## Maine Revised Statutes

# Title 22: HEALTH AND WELFARE

## Chapter 258-A: BOARD OF PESTICIDES CONTROL

## §1471-B. BOARD OF PESTICIDES CONTROL

**1**. **Board established.** The Board of Pesticides Control is established by Title 5, section 12004-D, subsection 3, within the Department of Agriculture, Conservation and Forestry. Except as provided in this chapter, the board must be composed of 7 members, appointed by the Governor, subject to approval by the joint standing committee of the Legislature having jurisdiction over agricultural matters and confirmation by the Senate. To provide the knowledge and experience necessary for carrying out the duties of the board, the board must consist of the following members: one person with practical experience and knowledge regarding the agricultural use of chemicals; one person who has practical experience and knowledge regarding the use of chemicals in forest management; one person from the medical community; a scientist from the University of Maine System having practical experience and expertise in integrated pest management; one commercial applicator; and 2 persons appointed to represent the public. The 2 members appointed to represent the public must represent different geographic areas of the State. The term must be for 4 years, except that of the initial appointees, 2 shall serve 4-year terms, 2 shall serve 3-year terms, 2 shall serve 2-year terms and one shall serve a one-year term. Any vacancy must be filled by an appointment for the remainder of the unexpired term.

[ 2011, c. 119, §1 (AMD); 2011, c. 119, §2 (AFF); 2011, c. 657, Pt. W, §5 (REV) .]

**2**. **Organization of the board.** The board shall elect a chair and any other officers it determines necessary from among the membership. The board shall meet at the call of the chair or at the request of any 3 members. Four members constitute a quorum and, except as otherwise provided in this subsection, any action requires the affirmative vote of the greater of either a majority of those present and voting or at least 2 members. Any action by the board requesting that the Attorney General pursue a court action against an alleged violator of any law or rule requires an affirmative vote by 3 members or a majority of those present and voting, whichever is greater. The chair and any other officers shall serve in those capacities for a period of one year following their elections.

[ 1989, c. 841, §4 (AMD) .]

**3**. **Compensation of the board.** Each public member shall be compensated according to the provisions of Title 5, chapter 379.

[ 1983, c. 812, §120 (RPR) .]

**4**. **Director.** The commissioner shall appoint a director, with the approval of the board. The director shall be the principal administrative, operational and executive employee of the board. The director shall attend and participate in all meetings of the board, but may not vote. The director, with the approval of the commissioner and the board, may hire whatever competent professional personnel and other staff he deems necessary. All employees of the board shall be subject to Title 5, Part 2. The director may obtain office space, goods and services as required.

[ 1979, c. 644, §3 (NEW) .]

**5**. **Staff.** The board must establish standards for the delegation of its authority to the director and staff. Any person aggrieved by a decision of the director and staff has a right to a review of the decision by the board. The Commissioner of Agriculture, Conservation and Forestry shall provide the board with administrative services of the department, including assistance in the preparation of the board's budget. The commissioner may require the board to reimburse the department for these services.

[ 1989, c. 841, §5 (AMD); 2011, c. 657, Pt. W, §6 (REV) .]

**6**. **Registration of pesticides.**

[ 1981, c. 112, §1 (RP) .]

**7**. **State contracts.** Notwithstanding any other provisions of law, members of the board are eligible to contract with the State when the contracts are awarded in accordance with normal bidding procedures of the Department of Administrative and Financial Services. Members also are eligible to receive grants when grants are awarded in accordance with normal state procedures. A member may not vote on the award of a contract or grant for which that member has submitted a bid or proposal.

[ 2007, c. 466, Pt. A, §40 (RPR) .]

**8**. **Meetings.** The board shall periodically meet in various geographic regions of the State. When considering an enforcement action, the board shall attempt to meet in the geographic region where the alleged violation occurred.

[ 1989, c. 841, §6 (NEW) .]

SECTION HISTORY

1975, c. 293, §4 (AMD). 1975, c. 397, §2 (NEW). 1977, c. 696, §181 (AMD). 1979, c. 644, §3 (RPR). 1979, c. 731, §19 (AMD). 1981, c. 112, §1 (AMD). 1981, c. 470, §A66 (AMD). 1981, c. 632, §§1,2 (AMD). 1983, c. 309, (AMD). 1983, c. 812, §§119,120 (AMD). 1985, c. 779, §60 (AMD). 1985, c. 785, §A95 (AMD). 1987, c. 702, §2 (AMD). 1989, c. 503, §B83 (AMD). 1989, c. 841, §§4-6 (AMD). 1991, c. 376, §45 (AMD). 2007, c. 466, Pt. A, §40 (AMD). 2007, c. 466, Pt. B, §17 (AMD). 2011, c. 119, §1 (AMD). 2011, c. 119, §2 (AFF). 2011, c. 657, Pt. W, §§5, 6 (REV).

