**Supplementary Table 1.** Evaluation of the literature classified based on whether results in peer-reviewed research does [S] or does not [N] support a threat impacting the eastern North American population of monarch butterflies (*Danaus plexippus*) and whether the threat may increase. Studies identified as [-] do not draw conclusion on the future risk to monarchs.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Conservation threat** | **Type of study** | | | **Results** | **Effect on the summer breeding or overwintering population** | **Is there an effect on monarch butterflies?** | **Is there evidence the threat will persist or increase?** | | **Reference** |
| **Availability of suitable environmental conditions** | | | | | | | | | |
| Adverse weather events | [Field\_data] | | | Drought occurring in Texas in 2010-2011 thought to limit nectar sources, but had minimal impact on butterfly lipid stores, potentially due to alternative sources available at overwintering sites in Mexico. | overwinter | [N] | [-] | | Brower et al., 2015 |
|  | [Field\_data] | | | Storm damage in 2016 at the Monarch Butterfly Biosphere Reserve (MBBR) resulted in declines of 38% in Pelón, 31% in Chincua, and 7.4% in Rosario. | summer | [S] | [-] | | Brower et al., 2017 |
|  | [Mod] | | | In a population model, included weather-induced mortality events in Mexico on monarch butterfly rates. Threat of severe weather events was predicted to decline at overwintering sites. | overwinter | [N] | [N] | | Flockhart et al., 2015 |
|  | [Mod] | | | Increasing frequency of extreme weather events likely to have negative impact on survival of monarchs at all stages in the life cycle. | summer/overwinter | [S] | [S] | | Hunt and Tongen, 2017 |
| Climate change | [Control\_data] | | | Growth rate of common milkweed (*Asclepias syriaca*) was increased with elevated temperature and decreased under water stress. Greater growth and tolerance to water stress observed at higher latitudes in Wisconsin, USA. Larval growth rates increased by 38% under elevated temperatures and by 13% when reared on water stress plants. | summer | [N] | [-] | | Couture et al., 2015 |
|  | [Field\_data] | | | Precipitation during winter and spring positively influences, while mean maximum temperatures negatively affected, growth of sacred fir (*Abies religiosa*) and the smooth-bark Mexican pine (*Pinus pseudostrobu*). The sacred fir was more sensitive to temperature variations than the smooth-bark Mexican pine, suggesting that drier climate projections could negatively impact sacred fir growth rates in monarch butterfly overwintering habitat. | overwinter | [S] | [S] | | Carlón-Allende et al., 2018 |
|  | [Mod] | | | Climate projections integrated with breeding niche models predict northward range expansion over the next 50 years. | summer | [S] | [S] | | Batalden et al., 2007 |
|  | [Mod] | | | Optimal conditions at overwintering sites will reduce the area occupied by 73-100% by 2050. | overwinter | [S] | [S] | | Barve et al., 2012 |
|  | [Mod] | | | Population abundance sensitive to climate change on non-breeding grounds, but models predicted higher population sizes relative to the influence of milkweed loss on breeding grounds. | summer | [N] | [S] | | Flockhart et al., 2015 |
|  | [Mod] | | | Northward progression of *Asclepias* spp. likely to affect availability of suitable breeding habitat. | summer | [S] | [S] | | Lemoine, 2015 |
|  | [Mod] | | | Ecological niche models predicted that precipitation and diurnal temperature range predicted habitat use in Mexico and that conditions would be deemed unsuitable across the overwintering range in 50-year climate projections. | overwinter | [S] | [S] | | Oberhauser and Petersen, 2003 |
|  | [Mod] | | | Bioclimate model was driven by mean temperature in the warmest month, winter temperature, and precipitation that resulted in an estimated 96.5% loss of the sacred fir by 2090, restricting overwintering habitat. | overwinter | [S] | [S] | | Sáenz-Romero et al., 2012 |
|  | [Mod] | | | Population size was negatively associated with early warm temperatures and positively associated with later warm temperatures. | summer | [S]/[N] | [S] | | Thogmartin et al., 2017b |
|  | [Mod] | | | Daily temperature and rainfall were determined for 25 locations across the breeding range from 1970-2010 and applied in a CLIMEX model, but no trends of climate on monarch population abundance was observed. Suggests other factors, including deforestation and loss of milkweed, may contribute to declines. | summer | [N] | [N] | | Zalucki et al., 2015 |
