (p. 23)	x	x		x	x		http://www.mlmp.org
POPULATION CENSUSES	NABA Butterfly Counts (p. 26)	x	x		x	x		http://www.naba.org
	Butterfly Monitoring Networks (multiple programs) (p. 27)	x	x		x	x	x	various
	Fall migration and stopover sites (multiple programs) (p. 29)		x				x	various
	Project Monarch Alert (p. 32)			x		x		http://www.calpoly.edu/~bio/Monarchs/index.html
MIGRATION	Monarch Watch (p. 35)		x			x		http://www.monarch-watch.org
	Texas Monarch Watch (p. 37)		x		x	x		www.tpwd.state.tx.us/learning/texas_nature_trackers/monarch/
	Journey North (p. 38)		x	x	x	x		http://www.learner.org/jnorth
	Correo Real (p. 41)		x					none
	Flight vectors (p. 42)		x		x			none
INDIVIDUAL MONARCH ASSESSMENTS	Project Monarch Health (p. 43)	x	x	x	x	x		http://www.monarch-parasites.org
	Monarch Vital Statistics (p. 44)	x	x	x	x			http://www.monarchlab.org

** Programs are marked as having a centralized data repository if one organization maintains a database for multiple sites across a broad geographic region.*
*** Programs are marked as a single site if there are multiple programs within the category that are specific to one location.*

The following sections provide information on the goals and history of monitoring programs, their protocols, and how the data are used. We include fairly detailed summaries of the protocols of each project to help you determine if the projects are appropriate for your circumstances, but anyone who would like to contribute data to a specific project should visit the relevant website or contact organizers.

If you do not have access to the Internet, a companion annex (available at http://www.cec.org/monarch) includes complete protocols and data sheets for some of the programs. For readers whose primary language is not English, the annex will also be a valuable resource, since most project websites are in English.

We still know very little about the extent to which monarchs use different milkweed species, and how they perform when they consume different species as larvae.

4 HABITAT ASSESSMENTS

No independent programs currently monitor monarch habitat, whether it be the milkweed community, nectar sources, or overwintering sites. However, data on monarch habitat, particularly when monarch presence and absence is noted, provide a more complete understanding of monarchs' biological requirements, threats to their populations, and causes of variations in monarch population sizes. Here, we focus on methods for monitoring the presence and abundance of larval host plants and adult nectar sources.

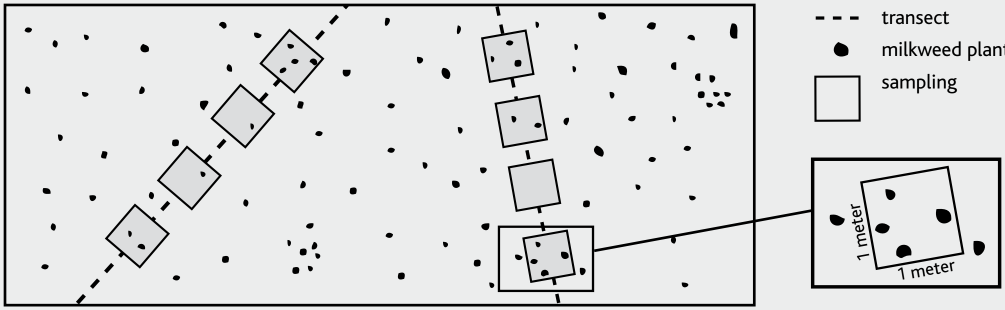
Milkweed

Information about the use of different milkweed species by monarchs, the phenology and distribution of milkweed species, and milkweed condition will provide important information that can be used in monarch conservation projects and habitat assessments. We still know very little about the extent to which monarchs use different milkweed species, and how they perform when they consume different species as larvae. We also know very little about the effect of habitat type, climate or land use patterns on the abundance of different milkweed species.

Here, we describe monitoring protocols for assessing the density, condition and species composition of milkweed plants.

Density

The protocol described here refers to Monarch Larva Monitoring Project (MLMP) activities (detailed directions and data-reporting forms can be found online; see below).



Milkweed density protocol diagram. This diagram, not drawn to scale, illustrates two transects, with 1-meter squares in which milkweed density is measured.

Because milkweed may not all be above-ground at the beginning of the season, density measurements are generally conducted at the middle of the monarch breeding season in a given area, when all of the milkweed is up and before it has begun to **senesce**. In most places farther north than 35° latitude, density would be best measured in June. In areas farther south than 35° latitude, density should be measured in May.

Milkweed density can be measured in two ways. If you can easily count all of the milkweed plants at your site, record the actual number of milkweeds at the site and the area of the site (in square meters). Then divide the number of milkweeds by the area to obtain the number of milkweeds per square meter. This number will usually be very small (less than 1). If your site has too many milkweed plants to count, you'll need to estimate plant density by a random sampling process. There are many ways to estimate plant density; the MLMP uses a modified belt **transect** method that involves counting milkweed plants within several 1-meter-square areas along randomly-chosen transects. The goal of any sampling process is to obtain data that are representative of the whole site. It is important not to let the presence or absence of milkweed influence your choice of samples; if you sample any areas because they include milkweed, you will be overestimating density.

If your site contains more than one milkweed species, you can either record the overall density of milkweed, or record the density of each species separately. If you record overall density, be sure to note which species are present at your site. This method works best for milkweed species that do not grow in clumps; it is difficult to assess the density of species like *Asclepias incarnata* and *A. tuberosa* for this reason.

Quality/Condition

Milkweed quality data can be used to assess whether female monarchs choose milkweed plants randomly within a site, or if there are characteristics of milkweed plants that make some plants more likely to be chosen for **oviposition**. This will help monarch biologists to understand what characteristics make an individual plant or an entire species of milkweed a "good" host plant for monarchs. These data can also be used to assess how plant quality changes throughout a season in one site, or how it varies between sites in different locations.

The MLMP website includes directions for measuring several characteristics of milkweed plants. These characteristics include the number and kinds of invertebrates present on the plants, the species of milkweed present in an area, the height of the plants, the flowering status, the proportion of the leaves that are yellowed or senescing (aging), and the proportion of leaf material that has been eaten by herbivores or affected by disease or air pollution.

This milkweed plant is yellowing and dying.

States and provinces where plants in the genus Asclepias *are found. (from the USDA PLANTS Database)*

It is important to choose random plants to ensure unbiased sampling. In the MLMP protocol, volunteers randomly choose a direction to walk through the monitoring site, and measure plants that they encounter every 5 or 10 paces (or some other previously-determined distance).

Monarch Watch is developing a protocol and data repository for monitoring several growth stages (or phenophases) for milkweeds, including the date of first emergence from soil, the first flower bud, the first open flower or floret on a flower head, the last flower on a flower head, the first seed pod and the first open seedpod. This information will help to determine the effects of proximate seasonal conditions and long-term effects of climate change on the plants on which monarchs depend. More details on this project can be accessed on the Monarch Watch website (see pp. 35–36).

Species Composition

The USDA plant database reports that *Asclepias* species (milkweed) grow in every US state except Alaska, and in the entire southern tier of Canadian provinces. The distribution of milkweed in Mexico is poorly understood, but we do know that monarchs breed throughout the year in the Mexican states of Morelos, Guerrero, México, Oaxaca, Veracruz, San Luis Potosí, Chiapas, Michoacán, and Hidalgo (Montesinos 2003). Montesinos (2003) reports finding eggs and larvae on *A. curassavica* in all of these locations, and on *A. glaucescens* in Michoacán.

Monitoring the presence and abundance of different milkweed species in specific locations will be very valuable, as will monitoring the use of these species by monarch larvae. While there are not specific existing programs to do this, protocols for MLMP site descriptions include questions about the milkweed species present in an area, and thus provide a central repository for data.

Table 2 lists many of the milkweed species found in North America, and the states and provinces in which they are found. You can use this list to determine what species to look for in your area. The USDA plant database has more-detailed range maps and pictures of each species. At this point, there is no such database for milkweed in Mexico, but many species found in the southern United States are also found in Mexico.

Four milkweed species found in North America:
a) *A. oenotheroides;*
b) *A. syriaca;*
c) *A. tuberosa;*
d) *A. viridis.*

Table 2. Selected milkweed species, with US state and Canadian province ranges[3]

Asclepias amplexicaulis – clasping milkweed	Alabama, Arkansas, Connecticut, District of Columbia, Delaware, Florida, Georgia, Iowa, Illinois, Indiana, Kansas, Kentucky, Louisiana, Massachusetts, Michigan, Minnesota, Missouri, Mississippi, North Carolina, Nebraska, New Hampshire, New Jersey, New York, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, Tennessee, Texas, Virginia, Vermont, Wisconsin, West Virginia
Asclepias angustifolia – Arizona milkweed	Arizona
Asclepias asperula – spider milkweed	Arizona, California, Colorado, Idaho, Kansas, New Mexico, Nevada, Oklahoma, Texas, Utah
Asclepias californica – California milkweed	California
Asclepias curassavica – bloodflower	California, Florida, Hawaii, Louisiana, Texas, Puerto Rico, Virgin Islands
Asclepias eriocarpa – woollypod milkweed	California
Asclepias erosa – desert milkweed	Arizona, California, Nevada, Utah
Asclepias exaltata – poke milkweed	Canada: Ontario, Quebec, USA: Alabama, Connecticut, Delaware, Georgia, Illinois, Indiana, Kentucky, Massachusetts, Maine, Michigan, Minnesota, North Carolina, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, South Carolina, Tennessee, Virginia, Vermont, Wisconsin, West Virginia
Asclepias fascicularis – Mexican whorled milkweed	California, Indiana, Nevada, Oregon, Utah, Washington
Asclepias feayi – Florida milkweed	Florida
Asclepias fruticosa – African milkweed	California
Asclepias glaucescens – nodding milkweed	Arizona, New Mexico, Texas
Asclepias hirtella – green milkweed	Canada: Ontario, USA: Arizona, Georgia, Iowa, Illinois, Indiana, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Missouri, Mississippi, Ohio, Oklahoma, Tennessee, Wisconsin
Asclepias humistrata – pinewoods milkweed	Alabama, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina

