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Conservation and Management of Western Monarchs on Department of Defense Lands: Implications of Breeding Phenology

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Conservation and Management of Western Monarchs on Department of Defense Lands: Implications of Breeding Phenology

DoD Legacy Resource Management Program: NR 19-001

Final report for the Department of Defense Legacy Natural Resources Program

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Acronyms

AFB = Air Force Base
DoD = Department of Defense
DOY = Date of Year
ESA = Endangered Species Act
GAM = Generalized Additive Model
INRMPs = Integrated Natural Resources Management Plans
JBLM = Joint Base Lewis McChord
NAS = Naval Air Station
NOAA = National Oceanic and Atmospheric Association
NWR = National Wildlife Refuge
NWSTF = Naval Weapons Systems Training Facility
USFWS = US Fish and Wildlife Service
YTC = Yakima Training Center

EXECUTIVE SUMMARY

Monarch butterflies (*Danaus plexippus)* have declined dramatically across North America. Monarchs in the West have declined by over 99 percent since the 1980s, with a sharp population crash observed in 2018 and another sharp crash in 2020, when overwintering counts dropped to fewer than 2000 butterflies. In December 2020, monarch butterfly became a candidate for protection under the US Endangered Species Act, a status in which USFWS determined that the species warrants protection but protection is precluded by higher priority listing actions.

Breeding phenology differs between eastern and western populations. Western monarchs overwinter in California and breed and migrate across the West, including a considerable portion of Department of Defense (DoD) land. Monarchs which breed west of the Rockies occur broadly and are distinct from the larger eastern population. Eastern monarchs breed in successively northbound generations. Western monarchs do not follow this pattern, and basic information is not available to construct management strategies that reduce conflict with active military training.

The primary purpose of this work is to determine seasonal timing of monarch butterflies in locations across the West, and to use this information to increase the efficiency and effectiveness of managing habitat for monarchs on DoD lands. This will help DoD land managers maximize the use of these lands for training while considering the needs of a widespread at-risk species. See the associated Best Management Practices document associated with this project: *Monarch Conservation on Department of Defense Lands in the West: Best Management Practices* (McKnight et al. 2021).

We used systematic surveys across the breeding range in 2017, 2018 and 2019 to gain understanding of the seasonal of timing of monarch breeding across the West. We conducted monthly surveys— about the time it takes for monarchs to complete one generation— throughout the expected breeding season at installations in the West and regions nearby and documented abundance of monarch life stages (eggs, larvae, pupae and newly emerged adults) as evidence of site-based breeding phenology. In 2017 and 2018, five installations included Vandenberg AFB in California, NWSTF Boardman in Oregon, JBLM Yakima Training Center in Washington, NAS Fallon in Nevada, and Mountain Home AFB in Idaho. In 2019, we added Beale AFB in Northern California. We used Generalized Additive Models (GAMs) to understand monarch breeding phenology. Because our work spans a broad geographic area, our approach allows us to make inference about the western monarch population from relatively sparse data and acts as a building block for constructing a demographic model of western monarchs in future work.

Based on work in 2017 and 2018, we learned the following from our surveys and associated analyses:

- Western monarchs breed throughout the season consistent with a population which expands in distribution throughout the breeding season rather than one that shifts throughout the breeding season.
- Milkweed diversity within a region is a key component of western monarch habitat
- Monarchs are selective in their use of milkweeds. When multiple milkweed species were available, monarchs selected *A. cordifolia, A. incarnata* and *A. speciosa* more often than other available milkweed species in some years and other years were not selective.
- At the rangewide scale, milkweed does not appear limiting nor was it likely to be a primary factor responsible for the 2018 crash. However, at local scales and at critical times of year (spring), milkweed may be limiting.
- We see evidence of a marked decline in abundance before the beginning of the 2018 breeding season, indicating that factors responsible for the 2018 crash occurred before the beginning of the breeding season.

In 2019, additional findings include:

- Monarchs prefer habitat close to shade and trees. Females will select this habitat structure for oviposition when it is available.
- Seasonal timing of breeding shifted later over the three-year study. In 2019, monarchs arrived at the inland breeding areas almost a month later than in 2017 and 2018.
- Additional years of monitoring would be required to determine if the breeding phenology is directionally shifting to arriving at locations farther from the coast later in the season.

These findings have direct application to DoD natural resource management including:

- Installation management of monarch breeding habitat is not linked to the 2018 population crash because the causal drivers of the crash likely occurred before the beginning of the 2018 summer breeding season.
- Across the West, broad landscape-scale milkweed limitation in the breeding range is not a dominant driver of the recent population crashes in 2018 and 2020.
- Enhancement of breeding habitats at key times of year (spring), in focal microhabitats (in areas with some shade) and/or in key regions (California's Central Valley) might contribute to population recovery.
- Recommendations including regional windows for seasonal timing of habitat management were developed to balance training needs with use of breeding habitat by monarchs.
- The map for timing of regional habitat management is dynamic. Directional shifts in breeding phenology will impact this guidance document. We recommend continued monitoring of breeding phenology to determine if installation managers will need to modify their management timing in the future with changes in monarch migration phenology.
- Installation-specific guidance for INRMPs was developed within our Best Management Practices document. See *Monarch Conservation on Department of Defense Lands in the West: Best Management Practices* (McKnight et al. 2021).

- Continued sparse but systematic monitoring across the western landscape can provide broad guidance for installations if the monarch is protected under the Endangered Species Act.

Understanding monarch habitat use on DoD installations is crucial to maximizing proactive management for monarchs while minimizing interruption of operations. Continued and future programs such as this Legacy-funded program provide a basis for tailoring management to ecosystem and species needs in balance with mission of installations for DoD use of the lands.

INTRODUCTION

The monarch butterfly (*Danaus plexippus plexippus*) has experienced dramatic declines across North America. Western monarchs, which overwinter in coastal California, declined by 97% between the 1980s and the mid-2010s; and in 2018, the population dropped even further for a total estimated decline of >99% and remained at this precipitously low level in 2019 at fewer than 30,000 wintering butterflies. In 2020, the wintering numbers dropped by another order of magnitude – to fewer than 2,000 overwintering monarchs (Pelton and McKnight 2021, Xerces Society 2021). Analyses in 2017 indicated a quasi-extinction risk of 72% in 20 years and 86% in 50 years (Schultz et al. 2017; Pelton et al. 2019). Even with these dire projections, population numbers with fewer than 2000 overwintering butterflies was a shock to scientists and the conservation community alike. This is a far greater decline than that observed in the eastern monarch population, which overwinters in central Mexico and has declined by an estimated 80% since the mid-1990s; the eastern population has a quasi-extinction risk of 11-57% in 20 years (Semmens et al. 2016). Declines in western monarchs have been documented in both declines in the overwintering sites and in spring and summer monitoring over the past 40 years along a latitudinal transect that spans Northern California (Espeset et al. 2016)


Photo by S. McKnight/Xerces Society

As monarch populations have rapidly declined in a single human generation, many are wondering what they can do to save the monarch and its milkweed host plant. While guidance to answer this question for monarchs is in development for the eastern and central areas of the U.S. (see *Monarch Joint Venture's Mowing for Monarchs*, the NRCS and USFWS' *Monarch Butterfly Conference Report*, and MAFWA's *Mid-America Monarch Conservation Strategy 2018-2038* and guidance for how land managers can conserve and revive monarch populations in the Western U.S. has only recently been developed (see Xerces' *Managing for Monarchs in the West* , the recent *Nationwide Candidate Conservation Agreement for Monarchh Butterfly on Energy and Transportation Lands* and WAFWA's *Western Monarch Butterfly Conservation Plan 2019-2069*). This lack of guidance has been due in part to lack of knowledge about when and where monarchs occur in the landscape across the West.

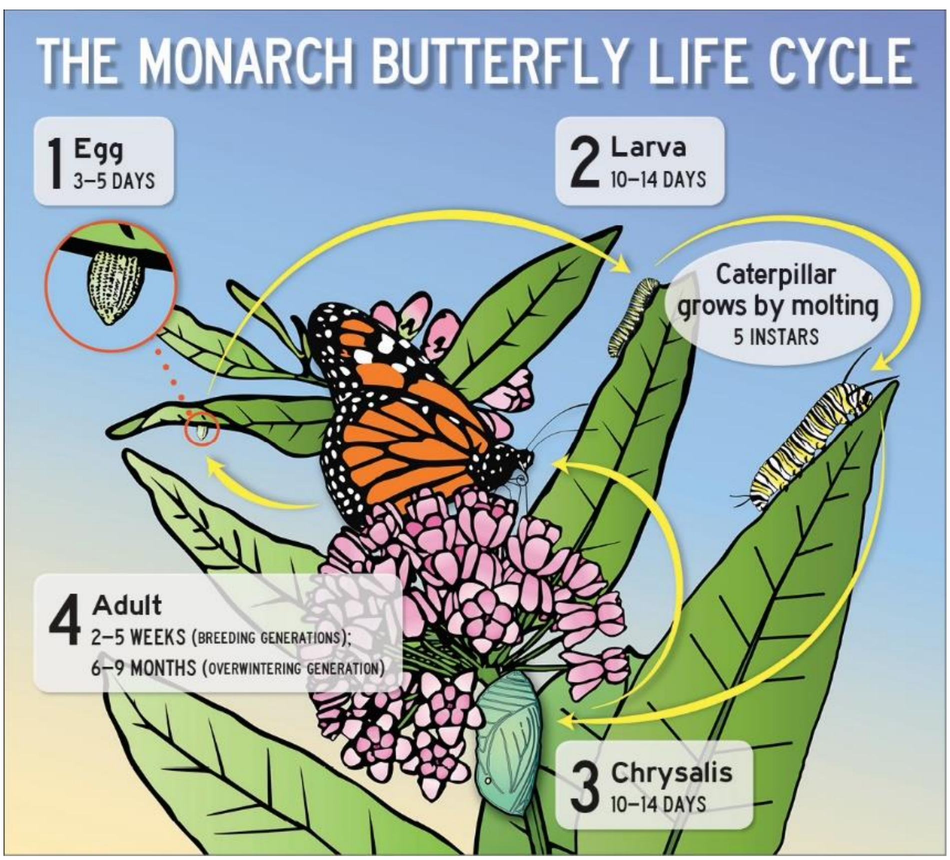
This project addresses a key part of this gap by investigating the seasonal timing of monarchs across the West. We conducted field surveys 2017, 2018 and 2019 across six military installations in the West (Vandenberg Air Force Base (AFB) and Beale AFB in California, Naval Weapons Systems Training Facility (NWSTF) Boardman in Oregon, Joint Base Lewis McChord (JBLM) Yakima Training Center in Washington, Naval Air Station (NAS) Fallon in Nevada, and Mountain Home AFB in Idaho). Based on our analyses, we developed broad management recommendations and windows for managing existing monarch habitat and, where appropriate, restoring habitat on military installations in the West.

MONARCH BIOLOGY

An introduction to the monarch life cycle, migration and distribution and breeding habitat are included in the prior report on this project (Schultz et al. 2019). We condense these sections here for ease of understanding this report but refer the reader to the earlier report for additional details.

Like all butterflies, the monarch's life cycle includes an eggs, caterpillars, pupae and adults (Figure 1). Within an annual cycle, monarch butterflies complete multiple generations, with breeding several times throughout each season. Focal resources for butterflies include hostplants for growing caterpillars and nectar flowers which provide nutrition for adults. Female monarchs lay eggs on milkweed (*Asclepias* spp.) and related plant genera. Caterpillars (larvae) rely milkweeds as their sole source of for food as they develop through five instars. Multiple generations are produced over the spring and summer, with the fall generations migrating to overwintering sites. Spring and summer generations typically live 2-5 weeks as adults while overwintering butterflies may live 6-9 months.

Figure 1. Monarch butterfly life cycle.



Migration and Distribution

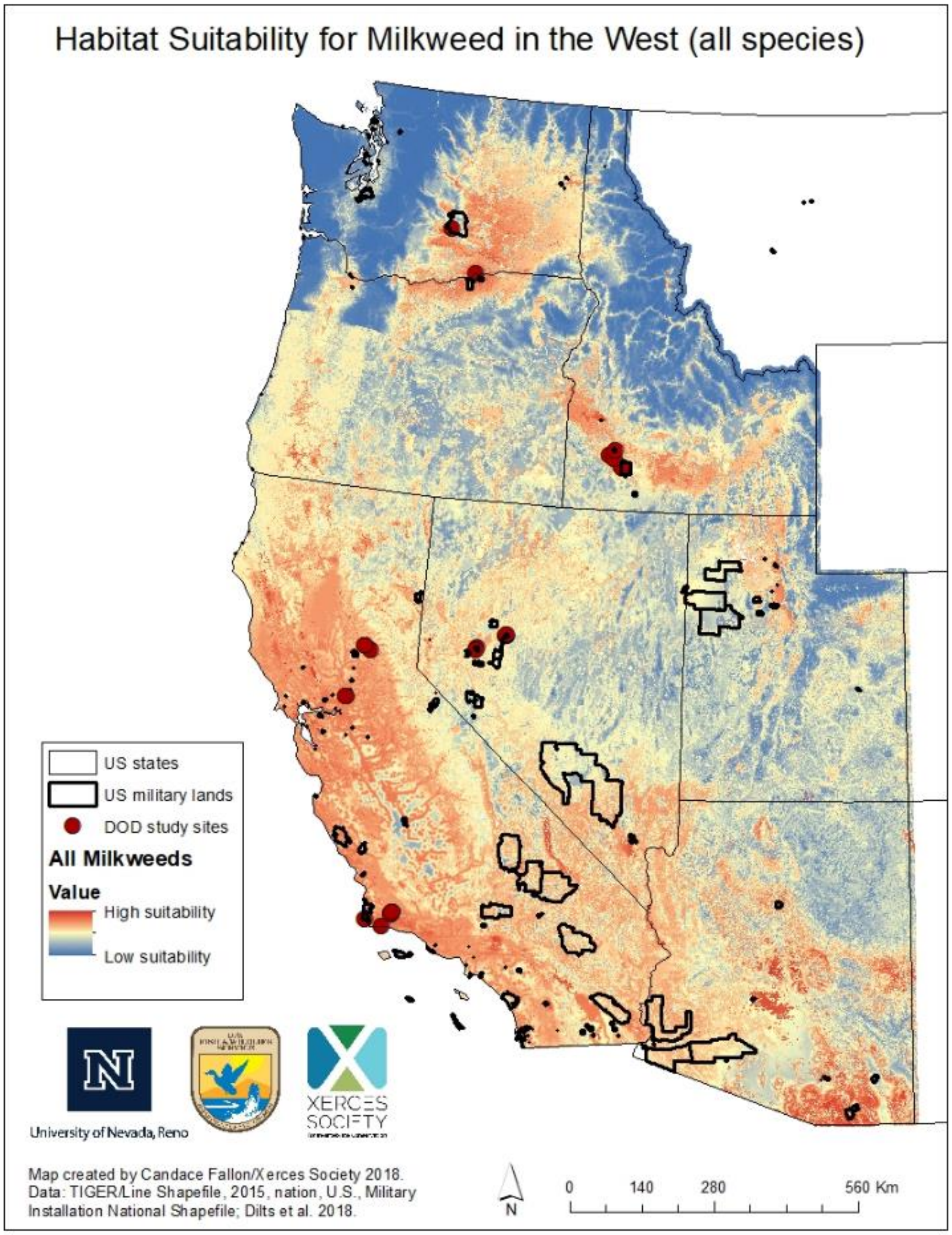
Monarchs are found throughout North America, as well as Hawaii, other Pacific Islands, Australia, New Zealand, Spain, and Portugal. The western monarch population, which breeds west of the Rocky Mountains, migrates to and overwinters in forested groves along the Pacific coast stretching from Mendocino, California, south into western Baja, Mexico as well as central Mexico. Each spring, migratory monarchs leave their overwintering grounds to seek out milkweed in their spring and summer breeding range—which is broadly distributed across the United States as far north as Southern Canada. In the West, monarchs are thought to breed continuously from spring through fall in California, Nevada, and Arizona and subsequent generations continue to travel north and east into the interior of the continent throughout the summer. As fall approaches, native milkweeds senesce, and monarchs start to migrate to the overwintering grounds rather than reproduce. In the West, monarchs generally migrate in a dispersed manner, but sometimes large aggregations are spotted— especially in nectar- and water-rich areas in the arid West. Once the butterflies reach their overwintering grounds—typically in September or October in California—they form clusters with other butterflies to conserve warmth and settle in for the months ahead. Overwintering monarchs in California are typically in reproductive diapause—conserving their fat for survival and spring dispersal—until February or March. Western monarchs are also known to breed year-round on native, evergreen milkweeds in parts of Arizona and in areas of southern California or coastal California where non-native tropical milkweed planted in urban gardens remains green year-round.