|  | [Mod] | | | Long-term environmental data obtained from the National Oceanic and Atmospheric Administration from 1996-2008 in Ohio and Texas were used to assess climatic factors on population abundance. High precipitation in Texas drives monarch abundance in Ohio, but conditions in Ohio do not affect the timing of arrival. Abundance on summer breeding grounds highest in warm temperatures and influenced minimally by precipitation. | summer | [N] | [N] | | Zipkin et al., 2012 |
| **Deforestation** | | | | | | | | | |
|  | | [Field\_data] | | Closed canopy required to buffer temperature fluctuations and improve overwintering monarch survival due to mass loss during migration. | overwinter | [S] | [-] | | Alonso-Mejía et al., 1997 |
|  | | [Field\_data] | | Higher rates of bird predation in forest canopies (i.e., low tree density, low basal area, and low canopy coverage) compared to closed canopies. | overwinter | [S] | [-] | | Alonso-Mejía et al., 1998 |
|  | | [Field\_data] | | Open canopies increased cooling, resulting in lower body temperature and increasing the chance of mortality. | overwinter | [S] | [S] | | Anderson and Brower, 1996 |
|  | | [Field\_data] | | Aerial photographs taken in 1971, 1984, and 1999 in the MBBR were used to assess forest degradation, with 44% of conserved forest being degraded at an annual rate up to 2.4%. | overwinter | [S] | [S] | | Brower et al., 2002 |
|  | | [Field\_data] | | Forest degradation is most evident 1 km radial from colony center at overwintering sites and these areas also had less forest coverage by monarchs than those 100 m from colony center. | overwinter | [S] | [-] | | Williams et al., 2007 |
|  | | [Field\_data] | | Firs were 1.4°C warmer than ambient forest temperature, reducing the energetic cost of overwintering and mortality. | overwinter | [S] | [-] | | Brower et al., 2009 |
|  | | [Field\_data] | | Dense forests increase overwintering survival by providing a suitable microclimate for monarchs as butterflies select least hazardous temperatures (i.e., intermediate tree heights that are warm at night and in early morning). This emphasizes the risk imposed by logging at overwintering sites. | overwinter | [S] | [-] | | Brower et al., 2011b |
|  | | [Field\_data] | | Loss of 2,227 ha of firs within the MBBR at Michoacán, México, from 2006-2010, corresponding to 556.75 ha year-1. | overwinter | [S] | [S] | | Champo-Jiménez et al., 2012 |
|  | | [Field\_data] | | Deforestation between 2003-2009 resulted in 1,105 ha of loss and 881 ha of degradation, partly attributed to logging, reducing vital closed canopy cover by 968 ha and semi-closed canopy cover by 413 ha. | overwinter | [S] | [S] | | García, 2011 |
|  | | [Field\_data] | | Though conservation measures protected 3-16% of high quality habitat, only a maximum of 2.5% of forest with >70% canopy cover was protected. | overwinter | [S] | [-] | | Honey-Rosés et al., 2011 |
|  | | [Field\_data] | | Deforestation was greater in regions without Forest Management Protection Programs in MBBR at Michoacán state and forest disturbance was partly attributed to logging. | overwinter | [S] | [S] | | Navarrete et al., 2011 |
|  | | [Field\_data] | | Aerial photographs and satellite images were examined between 1971-1994 and determined annual deforestation rate of 0.1% and annual disturbance (e.g., from timber harvesting) rate of 1.3%. | overwinter | [S] | [S] | | Ramírez et al., 2003 |
|  | | [Field\_data] | | Aerial photographs and satellite images of the MBBR from 2001-2012 showed clearing of 1254 ha of forest. | overwinter | [S] | [S] | | Vidal et al., 2014 |
|  | | [Field\_data] | | Surface area occupied by overwintering monarchs decreased by 44% in 2013-2014 from the previous season, likely caused by forest loss and degradation. | overwinter | [S] | [S] | | Vidal et al., 2014 |
|  | | [Mod] | | Population models including forest loss as the primary driver showed higher population sizes relative to when milkweed loss was identified as the primary mechanism of declines. Though, reduction in forest cover resulted in greater risk of a high mortality event. | overwinter | [S] | [S] | | Flockhart et al., 2015 |
|  | | [Mod] | | Deforestation a primary obstacle to the conservation of monarchs, but current levels of illegal logging and deforestation unlikely to be primary driver for decline. | overwinter | [S] | [N] | | Hunt and Tongen, 2017 |
|  | | [Mod] | | Demographic models suggest that monarch population growth rates could increase with improved breeding and overwintering habitat. | summer/overwinter | [S] | [N] | | Oberhauser et al., 2017 |
| **Contaminants** | | | | | | | | | |