3 The area of distribution in Mexico is not included because relevant data are not available.

Asclepias incarnata – swamp milkweed	Canada: Manitoba, Ontario, Quebec, New Brunswick, Nova Scotia, Prince Edward Island, USA: Alabama, Arizona, Colorado, Connecticut, District of Columbia, Delaware, Florida, Georgia, Iowa, Idaho, Illinois, Indiana, Kansas, Kentucky, Louisiana, Massachusetts, Maine, Michigan, Minnesota, Missouri, North Carolina, North Dakota, Nebraska, New Hampshire, New Jersey, New Mexico, Nevada, New York, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Utah, Virginia, Vermont, Wisconsin, West Virginia, Wyoming
Asclepias involucrata – dwarf milkweed	Arizona, Colorado, Kansas, New Mexico, Oklahoma, Texas, Utah
Asclepias labriformis – Utah milkweed	Utah
Asclepias lanceolata – fewflower milkweed	Alabama, Delware, Florida, Georgia, Louisiana, Mississippi, North Carolina, New Jersey, South Carolina, Texas, Virginia
Asclepias lanuginosa – sidecluster milkweed	Canada: Manitoba, USA: Iowa, Illinois, Kansas, Minnesota, North Dakota, Nebraska, South Dakota, Wisconsin
Asclepias latifolia – broadleaf milkweed	Arizona, California, Colorado, Kansas, Nebraska, New Mexico, Oklahoma, Texas, Utah
Asclepias lemmonii – Lemmon's milkweed	Arizona
Asclepias linaria – pineneedle milkweed	California, Arizona
Asclepias linearis – slim milkweed	Texas
Asclepias longifolia Michx. – longleaf milkweed	Alabama, Arkansas, Delaware, Florida, Georgia, Lousiana, Mississippi, North Carolina, South Carolina, Virginia, West Virginia (Picture)
Asclepias macrotis – longhood milkweed	Arizona, Colorado, New Mexico, Oklahoma, Texas
Asclepias meadii – Mead's milkweed	Iowa, Illinois, Indiana, Kansas, Missouri, Wisconsin (Drawing)
Asclepias nivea – Caribbean milkweed	Puerto Rico, Virgin Islands
Asclepias oenotheroides – zizotes milkweed	Colorado, Louisiana, New Mexico, Oklahoma, Texas
Asclepias ovalifolia – oval-leaf milkweed	Canada: British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, USA: Iowa, Illinois, Michigan, Minnesota, North Dakota, South Dakota, Wisconsin, Wyoming
Asclepias pedicellata – savannah milkweed	Florida, Georgia, North Carolina, South Carolina
Asclepias perennis – aquatic milkweed	Alabama, Arkansas Florida Georgia, Illinois, Indiana, Kentucky, Louisiana, Missouri, Mississippi, South Carolina, Tennessee, Texas

Asclepias physocarpa – balloonplant	Hawaii
Asclepias prostrata – prostrate milkweed	Texas
Asclepias pumila – plains milkweed	Colorado, Kansas, Montana, North Dakota, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, Wyoming
Asclepias purpurascens – purple milkweed	Canada: Ontario, USA: Arkansas, Connecticut, District of Columbia, Delaware, Iowa, Illinois, Indiana, Kansas, Kentucky, Louisiana, Massachusetts, Maine, Michigan, Minnesota, Missouri, Mississippi, North Carolina, New Hampshire, New Jersey, New York, Ohio, Oklahoma, Pennsylvania, Rhode Island, Tennessee, Texas, Virginia, Wisconsin, West Virginia
Asclepias quadrifolia – fourleaf milkweed	Canada: Ontario, USA: Alabama, Arkansas, Connecticut, Delaware, Georgia, Illinois, Indiana, Kansas, Kentucky, Massachusetts, Missouri, North Carolina, New Hampshire, New Jersey, New York, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, Tennessee, Virginia, Vermont, West Virginia
Asclepias quinqueden-tata – slimpod milkweed	Arizona, New Mexico
Asclepias rubra – red milkweed	District of Columbia, Delaware, Florida, Georgia, Louisiana, Mississippi, North Carolina, New Jersey, New York, Pennsylvania, South Carolina, Texas, Virginia
Asclepias speciosa – showy milkweed	Canada: British Columbia, Alberta, Saskatchewan, Manitoba, USA: Arizona, California, Colorado, Iowa, Idaho, Illinois, Kansas, Michigan, Minnesota, Montana, North Dakota, Nebraska, New Mexico, Nevada, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, Wisconsin, Wyoming
Asclepias stenophylla – slimleaf milkweed	Arizona, Colorado, Illinois, Kansas, Louisiana, Minnesota, Missouri, Montana, Nebraska, Oklahoma, South Dakota, Texas, Wyoming
Asclepias subulata – rush milkweed	Arizona, California, Nevada
Asclepias subverticillata – horsetail milkweed	Arizona, Colorado, Idaho, Kansas, New Mexico, Nevada, Oklahoma, Texas, Utah, Wyoming
Asclepias sullivantii – prairie milkweed	Canada: Ontario, USA: Arkansas, Iowa, Illinois, Indiana, Kansas, Michigan, Minnesota, Missouri, North Dakota, Nebraska, Ohio, Oklahoma, South Dakota
Asclepias syriaca – common milkweed	Canada: Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick, Nova Scotia, Prince Edward Island, USA: Arkansas, Connecticut, District of Columbia, Delaware, Iowa, Illinois, Indiana, Kansas, Kentucky, Louisiana, Massachusetts, Maine, Michigan, Minnesota, Missouri, Montana, North Carolina, North Dakota, Nebraska, New Jersey, New York, Ohio, Oklahoma, Oregon, Pennsylvania, South Dakota, Tennessee, Virginia, Vermont, Wisconsin, West Virginia
Asclepias texana – Texas milkweed	Texas
Asclepias tomentosa – tuba milkweed	Florida, North Carolina, South Carolina, Texas

Asclepias tuberosa – butterfly milkweed	Canada: Ontario, Quebec, USA: Alabama, Arkansas, Arizona, Colorado, Connecticut, District of Columbia, Delaware, Florida, Georgia, Iowa, Illinois, Indiana, Kansas, Kentucky, Louisiana, Massachusetts, Maine, Michigan, Minnesota, Missouri, Missis-sippi, North Carolina, Nebraska, New Hampshire, New Jersey, New Mexico, New York, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Dakota, Tennessee, Texas, Utah, Virginia, Vermont, Wisconsin, West Virginia
Asclepias uncialis – wheel milkweed	Arizona, Colorado, New Mexico, Nevada, Utah
Asclepias variegata – redring milkweed	Canada: Ontario, USA: Alabama, Arkansas, Connecticut, District of Columbia, Delware, Florida, Georgia, Illinois, Indiana, Kentucky, Louisiana, Missouri, Mississippi, North Carolina, New Jersey, New York, Ohio, Pennsylvania, South Carolina, Tennes-see, Texas, Virginia, West Virginia (Picture)
Asclepias verticillata – whorled milkweed	Canada: Saskatchewan, Manitoba, Ontario, USA: Alabama, Arkansas, Connecticut, District of Columbia, Delaware, Florida, Georgia, Iowa, Illinois, Indiana, Kansas, Kentucky, Louisiana, Massachusetts, Michigan, Minnesota, Missouri, Mississippi, Montana, North Carolina, North Dakota, Nebraska, New Jersey, New Mexico, New York, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Virginia, Wisconsin, West Virginia, Wyoming
Asclepias vestita – woolly milkweed	California
Asclepias viridiflora – green comet milkweed	Canada: British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, USA: Alabama, Arkansas, Arizona, Colorado, Connecticut, District of Columbia, Delaware, Florida, Georgia, Iowa, Illinois, Indiana, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Missouri, Mississippi, Montana, North Carolina, North Dakota, Nebraska, New Jersey, New Mexico, New York, Ohio, Oklahoma, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Virginia, Wisconsin, West Virginia, Wyoming
Asclepias viridis – green antelopehorn	Alabama, Arkansas, Florida, Georgia, Illinois, Kansas, Kentucky, Louisiana, Missouri, Mississippi, Nebraska, Ohio, Oklahoma, Tennessee, Texas
Asclepias viridula – southern milkweed	Florida

Websites

Monarch Larva Monitoring Project: http://www.mlmp.org
Monarch Watch: http://monarchwatch.org/blog/2008/02/29/milkweed-and-nectar-plant-phenology-project/ (link to milkweed phenology information)
USDA Asclepias distribution maps and images: http://plants.usda.gov/java/profile?symbol=ASCLE

Nectar Sources

Few studies, if any, have focused on monarch nectar resources. For example, we don't know if monarchs are limited by nectar, or if it is easy for them to find enough to survive as they breed, migrate and overwinter. We also do not know the primary nectar plants for monarchs, nor the overlap of milkweed and nectar plant distribution. Volunteers in the Monarch Larva Monitoring Project are asked to record the plants that are in bloom during their weekly monitoring sessions, and this information will provide some answers to the above questions. However, there is no central data repository for information on monarch use of different nectar sources.

Monarch Watch has recently begun a program to record the dates of first flowering of a small number of plants from which monarchs are known to obtain nectar. The list of plants that Monarch Watch is following could provide the beginning of a nectar-source monitoring program (for information on these species, visit the USDA plant database (see link below):

Spring Nectar Sources (April–May)

Syringa vulgaris — Common lilac
Taraxacum officinale — Common dandelion
Prunus americana — American plum

Summer (June–July)

Cephalanthus occidentalis — Common button bush
Echinacea purpurea — Eastern purple coneflower
Vernonia fasciculata — Prairie ironweed

Fall (August–October)

Helianthus annuus — Common sunflower
Oligoneuron rigidum (*Solidago rigida*) — Rigid goldenrod
Liatris aspera — Tall blazing star
Verbesina virginica — Frost weed
Symphyotrichum ericoides (*Aster ericoides*) — White heath aster

In addition to tracking the presence and flowering status of the above species, documentation of any flowers used by monarchs would be useful.

Websites

Monarch Larva Monitoring Project: http://www.mlmp.org
Monarch Watch: http://monarchwatch.org/blog/2008/02/29/milkweed-and-nectar-plant-phenology-project/
(link to milkweed phenology information)
USDA Plant Database: http://plants.usda.gov/index.html

Nectaring monarch

5 BREEDING POPULATION MONITORING

Monarch Larva Monitoring Project

Background and Goals

The overarching goal of the Monarch Larva Monitoring Project (MLMP) is to better understand how and why monarch populations vary in time and space. Specific questions address how monarch population densities fluctuate throughout the breeding season in different parts of North America, the stages at which the highest mortality occurs, plant qualities that affect female monarch host plant choice, the timing of movement of reproductive monarchs throughout their breeding range, and variation in monarch **recruitment** with habitat characteristics.

The overarching goal of the Monarch Larva Monitoring Project (MLMP) is to better understand how and why monarch populations vary in time and space.

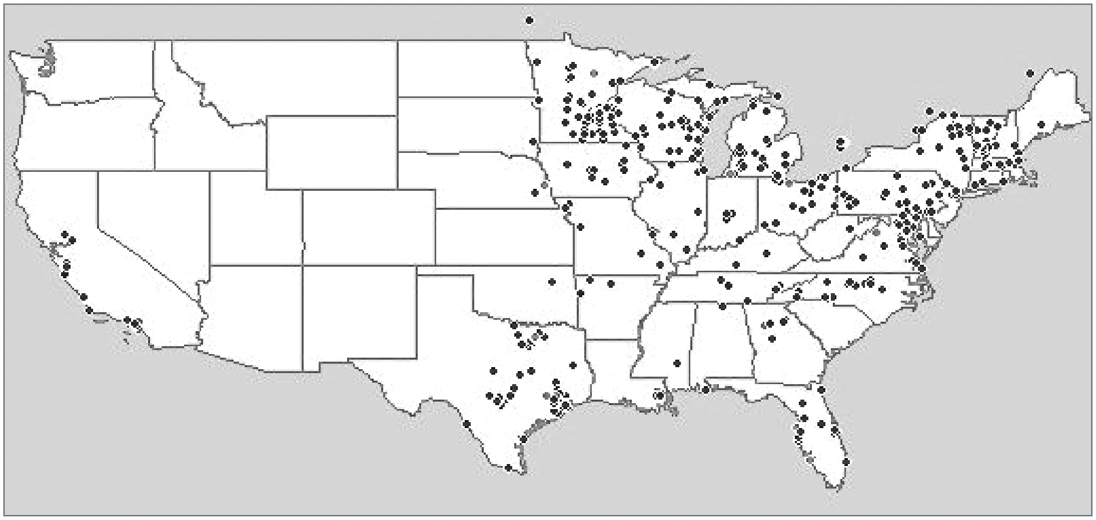
MLMP volunteers conduct weekly monarch and milkweed surveys, measuring per plant densities of monarch eggs and larvae and milkweed quality. The project began in 1997 at the University of Minnesota, and has been supported by the National Science Foundation (http://www.nsf.gov), the Monarchs in the Classroom program (http://www.monarchlab.org) and the Xerxes Society (http://www.xerces.org). Volunteers have monitored well over 800 sites in 34 US states and two Canadian provinces. Monitoring sites range from undeveloped areas such as nature preserves and restored prairies to developed areas such as roadsides and backyard gardens.