Breeding Habitat

Breeding monarchs require larval and adult resources as well as habitat structures to promote their growth and development. Potential breeding habitat for monarchs is defined by presence of milkweed. Milkweed grows in a variety of habitat types from barren desert slopes to wet meadows in both disturbed and undisturbed areas. Some milkweed species are adapted to natural disturbances, and are commonly found on roadsides, along irrigation ditches or canals, in or adjacent to irrigated agricultural fields, in burned areas, or along stream or river banks, while others may be more sensitive to disturbance and have more specific habitat associations. Western monarch eggs and caterpillars have been observed in all of these habitat types.

Milkweed in the West includes 23 species in the six states included in this project (see Figure 2). The primary limits to milkweed distribution are elevation and proximity to the Pacific Coast. Milkweeds generally do not occur above 9,000 feet throughout the study region, with one exception, Hall's milkweed (*A. hallii*), in Nevada. At this time, we lack data on the use of high elevation milkweed species by monarchs as larval hosts.

Figure 2. Habitat suitability for milkweed in the West with US military lands and study sites outlined



Six milkweed species were encountered in our study areas. Information on additional milkweed species in the West can be found in an appendix of our companion document, Monarch Conservation on Department of Defense Lands in the West: Best Management Practices. (All pictures in this section by Stephanie McKnight/Xerces Society)

Asclepias cordifolia. Heartleaf milkweed. This milkweed grows in dry, rocky areas in woodlands, chaparral, and evergreen forest. It is also found on slopes and hillsides in rocky or gravelly soil in chaparral, juniper woodland, shrub steppe, and open pine and fir forests and on lava flows. Typical phenology is April – July. This milkweed was encountered in Northern California study areas.

Asclepias cryptoceras, Pallid milkweed. This milkweed grows in dry, open, barren places such as washes, slopes, and hillsides, in pinyon-juniper woodland, sagebrush communities, salt desert shrublands, and aspen zones. May grow in clay, sand, gypsum, or serpentine soils. Typical phenology is from April – June. This milkweed was only encountered in Idaho study areas.

Asclepias eriocarpa, Woollypod milkweed. This milkweed grows in dry, rocky areas in many plant communities, including valley grassland, chaparral, and foothill woodland. It also grows along stream banks and roadsides. Typical phenology is May - October. This milkweed was only encountered in California study areas.

Asclepias fascicularis, Narrowleaf milkweed. This milkweed is widely distributed across the West. This milkweed grows in grasslands, wetland-riparian areas, woodlands, and chaparral. In the Great Basin it grows in pinyon-juniper, sagebrush, and mountain brush communities, and moist to dry places including stream banks, roadsides, the banks of irrigation ditches, and fallowed fields. Typical phenology is from April – October, depending on region. This milkweed was encountered in study areas in California, Nevada and Oregon.

Asclepias incarnata, swamp milkweed. This milkweed grows in wet, flat, grassy meadows as well as streams and ditch-banks, marshes, and moist or wet ground and is occasionally found growing in water. Typical phenology is from June - August. This milkweed was only encountered in Idaho study areas.

Asclepias speciosa, Showy milkweed. This milkweed is widely distributed across the West. It grows in dry to moist soil in open, sunny areas and occurs in many plant communities including wetlands, meadows, savannah, and forest clearings, as well as disturbed sites along roadsides, railways, and waterways. It is widely tolerant of alkaline soils and can become weedy in cultivated fields, pastures, and along roadsides, railways, and around habitations. Typical phenology is from May – September, depending on region. This milkweed was encountered in all study regions except Southern California.

In addition to larval resources, monarchs require sufficient nectar resources throughout the breeding season. During peak flowering season, monarchs often nectar on milkweed flowers. However, monarchs, like many butterflies, are nectar generalists and will nectar on a diversity of wildflower species. Over 150 different nectar plant species have been reported as being used by monarchs in the West (Xerces Society, unpublished data). Milkweeds (*Asclepias* spp.) make up about a third of all nectaring observations reported, highlighting their importance not only as caterpillar hosts but also as nectar sources for adults. In butterflies, sufficient nectar enhances both adult survival and female fecundity (O'Brien et al. 2004). Because western monarchs may fly great distances between oviposition events, providing enough fuel to support these dispersal events may be critical to supporting the population. However, detailed understanding on required diversity and abundance of nectar is lacking,


Photo by S. McKnight/Xerces Society

Finally, habitat structure may be critical to successful breeding in many parts of the western monarch range. Western habitats have a great diversity of climates, soil times and ecological environments. Observations suggest that monarchs may prefer areas that are close to riparian areas or wetland seeps, especially in arid parts of the West (Dingle et al. 2005). In addition, monarchs are often attracted to trees and shrubs which may provide shade and roosting structure. Like nectar, greater understanding about relative importance of these factors for western monarchs would substantially help managers and installation biologists in planning efforts to protect and enhance habitat for monarchs. A significant focus of this report is evaluating the potential importance of vegetation structure for monarch breeding habitat, especially during increasingly hot summers in the West.


Photo by C. Schultz/WSU

THREATS TO WESTERN MONARCHS

Western monarch butterfly faces multiple stressors across its range (Crone et al. 2019). Threats broadly include loss and degradation of breeding and wintering habitat, pesticides, climate change, parasites and diseases (for further discussion of threats, see our companion document, Monarch Conservation on Department of Defense Lands in the West: Best Management Practices*,* McKnight, et al. 2021). Changes in all of these factors have occurred over the same time period as the decline in the western monarch population. Recent analyses to disentangle these factors suggest the overarching importance of changes in land use (including development and pesticides), which has implications for the importance of local action by managers and installation biologists on efforts to recover western monarchs over the long-term (Crone et al. 2019; James, 2019, Forister, et al. 2021).

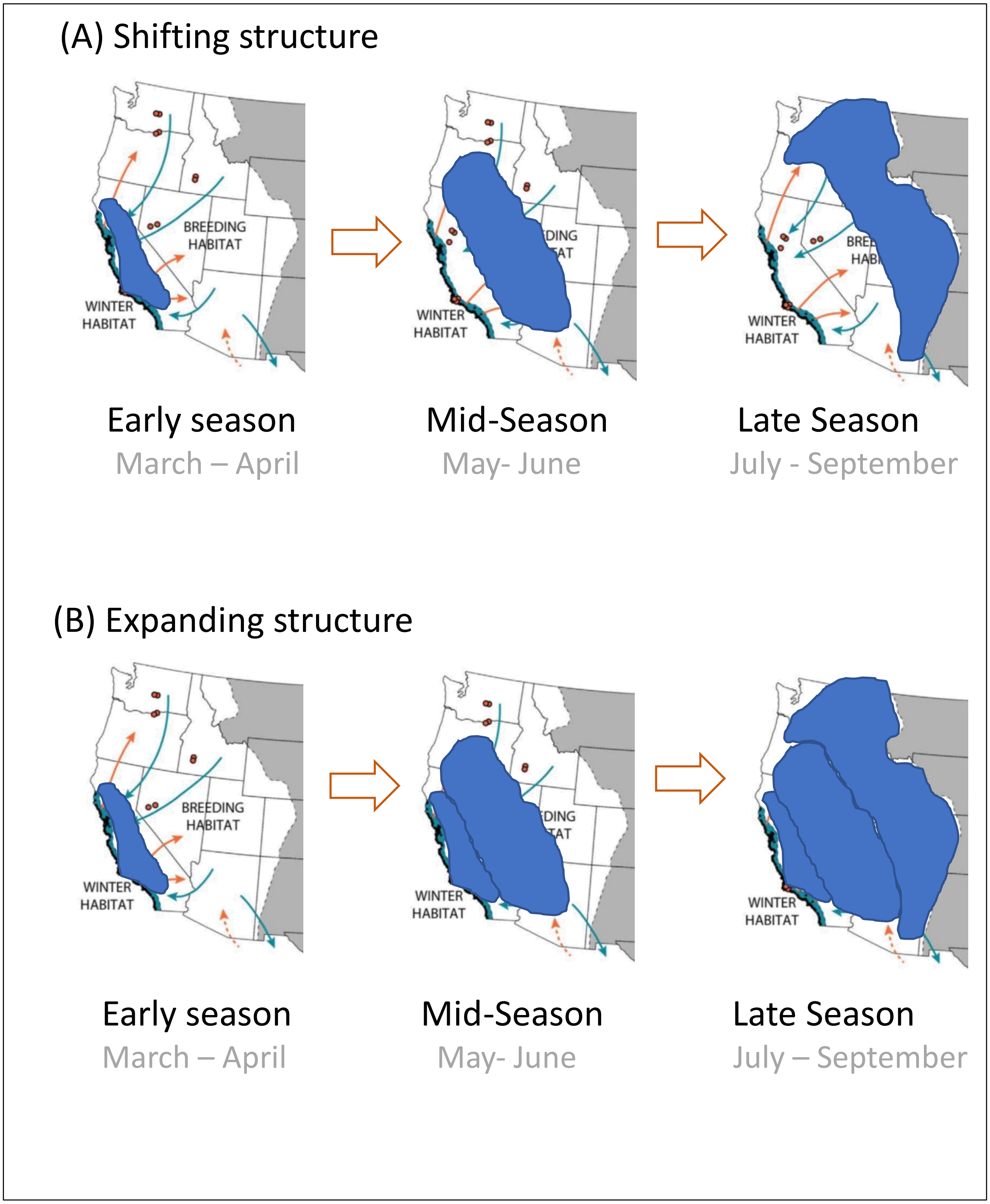
PROJECT OBJECTIVE

Our work advances knowledge to meet emerging threats, as highlighted in the 2017 DoD Legacy Areas of Emphasis: Planning to Address and Adapt to New and Emerging Threats. This includes "mitigation of possible future restrictions to training, testing or operations resulting from species declines, habitat and loss and regulatory actions." If monarchs are listed under the ESA, habitat management could impact nearly all DoD installations. Efficient and effective species conservation planning require knowledge of essential aspects of a species' biology.

Recovering at-risk species requires managing habitat throughout a species' life cycle; central to this goal is an understanding of basic phenology (timing of major life history events). Earlier studies of western monarch posit a range of potential population structures and migration strategies. Wenner and Harris (1993) suggest that monarchs overwintering in coastal California primarily expand their range during warmer times of year and contract during cooler times, a hypothesis termed the *local recruitment* hypothesis (Wenner and Harris 1993, Stevens and Frey 2010). Alternatively, long-distance migration has been hypothesized in prior decades, including classic tagging studies by the Urquharts and colleagues in which tagged butterflies from inland locations were observed wintering in coastal California (Urquhart and Urquhart 1977), the *long distance migration* hypothesis. Moreover, within the global distribution of monarchs, populations are known to exhibit *complete migration*, in which breeding and non-breeding generations do not overlap, *non-migratory* or *resident populations*, in which the population is resident year-round, and *partial migration*, in which some individuals migrate away from the wintering grounds and others are resident year-round (Dingle et al. 2005, Malcolm 2018, Satterfield et al. 2018). Although there are increasing numbers of resident monarchs (Crone and Schultz 2021) recent studies reinforce the importance of long-distance movements to the persistence of a migratory population. James et al (2018) and James and Kappen (2021) recovered tagged individuals from distant locations in Oregon, Washington and Idaho in coastal California. In addition, isotopic studies by Yang and colleagues indicate as much as 1/3 of the overwintering population may originate in these distant sites (Yang et al. 2016).

Thus, the preponderance of studies consistently support long-distance migration as an important component of the western migratory population (Nagano et al. 1993, Dingle et al. 2005, Yang et al. 2016, James et al. 2018). However, prior to our first report on this project (Schultz et al. 2019), for western monarch we lacked information on the seasonal structure of the breeding population to discriminate between a *shifting* population structure and an *expanding* population structure (Figure 3), which is critically important to managers in implementing on-the-ground efforts timed to minimize impacts on at-risk populations. Our initial findings are strongly consistent with an *expanding* population structure. One objective of this work is to build on prior work to ask if this pattern is consistent across years. In addition, we seek to gain understanding of aspects of habitat requirements critical to supporting successful breeding of western monarch. Our second objective is to evaluate the potential importance of vegetation structure for monarch breeding habitat, especially during increasingly hot summers in the West. Understanding the western monarch breeding phenology and habitat needs are vital to guiding efficient management actions, especially to directing timing to reduce conflict with military training and operational use of DoD lands. Thus the objective of our work is to fill major gaps about western monarch breeding biology and phenology to facilitate management of western monarch populations by DoD Natural Resource managers.