| **Exposure to GM crops and *Bacillus thuringiensis* (*Bt*)** | | [Control\_data]/ [Field\_data] | | Larvae exposed to *Bt* anthers had increased development time and reduced feeding, resulting in lower mass and survival, compared to controls. Late instars were more tolerant to *Bt*. Anther density present on common milkweed was not found at toxic levels. | summer | [S] | [N] | Anderson et al., 2004 | |
|  | | [Control\_data] | | Monarch larvae consumed minimal amounts of *Bt* anther, but exposure to anthers and pollen resulted caused delayed development time (1.8 days longer) and lower mass (64% reduction) in pupae relative to controls. | summer | [S] | [-] | Anderson et al., 2005 | |
|  | | [Control\_data] | | Monarch larvae exposed to *Bt* corn pollen as larvae were 23.7% less likely to reach adulthood. When examined over the breeding range in the Corn Belt region of the US, exposure to *Bt* corn pollen prolonged development time (1.8 days), lower mass (5.5% reduction), and increased mortality by 0.6%. | summer | [S] | [S] | Dively et al., 2004 | |
|  | | [Control\_data] | | *Bt* toxins Cry9 and Cry1F are non-toxic to first instar larvae. Larvae are sensitive to Cry1Ab and Cry1Ac proteins, but this declined with age. Results suggest pollen from Cry1Ab, Cry1F, and Cry9C *Bt* corn has minimal effects on monarchs. | summer | [N] | [-] | Hellmich et al., 2001 | |
|  | | [Control\_data] | | Monarch larvae feeding on common milkweed exposure to *Bt* corn pollen had 20% mortality after 20 hours and up to 70% after 120 hours of exposure. No sub-lethal effects observed in adults. | summer | [S]/[N] | [S] | Jesse and Obrycki, 2000 | |
|  | | [Control\_data]/ [Field\_data] | | Monarchs were observed on 21 of 35 common milkweed (*A. syriaca*) plants in *Bt* corn fields. No difference in survival curves for monarchs between *Bt* and non-*Bt* corn fields, but, after excluding predators found a trend for higher rates of mortality among larvae exposed to *Bt* corn pollen and anthers (but it was not significant at a 0.05 level). | summer | [S]/[N] | [S] | Jesse and Obrycki, 2004 | |
|  | | [Control\_data] | | Exposure to *Bt* pollen reduced feeding and mass in monarch larvae. | summer | [S] | [-] | Losey et al., 1999 | |
|  | | [Control\_data] | | Instars exposed to Event-176 (i.e., low dose pollen) weighed 18% less than those exposed to Bt11 or Mon810. Exposure to Event-176 at 67 pollen grains per cm2 on milkweed resulted in 60% lower survivorship in larvae, but no effect on development and survival were observed with Bt11 or Mon810. | summer | [S]/[N] | [-] | Stanley-Horn et al., 2001 | |
|  | | [Control\_data] | | Higher proportions of eggs were recovered from milkweed patches in isolation of *Bt* corn and without contamination from corn pollen. No effects were observed on oviposition behaviour. | summer | [S] | [-] | Tschenn et al., 2001 | |
|  | | [Control\_data]/ [Field\_data] | | Monarch larvae mortality not associated with proximity to and exposure to pollen from *Bt* corn. | summer | [N] | [-] | Zangerl et al., 2001 | |
|  | | [Field\_data] | | Monarch butterflies laid eggs equally on common milkweed and honeyvine milkweed. Though monarchs use honeyvine milkweed in Kentucky, migratory monarchs are unlikely to be impacted by the presence of honeyvine milkweed as migration through the region occurs after *Bt* pollen shedding. | summer | [N] | [-] | Bartholomew and Yeargan, 2001 | |
|  | | [Field\_data] | | Survival was similar on milkweed near *Bt* corn and non-*Bt* corn. Larval mortality was lowest close to *Bt* corn. | summer | [N] | [-] | Koch et al., 2003 | |
|  | | [Field\_data] | | Monarchs use milkweed throughout the breeding season, commonly on agricultural land, which results in exposure to *Bt* corn predominantly in the northern portion of the range. | summer | [S] | [-] | Oberhauser et al., 2001 | |
|  | | [Field\_data] | | *Bt* pollen density in cornfields ranged from 600-1400 grains per cm2 and decreased towards the field edge. | summer | [S] | [S] | Pleasants et al., 2001 | |
|  | | [Field\_data] | | Natural areas and sites with higher milkweed density had lower egg density based on records from 1997-2014 obtained by the Monarch Larva Monitoring Project. Area occupied on the overwintering grounds was positively correlated with egg density and negatively related to the percent crop area planted in herbicide-resistant crops. | summer | [S] | [S]/[N] | Stenoien et al., 2015 | |
| Herbicides | | [Mod] | | Dicamba use was correlated with population size positively in the northern, but negatively in the southern, portion of the breeding range. | summer | [S]/[N] | [S] | Thogmartin et al., 2017b | |