MLMP volunteers enter their data into an online database. Site- and state-specific monarch densities are visible to volunteers and anyone who visits the site as soon as the relevant data are entered. Additionally, the website includes summaries of patterns and findings in an annual newsletter and other updates.

The MLMP has documented several temporal and spatial patterns in monarch population dynamics. One such pattern is the widespread egg-laying that occurs in Texas and other southern US states during the fall migration, a time when most monarchs are non-reproductive. All MLMP sites in the southern United States show either no or very few monarchs during mid-summer, but a final late summer or early fall generation is observed every year (Prysby and Oberhauser 2004; MLMP 2007). Calvert (1999) documented this pattern, but the extent to which monarchs laid eggs in the fall was not known. While the pattern is evident in areas in which milkweed grows naturally and in which it has been planted, egg densities are higher in areas with the non-native tropical milkweed (*Asclepias curassavica*) (Batalden 2006). It is possible that monarchs become reproductive as they are exposed to healthy milkweed, and that planting non-native host plants in watered gardens is affecting monarch reproductive biology.

Recently, MLMP data were used to generate ecological niche models of monarchs' predicted responses to human-caused climate change (Batalden et al. 2007). Data collected by MLMP volunteers provide dates and locations for monarch presence. These data, combined with climate change models, predicted severe northward shifts in the monarchs' habitat 50 years from now, necessitating a longer and faster migration. It is unknown whether monarchs will be able to respond to these shifts, but further monitoring will help to answer this question.

Locations of MLMP monitoring sites.



MLMP data have also been used to document regional, annual and site specific patterns in rates of parasitism by the tachinid fly ***Lespesia archippivora*** (Oberhauser et al. 2007). Mortality rates caused by this parasitoid show high site-to-site variation, with up to 90 percent of monarchs from some isolated milkweed patches being infected. Additionally, there are region-wide annual patterns, with some years exhibiting particularly high rates of parasitism.

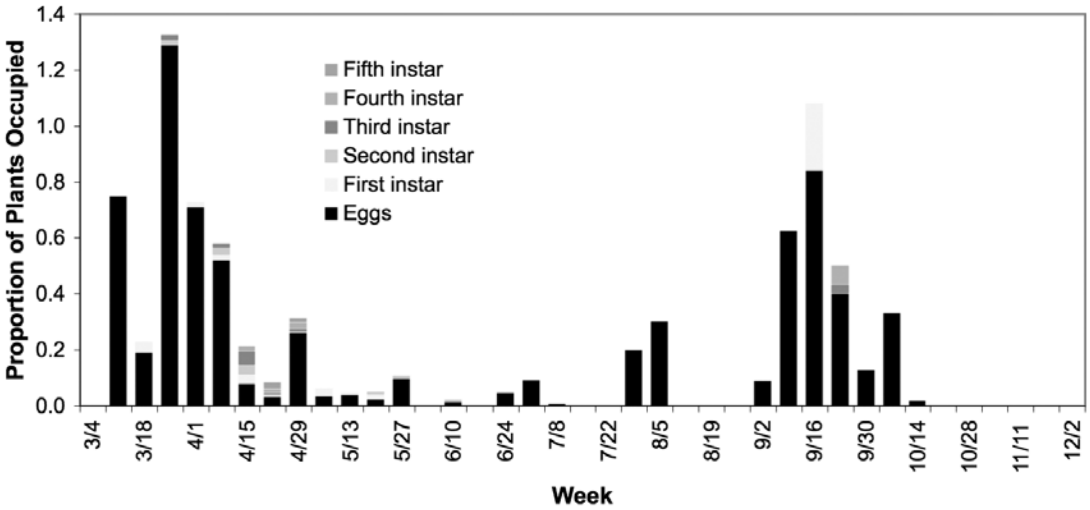
Comparisons of monarch densities from year to year show a great deal of variation (MLMP 2007), and ongoing analyses of these densities and their congruence with findings from other projects will lead to increased understanding of the factors that affect monarch populations.

Protocol

Volunteers locate their own monitoring sites, which must contain milkweed. Ideally, sites have at least 30 milkweed plants, but can be located almost anywhere. Milkweed can be found in undeveloped areas such as nature preserves and restored prairies or in developed areas such as roadsides and backyard gardens. Sites should be located in areas that can be monitored regularly, preferably every week while milkweed is present. Volunteers conduct a site description using a form provided on the MLMP website, and update their site data every year. Annual updates include an estimate of milkweed density.

The MLMP monitoring protocol is divided into four different activities. Prepared data sheets for the activities are available online, and some have multiple versions, depending on the age of the monitors. Kits that include materials that help with monitoring are also available.

Estimating Monarch Densities: This activity is the heart of the MLMP. On a weekly basis throughout the time that milkweed is growing in their area, volunteers examine as many milkweed plants as possible, keeping track of the number of plants examined and recording the number of eggs and monarch larvae that they observe. This procedure generates a weekly estimate of monarch density at each monitoring site, measured as a proportion of milkweed plants with monarchs on them.



Monarch density in Texas in 2007 (MLMP 2007). Spring eggs and larvae are offspring of the overwintering generation, which then continue migrating north for the summer. Few monarchs remain in Texas during the summer. The reoccurrence of eggs and larvae in the fall is a sign that some monarchs coming from the North reproduce in the South.

Weather Conditions: Many volunteers choose to record temperature and precipitation at their site. Data forms for recording weather information are available

Parasitism Rates: Natural enemies have a large impact on monarch populations, and MLMP volunteers collect data on a group of natural enemies called parasitoids, organisms whose young develop inside the monarch larvae, eventually killing them. These data help determine how this mortality factor varies in populations of different densities and at different times and locations. Volunteers collect 4th or 5th instar larvae from their site, and rear them larvae indoors, recording whether they survive to adulthood, and, if not, what caused their death.

Comparisons of Plants That Are Occupied and Not Occupied by Monarchs: Data collected in this activity help to determine what characteristics are important to female monarchs when they choose a plant on which to lay an egg. This information will help monarch biologists to understand what makes an individual plant, or a milkweed species, a good host plant for monarchs. Volunteers measure several characteristics of plants that have monarchs on them and a random set of plants at their site. Comparing these two groups of plants allows program coordinators to determine if females choose plants based on specific characteristics.

Website

Monarch Larva Monitoring Project: http://www.mlmp.org

6 POPULATION CENSUSES

NABA Butterfly Counts

Background and Goals

North American Butterfly Association (NABA) Butterfly Count volunteers from the United States, Canada and Mexico census all species of butterflies sighted within a 15-mile-diameter circle on a specified day.

North American Butterfly Association (NABA) Butterfly Count volunteers from the United States, Canada and Mexico census all species of butterflies sighted within a 15-mile-diameter circle on a specified day. These counts began as the 4th of July Butterfly Count and now are usually held on several days in early July and the few weeks before and after that date. Because they depend on the best timing for butterfly observation in each geographic area, counts in the southern part of North America span May through August.

There are three main purposes and outcomes of the NABA Butterfly Counts (NABA 2007). First, the results of the counts provide information about the geographical distributions and population sizes of the species sighted. The results detect changes in butterfly populations and can be used to determine the effects of weather and habitat change on many different species. Secondly, the program promotes socialization among butterfly enthusiasts and encourages others to become interested in butterflies. Finally, the counts create publicity for butterflies and their conservation needs.

The first 4th of July Butterfly Count occurred in 1975, and was initiated by the Xerces Society (Swengel 1990). The Society modeled the methods after the longstanding Christmas Bird Counts, sponsored by the National Audubon Society. Volunteers in the first Butterfly Count surveyed just 29 different sites, but in 2006, 483 counts were held in 48 states, 3 Canadian provinces, and 2 Mexican states (NABA 2007). NABA incorporated the Butterfly Count into its programming in 1993.

At its inception, the 4th of July Butterfly Count was not designed primarily for scientific data collection, but rather as a tool to excite butterfly enthusiasts. Thus, there are barriers to rigorous scientific analysis of its data, as is also the case with the Christmas Bird Count (Swengel 1995). Year-to-year inconsistencies in route, methods or observer numbers could lead to exaggerated reports of increases or decreases in abundance. Still, these continent-wide data would otherwise be impossible to gather, and several analyses have demonstrated the usefulness of NABA Butterfly Count data. Monarch butterflies, being easily identifiable, common, and habitat generalists, are well suited for analyses of count data. Data are likely to be accurate and sample sizes are large.

An analysis of monarch count data from 1979 to 1988 for sites with counts held between June 27 and July 24 reveals much fluctuation in the number of monarchs/party-hour (Swengel 1990). While the data are more effective at demonstrating the existence of fluctuations and trends than specific factors that cause these trends, some fluctuations can be attributed to specific events. For example, a sharp decline in monarchs from 1987 to 1988 is attributable to a severe drought. Other major monarch fluctuations often occur in conjunction with significant weather perturbations, including El Nino Southern Oscillation and volcanic eruptions. In years when monarch populations shift without obvious weather-related causes, other factors, including disease, parasites and predators, could be to blame.

Protocol

The location of all counts and contact information for the compilers can be accessed via NABA's online maps. Volunteers can join an existing count, or start their own.

NABA Butterfly Counts incorporate several locations within a 15-mile-diameter circle. While one person can conduct the entire count, several individuals visiting several habitats within the count circle produce better data. Groups repeating a count held a previous year must use the same locations and habitats as before.

Some sites include garden watchers. These participants count butterflies in their own garden, with one garden counting as one site. Butterflies seen by garden watchers are totaled with those seen by other count volunteers.

Volunteers report adult butterflies observed alive in the wild during a single, one-day period. The count form includes a list of scientific and English names of butterflies; if counters see a species not included on the form, they use the "Additional Species" section to write in the species observed. They also submit the number of party-hours and party-miles spent at the census. A party-hour is defined as the sum of hours each group of counters spent tallying butterflies on a given count. NABA requires a minimum of six party-hours for all counts, except
in extenuating circumstances. Party miles include the number of miles traveled on foot by each party.