Figure 3. Cartoon of breeding season population structure.
(A) Shifting structure, (B) Expanding structure

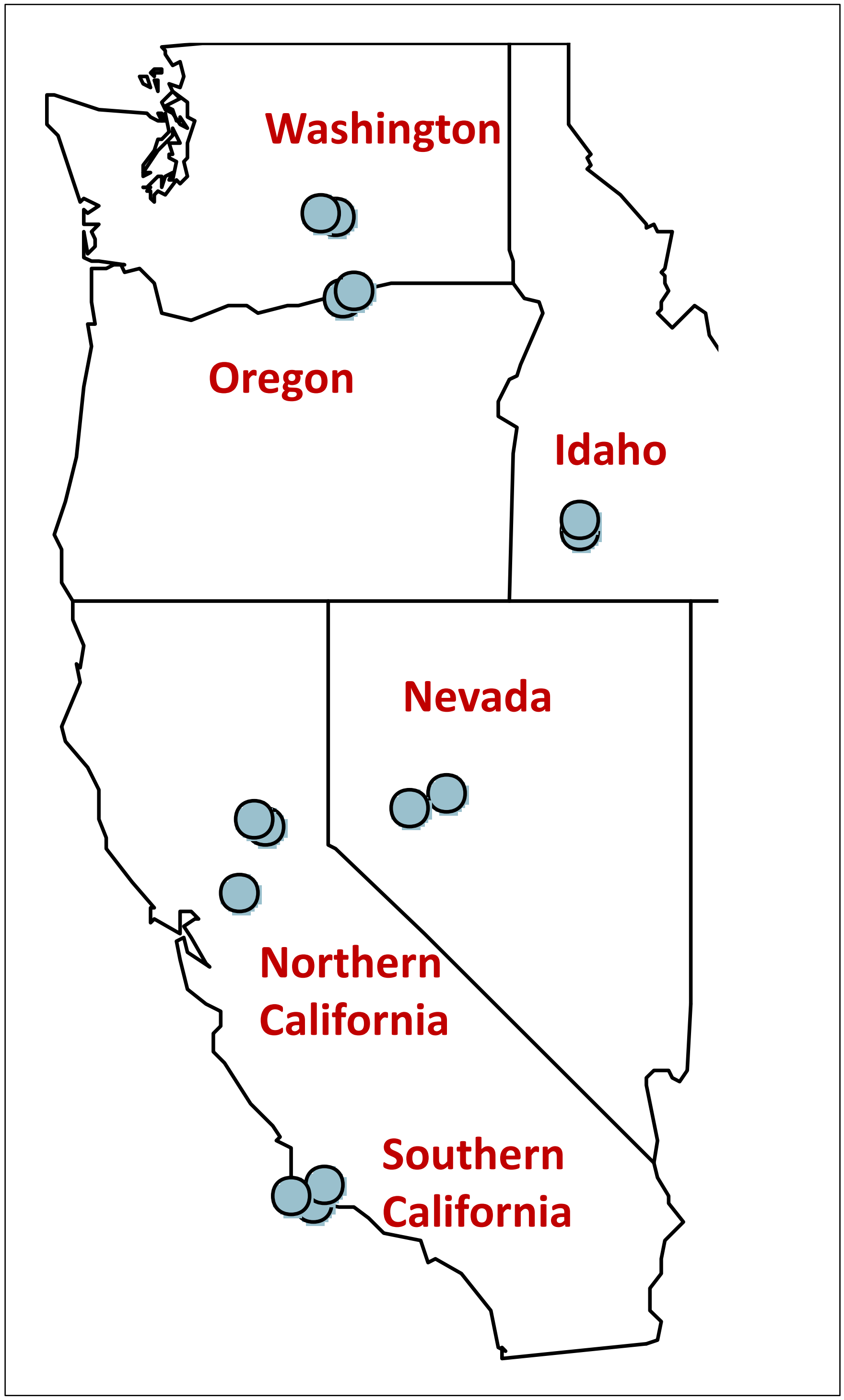


PROJECT METHODS

To meet Project Objectives, we monitored monarch habitat (e.g., known hostplant populations) at selected DoD sites that span the region known to make significant contributions to the overwintering population in coastal California. Our region of interest is based on work indicating that one third to one half of overwintering monarchs in California breed in Oregon, Washington and/or Idaho, and likely have spring migration and breeding populations that move through California and Nevada (Yang et al. 2016). In addition, in 2019 we added a new component to the work based on 2017 and 2018 insights. Specifically, we adjusted the design to quantify the potential importance of local environmental factors - tree cover and proximity to water – for monarch habitat at two focal study sites with extensive spatial heterogeneity, Oregon (NWSTF Boardman and nearby areas) and Northern California (Beale AFB). Beale AFB is a new installation in Year 3 of our project and in a critical part of the western monarch range relative to phenology and the monarch life cycle.

We conducted monthly surveys (about the time it takes for monarchs to complete one generation from egg to adult) throughout the expected breeding season in the six regions at DoD installations and nearby areas (Southern California, Northern California, Nevada, Idaho, Oregon and Washington, Figure 4). In each region, we selected a study area at the focal DoD installation as well as nearby natural areas to capture the range of potential high quality monarch breeding habitat in the region (n= 15 study areas across all regions). Study areas were initially identified based on presence of milkweed in historic and current records, as collated in the Xerces Society's Western Milkweed and Monarch Mapper (www.monarchmilkweedmapper.org) and ground-truthed with visits in early 2017. We documented abundance of all monarch life stages (eggs, larvae, pupae and newly emerged adults) as evidence of site-based breeding phenology.

Figure 4. Survey sites within 6 regions: Southern California, Northern California, Nevada, Idaho, Oregon and Washington



Project Installations and Nearby Sites

Southern California - *Vandenberg AFB*, *Gaviota State Park*, *and Sedgwick Reserve*

Vandenberg Air Force Base (34.61 N, 120.59 W) and Gaviota State Park (34.47 N, 120.23 W) are west of Lompoc and north of Goleta in southern California along the coast of the Pacific Ocean. Sedgwick Reserve (34.69 N, 120.04 W) is 60 km east of Vandenberg AFB just outside of Los Padres National Forest. Vandenberg AFB and Gaviota State Park are coastal scrub habitats along the Pacific Coast containing plants such as coyote bush and California buckwheat. Sedgwick occurs in Valley oak savannah and grey pine forests of the Coastal Mountain range. *Asclepias fascicularis* occurs in small single patches on Vandenberg AFB and Gaviota State Park, and *A. fascicularis* and *A. eriocarpa* occur in small scattered patches at Sedgwick Reserve. All Southern California sites were surveyed once per month. In 2017 we conducted 6 surveys, from late April to early October and in 2018 and 2109 we conducted 8 monthly surveys from late March to October

(*A. eriocarpa,* photos by Stephanie McKnight, Xerces Society for Invertebrate Conservation)

Northern California – *Beale AFB*, *South Yuba State Park*, *Grass Valley*, *and Stone Lakes NWR*

Beale AFB (39.10 N, 121.392 W) is approximately 15 miles west of Yuba City in Northern California. South Yuba River State Park (39.29 N, 121.19 W) is approximately 50 km east of Yuba City in Northern California and follows the South Yuba River; Grass Valley, CA (39.21 N, 121.04 W) is 25 km southeast of South Yuba River State Park; and Stone Lakes National Wildlife Refuge (38.36 N, 121.49 W) is approximately 25 km south of Sacramento, CA. South Yuba State Park, Beale AFB and Grass Valley occur in the Central California Foothills with mixed forests of Ponderosa pine, gray pine, and deciduous oak trees. *Asclepias cordifolia* and *A. fascicularis* both occur at South Yuba in small isolated patches along moderate to steep slopes and roadsides above the South Yuba River. *Asclepias speciosa* and *A. eriocarpa* occur in small patches in an open meadow. *Asclepias speciosa, A. fascicularis,* and *A. eriocarpa* occur at Beale AFB. Stone Lakes NWR is in the Central Valley, and *A. fascicularis* occurs in small to large patches in seasonal wetlands and on the margins of perennial wetlands. All Northern California sites were surveyed once per month, with Beale AFB only being surveyed in 2019. In 2017 we conducted 6 monthly surveys, from late April to early October and in 2018 and 2019 we conducted 8 monthly surveys from late March to late October.

(*A. fascicularis,* photos by Stephanie McKnight, Xerces Society for Invertebrate Conservation)

Nevada - *NAS Fallon*, *Stillwater NWR*, *and Dixie Valley*

Naval Air Station Fallon (39.42 N, 118.70 W) is in western Nevada approximately 110 km east of Reno and just north of Carson Lake. Stillwater National Wildlife Refuge (39.51 N, 118.51 W) is 15 km northeast of NAS Fallon along the Stillwater Point Reservoir. Dixie Valley (39.67 N, 118.08 W) is located 60 km northeast of NAS Fallon just west of the Central Nevada Bald Mountains. All sites occur in Great Basin intermountain cold desert shrub with small spring fed wetlands, and extensive systems of irrigation ditches and canals. *Asclepias speciosa* and *A. fascicularis* occur in small patches along irrigation ditches, canals, springs, and wetlands at both NAS Fallon and Stillwater NWR. Nevada surveys occurred once per month. In 2017 we conducted 5 monthly surveys, from May to September and in 2018 and 2019 we conducted 7 monthly surveys from late April to October.

(*A. speciosa*, photos by Stephanie McKnight, Xerces Society for Invertebrate Conservation)

Idaho *- Mountain Home AFB and C.J. Strike Reservoir*

Mountain Home Air Force Base (43.05 N, 115.86 W) is in southwestern Idaho just north of the Snake River. Mountain Home AFB occurs in the Mountain Home Uplands of the western Snake River Plain. This region is comprised of arid sagebrush steppe and grasslands with mesic soils, flanking the lower riparian areas and wetlands along the Snake River. Mountain Home AFB has small scattered patches of *Asclepias speciosa* in open disturbed areas and along roadsides in arid sagebrush steppe and grassland, and one small isolated patch of *A. cryptoceras var. davisii* on steep rocky slopes in sagebrush steppe. *A. incarnata* occurs in large patches adjacent to *A. speciosa* in emergent wetlands dominated by bulrush, cattail, and large stands of Russian olive trees adjacent to the CJ Strike Reservoir of the Snake River. Mountain Home was surveyed once per month. In 2017 we conducted 4 monthly surveys, from July to September, in 2018 we conducted 5 monthly surveys from May to September and in 2019 we conducted 4 monthly surveys from June to September.

(*A. speciosa* and *A. incarnata,* photos by Stephanie McKnight, Xerces Society for Invertebrate Conservation)

Oregon *- NWSTF Boardman and Umatilla NWR*

Naval Weapons Systems Training Facility Boardman (45.75 N, 119.68 W) and Umatilla National Wildlife Refuge (45.89 N, 119.57 W) are in eastern Oregon near and along the Columbia River, respectively. Like the Washington sites, both NWSTF Boardman and Umatilla NWR are on the Columbia Plateau and are characterized by the same floral and faunal communities. NWSTF Boardman is approximately 5 km south of the Columbia River, and *A. speciosa* is the only milkweed species that occurs at the facility. Umatilla NWR spans several kilometers on both sides of the Columbia River, and two species of milkweed, *A. speciosa* and *A. fascicularis* occur in large patches along sloughs that flow into the refuge and in tree stands along the river. Umatilla NWR was surveyed twice per month, and NWSTF Boardman was surveyed once per month. Oregon sites were surveyed from early June to early October in 2017, from late May to early October in 2018 and from June to early October in 2019.

(*A. speciosa* on the left, *A. fascicularis* on the right, photos by C. C. Thomas, Washington State University)

Washington *– JBLM Yakima Training Center and Lower Crab Creek*

Yakima Training Center (YTC) (46.67 N, 120.37 W) is located northeast of Yakima, WA and spans between the Yakima and Columbia Rivers. Lower Crab Creek (46.83 N, 119.87 W) is east of the Columbia River adjacent to YTC. Both sites are on the Columbia Plateau, part of the larger Columbia Basin. The Columbia Plateau is characterized by deep loess soils and sagebrush steppe flora common in the arid Intermountain West in the United States. *Asclepias speciosa* is the only milkweed species found at these sites and only occurs near water and nearby Russian olive canopy cover. Yakima Training Center and Lower Crab Creek were surveyed from mid-June to August in 2017 and from mid-June to early October in 2018 and 2019.

(*A. speciosa,* photos by C. C. Thomas, Washington State University)

Survey Methods

Each selected site was surveyed about once per month throughout the likely breeding season in 2017, 2018 and 2019. At sites with limited milkweed (less than 500 stems), surveys included all available milkweed in each survey. At sites with moderate to abundant milkweed, transects were selected in optimal breeding locations. In 2017, transects were 50 m long x 30 cm wide and recorded in 5 m intervals to facilitate repeated search of the same milkweed stems in each survey. Sites included at total of 50 – 2000 milkweed stems per survey, depending on milkweed species and density. In 2018, transects at some sites in Oregon and Washington were replaced with patch counts in which 2 m x 2 m patches were repeatedly surveyed instead of transects to facilitate repeatability in the survey. In addition, due to non-systematic surveys at Washington sites in 2017 and absence of immature monarchs in 2018, Washington sites are excluded from some of the analyses below. At each monitoring location, the following data were collected: location (latitude and longitude), elevation, shade cover and distance to water. In each surveyed unit, we counted milkweed stems and noted milkweed species and phenological stage of each stem (vegetative, flowering and senescing). We inspected each stem for immature monarchs and noted immature stage (egg, instar 1 – 5, pupa). In addition, number of adult monarchs observed, sex and wing wear were noted during the survey. In 2019, we added 2 m x 2 m plots at three areas on Beale AFB. In addition, these areas were split between habitats with full sun, and those that were within shade of small trees or shrubs for at least part of the day.