|  | | [Mod] | | 2,4-dichlorophenoxyacetic acid application is correlated with population size positively in the northern, but negatively in the southern, portion of the breeding range. | summer | [S]/[N] | [S] | Thogmartin et al., 2017b | |
|  | | [Mod] | | Across the breeding range, population size was negatively correlated with cumulative glyphosate use. Population declines likely related to loss of milkweed as a result of high prevalence of herbicide-resistant crops. | summer | [S] | [S] | Thogmartin et al., 2017b | |
| Insecticides | | [Control\_data] | | Permethrin application resulted in longer development time and lower survival in larvae compared to controls and decreased survival in ovipositing females exposed to plants sprayed 1-day prior. | summer | [S] | [-] | Oberhauser et al., 2006 | |
|  | | [Control\_data]/[Field\_data] | | Adult monarchs fed syrup containing imidacloprid lived longer than free-ranging individuals, but larval survival was significantly reduced. | summer | [S]/[N] | [-] | Krischik et al., 2015 | |
|  | | [Control\_data] | | Monarchs exposed to resmethrin spray developed into smaller adults and exposure soon after application (i.e., 1 day) resulted in larval mortality. | summer | [S] | [-] | Oberhauser et al., 2009 | |
|  | | [Control\_data] | | RNA interference (RNAi) provides a tool to knockdown genes and provides the basis for alternative pest control treatments, particularly by means of ingestion. Dietary ingestion of v-ATPase A dsRNA resulted in resulted in variation in growth times depending on the instar stage, but no overall differences were observed in development time and survival. | summer | [N] | [-] | Pan et al., 2017 | |
|  | | [Control\_data] | | LC50 of the neonicotinoid clothianidin in monarch butterflies at 15.63 and sublethal effects on larval size at 1 ppb. | summer | [S] | [-] | Pecenka and Lundgren, 2015 | |
|  | | [Control\_data] | | Instars survivorship and mass were reduced with exposure to λ-cyhalothrin. | summer | [S] | [-] | Stanley-Horn et al., 2001 | |
|  | | [Mod] | | Population size was negatively correlated with neonicotinoid use across the breeding range, but best fit models predicting declines did not include total neonicotinoid application. Neonicotinoids weakly determined population abundance. | summer | [S] | [N] | Thogmartin et al., 2017b | |
| **Breeding habitat loss** | | | | | | | | | |
| Habitat fragmentation and urbanization | | [Control\_data] | | 5th instar monarch larvae exposed to simulated traffic noise for 2 hours exhibited an increase in heart rate, suggesting a potential stressor, but this effect was not present after 7-12 days of chronic exposure. | summer | [S/N] | [-] | Davis et al., 2018 | |
|  | | [Field\_data] | | Data collected from transects along roadsides in Illinois was used to assess mortality from vehicular collision. Peak mortality occurred during migration, with an estimated 500,000 individuals killed per week. | summer | [S] | [-] | McKenna et al., 2011 | |
|  | | [Field\_data] | | Roadsides may act as an ecological trap, concentrating butterflies in roadside prairies and increasing *OE* infections. However, there was no difference in the proportion of infected monarchs between roadside prairies and managed prairies. | summer | [N] | [-] | Mueller and Baum, 2014 | |
|  | | [Mod] | | Migration rate slowed when habitat area dropped below 25%, with migration rates showing greater reduction in fragmented landscapes. | summer | [S] | [-] | Collingham and Huntley, 2000 | |
|  | | [Mod] | | Movement paths in a spatially-explicit agent-based model show preferential use of high density milkweed areas in a fragmented landscape. Increased perceptual range and decreased spatial memory reduced the area used. | summer | [S] | [S] | Grant et al., 2018 | |
| Nectar sources | | [Mod] | | Improving nectar availability during migration in Mexico and the Southern US and during breeding in the Southern and Northeastern US may increase monarch population growth rates. | summer | [S] | [S] | Oberhauser et al., 2017 | |
| Host plants | | [Control\_data] | | 10.5-21.7% oviposition on swallow-wort plants (*Vincetoxicum* spp.) relative to common milkweed in choice tests. 15.4% of monarch eggs were found on plots containing a low proportion of swallow-warts relative to common milkweed and was over five times greater when milkweed abundance was low. | summer | [S] | [-] | Casagrande and Dacey, 2007 | |