**Chamberlain, Anne**

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**From:** Paul Schlein
**Sent:** Friday, December 09, 2016 12:58 PM
**To:** Pesticides
**Cc:** Struble, Dave; Donahue, Charlene; Groden@maine.edu; Jennings, Henry; Chamberlain, Anne
**Subject:** Board Meeting Agenda Submission

Dear Board of Pesticides Control,

Please add this to the agenda for next Friday's Board meeting.

It has come to my attention that the Maine Forest Service is looking to fund a $50,000 grant for research at the University of Maine on alternatives for the control of browntail moth. Details would need to come from the MFS and UMaine, but, as I see you are actively discussing the browntail moth issue at this very moment, with items on next week's agenda, this seems like the perfect time to bring this to your attention. Funding this urgently needed research would seem to also be a perect fit in the Board's mission to reduce reliance on pesticides.

I think the word "urgent" may not be strong enough, as I have just read in this week's *Forecaster* (http://www.theforecaster.net/brunswick-residents-prepare-to-take-on-browntail-moths/) that the current estimate of 64,000 infested acres is a conservative one, and that next season's coverage is expected to expand to a far greater range.

Thank you for your timely consideration of this issue.

Sincerely,
Paul

P.S. I am copying the MFS and UMaine with this mesage, in the event they would like to send any additional information by next Tuesday, 12/13, 8:00 AM, to be included with the Board packet (http://www.maine.gov/dacf/php/pesticides/meetings.shtml#policy).

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Paul Schlein
Arrowsic, Maine

the FORECASTER
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# Brunswick residents prepare to take on browntail moths

*By Callie Ferguson on December 7, 2016@calliecferguson*

BRUNSWICK — A group of about a dozen residents have launched a grassroots education campaign on ways to stymie an anticipated infestation of browntail moths.

It follows a recent survey that projected the spring population of moths might balloon to three times the size of last summer's outbreak.

While the group is focused on community outreach, member Kathy McLeod said the mission "could evolve into pressure being put on the state" – although state officials have indicated they're unlikely to supply any direct funding to municipalities.

The Browntail Action Group formed and has met at least three times since an October event at Curtis Memorial library, where a panel of experts shared methods to proactively decrease the number of spawning caterpillars next year.

The library event drew close to 200 people, signaling wide public interest after an outbreak left some residents with painful rashes and damaged trees.

State forest entomologist Charlene Donahue sat on the panel, and, in a phone call Monday, she said the last infestation on that scale was likely 100 years ago.

The most recent statewide outbreak of moths took place in 2003, and defoliated 10,000 acres of trees.

This past summer's infestation, however, spread across 25,000 acres – and next summer, she said, could be almost three times as large.

Citing a recent aerial survey, Donahue said at least 64,000 acres of trees are implicated, identifiable by their brown leaves. But that's a conservative estimate, she added, given that not all infected leaves turn brown; she plans to conduct another survey this month.

After the library panel, Action Group founder Esther Mechler stood up and collected the names of those who might be interested in forming a group to combat the issue at a local level. This week, they will post 2,000 fliers around town with information about what residents can do now to reduce caterpillar populations in the spring.

“Now is the time to prune out any nests you can reach,” the flier reads. “By removing and destroying just 10 of these nests, you could prevent as many as 4,000 new caterpillars from hatching out this spring.”

Residents can destroy nests by dunking them in soapy water or burning them, according to the group.

Mechler said the next Action Group meeting will take place Dec. 20 at Town Hall.

Town Council Chairwoman Sarah Brayman said this sort of grassroots effort is an important supplement to actions taken by the town because the group has “the ability to reach out into the community and talk to people.”

“I think potentially this could be a huge issue for the town,” Brayman said. “(The council doesn’t) have the resources, time and money to get out into the community in the manner that might be needed for this.”
Neighbor-to-neighbor outreach especially matters with this issue, she said, because the failure to coordinate prevention efforts could undermine the success of those who do undertake them. Because the catepillar’s toxic hairs travel in the wind, a stiff breeze is all it takes for airborne hairs from a neighbor’s infected tree to undo the work on trees that were treated next door.

“You really need a public or community effort,” Brayman emphasized.

Town Manager John Eldridge said he plans to meet with colleagues in Sagadohoc County later this month to discuss coordinated efforts to combat the issue, such as joint-purchasing chemicals to spray trees. According to information provided by the action group, there are a variety of chemical and bacterial pesticides that arborists use to inject or spray trees to kill moths.

Brayman believes that state action is warranted, given the scale of the problem.

“I think it’s a public health issue and potentially an environmental disaster and I believe the state could be involved,” Brayman said Monday.

However, state entomologist Dave Struble said Wednesday morning that he doubts the Maine Forest Service would provide direct funds to assist municipalities.