Garden watchers report the highest number of individuals of a species seen at one time in the garden; they do not sum all observations for one day since the same butterflies may be returning to the garden multiple times. Butterflies seen by garden watchers are included with the other count totals. Time spent garden watching is included in the total party-hours, but not in the party-miles.

At its inception, the 4th of July Butterfly Count was not designed primarily for scientific data collection, but rather as a tool to excite butterfly enthusiasts.

Websites

North American Butterfly Association: http://www.naba.org
Check websites of local nature centers or butterfly groups for counts in your area.

Butterfly Monitoring Networks

Background and Goals

Butterfly censusing programs enable people to assess the abundance of butterflies in their locality. This information can be used to document changes in abundance, the numbers of species present in different areas, and the impacts of plant management activities. Most existing butterfly censusing programs focus on all butterfly species, but it is easy to extract data for a particular species, such as the monarch butterfly. Annual butterfly counts, like the ones conducted by NABA (see above), provide a big picture of how butterfly species are doing, but are less useful for detailed analyses since they are only conducted once a year at any given site. Monitoring programs that involve repeated measures within a year address the need for more detailed data. Here, we describe a few such programs. Individuals and organizations who would like to be involved in these censusing programs could join an existing program if one is available in their area, or start one of their own.

Ohio Butterfly Monitoring Network volunteers conducting a Pollard transect survey

In 1987, The Nature Conservancy decided to explore the effects of management on animals by creating a butterfly monitoring network (BMN). The network began monitoring at seven sites in the Chicago, Illinois, area. Now, more than 100 sites throughout Illinois are monitored every year. Other states and regions are adopting the Illinois protocols and forming their own BMNs. The Ohio Lepidopterists' Society has been conducting a similar program in its state since 1996, and Iowa, Florida and Indiana also have BMNs. Additionally, some individuals conduct similar projects. For example, a couple in northern Minnesota have monitored the area near their home almost daily for over a decade, using the protocol outlined below.

Data from the Illinois and Ohio BMNs are currently being analyzed to determine how and when monarchs move into the central and northern part of their range. By comparing these data with data on eggs and larvae, we can determine which generations are reproductive and which are not. The data can also be used to show compatibility of species with a variety of land management techniques, and population trends of different butterflies. These results will help land managers conserve butterflies in their regions.

Protocol

All of the BMNs use a method that enables people with relatively little experience to assess butterfly abundance using routine periodic transect counts. The method follows one used in a British butterfly monitoring program, and was originally developed at Monks Wood Experimental Station in Great Britain. It is often called the Pollard Transect method, after its developer (Pollard 1977, 1991; Pollard and Yates 1993).

The transect is a fixed route along which periodic walks are made. Once chosen, it should not be altered, since accurate comparisons depend on week-to-week and year-to-year continuity. It should be reasonably representative of the locality as a whole, although it is also interesting to include areas that are managed differently, attract more species than others, or contain a population of a particularly interesting or local species.

Butterfly counters walk their transects at an even pace, counting only the butterflies which come within the transect width. Transects should be of manageable length, bearing in mind the fact that they must be walked at least weekly, and that counting may take a long time when there are many butterflies present. They should have obvious boundaries and fixed widths. The precise width is not important, but recording becomes more difficult if it is over about 4.5 meters (~15 feet). A fixed route can be marked out to ensure that the same path is followed. If it is necessary for some sections to be covered twice due to overlapping paths, butterflies should be recorded only on the first occasion that the section is covered. A loop works best.

In the statewide BMNs, trained volunteers collect and submit data each summer from an assigned site. They usually commit to conducting a certain number of site visits each summer, and hopefully continue for multiple seasons. Each census generally takes one to two hours. Most states provide training workshops to teach the censusing method and butterfly identification, and also provide ongoing support.

All statewide monitoring programs need more volunteers. To learn how to join existing programs, visit the websites listed below. If your state does not have a BMN, you could contact local North American Butterfly Association volunteers, the directors of existing programs, or state or provincial natural resource agencies. All existing networks were started by a few interested individuals!

Websites

Illinois Butterfly Monitoring Network: http://bfly.org/
Ohio Butterfly Monitoring Network: http://www.ohiolepidopterists.org/bflymonitoring/
Northwest Indiana Butterfly Monitoring Network: http://bfly.org/indiana.html
Florida Butterfly Monitoring Network: http://www.flbutterflies.net/
North American Butterfly Association: http://www.naba.org/
(Some NABA chapters sponsor butterfly monitoring networks.)

Censuses at Fall Migration and Stopover Sites

Background and Goals

We still have very rudimentary understanding of where and when monarchs stop during their migration, how environmental conditions influence their stopover behavior, and what annual and within-season variation exists. To address this gap in our understanding, several programs monitor the size, timing and location of the autumn migration at specific locations. Although they share the same goals and general design, their methods vary. Some conduct censuses while monitors are walking or driving along a predetermined transect, similarly to the methods used for NABA's Butterfly Counts and other adult censuses. However, many migratory monitoring programs also conduct censuses of roosting monarchs in the early morning or evening. Others follow the methods of migratory bird watchers, where volunteers remain in place and count the numbers of monarchs seen flying overhead. Regardless of methods, each monitoring program seeks to further describe general patterns of migratory and stopover behavior of monarchs. What distinguishes these programs from other adult monarch censuses is the focus on the fall migration.

Published data from fall migration counts have provided important information on monarch migration.

The longest-running project is on Cape May, New Jersey. Every year since 1992, Dick Walton and many collaborators have conducted censuses of migrating monarchs on Cape May, a peninsula bordered by the Atlantic Ocean and Delaware Bay (Walton and Brower 1996; Walton et al. 2005). Volunteers drive along a transect to census monarchs that cluster during their annual southward migration. A study using similar methods has been conducted in the Chincoteague National Wildlife Refuge on Assateague Island, a barrier island on the Delmarva Peninsula in Virginia, beginning in 1997 (Gibbs et al. 2006).

Another census has taken place on Long Point, Ontario, on the north shore of Lake Erie, since 1995 (Crewe et al. 2007). The ecosystems on this narrow peninsula with sandy beaches, dunes, wetlands, meadows, savannahs, and forests are thought to be the best remaining in the Great Lakes basin (Crewe et al. 2007). Because of this, and the large numbers of migratory monarchs here, the Canadian government designated this site as an International Monarch Butterfly Reserve in 1995. This census only utilizes walking transects.

Another program monitoring the fall migration involves volunteers working in the Peninsula Point Recreation Area, administered by the United States Department of Agriculture Forest Service (Meitner et al. 2004). This project, started in 1996, is located on the northern shore of Lake Michigan at a migratory stopping point for monarchs. Volunteers census roosting monarchs in the morning and travel by walking along a transect during the day.

Finally, on the southern tip of the Delmarva Peninsula, at the Coastal Virginia Wildlife Observatory and the Eastern Shore of Virginia National Wildlife Refuge, monitors counted migrating monarchs during 1998–2000, using techniques typical of those used in studies of migrating raptors.

Published data from fall migration counts have provided important information on monarch migration. A comparison of the Cape May monitoring data with the monitoring data from Chincoteague National Wildlife Refuge, from 1997 to 2004, shows similar population trends at both sites (Gibbs et al. 2006), reinforcing the reliability of these methods as monitoring tools.

Walton et al. (2005) synthesized the data from Cape May for the years 1992–2004. They detected significant annual, diurnal, and within-season temporal variation, with an average of 3,490 monarchs sighted per year. The peak migration over Cape May occurs in early October, and these numbers can be used as an index of the northeastern monarch population size. When comparing peaks over the 12 years, it is apparent that this is a highly fluctuating population. The Cape May data also reveal that the migration comes in about seven waves per year (Walton et al. 2005). A wave is defined as a period of one or more days with more monarchs sighted than the average, separated by one or more below-average days.

Protocols for monitoring monarchs during the fall migration depend a great deal on the characteristics of specific sites.

An analysis of the data collected at Peninsula Point, Michigan, does not show a consistent timing of peak migration, as was observed at Cape May (Meitner et al. 2004). Peninsula Point data are correlated with environmental variables. North winds, warmer temperatures, and low cloud cover all increased the numbers of migratory monarchs (Meitner et al. 2004). Migration data from Long Point, Ontario show that monarch counts were greatest during periods when the wind originated from the northwest – southwest quadrant, with 60 to 80 percent cloud cover, and temperatures around 20°C (Crewe et al. 2007). The higher numbers of monarchs in Ontario in unfavorable conditions are probably due to monarchs accumulating here until migrating conditions improve.

Protocols

Protocols for monitoring monarchs during the fall migration depend a great deal on the characteristics of specific sites. Some censuses are conducted from cars, some on foot, some daily, some weekly, and some from single locations. As long as the data are collected consistently from day to day, week to week and year to year, useful patterns can be obtained. Below, we describe methods used at a variety of sites. Organizations and individuals are encouraged to use these to develop protocols for their own sites.

Driving Census. In Cape May, NJ, from September 1 to October 31, monitors conduct two or three driving censuses per day, over an 8-km standard transect. The route intersects a variety of habitats, including southern hardwood forest, agricultural fields, brackish wetland meadow, suburban neighborhoods, and coastal dunes along the Atlantic Ocean and Delaware Bay (Walton and Brower 1996). Volunteers record the number of monarchs observed nectaring, flying or resting, as they drive at a speed of 32–40 km/hr. Stops are not made to count concentrations of butterflies. Additional data include starting and elapsed times and local weather data.

Walking Census. At Long Point, Ontario, monarch monitoring occurs at two points on the long, narrow peninsula: the Tip, at the eastern end of Long Point and Breakwater, about halfway between the tip and the base of the peninsula (Crewe et al. 2007). The Tip site is dominated by dry, open, early-successional eastern cottonwood–red cedar sand dunes. Milkweed and a favorite nectar plant, dense blazing star (***Liatris spicata***), are common here.

The Breakwater site is a mid-successional oak-maple savannah that contains some milkweed but no blazing star.

Volunteer monitors conduct daily walking censuses of migrating monarchs. At the Tip site, these counts are carried out from the beginning of August through mid-October, but waterfowl hunting season restricts Breakwater access after late September (Crewe et al. 2007). Surveyors spend one hour between 2:00 p.m. and 5:00 p.m. walking along a prescribed path. Counts include monarchs observed nectaring, resting or flying through the area. Observers also collect data on weather variables. They record cloud cover to the nearest 10 percent, wind direction (on a 16-point scale), wind speed, and temperature.

Walking Census and Roosting Counts. Between the second week of August and the third week of September, volunteers conduct three counts daily at Peninsula Point, Michigan. These involve a combination of counting roosting monarchs and walking a transect line (Meitner et al. 2004). Before each of the three counts, observers record relevant environmental variables, such as wind direction and speed, temperature, and cloud cover. Cloud cover is estimated by the amount of sun that is obscured by clouds, on a 5-point scale.