|  | | [Control\_data] | | Monarchs showed no preference for swallow-wort plants (*Vincetoxicum nigrum* and *Vincetoxicum rossicum*) during egg deposition in laboratory choice and no-choice tests, but larvae consumed a greater proportion of leaves from common milkweed. Mass was lower on swallow-wort and survival decreased by 44% on *V. rossicum* and 14% on *V. nigrum* compared to milkweed. | summer | [S] | [-] | DiTommaso and Losey, 2003 | |
|  | | [Control\_data] | | Swamp milkweed (*Asclepias incarnata*) had the greatest preference for oviposition, whereas narrowleaf milkweed (*A. fascicularis*) had the lowest preference. Larval survival was high on both species and preference did not differ between eastern and western populations of monarch butterflies. | summer | [S] | [-] | Ladner and Altizer, 2003 | |
|  | | [Control\_data] | | Monarchs showed no preference for dog-strangler vine (*Cynanchum rossicum*) during egg deposition in laboratory choice and no-choice tests and larvae preferentially consumed leaves from common milkweed. Larvae reared on dog-strangler vine died within 96 hours. | summer | [S] | [-] | Mattila and Otis, 2003 | |
|  | | [Control\_data] | | Monarch larvae can survive on poke milkweed (*A. exaltata*), tall green milkweed (*A. hirtella*), swamp milkweed, showy milkweed (*A.speciosa*), prairie milkweed (*A. sullivantii*), common milkweed, butterfly milkweed (*A. tuberosa*), whorled milkweed (A*. verticillata*), honeyvine milkweed (*Cynanchum laeve*) with probability of survival between 30-75%. | summer | [S] | [-] | Pocius et al., 2017a | |
|  | | [Control\_data] | | Monarch larvae can survive on poke milkweed, tall green milkweed, swamp milkweed, showy milkweed, prairie milkweed, common milkweed, butterfly milkweed, whorled milkweed, honeyvine milkweed, but larvae reared on *C. leave* were an instar behind and those fed whorled milkweed had a higher mass. | summer | [S] | [-] | Pocius et al., 2017b | |
|  | | [Control\_data] | | Egg counts from 2015-2017 in Iowa showed free-flying wild monarchs preferentially oviposited on common and swamp milkweed, while fewer eggs were recorded on poke, butterfly, tall green, whorled, and honeyvine milkweed. | summer | [S] | [N] | Pocius et al., 2018 | |
|  | | [Control\_data] | | Monarchs suffered lower *OE* parasite infection when reared on tropical milkweed (*A. curassavica*) than on swamp milkweed, though cardenoloide induction was unlikely to influence resistance. | summer | [S] | [-] | Tao et al., 2018 | |
|  | | [Control\_data] | | Larvae developed faster on honeyvine milkweed than common milkweed and, though not significant, larval mass was lower on honeyvine milkweed. Survival was 14% higher on common milkweed. | summer | [S] | [-] | Yeargan and Allard, 2005 | |
|  | | [Field\_data] | | Immature larvae (5.7x) were found in greater numbers on tropical milkweed (*A. curassavica*) compared to common milkweed, likely due to the higher cardenolide concentration that would provide defence against predators after consumption. | summer | [S] | [-] | Malcolm and Brower, 1986 | |
|  | | [Field\_data] | | Migrants at sites with year-round residents were more likely to have *OE* infection. Exotic milkweed may attract migrants, allowing them to break reproductive diapause and increasing risk of infection. | summer | [S] | [-] | Satterfield et al., 2018 | |
| Milkweed loss | | [Field\_data] | | Glyphosate resistant crops have resulted in a decrease in milkweed, which was present in 50% of corn and soybean crops in Iowa in 1999 and only 8% in 2009. | summer | [S] | [S] | Hartzler, 2010 | |
|  | | [Field\_data] | | No statistically significant declines observed over 22 years in the northern portion of the breeding range, suggesting that populations were able to recover during the breeding season, contrary to the milkweed limitation hypothesis. | summer | [N] | [N] | Inamine et al., 2016 | |
|  | | [Field\_data] | | Milkweed was found on about 60% of roadsides surveyed, with common milkweed being the most common species observed. At low densities, milkweed presence per unit area was positively correlated with monarch density. | summer | [S] | [-] | Kasten et al., 2016 | |
|  | | [Field\_data] | | Egg densities were highest on small (<16 m2) and low-density (0.1-2 milkweed per m2) patches in agricultural landscapes. Predators were most abundant on medium-sized milkweed patches. | summer | [S] | [-] | Pitman et al., 2018 | |
|  | | [Field\_data] | | Estimated a 58% decline in milkweed in the Midwestern US, coinciding with an increase in glyphosate-tolerant crops, and an 81% decline in monarch butterfly production between 1999-2010, which, in turn, was correlated with the overwintering population size in Mexico in the subsequent year. | summer | [S] | [S] | Pleasants and Oberhauser, 2013 | |