“I see state money to help oversee the operation,” he said, meaning that state aid would come in the form of oversight, not funding. “You’ve watched the elections over the last few years and you tell me. There’s not a lot of resources.”

As far as what the Forest Service can do, “the state’s involvement was always in (developing prevention methods), and our technical assistance to the town was helping them run their projects,” Struble said, referring to the work Donahue is already doing.
Struble recommended that the towns approach the Bureau of Health or the Maine Center for Disease Control for direct aid.

Donahue said the issue "is high on our response list" in that regard, and she is communicating with agencies across the state to prepare for next spring.

Later this month, she will meet with arborists and pesticide applicators to discuss best practices. She is also in touch with the state pesticide board of control to make sure that state legislation is up to date with contemporary practices and chemical agents.

However, McLeod worried that pesticide applicators are overwhelmed; the local service she uses isn't taking on new customers after last summer's outbreak.

"We may be constrained by who's available to do the work with the equipment," Struble said, echoing McLeod. "That's not a cheering piece of news, but that's reality."

Even if the manpower is available, Struble said pesticides, while an effective way to combat browntail moths, can be a contentious issue because of the environmental impact. He said biological, bacteria-based spray exists, but there is "no silver bullet" that has yet to balance environmental impact with efficacy.

**Callie Ferguson can be reached at 781-3661 ext. 100, or [cferguson@theforecaster.net](mailto:cferguson@theforecaster.net). Follow Callie on Twitter: [@calliecferguson](https://twitter.com/calliecferguson).**

Browntail moth nests like the one shown here can be clipped from trees in early winter to prevent the caterpillars from spawning in the early spring.


*Reporter on the Brunswick/Harpswell beat. Proud Bowdoin grad that you can find reporting on municipal, school, and community news, or inside the many coffee and sandwich shops around the Midcoast. Callie can be reached at 207-781-3661 ext. 100.*

## Chamberlain, Anne

**From:** jody spear
**Sent:** Saturday, December 10, 2016 10:59 AM
**To:** Chamberlain, Anne
**Subject:** Fwd: Scientists propose ten policies to protect vital pollinators

For Friday's packet

https://www.sciencedaily.com/releases/2016/11/161124150203.htm#.WEwlnAH37RI.email

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# Scientists propose ten policies to protect vital pollinators

*Date:* November 24, 2016
*Source:* University of East Anglia

*Summary:* Pesticide regulation, diversified farming systems and long-term monitoring are all ways governments can help to secure the future of pollinators such as bees, flies and wasps, according to scientists.

**FULL STORY**

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### Pesticide regulation, diversified farming systems and long-term monitoring are all ways governments can help to secure the future of pollinators such as bees, flies and wasps, according to scientists.

In an article published in the journal *Science*, a team of researchers has suggested ten clear ways in which governments can protect and secure pollination services -- vital to the production of fruits, vegetables and oils.

A recent global assessment by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) confirmed that large-scale declines in wild pollinators are happening in north Europe and North America.

The ten policies report, led by Dr Lynn Dicks at the University of East Anglia who also took part in the assessment, expands on its findings to provide clear suggestions on how to tackle the problem.

Dr Dicks said: "The IPBES report has made it very clear that pollinators are important to people all over the world, economically and culturally. Governments understand this, and many have already taken substantial steps to safeguard these beautiful and important animals. But there is much more to be done. We urge governments to look at our policy proposals, and consider whether they can make these changes to support and protect pollinators, as part of a sustainable, healthy future for humanity.

"Agriculture plays a huge part. While it is partly responsible for pollinator decline, it can also be part of the solution. Practices that support pollinators, such as managing landscapes to provide food and shelter for them, should be promoted and supported. We also need to focus publicly funded research on improving yields in farming systems like organic farming, which are known to support pollinators."

"Pressure to raise pesticide regulatory standards internationally should be a priority. The World Health Organisation and the Food and Agriculture Organization of the United Nations have worked for many years to develop a global code of conduct on pesticide management, but there are still many countries that don't follow it. This means pesticides are in widespread use that are unacceptably toxic to bees, birds, even humans."

The report stresses the need to develop more in-depth knowledge about the status of pollinators worldwide. Dr Dicks said: "We need long-term monitoring of pollinators, especially in Africa, South America and Asia, where there is little information about their status, but the processes driving declines are known to be occurring."