PROJECT FINDINGS

Section 1: Expanding vs Shifting Population Structure

Monarch phenology

Overview and Analysis

Determining if western monarch has an expanding vs shifting population structure is a primary objective of this project (Figure 3). Our surveys were designed to detect these patterns in the population structure. We fit Generalized Additive Models (GAMs) to the number of immatures (summed over all stage classes) per milkweed stem. These analyses used Poisson family, log-link models with the number of immatures as the dependent variable and an offset of natural log-transformed milkweed stems per plot. We included year as a categorical fixed effect, and a smooth function of day of year. Models were restricted to 4 knots (one fewer than the number of observations at each site in each year). Likelihood ratio tests were used to evaluate statistical significance of year, day of year, and their interaction. We analyzed data from each region separately, since we knew *a priori* that monarchs arrive at different times in different regions. To evaluate overall trends among years, we also fit an identical model to data from all sites combined across regions. Models were fit using the gam function in the mgcv package (Wood 2011) in R (R_Core_Team 2018), using default settings except as noted above. Statistical comparisons were done with marginal hypothesis tests, calculated using the lrtest function in the lmtest (Zeileis and Hothorn 2002) package in R.

Results and Discussion

As expected, nearly all analyses showed significant seasonality (i.e., significant smooth term of day of year, Table 1 and Figure 5). In 2017, when monarchs were more abundant, our analyses indicate breeding throughout the season in Southern and Northern California from April – October. In Nevada and Idaho, the breeding seasons were shorter (May – September and June – September, respectively). In Oregon in 2017, there was a distinct pulse in June and another in August, suggesting two distinct generations. Together, our monitoring data are consistent with an expanding population that spreads across the range rather than one that shifts throughout the breeding season (Figure 3). That is, if western monarchs were exhibiting a shifting population structure, we would expect that regions with early spring breeding, such as Southern and Northern California, would have an absence of breeding in the summer. Instead we observe continuous breeding in these areas as the population expands into northern and eastern regions on the West throughout the summer.

Table 1. Analysis of phenological patterns of monarch butterfly immatures, 2017-2019

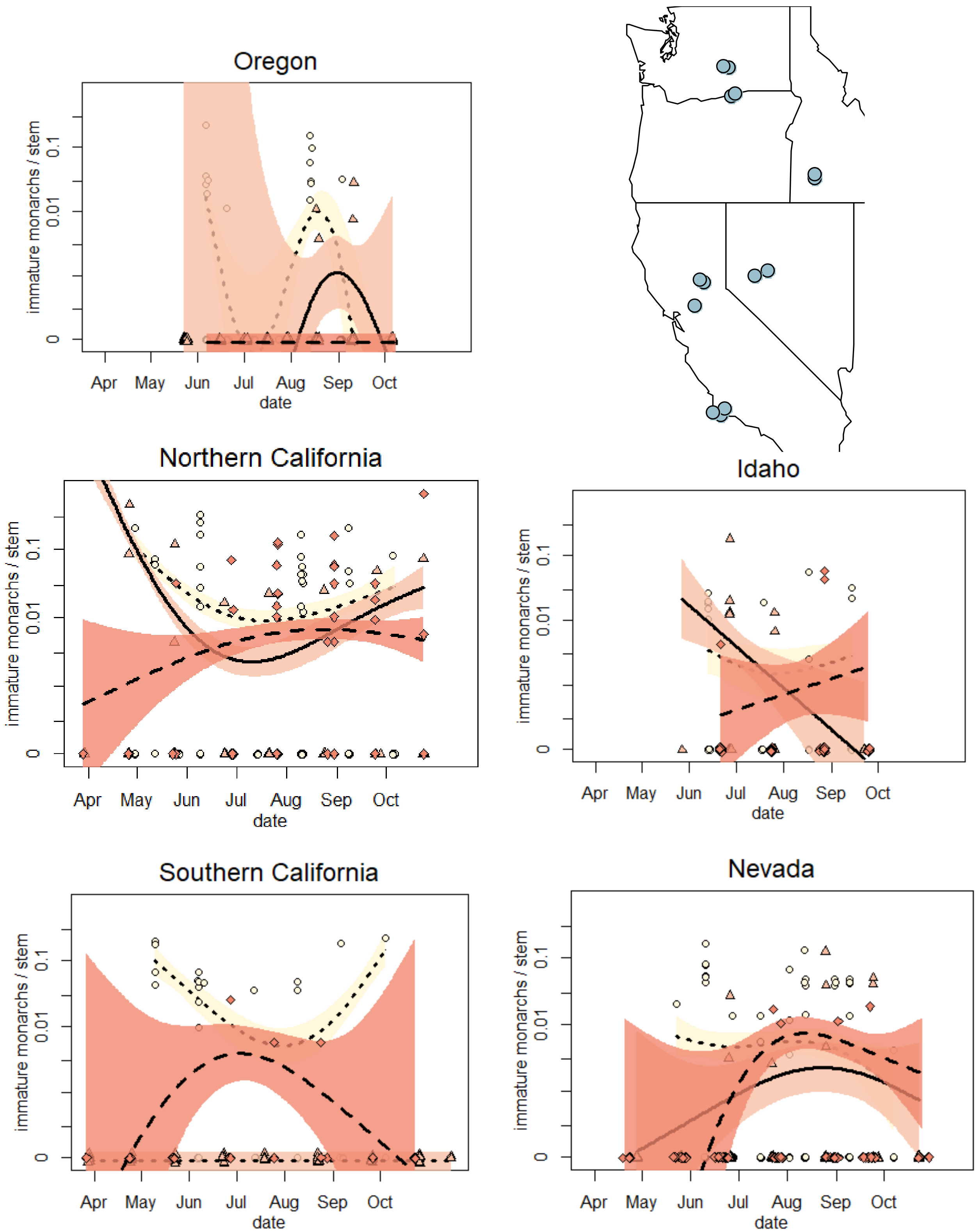
		Year			Day of year (DOY)			DOY x year		
	Region	χ2	df	P	χ2	df	P	χ2	df	P
Analysis of monarch immatures per milkweed stem										
	Overall	180.2	2.0	<0.001	329.3	3.0	<0.001	73.2	4.4	<0.001
	Oregon	69.1	2.0	<0.001	22.3	2.9	<0.001	31.4	2.9	<0.001
	Idaho	4.8	1.6	0.090	3.9	1.0	0.048	14.6	2.9	0.002
	Nevada	14.2	1.9	<0.001	7.5	2.5	0.056	15.0	3.3	0.002
	N. California	52.2	2.0	<0.001	180.4	3.0	<0.001	49.4	4.5	<0.001
	S. California	156.3	2.7	<0.001	329.3	2.7	<0.001	73.1	3.0	0.990

Overall, monarch numbers were lower in 2018 and 2019 compared to 2017—there was a strong effect of year. In 2017 we counted 238 immature monarchs (eggs, larvae and pupae) across all sites and surveys. In 2018 this dropped to 95 immature monarchs and was relatively similar in 2019 with 91 immature monarchs counted. This is consistent with the low numbers of monarchs observed at the overwintering sites at Thanksgiving following these summer breeding seasons (*see Introduction*, Pelton and McKnight 2021, Xerces Society 2021).

We observed a significant effect of interaction of Day of Year (DOY) with Year, indicating that phenology is shifting from year to year. We find that breeding is shifting later such that sites farther from the coast are colonized later in the season, suggesting a directional change in breeding phenology consistent with observed trends in the spring migration (Figure 5, C. Edwards, unpublished analyses). This is also consistent with monarchs not reaching areas that are farthest from coastal wintering sites. This suggests that there are differences in when breeding peaks in different regions each year. The monarchs arrived later at breeding sites in Northern and Southern California, Nevada and Idaho. In Oregon, the sites farthest from the overwintering areas, we observed no breeding in 2019. We hypothesize one of two mechanisms may be driving these observed patterns. We may be observing a density-dependent pattern in which smaller population sizes expand more slowly across the breeding season and are less likely to breed in habitats farther from the overwintering sites. The absence of breeding in Washington sites in both 2018 and 2019, and absence of breeding in Oregon sites in 2019, is consistent with this hypothesis. Alternatively, weather conditions or other local factors may contribute to monarchs remaining closer to the coast and using local resources for more of the season in 2019.

Our efforts were limited to systematic but low frequency surveys of a few sites per region and therefore limited relative to the vastness of the Western landscape. To further resolve these phenological windows within a region would require sampling throughout the breeding season at multiple sites (at least 7-10 sites) within a region rather than 2-4 sites and more frequent sampling (twice a month instead of once a month), especially given the sharp drop at Thanksgiving 2020 which suggests even sparser numbers of migratory monarchs in the current western monarch landscape.

Figure 5. Immature monarchs/milkweed stem within each region.
Circles = 2017; triangles = 2018; diamonds = 2019. No immature monarchs observed in Washington in 2017, 2018 or 2019 so no figure provided



Demography and Breeding Generations

Overview and Analysis

An objective of the project is to estimate stage-specific larval survival in each region. This is a component of estimating population growth to estimate the contribution of monarch breeding in each region to the annual population growth of western monarch butterflies. These estimates are limited by the extremely sparse breeding populations in the West. When we started this research, the overwintering population was ~ 300,000 monarchs, but by the season it was completed in 2019, it was less than 30,000 and is now even smaller. Thus, we present the collective information we have garnered through this work with the caveat of limitations due to the rapidly declining population of migratory monarchs.

Results and Discussion

From 2017-2019, we observed 424 immature monarchs across all sampled sites and surveys, the majority of which were in Northern California (53%). Beale AFB, which was added to the project in 2019, makes a particularly important contribution – the site at which we observed 45 immatures in a year in which 91 immatures were observed at all sites combined (Table 2).

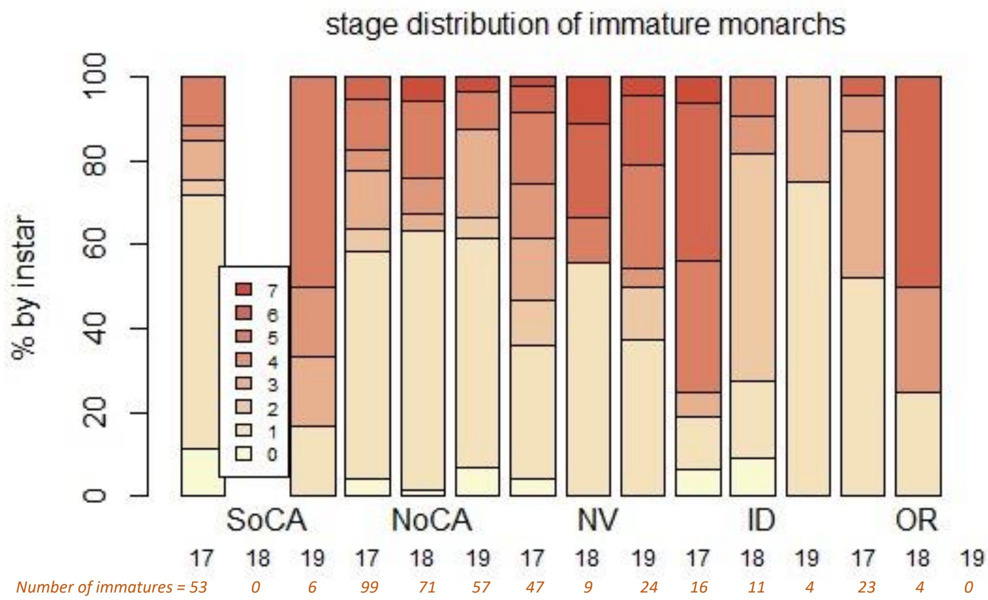
In the early years of the study (2017) and the locations with the greatest numbers of immature monarchs (Northern California), the stage distribution is heavily weighted towards eggs (Figure 6).

Table 2. Number of immature monarchs observed by region and site

Region		2017	2018	2019
Southern California	Gaviota State Park	2	0	0
	Sedgewick Reserve	29	0	6
	Vandenberg AFB	22	0	0
Northern California*	Beale AFB*	--	--	45
	Grass Valley*	15	2	--
	South Yuba State Park	57	63	6
	Stone Lakes NWR	27	6	6
Nevada	NAS Fallon	47	9	24
Idaho	Mountain Home AFB	16	11	4
Oregon	NWSTF Boardman	0	0	0
	Umatilla NWR	23	4	0
Washington	Lower Crab Creek	0	0	0
	JBLM Yakima Training Center	0	0	0

*In Northern California, Beale AFB was added to the surveys in 2019 and Grass Valley was dropped.

Figure 6. Stage distribution of immature monarchs.
0 = empty eggs; 1 = eggs; 2-6 = instars; 7 = pupae



One of the objectives of this work is to estimate number of breeding generations across the breeding range. A shifting population structure (Figure 3A) might imply that each part of the range has a similar number of breeding generations each year (e.g. 1-2 generations) with the breeding shifting inland and north throughout the breeding season. In contrast, an expanding population structure (Figure 3B) leads to a larger number of breeding generations close to the coast and a smaller number as the monarchs move inland and north within each annual cycle. Generation time during the breeding season is the number of days from egg through adult.

We estimate development time in the wild as ~ 32 days (Warchola and Crone, unpublished analyses from field enclosures in Iowa) and adult lifespan of 6 days (Warchola and Crone, unpublished analyses of apparent survival from mark-recapture experiments in Iowa) to 23 days. Together these data lead to an estimate of generation time of 38-56 days. We note that there are no comparable estimates of development time and adult survival in the wild from western monarch at this time. Development time is often temperature-dependent, so larval development may be faster in California and other parts of the West than summer in Iowa. Given these estimates, we use 40 days as an estimate of generation time during the breeding season for western monarch and combine this with the activity window during which we observed monarch breeding at sites in this study in 2017-2019.