|  | | [Field\_data] | | Observed declines of 68% in milkweed abundance in Illinois between 1997-2016, likely resulting from changes in agricultural practices, and likely contributing to population declines. | summer | [S] | [S] | Zaya et al., 2017 | |
|  | | [Mod] | | Predicted a loss of 1.49 billion milkweed plants from 1995-2013 (21% decline) with the highest loss occurring in the Central region of the United States and monarch breeding range. Considered to be the primary driver of monarch butterfly declines. | summer | [S] | [S] | Flockhart et al., 2015 | |
|  | | [Mod] | | Reduced milkweed availability increases caterpillar density on host plants and reduces survival. | summer | [S] | [S] | Hunt and Tongen, 2017 | |
|  | | [Mod] | | Improving milkweed availability during breeding in the Southern and Northeastern US may increase monarch population growth rates. | summer | [S] | [S] | Oberhauser et al., 2017 | |
|  | | [Mod] | | From 1999 to 2014, an estimated 850 million milkweed were lost from corn and soybean fields and, from 2008-2014, 11 million were lost from grasslands, resulting in a decline of nearly 40%. 1.6 million milkweed plants are required to increase monarch populations to 6 ha conservation goal. | summer | [S] | [S] | Pleasants, 2017 | |
|  | | [Mod] | | Milkweed limitation is the likely cause of decline as population size on the summer breeding range corresponds with overwintering populations declines. | summer | [S] | [S] | Pleasants et al., 2017 | |
|  | | [Mod] | | Mean density at overwintering sites in Mexico estimated at 27.9 million monarch butterflies ha-1, resulting in a deficit in milkweed availability to support the population during the breeding season based on calculations from Pleasants (2017b). | summer | [S] | [S] | Thogmartin et al., 2017a | |
|  | | [Mod] | | Greater than 1.3 million new milkweed stems required to reach monarch population conservation goal. | summer | [S] | [S] | Thogmartin et al., 2017c | |
|  | | [Mod] | | Reduction in milkweed can affect fecundity (i.e., number of eggs laid) when plants are present at low density. However, individuals that are good searchers can improve success by exploring outside a habitat patch. | summer | [S] | [S] | Zalucki and Lammers, 2010 | |
|  | | [Mod] | | Habitat restoration along roadways, increasing the presence of milkweed, increased milkweed cover from 1-2% and resulted in an increase in egg production at an average of 51% when included an agent-based model. | summer | [S] | [S] | Zalucki et al., 2016 | |
| **Predation, parasites, and pathogens** | | | | | | | | | |
| Predation and parasitism | | | [Control\_data] | Survival increased to nearly 73% from predation by Asian lady beetle (*Harmonia axyridis*) when alternate prey, *Aphis nerii*, was presented. | summer | [S] | [-] | Koch et al., 2005 | |
|  | | | [Control\_data] | Milkweed genotype did not affect on predatory arthropods, but impact ants (*Formica podzolica*) via a negative influence on *Aphis* and *Myzocallis* aphids. Negative genetic correlation between aphids (in the presence of ants) and ants, independently, and monarch survival. | summer | [S] | [-] | Mooney and Agrawal, 2008 | |
|  | | | [Control\_data] | Predation on eggs by green lacewing larvae (*Chrysoperla rufilabris*) in the lab. | summer | [S] | [-] | Oberhauser et al., 2015 | |
|  | | | [Control\_data]/[Field\_data] | Monarch survival was 18% for aerial and terrestrial predators and 5% for ants and aphids. Up to 23% of monarchs were parasitized by tachnids. | summer | [S] | [S] | Prysby, 2004 | |
|  | | | [Control\_data] | Wasps (*Polistes dominulus*) consumed monarch larvae in the lab. | summer | [S] | [-] | Rayor, 2004 | |
|  | | | [Field\_data] | Higher rates of bird predation observed in open forest canopies (i.e., low tree density, low basal area, and low canopy coverage) compared to closed canopies. | overwinter | [S] | [-] | Alonso-Mejía et al., 1998 | |
|  | | | [Field\_data] | Observations of parasitism by tachinid flies on monarch butterflies. | summer | [S] | [-] | Arnaud, 1978 | |
|  | | | [Field\_data] | Observation of predation on monarch butterflies by turtle bugs (Pentatomidae), jumping spiders (Salticidae), ants (Formicidae), and tachnid flies (Tachinidae). | summer | [S] | [-] | Borkin, 1982 | |
|  | | | [Field\_data] | On average 15,067 butterflies per day are killed on average by black-backed orioles (*Icterus abeillei*) and black-headed grosbeaks (*Pheucticus melanocephalus*) at overwintering colonies in Mexico and select male monarchs, potentially due to differences between the sexes in fat or cardenolide content. | overwinter | [S] | [-] | Brower and Calvert, 1985 | |