The roosting count occurs at 6 a.m. and there is no set time limit. All monarchs roosting on or near the lighthouse are counted, so observers simply remain in the area until they count all monarchs present. Methods for the walking transects, which occur at 9 a.m. and 1 p.m. daily, are similar to the walking and driving transect methods for other programs. Volunteers record all monarchs, whether they are active or roosting. The transect runs along the peninsula trail, and observers walk at a standardized pace, without stopping, for 4 km, which takes about 45 minutes per transect. Because over 75 percent of the terrain is wooded, this count only targets monarchs flying closer to the ground. These walking transects, combined with the roosting counts, record migratory monarchs at Peninsula Point while they are engaged in stopover activities like foraging, resting, and roosting.

Hawk-watch Observations. Davis and Garland (2004) used a point-count technique, which is often used in raptor studies, to count migrating monarchs. The hawk-watch platform in Kiptopeke State Park, Virginia is about 5 m above ground, and has good visibility for the entire 360o radius. In this study, a hawk watcher counted any monarchs seen during the raptor count. The counting period was separated into three segments: from one hour after sunrise to 10 a.m., from 10:30 a.m. to 1 p.m. and from 1:30 p.m. to 4 p.m. A directory of hawk-watch sites is available online for volunteer monitors that may want to census monarchs using this technique.

Websites

Chincoteague Monarch Monitoring Project: http://mysite.verizon.net/robgibbs301/monarch.htm/
Hawk Watch Location Directory: http://www.virtualbirder.com/vbirder/onLoc/onLocDirs/HAWK/bg/Find.html
Journey North http://www.learner.org/jnorth
Monarch Migration Association of North America: http://mmana.org/
Monarch Monitoring Project (Cape May Bird Observatory): http://rkwalton.com/mon.html

While access to monarch overwintering colonies in Mexico is tightly controlled, and monitoring is conducted by professionals working with Profepa, UNAM, IPN and MBBR, volunteers help census monarchs in overwintering sites for the western migratory population.

Project Monarch Alert

Background and Goals

While access to monarch overwintering colonies in Mexico is tightly controlled, and monitoring is conducted by professionals working with Profepa, UNAM, IPN and MBBR, volunteers help census monarchs in overwintering sites for the western migratory population. Monarch populations west of the Rocky Mountains migrate to specific overwintering sites along the coast of California, where approximately 200,000 western monarch butterflies overwinter annually. These sites extend from Marin County, California, in the north, to San Diego County in the south.

Monarch butterflies require specific habitat and microclimate characters for winter survival. In California, monarchs choose sheltered groves of trees close to the ocean, in areas buffered from freezing winter temperatures and severe storms. Suitable habitat usually contains trees grouped in a U-shaped formation, with several rows of trees on the windward side of the grove that allows light to penetrate for warmth. The sites must also have a multi-tiered canopy for adequate protection from wind, cold and storms, and should allow light to penetrate enough to permit some exposure to sunlight but not enough to significantly heat the butterflies while in clusters. Too much heat causes the butterflies' metabolic rate to increase, and can lead to shortened overwintering life span.

Historically, western monarchs probably used native stands of Monterey pine (*Pinus radiata*), Monterey cypress (*Cupressus maculatum*) and Coast redwood (*Sequoia sempervirens*) for winter roosting, but now usually use introduced eucalyptus. Eucalyptus provide the vertical layering that monarchs require, and seem to be a suitable substitute for the native species, which have been lost to extensive land development and logging. Protection and management of monarch overwintering sites usually entails balancing the planting of eucalyptus against the eradicating of it as part of land management plans that mandate the removal of non-native tree species.

Given the unique and precarious circumstances of the monarch butterfly's existing western overwintering habitat, it is essential to monitor monarch overwintering sites in order to make scientific management recommendations to sustain future monarch butterfly populations.

The Ventana Wildlife Society (VWS), in collaboration with Helen Johnson and California Polytechnic State University at San Luis Obispo, is documenting population dynamics, health, and roost site quality of monarch butterflies in Monterey County. Results of that collaboration identified nine important overwintering sites in Monterey County: The Monarch Grove Sanctuary, George Washington Park, Point Lobos State Reserve, Palo Colorado Canyon in Big Sur, Andrew Molera State Park, Sycamore Canyon at Pfieffer Beach, a private property site in Big Sur, and Prewitt Creek and Plaskett Creek in Pacific Valley. These sites are managed by California Department of Parks and Recreation, the Forest Service, the City of Pacific Grove and private citizens.

Data collected by monitors working with Monarch Alert and other programs in the California monarch wintering sites are used to show within- and between-year changes in monarch population numbers. In many cases, monarch abundance appears to be correlated with the abundance and productivity of milkweed on the summering grounds, which in turn is linked to rainfall and land management (Ventana Wildlife Society 2008). The data also demonstrate a high degree of small-scale movements throughout the winter. Monarchs colonize many different locations in the late fall, but most of these locations are abandoned as the butterflies consolidate into fewer locations. Frey and Shaffer (2004) suggest that these movements may serve to mitigate consequences of physiological stressors caused by weather extremes. For example, habitats in San Luis Obispo County were abandoned after several days of hot, dry conditions. Thus, protection of multiple overwintering sites is crucial to the survival of monarch butterflies.

The VWS uses monitoring data to inform public and private landowners about the best ways to manage their monarch groves. Annual reports are stored on their website as PDF files, where they are accessible to all interested parties.

Protocol

To determine if monarch butterflies utilize a site for overwintering, VWS biologists visit a prospective site between sunrise and 0900 (9 a.m.) to determine habitat suitability, evaluate stand condition, and search for monarch butterflies in clusters. If monarchs are found, site monitoring will follow (see below). If the habitat looks suitable but monarchs are either not found or not clustering, a single follow-up visit will ensue 30 days later.

Surveys are conducted one day per week from October 1 to the last week of February, in the mornings, while temperatures are below flight threshold (13°C) and monarchs are still clustered. Surveys do not take place during heavy precipitation because of poor visibility, but will be made up on the next available "good weather" day.

Data collected during monitoring events include: date, site, observers, pre-count time start and end, count time start and end, presence of nectar and water sources, and observations of tagged or mating monarch butterflies. For every tree that has roosting monarch butterflies, the number of butterflies, tree species, tree identification number, and the aspect and height of clusters are recorded. The numbers of flying monarchs and monarchs on the ground are recorded separately. To estimate the number of butterflies in a cluster, observers estimate the number of monarch butterflies in a small area of a cluster and then extrapolate this count to arrive at a total count for the entire cluster. The average of the total counts of all observers is then recorded. Total butterflies on each tree are calculated by summing the cluster totals.

In some cases, butterflies are captured from overnight roosting clusters during the early morning, using a 10-meter multi-section pole with a net attached. They are then tagged with small, round self-adhesive stickers with a preprinted identification number and the VWS toll-free number, and their sex and wing condition are recorded.

Each year, project investigators prepare and submit monitoring reports using data collected from monarch butterfly surveys and tagging, and details on weather conditions collected from data-loggers (Hamilton et al. 2002; Frey et al. 2003; Hamilton et al. 2003).

The VWS conducts annual monarch butterfly monitoring workshops to promote continued collaboration among monarch butterfly enthusiasts and biologists for conducting long-term monitoring efforts in California. Participants are trained in standardized monarch butterfly population estimation techniques. Interested volunteers, or people who live in western North America and would like to learn what they can do for butterflies in their area should contact the VWS.

Monarchs in a eucalyptus tree

Monarch Alert captured roosting monarchs in extended butterfly net

Websites

Project Monarch Alert: http://www.calpoly.edu/~bio/Monarchs/index.html
Ventana Wildlife Society: http://www.ventanaws.org/conservation/monarchs.htm#updates

Monarch Butterfly Biosphere Reserve Monitoring

Background and Goals

Since the early 1990s, Conanp personnel in the MBBR and staff of the World Wildlife Fund–Mexico have monitored the areas and locations occupied by monarchs throughout the wintering season, with the assistance of local residents (Garcia-Serrano et al. 2004, Rendón-Salinas et al. 2007). Beginning in 2004, these monitoring activities have included biweekly measurements from November to March (Rendón-Salinas and Galindo-Leal 2005; Rendón-Salinas et al. 2006a, 2006b). Goals of MBBR monitoring include assessing the status of the eastern population during the single time that the population occupies a single area and determining rates and causes of overwintering mortality.

Protocol

In order to carry out research projects or monitoring activities of species within the Monarch Butterfly Biosphere, a formal request has to be submitted to the Directorate of the Reserve clearly establishing the protocol and goals for each project. Once an approval is granted, if the project's activities involve collecting or managing wild flora and/or fauna, a different permit has to be issued by the Dirección General de Vida Silvestre (DGVS, Wildlife Management Office). Local residents, who may be interested in increasing their knowledge, may take part in specific activities if the projects permit this participation.

Websites

WWF-Mexico: http://www.wwf.org.mx/wwfmex/index.php
Conanp: http://www.conanp.gob.mx/

Tagged monarch (Monarch Alert)

7 MIGRATION

Monarch Watch

Background and Goals

Monarch Watch is focused on the fall migratory generation. Volunteers place small tags on monarchs' wings as they migrate through their area in the fall. Before the monarchs' overwintering colonies were discovered in Mexico, researchers used tagging programs like this to discover where these butterflies spent each winter. While we now know the location of monarch overwintering sites, Monarch Watch data help answer questions about the pathways monarchs use during the fall migration, how the migration is influenced by weather events, and whether there are annual differences in migration patterns. Detailed analyses can also be used to determine regions from which most monarchs originate, differential success rates between monarchs in different regions, and mortality rates during the migration.

Multiple citizen science programs have utilized tagging to reveal key information about the patterns and timing of the fall monarch migration. The Insect Migration Association was established in 1952 to determine where monarch butterflies from the eastern population go in the winter and how they get there. This program lasted until 1994 and involved schoolchildren, naturalists, and other citizens in observing, capturing and tagging monarchs (Urquhart and Urquhart 1977; Urquhart 1987). Each tag carried a unique number and contact information for the Insect Migration Association. Taggers recorded the date and location when they tagged a monarch, and individuals that found tagged butterflies sent the identifying numbers and recovery date and location to the Association. In 1975, Kenneth Brugger, a volunteer helping Dr. Fred Urquhart in Mexico, and his wife Cathy Aguado found the monarch wintering grounds in central Mexico that had previously been unknown to the scientific community (Urquhart 1976). Although these sites had been known by local citizens, no one understood that the monarchs that blanketed these mountaintops had flown from breeding grounds as far away as Canada. This finding was made possible by the years of tagging data that had pointed to a location for wintering monarchs somewhere in this area. Even after the discovery of these sites, we are continuing to learn about monarch migration and overwintering from current tagging programs.

Multiple citizen science programs have utilized tagging to reveal key information about the patterns and timing of the fall monarch migration.

In 1992, Monarch Watch established a new volunteer-based tagging program to continue the study of fall migratory routes. This program operates under the same principles as the Insect Migration Association, with improvements in tag size, adhesive and placement. Data from the Monarch Watch program, along with new analyses of old tagging data, continue to provide new information on monarch movement across the continent, and on influences of weather and other environmental factors that vary from year to year (Rogg et al. 1999). Additional tagging programs in the western United States (Ventana Wildlife Society 2008) and other regions provide more localized data on migratory patterns.