Table 3. Breeding window and number of breeding generations in western monarch

Region	Seasonal Range of Observed Immatures	# of days	# of Generations
Southern California	May - October	180	4-5
Northern California*	May - October	180	4-5
Nevada	Late May - September	120	3-4
Idaho	Mid June – Mid September	90	1-2
Oregon	Mid June – Early September	80	1-2
Washington	Unknown no immatures observed in 2017-2019	--	1-2*

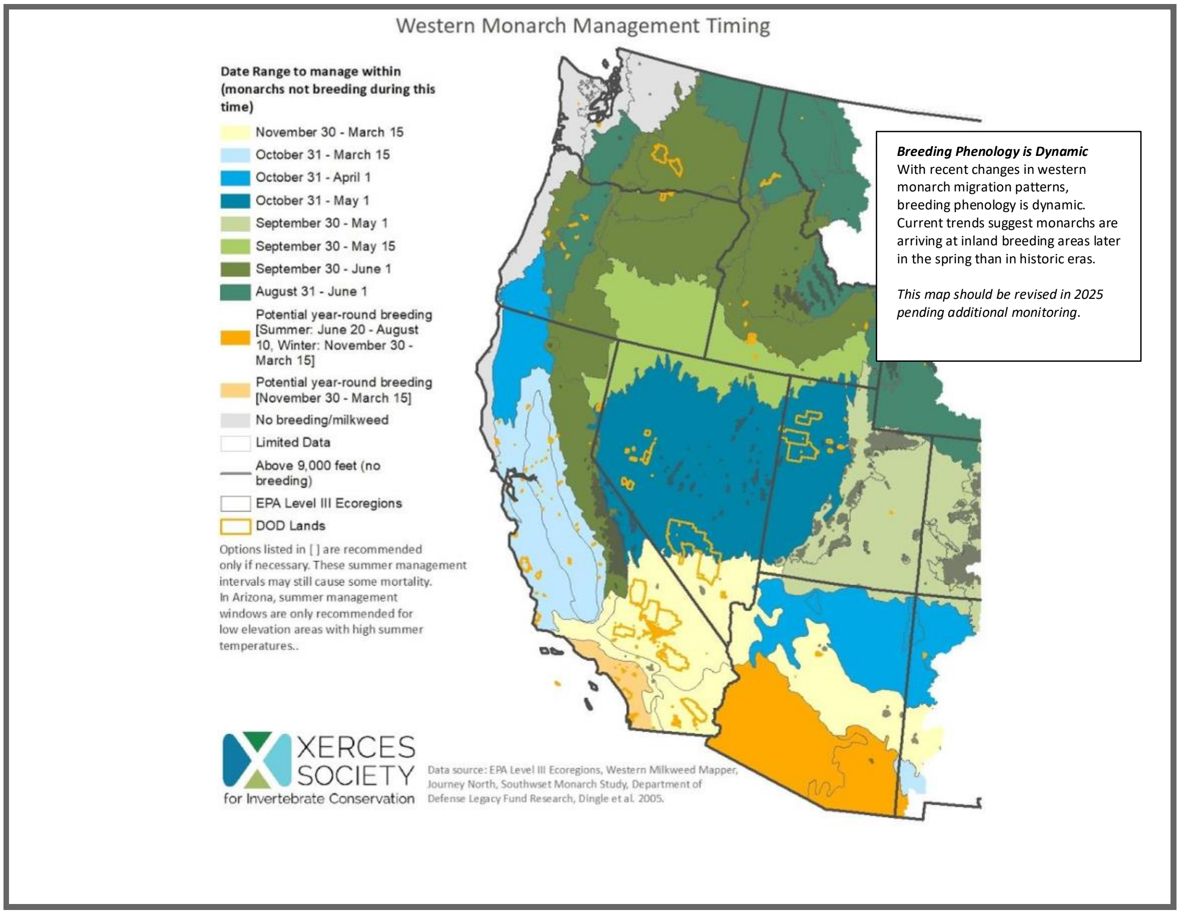
*Based on estimate of breeding season pre-2017 by David James based on observations of newly eclosed adults at Lower Crab Creek

Application – Management windows

Based on monitoring and analyses to date, we developed a set of management windows (Figure 7) to time management with times when monarchs are not actively breeding in the region. We integrated these management windows into broader management strategies in our companion report, McKnight et al, 2021, Monarch Conservation on Department of Defense Lands in the West: Best Management Practices.

It is important to note that this map is dynamic. This current project and other recent research indicate that there are directional trends in the timing of monarch breeding in the West. Spring migration from the coastal areas is at a slower rate, monarchs are arriving at spring breeding grounds far from the coast at later times in the season and use of breeding grounds in the Central Valley later into the season (also Edwards et al, unpublished analyses). This will influence recommended times to manage breeding habitat for monarchs. For example, we recommended a wider management window in the Central Valley (light blue) from Oct 31 to March 15 in the earlier report, but based on new breeding observations 2019, we now recommend a narrower management window from Nov 15 to March 15 in this report. If the current trends continue, it could suggest the reverse - wider management windows in Nevada, Idaho, Oregon and Washington because monarchs are in these regions for shorter breeding windows each year. In addition to changes in monarch migration behavior, changes in native milkweed distribution may influence the availability of breeding habitat in the future. Regions in coastal Oregon and western Oregon are outside the historic milkweed range but may become more suitable with changing climate. Future monitoring at our focal sites as well as incorporating data from monitoring from other efforts (e.g., Western Monarch and Milkweed Mapper) will be essential to refining these management windows as breeding patterns change in response to changing migration patterns.

Figure 7. Western monarch management windows



Section 2: Monarch Breeding Habitat Characteristics

Importance of microclimate for monarch habitat use

Overview and Analysis

Much of the work-to-date on monarch breeding habitat in North America has focused on the importance of milkweed abundance, distribution and diversity (e.g. Dilts et al. 2019; Pitman et al. 2018; Pocius et al. 2018). To a lesser degree, recent work has also started to focus on the importance of nectar resources – especially when monarchs are in breeding habitats before or after milkweed flowering (Baker & Potter 2019; Brower et al. 2006; Inamine et al. 2016). However, because altitude and aridity in the West may limit survival and breeding by monarchs, presence of milkweed and nectar is necessary but not synonymous with monarch habitat (Zalucki and Rochester 2004). To date, scant literature focuses on the importance of other structural elements of habitat which may have important implications for monarch use of the habitat. In the context of rising temperatures due to climate change, access to shade structure and water shade will be important to create climate "refugia" during periods of extreme heat and/or drought.

We designed our study and sampling protocols to include assessment of shade and distance to water as part of the core sampling protocols. At each 5-m segment on a survey transect or within each 2 m x 2 m plot, we scored overhead shade, shrub cover and tree cover on a 0-3 scale. We also noted distance to water either in the field or with use of an aerial photo when survey areas were far from water. In 2017, the site we identified with the greatest habitat heterogeneity was Umatilla NWR in Oregon. Open areas were fully exposed to extreme summer heat, with 14 days with > 100°F (37°C) in July and August (NOAA, 2017) Here we observed eggs and caterpillars on < 5% of transect segments in open sun but > 40% of transect segments in partial or full shade. Milkweed plants in the sun had few signs of herbivory and were tough/leathery while milkweeds in the shade had substantial monarch herbivory. These observations indicate that host plant quality and use by monarch butterflies may both depend on the environmental context. Therefore in 2018 we added additional areas in shade at Umatilla NWR and when we established survey areas at Beale AFB in 2019, we selected areas to span milkweed areas with sun and shade. It is important to note that shady areas with milkweed at Umatilla included areas under tall trees with dappled sunlight reaching the milkweeds. In contrast, at Beale the shadiest sites were close to shrubs and trees but not directly under tall trees. In addition, we measured temperatures at locations in sun and shade at Umatilla NWR in 2018 and Beale AFB in 2019.

Figure 8. Shade habitat
A) Beale AFB in California and B) Umatilla NWR in Oregon.

A) *A. fascicularis* at Beale AFB, photo by C. Schultz/WSU

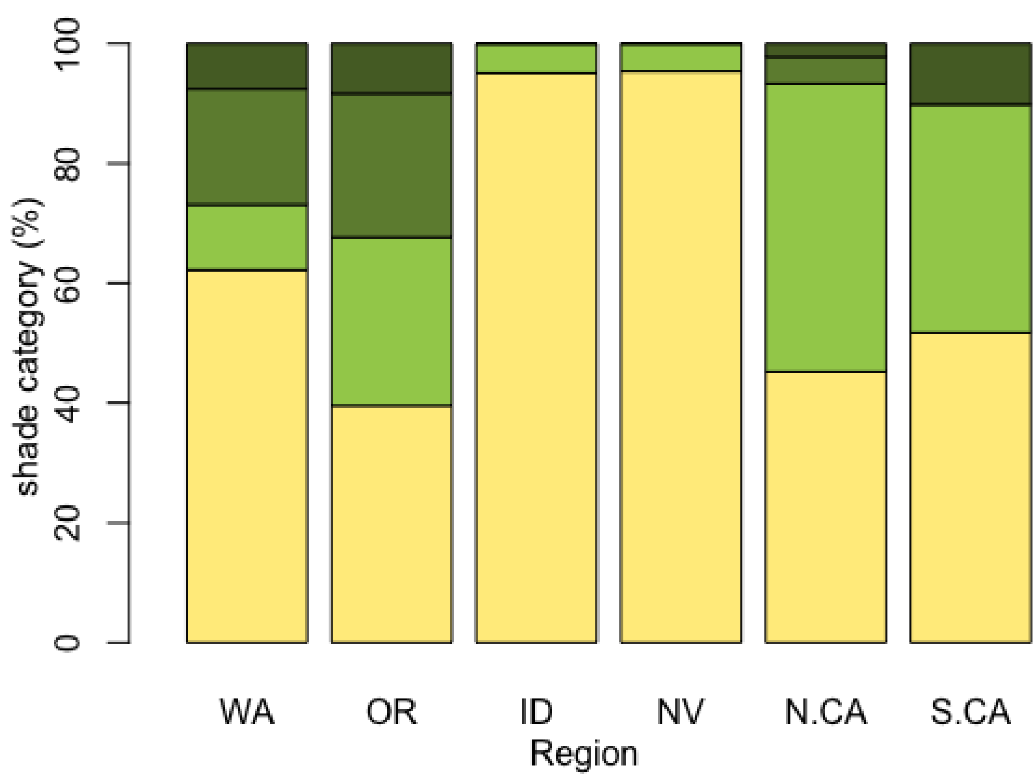
B) *A. fascicularis* and *A. speciosa* at Umatilla NWR, photo by C. Schultz/WSU

For each site, we counted the number of milkweed stems of in each shade category as well as the number of immature monarchs on each stem. We used negative binomial general linear model (glm.nb in package MASS, Venables & Ripley 2002) to evaluate use (locations of immature monarchs) vs. availability of shade habitat as follows. All shade categories with at least some shade were combined to compare immatures in the shade vs exposed habitat. In the models, the dependent variable was coded as the number of immatures in shade vs sun during that survey, relative to the total number of stems available in that survey. We tested whether monarchs preferred shade vs exposed milkweeds based on the available habitat. For this analysis, we deleted all cases in which availability was 0 (no shade/all sun).

Results and Discussion

Access to shaded milkweed breeding sites was variable across our surveyed areas. In sum, >1/3 of sampling units had at least partial shade in Washington, Oregon, Northern California and Southern California, while sampling units with shade comprised <10% of the sampling units in Idaho and Nevada (Figure 9).

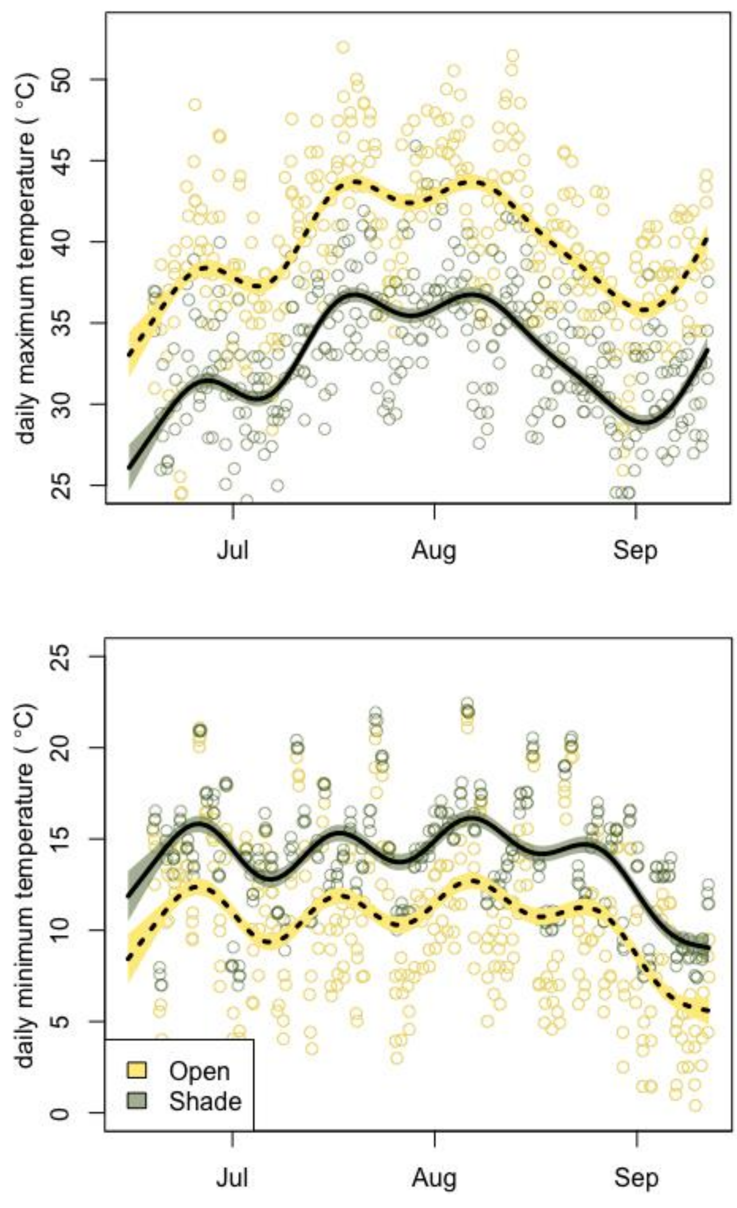
Figure 9. Available shade in surveyed plots
Yellow = full sun; light green = up to 50% cover; olive green = 50-90% cover; dark green = 100% cover (tall canopy but open understory with milkweeds)



In Oregon, at the sites that temperature was sampled, shaded plots were substantially cooler than in full sun during the day, but warmer than exposed plots at night. In Oregon in 2018, iButtons were placed in dense shade (category 3) vs open sun (Figure 10). Over the summer breeding season, the average maximum temperature in the shade was 7.0^{o}C cooler than plots in the sun while the daily minimum temperature was 3.4 ^{o}C warmer in the shade plots at night. As a result, the temperature range in the sun plots was, on average, 10.5^{o} – 39.8^{o} in the sun but was 13.9^{o} – 32.9^{o} in the shade. This is heavily influenced by the shade sites being under the open canopy of tall trees.