|  | | | [Field\_data] | Predation on monarch butterflies by a variety of species of birds at overwintering sites in Mexico is negatively related to colony size. | overwinter | [S] | [-] | Calvert et al., 1979 | |
|  | | | [Field\_data] | Predation on monarch butterflies by fire ants (*Solenopsis invicta*). | summer | [S] | [-] | Calvert, 1996 | |
|  | | | [Field\_data] | Fire ants (*Solenopsis invicta*) predated on monarch butterflies and reproductive success was greater inside exclosures. | summer | [S] | [-] | Calvert, 2004 | |
|  | | | [Field\_data] | Observations of black-backed orioles, black-headed grosbeaks, Steller’s jay (*Cyanocitta stelleri*), Scott’s oriole (*Icterus parisorum*), pine flycatcher (*Empidonax affinis*), Grey-barred wren (*Campylorhnchus megalopterus*), white-throated robin (*Turdus assimilis*), russet nightingale-thrush (*Catharus occidentalis*), bluebird (*Sialia* spp.), Gray silky-flycatcher (*Ptilogonys cinereus*), Townsend’s warbler (*Dendroica townsends*), and Rufous-sided towhee (*Pipilo erythriohthalmus*). | overwinter | [S] | [-] | Fink et al., 1983 | |
|  | | | [Field\_data] | Predation by black-backed orioles and black-headed grosbeaks resulted in over 60% mortality at overwintering sites in Mexico. | overwinter | [S] | [-] | Fink and Brower, 1981 | |
|  | | | [Field\_data] | Tachnid fly (*Lespesia archippivora*) parasitism was >30% in conservation sites and gardens. Density of milkweed did not affect parasitism. | summer | [S] | [-] | Geest et al., 2018 | |
|  | | | [Field\_data] | Observations from Los Angeles and Texas on predation by ants and crab spiders (Thomisidae). | summer | [S] | [-] | Lynch and Martin, 1993 | |
|  | | | [Field\_data] | Parasitism by *Pteromalus* spp. on pupae (rate up to 20%) in Minnesota. | summer | [S] | [-] | Oberhauser et al., 2015 | |
|  | | | [Field\_data] | Approximately 13% of monarch larvae were parasitized by tachnid flies as determined from 7 years of wild monarch collection by the Monarch Larva Monitoring Project. | summer | [S] | [-] | Oberhauser et al., 2007 | |
|  | | | [Field\_data] | Monarch larvae were collected and reared (n = 654), from which 12 tachnid flies emerged. Positive correlation between monarch density in the previous year and the proportion parasitized. | summer | [S] | [-] | Oberhauser et al., 2012 | |
|  | | | [Field\_data] | Predation on pupae by wasps in Minnesota. | summer | [S] | [-] | Oberhauser et al., 2015 | |
|  | | | [Field\_data] | Chinese mantids (*Tenodera sinensis*) consumed larvae in the field and lab. | summer | [S] | [-] | Rafter et al., 2013 | |
|  | | | [Field\_data] | Predation on monarch butterflies by birds observed at overwintering sites. | overwinter | [S] | [-] | Sakai, 1994 | |
|  | | | [Field\_data] | Observed predation by ants on monarch larvae. | summer | [S] | [-] | Watts, 2000 | |
|  | | | [Field\_data] | Observations of predation on monarch butterflies by dragonflies (*Hagenisu brevistylus*). | summer | [S] | [-] | White and Sexton, 1989 | |
|  | | | [Mod] | Predation by the Asian lady beetle (*Harmonia axyridis*) was predicted to be high in soybean fields relative to cornfields. | summer | [S] | [-] | Koch et al., 2006 | |
| *Ophryocystis elektroscirrha*  (*OE*) | | | [Control\_data] | Monarchs inoculated with a high concentration of *OE* spores had lower survival and emerged with smaller wingspans and body mass. Lifespan and reproductive success was also affected in males and activity levels in females. In wild populations, parasite load was negatively associated with size and condition (e.g., wing tatter and scale loss), and positively associated with mating activity. | summer | [S] | [-] | Altizer and Oberhauser, 1999 | |
|  | | | [Control\_data] | Experimental infection with *OE* led to shorter flight distances, slower flight speeds, and a greater loss of body mass relative to controls. | summer | [S] | [-] | Bradley and Altizer, 2005 | |
|  | | | [Control\_data] | Positive correlation between parasite load and adult larva longevity. | summer | [S] | [-] | de Roode et al., 2007 | |
|  | | | [Control\_data] | *OE* infection, replication, and virulence depends on host plant cardenoloide level. *OE*-infected monarchs had lower lifespan on low cardenoloide millkweed. | summer | [S] | [-] | de Roode et al., 2008a | |
|  | | | [Control\_data] | Positive correlation between within-host replication of *OE*, virulence, and transmission. | summer | [S] | [-] | de Roode et al., 2008b | |