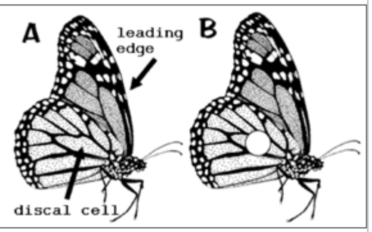
Monarch tagged by Monarch Watch volunteers in Hiawatha National Forest (Peninsula Point, Michigan)

Preliminary analyses of data from the Monarch Watch program show that more monarchs are tagged between 40° and 45° N latitude and 90° and 100° W longitude (O.R. Taylor personal communication), suggesting that more monarchs are located in these parts of the United States. Additionally, recovery rates of tagged butterflies in Mexico vary with tagging locations. A higher proportion of monarchs that were tagged between 95° and 105° W longitude are recovered in Mexico (O.R. Taylor personal communication), suggesting that monarchs from these locations are more successful at reaching the wintering grounds.

Tagging efforts can also be used to identify and evaluate migratory routes. During 1998–2000, on the eastern shore of Virginia, Garland and Davis captured 2190 fall-migrating monarchs, six of which were previously tagged. From this information, they were able to infer possible migration routes, rates of travel and how wind conditions affect these. They tagged all the monarchs they captured, and found that these monarchs were less likely to reach the Mexican overwintering sites in some years than others (Garland and Davis 2002).

Protocol

Only migratory monarchs should be tagged for the Monarch Watch program. As many as four generations of summer, non-migratory butterflies may occur in a given area, depending on latitude. Decreasing day lengths, fluctuating temperatures, and yellowing milkweed induce diapause, a period of reproductive arrest that accompanies the fall migration (Goehring and Oberhauser 2002).



Correct placement for Monarch Watch tags (Monarch Watch 2007)

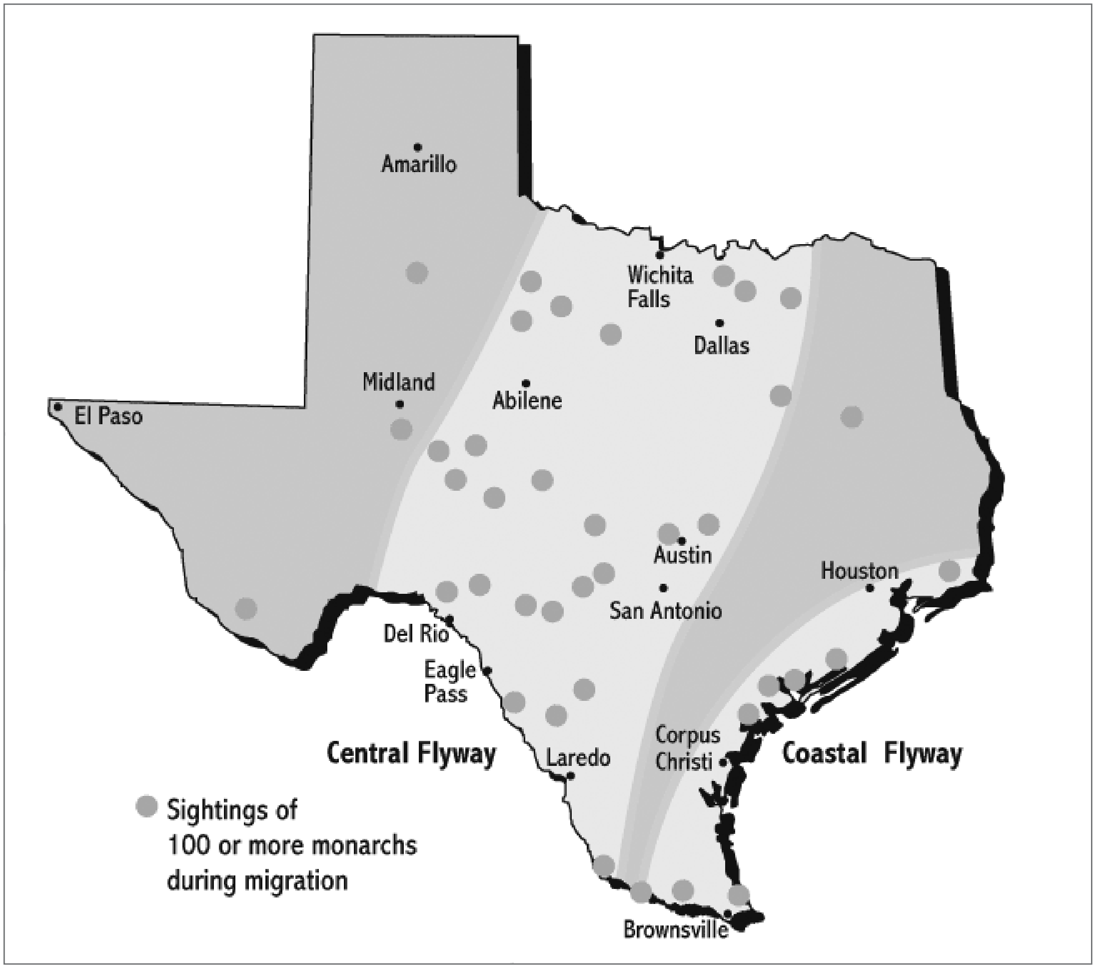
Tags can be ordered through the Monarch Watch website, and new tags must be used every year. There are unique identifying numbers on each tag that correspond to specific tagging seasons. Taggers obtain butterflies either by rearing immature monarchs from wild, or by capturing adult butterflies with a butterfly net. Monarchs spend a great deal of time nectaring as they head south; in fact, a monarch's weight will actually increases as it migrates (Brower 1985, Gibo and McCurdy 1993, Borland et al. 2004). Thus, a good place to look for large numbers of migratory monarchs is around tall late-blooming thistle (*Cirsium altissimum*), several species of sunflowers, and wild asters (Monarch Watch 2007).

Tags developed by Monarch Watch adhere to the wings without dropping off during their long migration. This position is close to the butterfly's center of gravity, and therefore will not harm it or impede flight (Monarch Watch 2007).

Datasheets are available online for recording the tag number and release date. Taggers record the sex of the monarch, and whether it was caught as an adult or reared it from an egg, caterpillar or pupa. Finally, they record the nearest city, state and zip code to the capture location.

Websites

Monarch Watch: http://www.monarchwatch.org
Ventana Wildlife Society: http://www.ventanaws.org/conservation/monarchs.htm#updates
(Western monarch population tagging program)



Sightings by Texas Monarch Watch participants have helped to understand the movement of monarchs through Texas through the Central and Coastal Flyways. Map from Texas Parks and Wildlife Department.

Texas Monarch Watch

Texas has a unique position along the migratory path, since virtually all monarchs in the eastern migratory population must pass through this state on their way to and from the Mexican overwintering sites. Texas Monarch Watch, run by the Texas Parks and Wildlife (TPW) Department, gathers information about migratory and resident populations of monarchs in Texas, and shares information about monarchs with the public. While this program is specific to Texas, the methods could be used in other states or provinces. The data that volunteers collect are summarized in TPW newsletters and shared with scientists and natural resource managers.

Data are collected in two ways. Individuals can report any monarch sightings to the Texas Monarch Hotline, including the location and date of the sighting as well as information about weather conditions in the area. Many individuals also keep a monarch calendar or journal, using a form that is available on the TPW website. Data recorded on the calendar focus on the timing and location of the fall migration.

Texas Monarch Watch data have been used to compile day-by-day snapshots of the migration throughout the entire state each year, and a long-term picture of when and where monarchs occur in Texas and how much they vary in abundance from year to year. From these data, we have learned that the fall southbound flight of monarchs is primarily restricted to two flyways. The Central Flyway is the larger of the two and extends from Interstate 35 to Midland and is roughly centered on the cities of Wichita Falls, Abilene, San Angelo, and Eagle Pass. The narrower second, or Coastal, Flyway extends about 20 miles inland along the Gulf Coast. It appears to widen in southern Texas, where monarchs veer away from the coast and head for their overwintering grounds in central Mexico.

Website

Texas Monarch Watch: http://www.tpwd.state.tx.us/nature
and http://www.tpwd.state.tx.us/learning/texas_nature_trackers/monarch/

Journey North is a nonprofit organization whose primary mission is to engage K–12 students in the global study of migration and seasonal change.

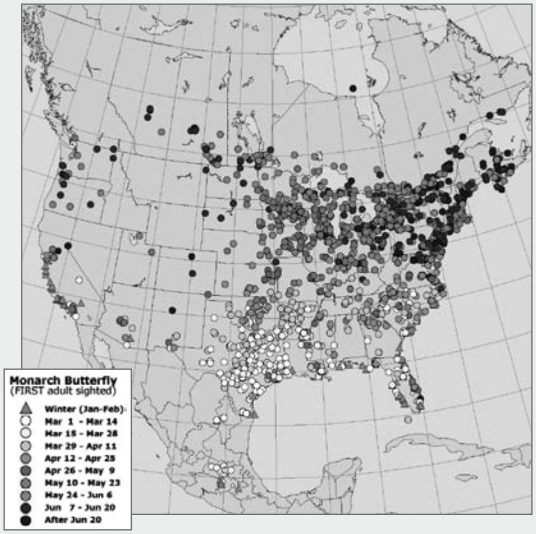
Journey North

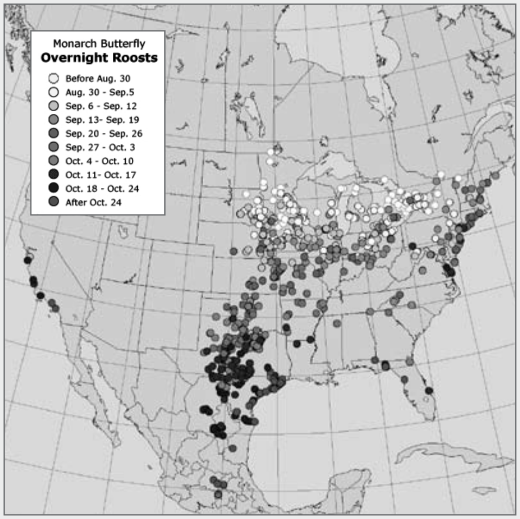
Background and Goals

Journey North is a nonprofit organization whose primary mission is to engage K–12 students in the global study of migration and seasonal change. The organization was established in 1994 with a grant from the National Fish and Wildlife Foundation. Ongoing support is provided by the Annenberg Foundation. Journey North provides an easy entry point for volunteers, with relatively simple protocols, strong online support, and immediate results. The program tracks the monarch's spring migration from Mexico, providing a picture of the monarch's annual spring recolonization of North America and factors that influence its timing. Volunteers report their first spring sightings of adult butterflies and a live map of the migration is produced on the Journey North website.