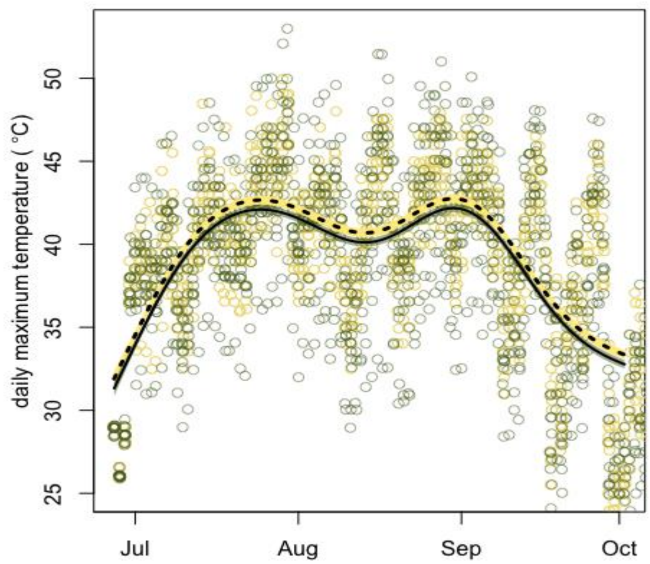
Figure 10. Temperatures in sun and shade plots at Umatilla NWR

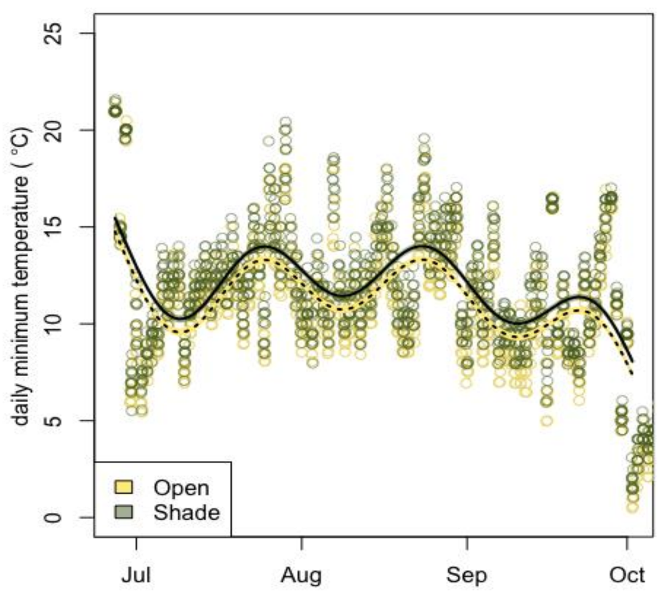
a) Average daily maximum in Summer 2018, b) average daily minimum in Summer 2018



In California at Beale AFB, at the sites that temperature was sampled, partially shaded plots were cooler than in full sun during the day, but warmer than exposed plots at night. The differences were less extreme than in Oregon, as expected from the available shade habitat at Beale AFB (Figure 11). iButtons were placed in partial shade (category 2) vs open sun. Over the summer breeding season, the average maximum temperature in the shade was 0.6°C cooler than plots in the sun while the daily minimum temperature was 0.7 °C warmer in the shade plots at night. As a result, the temperature range in the sun plots was, on average, 10.1° – 38.3° in the sun and it was 10.8° – 37.7° in the shade.

Figure 11. Temperatures in open and shade plots at Beale AFB.
a) Average daily maximum in Summer 2019, b) average daily minimum in Summer 2019





In our dataset, western monarchs use shaded habitat when it is available. They lay more eggs in shady areas and more eggs survive to larval stages (Figure 12). The importance of shade differed by region, year and season, which is consistent with periods of intense heat in July and August in some years (Tables 4 and 5 and Figure 13, average daily max temperature in July and August at Umatilla NWR was 35.1°, 33.9° and 32.1° in 2017-2019 and was 36.1°, 34.7° and 34.2° at Beale AFB). For reference, 37.7 ° C is 100 °F. At both Beale and Umatilla in 2017, there were more than a dozen days over 100°F in July and August, while Umatilla had 18 days over 100 °F in 2018 and Beale had only 9. Summer 2019 was not quite as hot, with only about 5 days over 100 °F in both locations. In addition, shade is more important in some regions in our study than others. This is consistent with the differences in temperature between sun and shade being much larger at some sites than others (e.g. Umatilla vs Beale). In addition, in some regions (e.g. Nevada and Idaho), we had few milkweed areas with monarchs which were close to shade. While in these cases, we cannot directly evaluate the potential importance of shade from study findings, we expect that our findings generalize to monarch behavior in the region and that monarchs would use shaded habitat if it were available.

Our data are limited by extremely sparse eggs during the peak of the summer breeding season due to the recent crash in the migratory monarch population. However, these data are suggestive that recovery efforts that enhance the availability of shaded habitat may encourage greater oviposition rates and/or higher rates of survival to larval stages.

Future work which included observations of butterfly oviposition behavior and/or tracking of larval survival in habitats with different microclimates would add to our knowledge of optimal habitat needs for western monarch during the breeding season.

Table 4. Analysis of shade use by monarchs
(Immatures/stem in shade vs sun)

	χ^2	df	P
Shade	5.6	1	0.018 *
Year	47.5	2	<0.001 ***
month	59.8	8	<0.001 ***
Shade x Year	16.9	2	<0.001 ***
Shade x month	26.3	7	<0.001 ***
Year x month	34.2	13	0.001**
Shade x Year x month	20.6	13	0.081

Table 5. Importance of shade by region
(with the caveat that some regions did not have much shade)

	χ^2	df	P
Shade	16.7	1	<0.001 ***
Region	129.6	4	<0.001 ***
Year	54.9	2	<0.001 ***
Shade x Region	10.3	4	<0.036 *
Region x Year	49.3	8	<0.001 ***

Figure 12. Habitat use by western monarch.
a) Eggs per milkweed stem in shade vs open habitat, b) average monarch larvae per stem

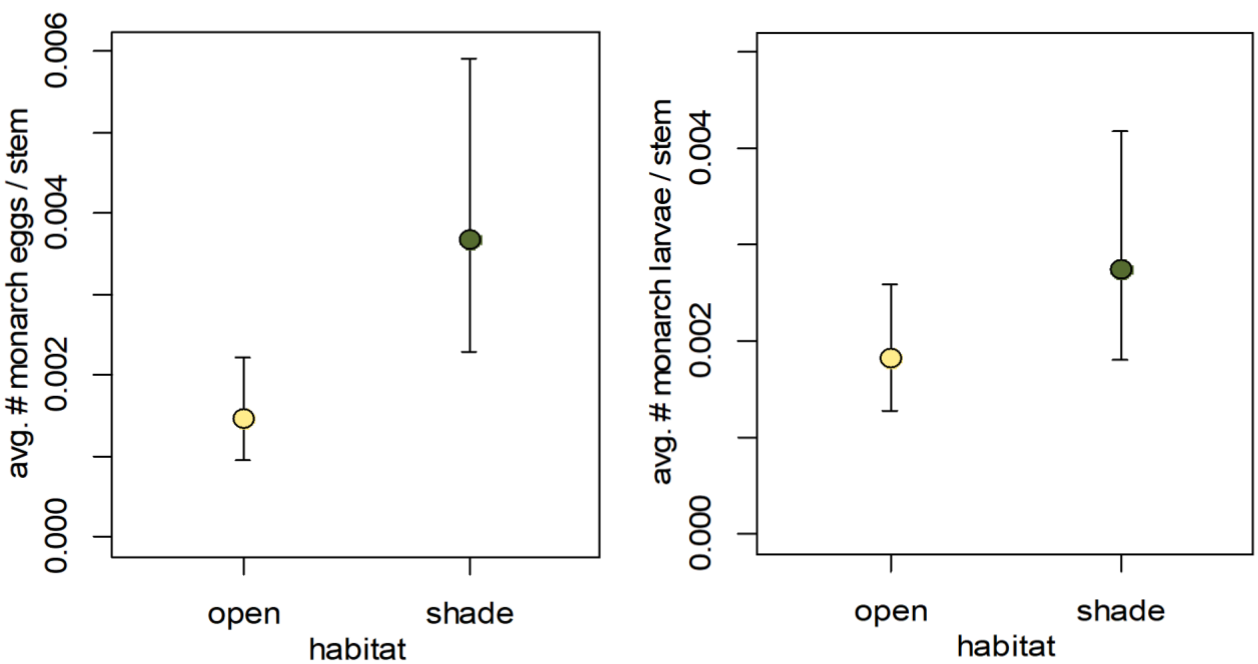
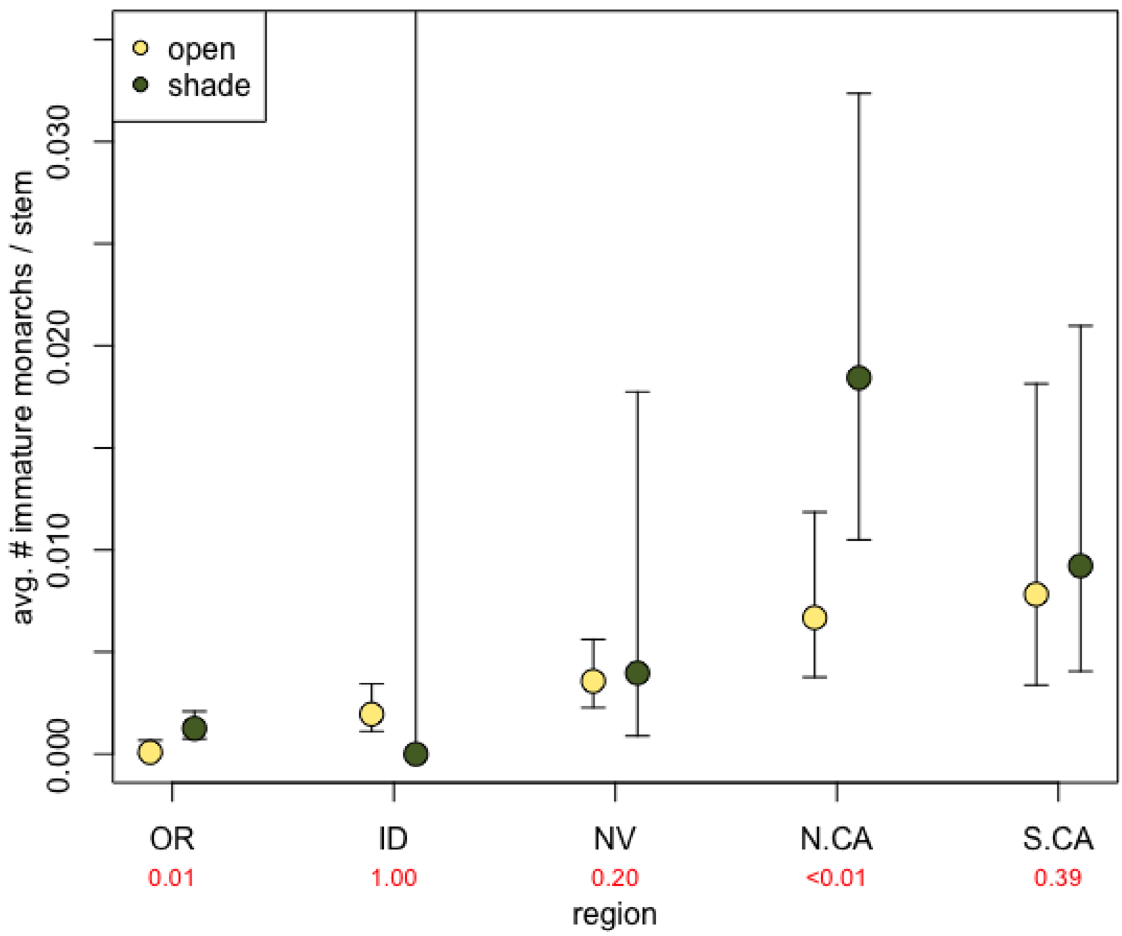


Figure 13. Monarch egg locations suggest that preference for shade differs by region. We note that in some regions (Idaho and Nevada, see Figure 9), there was not much shade available to select. Numbers below region refer to p-values for significance tests of sun vs shared within the region.



Milkweed diversity and its importance for monarchs

Overview

Availability of milkweed is a key habitat feature for monarchs to expand their distribution across the West throughout the breeding season Many herbaceous plant species have a relatively short seasonal phenology and are available for as hostplants for butterflies for a few weeks to a few months per year. To support breeding monarchs throughout a several month breeding season, a region may require a diversity of milkweed species with a range of phenologies. Study sites contained one to four milkweed species per region, with the greatest number of milkweed species in Northern California – the region with the longest window of seasonal breeding (Figure 14).

From these surveys, we were interested in understanding the importance of milkweed diversity to monarchs throughout the season. A standard approach in wildlife biology to address questions about the importance of focal resource is an analysis of use vs availability (Manly et al. 2002). In this case, do monarchs use resources in proportion to their availability, or do they use some species more often than expected based on their relative abundance?