|  | | | [Control\_data] | Monarchs infected with *OE* had shorter lifespans, lower fecundity. Greater spore loads resulted in higher transmission to eggs, mating partners, and the host plants. | summer | [S] | [-] | de Roode et al., 2009 | |
|  | | | [Control\_data] | *OE* virulence was positively related to transmission and higher infection levels. Higher virulence was observed in Western North American compared to eastern North American strains. | summer | [S] | [-] | de Roode and Altizer, 2010 | |
|  | | | [Control\_data] | Aphids can reduce the levels of cardenoloides in tropical milkweed (*Asclepias curassavica*) that is used by larvae to decrease the likelihood of *OE* infection. This results in an increased virulence and likelihood of transmission of *OE*. | summer | [S] | [-] | de Roode et al., 2011 | |
|  | | | [Control\_data] | Positive correlation between inoculum concentration and spore loads, while inoculation of first and third instars resulted in higher spore concentration in adults relative to when infection initially presented in fifth instars. | summer | [S] | [-] | Leong et al., 1997 | |
|  | | | [Control\_data] | Greater larval density results in increased *OE* infection probability, with impacts on body size, development rate, and longevity in monarchs in moderate- and high-density treatments. | summer | [S] | [-] | Lindsey et al., 2009 | |
|  | | | [Control\_data]/ [Field\_data] | Availability of tropical milkweed (*A. curassavica*) could alter migration patterns, resulting in higher *OE* infection prevalence among sedentary individuals. | summer | [S] | [S] | Satterfield et al., 2015 | |
|  | | | [Control\_data] | Monarchs suffered lower *OE* parasite infection when reared on tropical milkweed (*A. curassavica*) than on swamp milkweed (*A. syriaca*), though cardenoloide induction was unlikely to influence resistance. | summer | [S] | [-] | Tao et al., 2018 | |
|  | | | [Field\_data] | OE parasitism was detected in <2% of larvae collected from conservation sites and gardens. | summer | [S] | [-] | Geest et al., 2018 | |
|  | | | [Field\_data] | Up to 66.7% of monarchs were detected with *OE* on their wings at overwintering populations in Mexico. | summer | [S] | [-] | Leong et al., 1992 | |
|  | | | [Field\_data] | Roadsides may act as an ecological trap, concentrating butterflies in roadside prairies and increasing *OE* infections. However, there was no difference in the proportion of infected monarchs between roadside prairies and managed prairies. | summer | [N] | [-] | Mueller and Baum, 2014 | |
|  | | | [Field\_data] | Migrants at sites with year-round residents were more likely to have *OE* infection. Exotic milkweed may attract migrants, allowing them to break reproductive diapause and increasing risk of infection. | summer | [S] | [-] | Satterfield et al., 2018 | |
|  | | | [Field\_data] | Monarchs collected during summers of 1964-1965 exhibited viral infection resulting in significant larval mortality. | summer | [S] | [-] | Urquhart, 1966 | |
|  | | | [Mod] | Parasitism by *OE* negatively correlated population size across the breeding range. | summer | [S] | [S] | Thogmartin et al., 2017b | |
| Migratory culling | | | [Field\_data] | Presence of *OE* unlikely to contribute to overwintering mortality as average parasite load in breeding monarchs decreased with greater distance from overwintering sites. | summer | [S] | [S] | Altizer et al., 2000 | |
|  | | | [Field\_data] | No evidence for declines from censuses taken at Peninsula Point, MI, USA. Observed declines in Mexico may be attributed to reduced migratory success. | summer | [S] | [N] | Badgett and Davis, 2015 | |
|  | | | [Field\_data] | *OE* prevalence increased over the breeding season and was positively related to breeding activity. Prevalence decreased as monarchs progressed southward and was lower at overwintering sites in Mexico. | summer | [S] | [S] | Bartel et al., 2011 | |
|  | | | [Field\_data] | Infection prevalence was similar regardless of distance travelled, thereby not supporting the migratory culling hypothesis. Monarchs at southern latitudes had higher infection prevalence and infections increased over the breeding seasons, supporting migratory escape hypothesis. | summer | [N] | [-] | Flockhart et al., 2018 | |
|  | | | [Mod] | Migratory culling would predict a disconnect between population estimates in summering and overwintering monarch populations, but egg counts conducted by the Monarch Larva Monitoring Project were positively correlated with overwintering population size. | summer | [N] | [N] | Pleasants et al., 2017 | |