Journey North volunteers also track the fall migration. The fall study is helping to identify the monarch's overall fall migration pathway and specific locations and types of habitat that are essential during fall migration. Throughout the flyway, all overnight roosts are reported to Journey North and included on a real-time fall migration map. This study is documenting the locations of the hundreds of stopover sites monarchs use in any particular year during fall migration. The fact that large numbers of monarchs are in one place at one time points to the importance of these stopover sites. Initial results are helping to elucidate the location of monarch flyways and the timing of their use on a continental scale. Further scientific questions regarding the resources monarchs use at these sites can be pursued once information about when and where roosts form has been gathered. Citizen scientists can play a key role in advancing scientific understanding about this dynamic, ephemeral resource that monarchs use on a day-to-day basis during migration.

Before Journey North began, Cockrell et al. (1993) had conducted the most comprehensive study of the monarch's spring migration by surveying for immature stages of monarchs on milkweed transects in just 62 locations. Using the Internet, hundreds of Journey North observers can report data throughout the migratory pathways. When real-time weather maps and climate data became available on the Internet, it became possible to juxtapose migration events with weather patterns to analyze the pace of a season's migration against climate variables. Since 1997, all migration records and maps have been stored permanently on the website. In addition, weekly migration updates document unique qualities of each migration season. This information lets scientists look at the





Left. Location of first monarch sightings, documenting the northward movement of monarchs in the spring. Right. Location of roosting sites, documenting the southward movement of monarchs in the fall.

dynamics of monarch migration on a real-time basis. Coupled with weather maps, climate data and other geographic information, the data provide information with important conservation implications, including identifying main migration pathways and critical times of passage (Howard and Davis 2004), weather events or human activities that affect the population, and potential impact of climate change on the monarch's migration and range.

Beyond their scientific value, Journey North migration maps are valuable communication tools that can interest and involve the public in monarch conservation. From an educational perspective, Journey North provides real-time, real-life scientific data and accompanying educational materials.

Protocol

For quality control purposes, participants must register in order to contribute observations. Registration is free and privacy is secured. Journey North staff often contact observers by e-mail to verify sightings or collect additional information. Participants must be able to accurately identify a monarch butterfly and distinguish a monarch from look-alike species. The Journey North website and staff provide identification materials and support.

Spring Migration (the "Journey North"): Journey North tracks the leading edge of the migration by collecting observations of first sightings. Monarchs leave the Mexican overwintering sites in March, yet early monarchs may depart in late February. The first migrants typically appear in Texas sometime during the first half of March. By the last half of April most of the overwintering generation has died. Their offspring continue the northward journey. Typically, by the end of June the monarchs have spread throughout their breeding range in the United States and Canada. During this northward journey, participants report four types of sightings.

Fall roosting site in Texas

Sightings of pre-migration, or "winter," monarchs are those made during January or February anywhere in the breeding range, such as along the Gulf or Atlantic coasts. These observations appear on the migration map and indicate where pockets of monarchs may have survived the winter.

Sightings of first adult monarch butterflies are those made in March through June, as monarchs are spreading north and east. Participants watch for monarchs as they go about their daily activities, either using standardized observation methods (observe consistently, set aside a time of day, survey the same location, etc.) or simply reporting any monarch that they see. These "first sightings" indicate the leading edge of the spring migration.

Participants also report the first signs that monarchs are breeding in their area, their sightings of the first egg or first larva. These sightings indicate that monarchs are not simply moving through an area, but actually reproducing.

Finally, participants are asked to watch for the first milkweed to appear in the spring, and to record the date the first leaves unfold. The goal of this report is to document the timing of early milkweed growth across the breeding range.

Participants post their observations on the project website, entering the date of the sighting, and the nearest town, state or province. Space is provided for comments (weather conditions, monarch behavior, etc.). When available, observers provide the precise latitude and longitude coordinates of the location of the sighting. Otherwise, the computer system retrieves the coordinates of the nearest town, using a postal code database. All sightings are reviewed carefully by Journey North staff in case there is a need for follow-up communication.

Fall Migration (the "Journey South"): Fall migration observations are collected from August to December, when Journey North volunteers report sightings of overnight roosts and migrating monarchs. An overnight roost is a place, usually in one or more trees, where monarch butterflies gather and rest for the night during their fall migration, and may contain hundreds or even thousands of butterflies. The gathering must contain at least a dozen butterflies to be considered a roost; large gatherings of butterflies at nectar sources are not considered roosts. Detailed descriptions of typical roosting behavior, as well as pictures and more information, are available on the Journey North website. Tracking the roost sites documents the progression of the southward migration.

Journey North volunteers also watch for migrating monarchs, then count "monarchs per minute" or "monarchs per hour" to measure the pace of the migration. Journey North staff review all sightings and produce a map to illustrate the passage of peak migration.

Website

Journey North: http://www.learner.org/jnorth

Correo Real

Background and Goals

Correo Real is the Mexican counterpart to Journey North and shares the same goal of gathering migration data during the spring and fall migrations (see details above). As collaborative projects, the two programs bridge the English/Spanish language barrier between the United States and Mexico. Project Founder and Director Rocio Treviño manages a network of over 200 participants and collects data throughout the monarch's migration pathway in northern Mexico.

In 1992, *Protección de la Fauna Mexicana* (Profauna) began the *Correo Real* program with the goal of establishing a monarch conservation network along its migratory route in Mexico with the participation of school children and teachers. Recognizing the need for increased knowledge and information about the biology and conservation of the species, *Correo Real* provides training to teachers and children for collecting information about migratory monarchs. Participants record the number of butterflies the observe, the time of their observations, the butterflies' behavior (such as flying, feeding or resting), the locations and plants on which the butterflies feed or rest, and climate conditions. As part of the training activities, *Correo Real* has produced manuals and other educational materials. To date more than 3000 teachers have received training in the states of Coahuila, Nuevo León, Querétaro and San Luis Potosí.

When the program began all communication took place by mail thus the name "*Correo Real*" (Spanish for "Royal Mail"). This monitoring program has greatly contributed to the gathering of information in Mexico although much of this information remains to be analyzed.

Protocol

Correo Real collects migration sightings along with detailed notes about behavior of the monarchs (nectaring, flying, roosting, etc.) and the weather conditions at the time of sighting. The protocol matches that of Journey North/South as described above.

Website

Correo Real: http://www.profauna.org.mx/monarca/
E-mail: correo_real@prodigy.net.mx
Telephone: (844) 414–4997
Mailing address:
Rocío Treviño Ulloa
Nueva Vizcaya 480
Frac. Urdiñola
Saltillo, Coahuila C.P. 25020, México

Correo Real is the Mexican counterpart to Journey North and shares the same goal of gathering migration data during the spring and fall migrations.

Flight Vectors

Background and Goals

Scientists are making great strides in understanding monarch butterfly navigation. However, we still do not know exactly how monarchs from Ontario to North Dakota find the same roosting sites in the oyamel forests in the states of México and Michoacán in Mexico year after year. Clearly, they are using environmental information to guide their migratory flights, but what kinds of information do they use? By making systematic records of the directions in which monarchs fly, we can find clues to these mysteries. Flight directions are often call **flight vectors**, or **vanishing bearings**. This information will help us understand the flight paths monarchs take during their migration, whether or not individual monarchs are migratory, and how they respond to their geographic location.

Although there is no central location for flight vector data, these data have been used in several ways, and collecting flight vector information, especially in conjunction with other monitoring data, can provide valuable insights into monarch biology. We know that migrating monarchs show strong preferences for south and southwest flight paths in the fall, while monarchs in the summer show a random distribution of flight directions (Kanz 1977; Schmict-Koenig 1985; Perez and Taylor 2004). Thus, directional flight can be used to show whether individuals are migratory. Perez and Taylor (2004) used this definition of migratory flight behavior to show that monarchs continue to migrate even when they are reproductive (i.e., not in diapause). Taylor and Gibo (unpublished, Monarch Watch website) have collected evidence that monarchs start to migrate when the sun reaches angles of 56° to 47° over the horizon, again using flight vectors to determine when monarchs are migrating.

Flight vectors can be measured either upon the release of captive butterflies, or for butterflies flying overhead.

To learn more about the specific routes that monarch butterflies take from their breeding grounds in the northern United States and Canada to overwintering areas in the Transvolcanic Belt of central Mexico, and to investigate the guidance mechanism by which they locate these small overwintering sites, Calvert (2001) took flight vectors during different times of day and at different locations in Texas and Mexico. Monarchs were shown to employ either a time-compensating sun/sky compass or to follow other non-solar cues over open terrain. Upon reaching the Sierra Madre Oriental mountain range of eastern Mexico, monarchs change their course and follow this range.

Flight vector data are also simply interesting to collect and analyze. Interested individuals at any location could record these data for individual butterflies flying overhead throughout the time monarchs are in their area, documenting the **phenology** of directional and non-directional movement.

Protocol

Flight vectors can be measured either upon the release of captive butterflies, or for butterflies flying overhead. Release sites should have unobstructed, 360° flight access. Buildings, large trees, and even parking lots may deter flight in specific directions. Non-migratory butterflies are expected to fly randomly (in all directions), and biased flight (going in one direction) could indicate either migratory behavior or avoidance of flight deterrents. Before release, captured butterflies are generally cooled to between 0°C and 4°C to ensure that undirected escape responses are not recorded. This can be done in an ordinary cooler, but it is best to conduct the releases on a sunny day, so the cooled butterflies can warm up enough to fly. Butterflies are then placed on a sponge, or other uneven surface that provides a substrate into which the **tarsal** claws can hook, preventing the insects from being blown off prematurely. After the butterflies fly away from the sponge, their flight paths are recorded with a handheld compass.

To measure flight vectors of butterflies that are already in flight, recorders position themselves directly under the flight path, and watch the butterfly until it disappears. These observations should be made in open areas where flight behavior is not modified by hills, buildings, trees or other obstructions. The direction from the recorder's location to the spot on the horizon over which the butterfly disappears is its flight vector. Generally, most butterflies will fly in the same general direction during migration, and cover all compass directions when they are not migrating.

Website

Tactics and Vectors: http://www.erin.utoronto.ca/~w3gibo/
(While this website has not been updated since the late 1990s, it contains excellent information on measuring monarch flight vectors.)

8 INDIVIDUAL MONARCH ASSESSMENTS

Project MonarchHealth

Background and Goals

Monarch butterflies can be parasitized by a **protozoan parasite**, *Ophryocystis elektroscirrha* (*Oe*) (Altizer 2001). Unharmful to humans, this parasite can inhibit normal growth and decrease butterfly size and survival. *Oe* infects monarch caterpillars when they ingest spores accidentally deposited on milkweed leaves by egg-laying females. The parasite travels through the gut wall and replicates within the caterpillar, eventually finding its way to the outside of the adult's body. Altizer et al. (1997) show dramatic variations in parasite prevalence among wild populations. Parasite rate is inversely related to migratory distances, with the eastern migratory population having the lowest parasite levels.

The goal of Project Monarch Health is to increase knowledge of how the prevalence of Oe varies with time and location throughout North America.

The goal of Project MonarchHealth is to increase knowledge of how the prevalence of *Oe* varies with time and location throughout North America. This citizen science program began in 2006 (Project MonarchHealth 2007). Initial results showed that 12% of monarchs collected by volunteers were infected with *Oe*. The proportion of infected butterflies increased over time throughout the breeding season. Additional data will strengthen the results already reported, and allow comparisons of infection rates between populations and over time.