Table 6. Milkweed stems counted.
ASCO = *Asclepias cordifolia,* ACSR = *Asclepias cryptoceras,* ACER = *Asclepias eriocarpa,* ASFA = *Asclepias fascicularis,* ASIN = *Asclepias incarnate,* and ASSP = *Asclepias speciosa.*

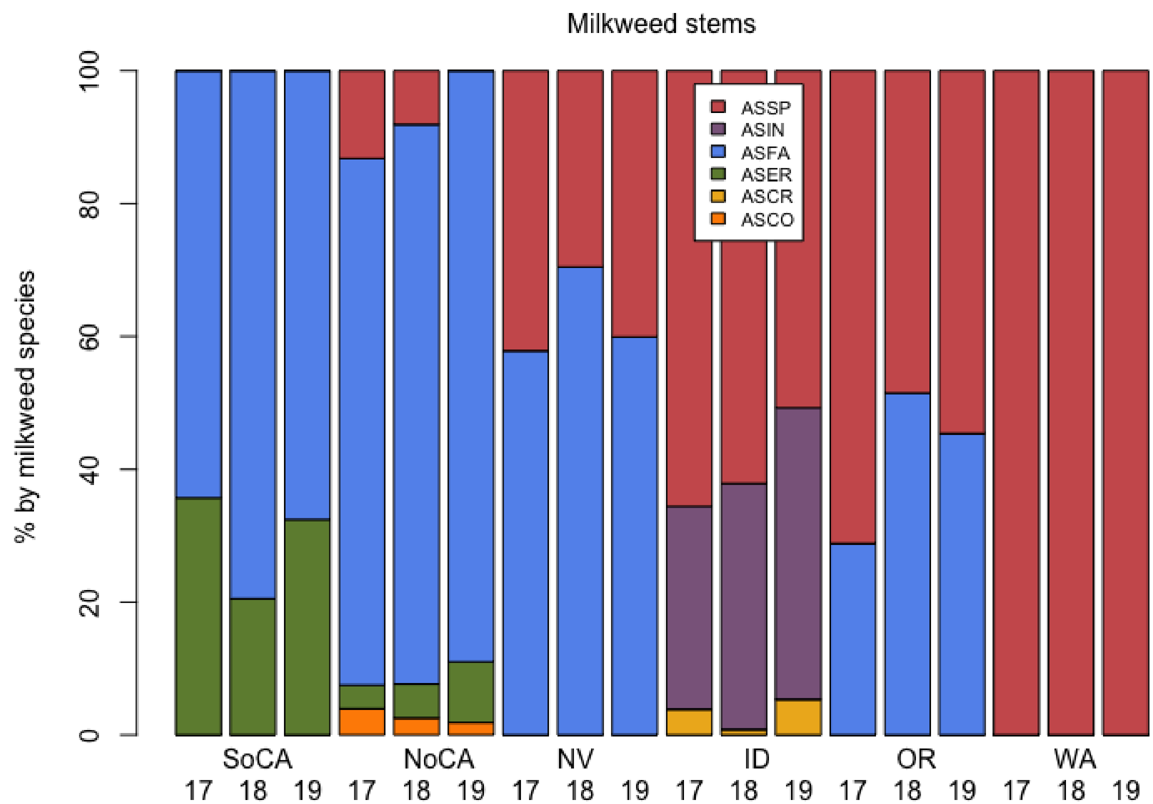
		ASCO	ASCR	ASER	ASFA	ASIN	ASSP
Southern California	2017	0	0	901	1622	0	0
	2018	0	0	803	3108	0	0
	2019	0	0	1105	2323	0	
Northern California	2017	238	0	213	4761	0	792
	2018	165	0	326	5396	0	516
	2019*	182	0	1088	10040	0	0
Nevada	2017	0	0	0	6630	0	4836
	2018	0	0	0	5785	0	2423
	2019	0	0	0	4174	0	2368
Oregon	2017	0	0	0	2062	0	5085
	2018**	0	0	0	13419	0	12641
	2019	0	0	0	4105	0	4151
Idaho	2017	0	288	0	0	2272	4874
	2018	0	59	0	0	2610	4376
	2019	0	208	0	0	2444	2988
Washington	2017	0	0	0	0	0	10430
	2018	0	0	0	0	0	11572
	2019+	0	0	0	0	0	6529

*In Northern California, Beale AFB was added to the surveys in 2019 and Grass Valley was dropped. This change added areas with ASER and ASFA and reduced the areas with ASSP

**Surveys in Oregon changed in 2018 to increase the likelihood of encountering immature monarchs, but was reduced to prior frequency (once a month instead of twice a month) in 2019 (see methods for additional details)

+ In Washington in 2019, Lower Crab Creek experienced a large fire in June, which impacted the number of ASSP in the early season

Figure 14. Milkweed stems by geographic location
(see footnotes below Table 2 for changes in survey areas within region over time)



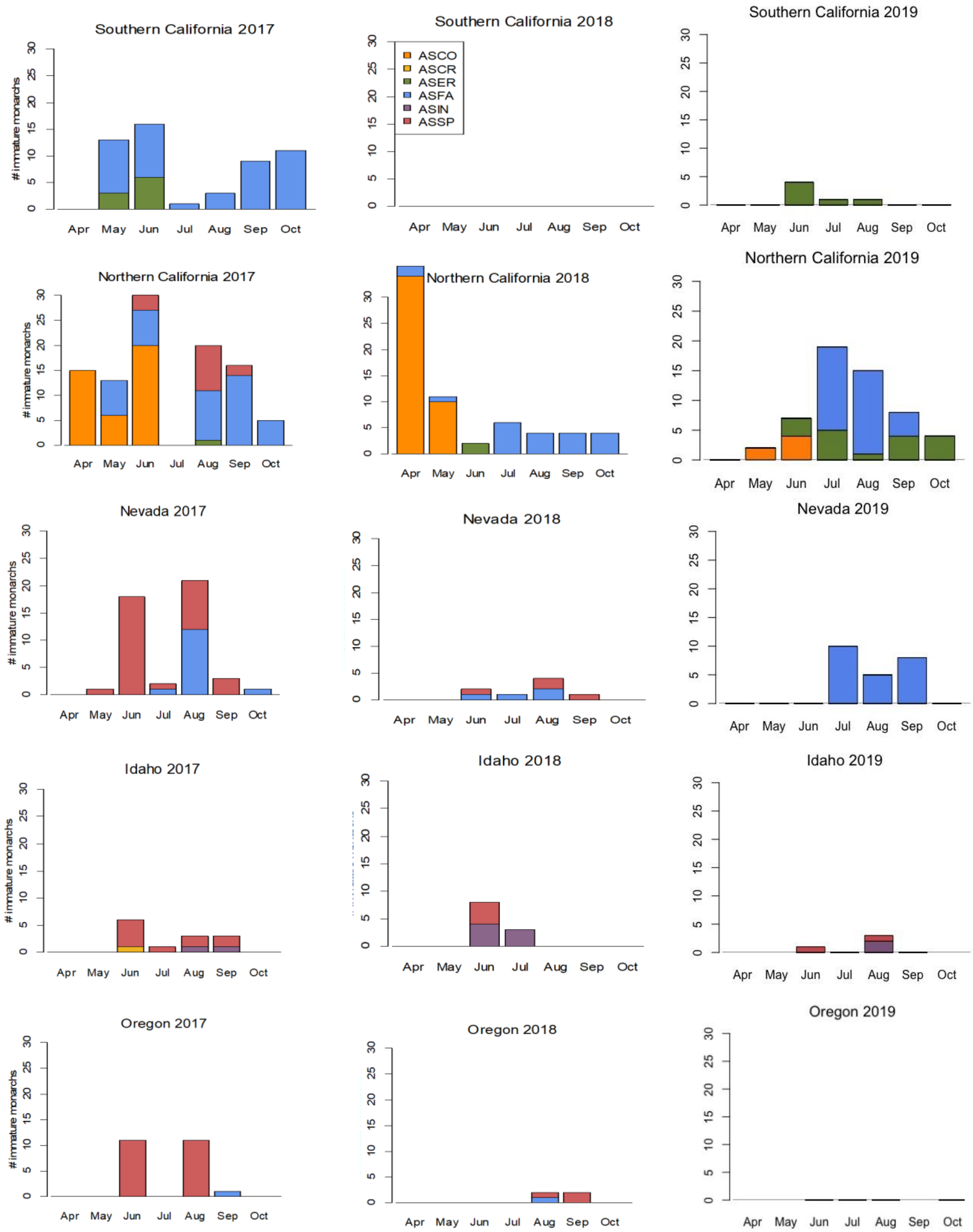
Analytic methods

For each site-survey, we counted the number of milkweed stems of each milkweed species (Figure 15) as well as the number of immature monarchs on each stem (Figure 16).

We used logistic regression to evaluate use (locations of immature monarchs) vs. availability as follows: First, we calculated the expected proportion of immatures on each species from the proportion of stems of each species in that survey. Then we performed logistic regression with the dependent variable coded as the number of immatures on each species during that survey, relative to the total number of immatures seen in that survey. We converted these numbers into successes (immatures on a target plant), and failures (immatures on all other plant species) notation. We tested whether this proportion differed among milkweed species and whether preferences differed among sites and years. For this analysis, we deleted all cases in which availability was 0 (no stems of that species), and all cases in which availability was 1 (only one species seen during a survey).

From these analyses we calculate selection coefficients for each milkweed species within each region x year combination. To interpret these coefficients, a value of 0.5 indicates no preference for a resource type in given region at the surveyed time. That is, use of a resource is strictly related to its availability. A value greater than 0.5 indicates preference for a resource relative to available resources. For example, if there were 2 stems of each of four milkweed species and monarch immatures were found on 1 stem of each milkweed species, the selection coefficient for all four milkweed species would be 0.5.

Figure 15. Immature monarchs encountered in surveys by milkweed species, region and year (on next page)


Southern California 2017
Southern California 2018
Southern California 2019
Northern California 2017
Northern California 2018
Northern California 2019
Nevada 2017
Nevada 2018
Nevada 2019
Idaho 2017
Idaho 2018
Idaho 2019
Oregon 2017
Oregon 2018
Oregon 2019
ASCO
ASCR
ASER
ASFA
ASIN
ASSP
immature monarchs
Apr May Jun Jul Aug Sep Oct
0 5 10 15 20 25 30

Results and discussion

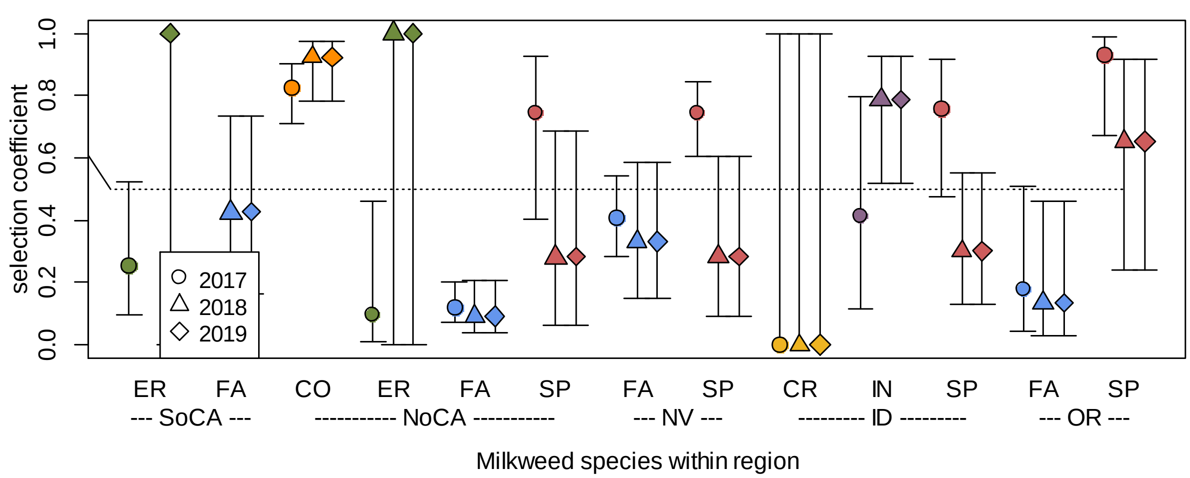
Our analyses indicate that monarchs select some milkweed species more than others, but that these effects are strongest in some regions (Table 7) and vary by year. Monarchs showed preferential use of *A. cordifolia* in Northern California and *A. speciosa* in Oregon. In addition, in some regions monarchs show preference in one year but no preference in another (e.g., *A. eriocarpa* in Northern California and *A. incarnata* in Idaho, Figure 16).

Because the immature monarchs were so scarce in 2018 and 2019, we have limited ability to detect preference for specific milkweed species in 2018 and 2019 (i.e., large error bars for selection coefficients in 2018 and 2019 in OR and NV with few observed immatures in any survey). This also limits our ability to detect differences between years. It would be valuable to repeat these surveys for multiple seasons to document if monarchs change their use of availability milkweed species in different years, with an understanding that preferences may shift with a changing climate that is predicted to differentially affect the palatability and/or nutrition of available milkweed species (Howard 2018, Svancara et al. 2019).

Table 7. Analysis of use vs availability of milkweed species by immature monarchs, 2017-2019

	χ^2	df	P
Milkweed Species	122.826	5	<0.001 ***
Species x Region	34.615	7	<0.001 ***
Species x Year	70.455	12	<0.001 ***
Species x Region x Year	51.869	9	<0.001 ***

Figure 16. Selection coefficient for milkweed species within each region and year combination.



Our results underscore the importance of milkweed diversity in supporting monarchs throughout the breeding season (see also Yang and Cenzer 2020). It also points to the importance of understanding factors (e.g., water, shade) that influence phenological differences in milkweed availability. Moreover, these results point to the importance of availability of monarch habitat at multiple sites and potentially multiple landowners within a region to provide regional habitat heterogeneity for breeding monarchs.

Milkweed abundance and phenology and its importance for monarchs

Resource availability is often a primary focal factor in identifying threats to at-risk species and in developing plans for their recovery. In butterflies, abundance of hostplants is fundamental to maintaining butterfly populations (Dennis 2010). For the eastern monarch, the predominant factor underlying many large conservation efforts is restoring milkweed across the breeding range (Pleasants 2017, Thogmartin et al. 2017). In contrast, a common observation in some parts of the West is that milkweed is abundant and it does not seem to be limiting. Our efforts were not designed to estimate availability of milkweed across the West, rather, we designed these to understand changes in monarch use of available habitat throughout the breeding season. However, we can use our approach to gain a greater understanding of the assumption that abundance and phenology of milkweed limits successful monarch breeding.

In addition, because there is interest in using monarch biology in eastern North America to draw inference about monarchs in western North America, we also compared density of immatures/stem in our surveys to estimates in the East.

Analytic methods

To gain greater understanding of milkweed phenology and abundance, we fit models parallel to models of immatures/stem for counts of milkweed stems per site. For this analysis, we summed milkweed stems over all transects within a site (Table 3). Each region had 3-4 sites, and these were monitored using transects at locations where milkweed stems were dense but by counting all stems where milkweeds were sparse. We also accounted for change in sampling area in Oregon in 2018. Therefore, we expect differences among sites, simply due to the nature of sampling. We included site as a fixed effect in these analyses to account for differences in sampling effort including changes in surveys effort; we do not discuss these effects further. Analyses of milkweed stems used gaussian (normal) family distributions, because counts of stems per site were very large and approximately log-normal; use of a gaussian model also accounts for overdispersion. Counts were summed over all milkweed species, and natural log-transformed prior to analysis. Residuals of these models were approximately normally distributed (based on visual inspection for being unimodal and approximately symmetric).

To compared milkweed use by monarchs in the West to milkweed use in the East, we compare our findings to Stenoien et al. (2015), who estimated resource use by monarchs the metric of mean max eggs/stem in the Upper Midwest from 1997-2014. These data are from a project in Monarch Lab at the University of Minnesota, the Monarch Larva Monitoring Project (MLMP) which is a community science project where volunteers select sites to monitor through the breeding season.

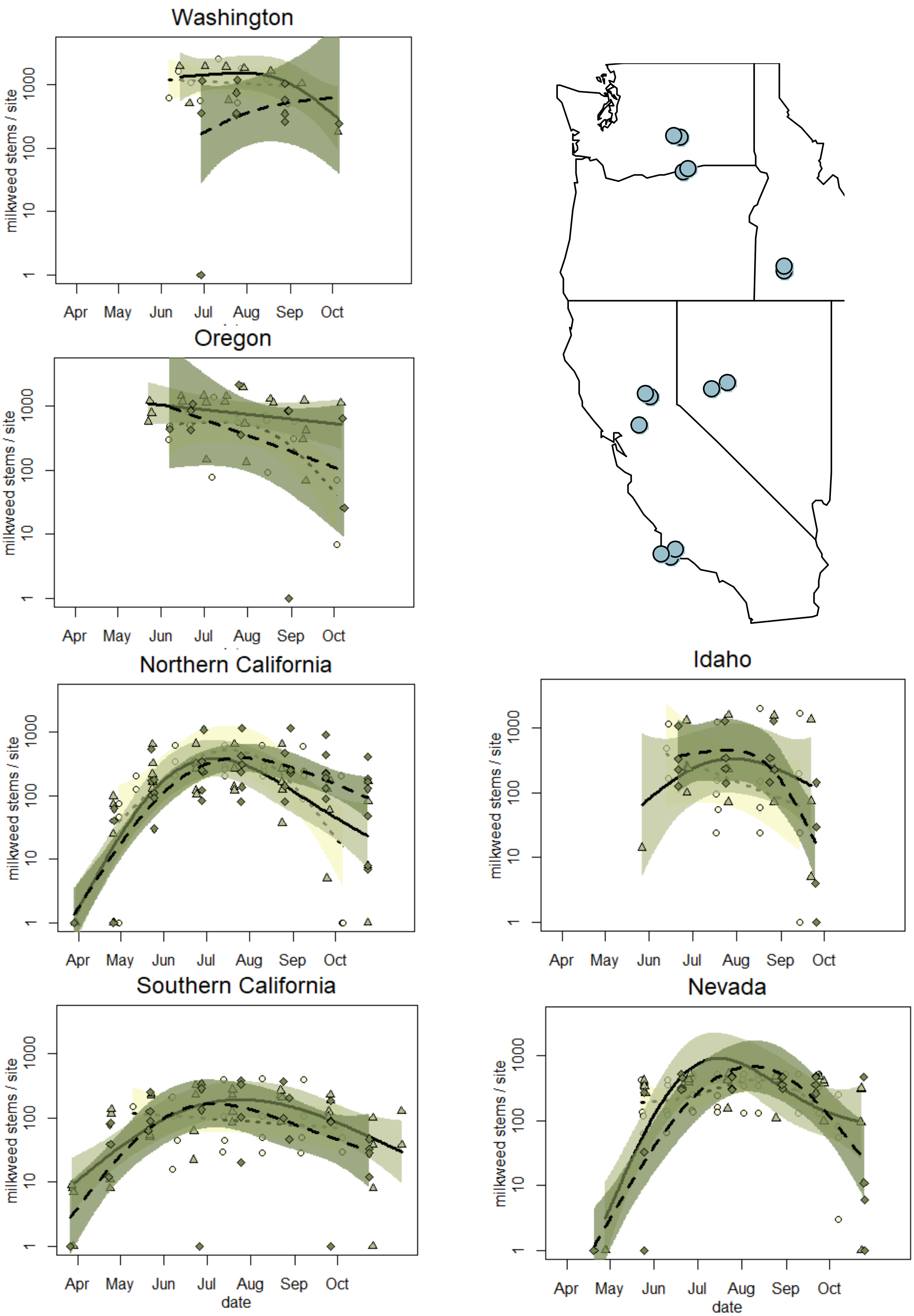
Results and discussion

We surveyed an average of 295.5 milkweed stems/site in 2017, 329.6 milkweed stems/site in 2018 and 262.7 stems/site in 2019 with a peak mid-summer (Figure 16). Milkweeds in each region were similar in each year but the seasonal timing differed between years in most regions (DOY x year interaction, Table 8, Figure 17). The increase in Washington sites at the end of the season is likely due to fire. Lower Crab Creek burned in June 2019. The site was flush with milkweed stems in August 2019.

Table 8. Analysis of phenology of milkweed stems per site within regions.

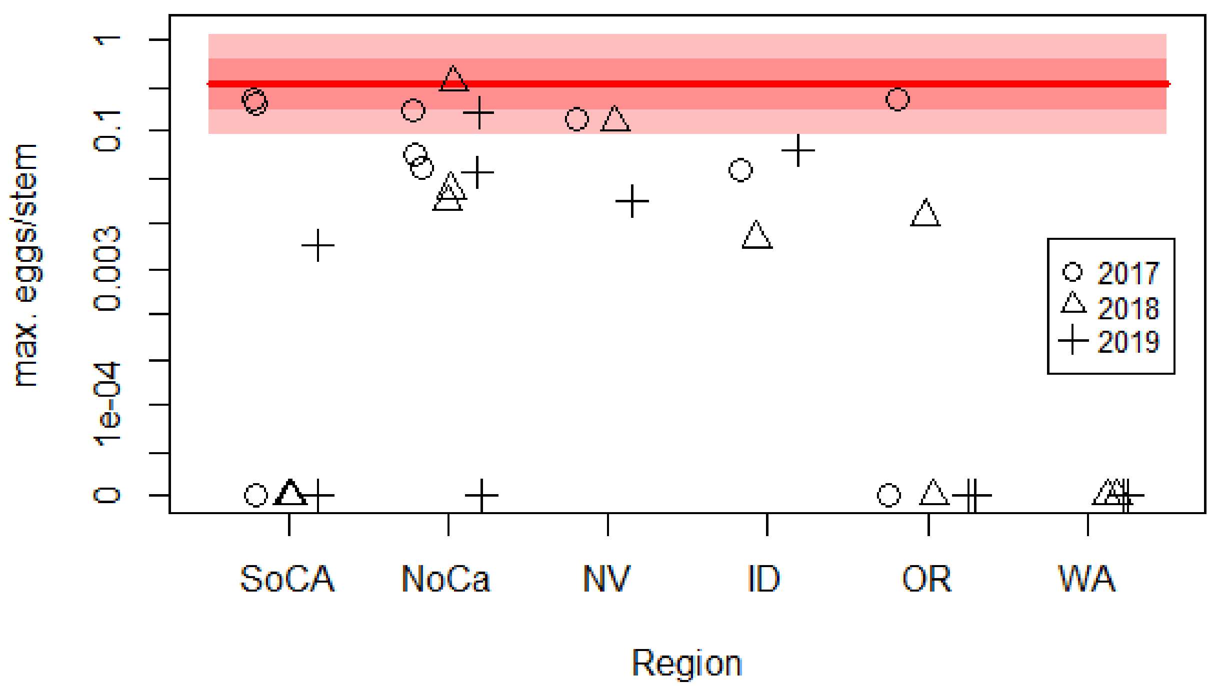
	Year			Day of year (DOY)			DOY x year		
Region	χ^2	df	P	χ^2	df	P	χ^2	df	P
Overall	5.4	2.0	0.060	252.3	2.9	<0.001	9.4	5.0	0.094
Washington	0.8	1.9	0.671	7.8	2.2	0.020	8.9	2.4	0.011
Oregon	8.4	2.2	0.150	16.7	2.5	<0.001	14.9	3.7	0.005
Idaho	<0.1	2.0	0.974	4.1	15.9	<0.001	9.3	2.9	0.025
Nevada	2.2	2.0	0.340	83.5	2.8	<0.001	20.7	4.7	<0.001
N. California	0.5	2.0	0.781	116.2	2.9	<0.001	15.7	4.9	<0.001
S. California	4.0	2.0	0.135	59.0	2.7	<0.001	3.5	3.3	0.321

Figure 17. Milkweed stems per site.
Circles = 2017; triangles = 2018; diamonds = 2019. (on next page)


Washington
milkweed stems / site
1
10
100
1000
Apr May Jun Jul Aug Sep Oct
Oregon
milkweed stems / site
1
10
100
1000
Apr May Jun Jul Aug Sep Oct
Northern California
milkweed stems / site
1
10
100
1000
Apr May Jun Jul Aug Sep Oct
Idaho
milkweed stems / site
1
10
100
1000
Apr May Jun Jul Aug Sep Oct
Southern California
milkweed stems / site
1
10
100
1000
Apr May Jun Jul Aug Sep Oct
date
Nevada
milkweed stems / site
1
10
100
1000
Apr May Jun Jul Aug Sep Oct
date

Using a metric of maximum observed eggs/stems at each site, the density of monarch eggs per stem is substantially less in 2017 -2019 than in the East from 1997-2014 (Figure 18). Because the density of eggs/stem is an order of magnitude (or more) lower in the West, the analysis indicates that milkweed is potentially less limiting in the West or, if milkweed is limiting, it may only be limiting in parts of the western monarch breeding range and/or during certain times of year. The analysis also suggests that it may be critical to consider habitat attributes besides milkweed abundance when considering monarch habitat in the West, such as shade and distance to water.

Figure 18. Maximum monarch eggs per stem.
Red line with shaded region is mean max eggs/stem and confidence intervals estimated from Figure 4 in Stenioin et al (2015).



In this project, surveyed areas were selected to maximize the likelihood we would encounter immature monarch stages. If we had, instead, randomly sampled milkweeds and surveyed those areas for immature monarchs, we expect that the egg density would have been far less than we observed. A challenge with a study with sparse breeding individuals is that if we randomly sampled milkweed stems for monarchs, it is possible we would not have detected any monarchs at all without substantially increasing the time invested in monthly sampling. Thus we expect these estimates provide an upper estimate of resource use by western monarchs in 2017, 2018 and 2019.

CONCLUSIONS AND BENEFITS TO DEPARTMENT OF DEFENSE

When a species occurring on military lands is listed under the Endangered Species Act, military training and operations can be negatively impacted. Should the monarch be listed, the impact to military training operations could be especially extensive, given the broad distribution of monarchs in the US. This project includes installations across 5 large western states with benefits to DoD lands across the West. This knowledge benefits the military mission by allowing managers to balance habitat protection with training activities. Developing and implementing proactive conservation strategies before the species becomes federally listed increases the probability that USFWS may find that listing this species is not warranted. Further, if a species which has had proactive management as a candidate does get listed, regulatory constraints placed on activities at the base are substantially reduced if the base has been proactive. To date, we see several specific benefits to DoD from this research program.

First, this research identifies timing within the monarch annual cycle most likely associated with recent large amplitude swings. That is our research indicates that the late wintering season and/or early spring breeding season is the timing likely associated with the dramatic crash in the population in 2018. This is critically important because it means this rapid drop from 2017 to 2018 was not directly caused by habitat management across much of the breeding range, which is the dominant habitat type we surveyed during this project. This indicates that installation management in monarch breeding areas were not a dominant driver of this recent acute decline.

Second, if a species such as monarch with a broad use of a large landscape is protected under the Endangered Species Act, a monitoring program such as this provides vital information about times during the life cycle that contribute to sharp drops and times that were less likely to make large contributions. This information provides vital flexibility to installation resource managers in responding to species' needs. Continuation of a program such as this can provide vital information to installation managers into the future. Although the surveys on the ground are relatively sparse (a few days per month in each of several broad regions), together they can highlight key processes in the population. Moreover, it provides insurance going forward that outside influences cannot point to installation resource management as a dominant contributor to population declines.

Third, this research indicates that broad-scale milkweed limitation was not the proximate cause of the 2018 crash (see 2019 report for more in-depth discussion of this analysis). Our analyses indicate that milkweed did not dramatically decline from 2017 to 2018. It is important to note that use of milkweed by monarchs, as measured by eggs/milkweed stem is orders of magnitude lower across the West than in the eastern population (Figure 18).

Fourth, this research advances our understanding of habitat use by monarchs. Western monarch shows strong preference to oviposit in milkweeds that are in shaded or partially shaded when these micro-habitats are available. This is particularly important in areas in the interior West in which the differences between exposed areas can be much hotter than shaded areas during the day (measured as 7.0°C difference, on average at our Oregon sites in 2018) and colder at night day (measured as 3.4°C difference, on average at this sites). As the climate grows hotter and drier during the peak of the summer breeding season in the West, if western monarch can successfully disperse across the West during the summer breeding season – we hypothesize it might be these microclimates that are limited rather than overall limitation of milkweed. This is of great benefit to installation resource managers because it suggests specific recommendations for milkweed enhancement if monarchs are protected and limits the footprint over which enhancement actions might be recommended.

Fifth, this research advances our understanding of monarch milkweed use. That is, milkweed use by monarchs varies by milkweed species. Regional milkweed phenology varies by year. Based on our analyses, increasing milkweed species diversity is important to increase the phenological window that milkweed is available for monarchs' use. This will buffer the population given yearly variation and shifts in timing of dispersal throughout the summer breeding range.

Sixth, this research provides specific recommendations for installation managers to enhance habitat value for breeding monarchs and provide contributions to this emblematic species. We developed a companion document, McKnight et al. 2021, Monarch Conservation on Department of Defense Lands in the West: Best Management Practices, including installations specific guidance for INRMPs. These recommendations are aimed at balancing training needs at each installation with resource needs by monarch butterflies. This is dynamic due to current trends in monarch migration and breeding phenology. Spring migration away from the coast is slower, resulting in later arrival of monarchs at breeding grounds farther from coastal California wintering sites. We recommend continued monitoring and revising this map in 2025.

Finally, our modeling work demonstrates that population increases or declines do not necessarily mean that the breeding habitat is getting worse. Although breeding habitat does not appear to be associated with the 2018 crash, habitat limitations at key times during the annual cycle and/or in key locations within the spatial distribution may play a key role in driving long-term declines in monarch abundance in the West. Habitat management and restoration to increase contact rates between milkweed and monarchs could be essential to allowing the monarch population to increase from its currently small population size. Such efforts on and off of DoD lands may be important to range wide persistence of western monarch.

Understanding monarch habitat use on DoD installations is crucial to maximizing proactive management for monarchs while minimizing interruption of operations. Continued and future programs such as this provide a basis for tailoring management to ecosystem and species needs in balance with mission of installations for DoD use of the lands.

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