More broadly, *Oe* is closely related to the parasite that causes malaria in humans. Studying this parasite in monarchs could illustrate how human influences, like spraying for malaria-carrying mosquitoes, affect disease infection rates.

Many diseases that affect humans and other wildlife are spread through migrating species, and this project will help researchers learn more about the interactions between diseases and their migratory hosts.

A similar project has been conducted in Mexico since 2003 by the National Polytechnical Institute (IPN) to increase data about the prevalence of *Oe* in overwintering colonies and its variation with the time and to assess normal microbial flora associated with overwintering monarchs. The second study involves collecting 50 to 60 butterflies during the winter, and analyzing their bacterial load. During an event of high monarch mortality, these microbial analyses will allow us to differentiate bacteria and fungi belonging to the normal flora from those which could be pathogens.

Monarch researchers have used physical appearance to understand monarch migratory patterns and mating behavior in the overwintering colonies.

Protocol

Project MonarchHealth participants register on the project website, then receive supplies needed to conduct sampling by mail. Refresher kits are available when the supplies are used up. Volunteers either catch adult monarchs or find wild caterpillars and rear them to adulthood. To sample for parasites, they use a cotton swab (Q-tip) to gently swab the butterfly's abdomen to pick up the parasite spores. They return swabs in pre-addressed envelopes to the University of Georgia, where MonarchHealth scientists microscopically analyze the sample, send volunteers the results of their sampling contributions, and post the results on a project website.

Website

Project MonarchHealth: http://www.monarchparasites.org/

Monarch Vital Statistics

Background and Goals

A great deal can be learned by comparing monarch appearance and behavior in different places and at different times. We know that monarch wings become more tattered and worn with age; thus we can compare the relative ages of monarchs. If we see many monarchs, but none are laying eggs, we can guess that they are all males, they are all too young to lay eggs, or they are all in reproductive diapause. Scientists can use observations such as these to learn more about aspects of monarch biology, such as migration and reproductive behavior.

There is no official monitoring program set up to receive monarch physical and behavioral characteristics data. The Monarch Lab at the University of Minnesota has a standardized protocol described on its website. Any data collected may be sent there to be analyzed.

Monarch researchers have used physical appearance to understand monarch migratory patterns and mating behavior in the overwintering colonies. Cockrell et al. (1993) compared wing conditions of the first monarchs to arrive in the spring in locations throughout the eastern US. Almost all of the butterflies they saw farther south than 36° latitude had very worn wings, suggesting that they were old. On the basis of this observation, and other evidence on the timing of the appearance of the monarchs, they concluded that these monarchs were part of the overwintering generation. On the other hand, almost all of the first butterflies observed north of 36° latitude were in good condition, suggesting that they were young. Cockrell et al. (1993) concluded that these monarchs were the offspring of the overwintering generation.

Oberhauser and Frey (1999) and Van Hook (1993) compared the condition of males that were mating in the overwintering colonies to those that were roosting in trees. They found that mating males weighed less, had poorer wing condition and more wing damage, had smaller wings, and were more likely to be infected with a protozoan disease than roosting males. They concluded that these mating males were in such poor condition that they would be unlikely to survive the spring migration, and were thus mating early in order to have some chance of passing their genes on to the next generation.

In migratory butterflies captured in Minnesota and Wisconsin in August and early September, wing length is larger than monarchs found in Texas in September and October (Borland et al. 2004). Comparisons of the mass of these same butterflies show that the Texas monarchs weigh more. Many hypotheses about these findings can be tested experimentally; perhaps butterflies with longer wings are able to fly faster, and thus arrive in Texas earlier, or perhaps butterflies that develop earlier consume higher quality milkweed and grow larger. The mass differences provide evidence of how important nectar sources are for monarchs as they migrate.

The appropriate way to measure forewing length. Shown here with calipers, measure from where the wing attaches to the thorax to the tip, or apex.

Protocol

Several "vital statistics" provide useful information about monarchs: their sex, mass, wing length, wing condition, and behavior.

Sexing: Male and female monarchs can be distinguished easily. Males have a black spot on a vein on each hind wing that is not present on the female. The ends of the abdomens are also shaped differently in males and females, and females often look darker than males and have wider veins on their wings.

Example of wing condition rating. Note the bare and faded spots on this monarch's wings. It has a wing condition of 3 on a scale of 1 to 5.

Mass: While the mass of a newly-emerged adult is determined by its life as a larva or pupa, the mass of older butterflies can change over the course of a day, as they do things like fly, eat, and mate. Mass will also change over the course of the adult life as butterflies use up the lipid reserves built up as larvae. Thus, the mass of a butterfly can provide information about what has happened to it as an adult. A balance (weighing scale) accurate to the nearest 0.01 gram (g) or, preferably, 0.001 g is necessary to weigh adult monarchs. Researchers use glassine envelopes, available from biological supply companies, to hold the butterflies as they're being weighed. It is also possible to use a folded piece of paper as an envelope. The empty envelope must first be weighed (tared), then the butterfly and envelope weighed together, and mass of the butterfly determined by subtraction. Adult monarchs weigh, on average, about 500 mg, or 0.5 g.

Wing Length: Wing length is interesting because it doesn't change from the time that the butterfly emerges, and is thus determined by the size of the larva when it pupates. So it actually gives us information about whether the monarch had enough to eat at the larval stage. Measure forewing length, from where it attaches to the thorax to the tip, or apex, of the wing. Calipers are the most accurate way to do this, but it is fine to use a small clear ruler that measures in millimeters (mm). Average monarch forewings are about 50 mm long.

Wing Condition: All Lepidoptera lose scales throughout their lives, and if you touch the wings of many butterflies or moths, you will be able to see a fine patch of these scales on your fingers. Even though monarchs don't lose many scales when you touch them, they do lose scales as they fly, attempt to mate, and brush against plants. It is thus possible to get a rough estimate of a monarch's age by looking at how many scales it has lost. Wing condition is usually assessed on a 5-point scale, with 1 = a newly emerged butterfly (wings are in perfect condition), 2 = very good condition (few scales lost), 3 = a few patches of missing scales (wings are slightly dull), 4 = large patches of missing scales (wings are very dull compared to a new monarch), and 5 = more than a third of the scales are missing (wings have transparent spots).

Behavior: Monarch behaviors can tell us a great deal about their status. Butterflies flying in a straight line are probably migrating, and behaviors such as nectaring, laying eggs, mating, roosting in a tree with other butterflies, flying in a non-directional manner, or chasing other butterflies are also relevant. For more information on measuring flight direction, see the Flight Vector section above. Collecting this information in different places and at different times can tell us a great deal about the yearly migratory cycle of monarchs.

Website

Monarch Lab, University of Minnesota: http://www.monarchlab.org

9 ACKNOWLEDGMENTS

The CEC would like to acknowledge Karen Oberhauser, from the University of Minnesota and the Monarch Butterfly Sanctuary Foundation, for her role as main author and editor of this monitoring book, as well as Rebecca Batalden, from the University of Minnesota, and Elizabeth Howard, from Journey North. We would also like to acknowledge all of the individuals and organizations who have developed, supported and sustained the many monarch monitoring programs that are described here. Without their efforts, much of what we know about monarch butterflies would still be a mystery. As well, we would like to acknowledge Andy Davis, for all he has done to make the results of many of these programs easily accessible to a broad audience. Finally, the CEC would like to express its gratitude to the following organizations, listed in alphabetical order: the United States Department of the Interior, the United States Forest Service, and the University of Minnesota.

10 GLOSSARY

Abdomen: the elongate hind part of the body, behind the thorax.

Abiotic: the non-living parts of an organism's environment (weather, temperature, rocks, etc.).

Aposematic: coloration that warns predators of distasteful prey.

***Asclepias*:** the genus of plants that contains milkweed, the host plants for monarch larvae. Monarchs eat many plants in the genus *Asclepias*.

Biotic: the living parts of an organism's environment (plants, animals, micro-organisms, etc.)

Cardenolides: poisons that seriously affect the hearts of vertebrates. They are related to digitalis, a chemical from the foxglove plant that is used in medicine to treat heart disease but can also be poisonous in large doses. Milkweed plants make these chemicals to protect themselves from being eaten.

Chorion: the hard outer shell of insect eggs. In general, the chorion is the outermost membrane enclosing the developing embryo. In reptiles, this layer lies just inside the shell, and in mammals the chorion becomes the placenta.

Diapause: a period of dormancy between periods of activity.

Eclosion: the process of emerging from the pupa.

Exoskeleton: a hard skeleton located on the outside of an invertebrate's body (in contrast to the internal skeleton of vertebrates) that protects it and serves as a point for muscle attachment.

Filaments: fleshy, black extensions at the front and rear of the monarch larvae, functioning as sense organs. Also called tentacles.

Flight vector: the direction of flight for an organism flying in a relatively straight line.

Frass: the solid waste product of insects.

Instar: a period between larval molts. There are five of these periods in the growth of a monarch larva.

Larva: (plural, **larvae**) the second stage, after the egg, in metamorphosis. Also known as "caterpillar," in butterflies and moths.

Lipid: organic compounds that are insoluble in water, and often used to store energy in organisms. Fats are lipids.

Mandible: strong "jaws" on the larval head.

Morphological: relating to the physical features of an organism.

Oviposition: the process of laying an egg.

Oyamel: a species of fir tree, endemic to the mountains of Central Mexico. Currently distributed on mountain peaks at elevations between 2400 and 3600 meters.

Parasite: organism that lives in or on a host's body and depends on the host for the nutrients and resources necessary to complete its life cycle. Parasites are usually smaller than their hosts (e.g., tapeworms that live in animal intestines) and usually do not kill the host directly, although they may weaken it and make it more susceptible to disease or predation.

Parasitoid: insect that lays its eggs on or inside another insect species (which is called its host). The eggs hatch and feed on the host from the inside, eventually killing it.

Phenology: the science of seasonal changes and their effects on the natural world.

Phenophase: a growth stage of a plant that is repeated annually, such as flowering or budding.

Proboscis: a feeding tube, for sucking nectar and other food. In monarchs, it is coiled under the head when not in use.

Protozoan: single-celled organism, in the kingdom *Protista*.

Pupa: (plural, **pupae**) the third stage in metamorphosis, coming after the larval stage.

Pupation: the act of changing from a larva to a pupa.

Recruitment: growth in the size of a population due to reproduction.

Senescing: getting old.

Spermatophore: a material packet delivered by males during mating that contains both sperm and other materials, notably proteins.

Stopover site: sites at which birds and butterflies stop during migration to rest and refuel their energy supplies.

Tarsa: **(**plural, **tarsi)** the second-to-last segment of insect legs (analogous to human toes). Butterflies stand and walk on their tarsi.

Thorax: the middle section of an insect's body. The wings (if present) and legs are attached to this segment.

Transect: a line or narrow belt used in ecological surveys to provide a means of measuring the distributions of organisms.

Unpalatable: having an extremely disagreeable taste.

Vanishing bearings: the direction in which an organism is flying, as measured from a spot over which the organism is observed to fly to the spot on the horizon at which it disappears, or vanishes.

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