The ten suggested policies in full are:

1. Raise pesticide regulatory standards

2. Promote integrated pest management (IPM)

3. Include indirect and sublethal effects in GM crop risk assessments

4. Regulate movement of managed pollinators

5. Develop incentives, such as insurance schemes, to help farmers benefit from ecosystem services instead of agrochemicals

6. Recognize pollination as an agricultural input in extension services

7. Support diversified farming systems

8. Conserve and restore "green infrastructure" (a network of habitats that pollinators can move between) in agricultural and urban landscapes

9. Develop long-term monitoring of pollinators and pollination

10. Fund participatory research on improving yields in organic, diversified, and ecologically intensified farming

Prof Simon Potts, co-author and research professor in Agri-Environment at the University of Reading, said: "The definitive UN report is a sign that the world is waking up to the importance of protecting these vital pollinators. We hope that by going a step further and implementing these top policy opportunities, we can encourage decision-makers to take action before it's too late.

"Three quarters of the world's food crops benefit from animal pollination, so we must safeguard pollinators to safeguard the supply of nutritious foods."

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**Story Source:**

Materials provided by **University of East Anglia**. *Note: Content may be edited for style and length.*

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**Journal Reference**:

1. L. V. Dicks, B. Viana, R. Bommarco, B. Brosi, M. d. C. Arizmendi, S. A. Cunningham, L. Galetto, R. Hill, A. V. Lopes, C. Pires, H. Taki, S. G. Potts. **Ten policies for pollinators**. *Science*, 2016; 354 (6315): 975 DOI: 10.1126/science.aai9226

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## Recommended Articles

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Pensoft Publishers, ScienceDaily , 2012

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Intergovernmental Platform on Biodiversity and Ecosystem Services, ScienceDaily , 2013

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University of California - Berkeley, ScienceDaily , 2006

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GenomeWeb , 2011

Genomics Takes on Agriculture in the Developing World
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Bird Flu Officials And Bernard Matthews Say Consumers Not At Risk

Catharine Paddock PhD, Medical News Today , 2007

POLICY FORUM

A bumblebee (*Bombus terrestris*) collecting pollen from a blueberry flower. Unregulated trade in bumblebees puts them outside their native range.

PHOTO: SALLY MUNDY/ALAMY STOCK PHOTO

BIODIVERSITY

# *Ten policies for pollinators*

## What governments can do to safeguard pollination services

*By* **Lynn V. Dicks,[1] Blandina Viana,[2] Riccardo Bommarco,[3] Berry Brosi,[4] María del Coro Arizmendi,[5] Saul A. Cunningham,[6] Leonardo Galetto,[7] Rosemary Hill,[8] Ariadna V. Lopes,[9] Carmen Pires,[10] Hisatomo Taki,[11] Simon G. Potts[12]**

Earlier this year, the first global thematic assessment from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) evaluated the state of knowledge about pollinators and pollination (*1*, *2*). It confirmed evidence of large-scale wild pollinator declines in northwest Europe and North America and identified data shortfalls and an urgent need for monitoring elsewhere in the world. With high-level political commitments to support pollinators in the United States (*3*), the United Kingdom (*4*), and France (*5*); encouragement from the Convention on Biological Diversity's (CBD's) scientific advice body (*6*); and the issue on the agenda for next month's Conference of the Parties to the CBD, we see a chance for global-scale policy change. We extend beyond the IPBES report, which we helped to write, and suggest 10 policies that governments should seriously consider to protect pollinators and secure pollination services. Our suggestions are not the only available responses but are those we consider most likely to succeed, because of synergy with international policy objectives and strategies or formulation of international policy creating opportunities for change. We make these suggestions as independent scientists and not on behalf of IPBES.

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### RISK REDUCTION

Pesticides are the most heavily regulated of the interacting drivers of pollinator declines (*7*). Risk assessment and use regulation can reduce pesticide hazards at national scales (*2*), yet such regulation is uneven globally. Many countries do not have national pesticide regulation and control systems or adhere to the International Code of Conduct on Pesticide Management (ICCPM), recently updated by the United Nations (*8*, *9*). International pressure to raise pesticide regulatory standards across the world should be a priority. This includes consideration of sublethal and indirect effects in risk assessment and evaluating risks to a range of pollinator species, not just the honey bee, *Apis mellifera*.

Another priority is to capitalize on the profile of integrated pest management (IPM) in international policies, such as the ICCPM (*9*) and the European Union's (EU's) Sustainable Use of Pesticides Directive (*10*). IPM combines pest monitoring with a range of pest control methods, such as crop rotation, field margin management, and biological control; pesticides are used as a last resort, only when other strategies are insufficient (*11*). IPM can decrease pesticide use and reduces risks to nontarget organisms, so it should be linked to pollinator health and pollination.

Genetically modified (GM) crops pose potential risks to pollinators through poorly understood sublethal and indirect effects (*1*). For example, GM herbicide-tolerant crops lead to increased herbicide use, reducing the availability of flowers in the landscape, but consequences for pollinators are unknown. GM crop risk assessments in most countries do not capture these effects. They evaluate only direct effects of acute exposure to proteins expressed in the GM plants, usually in terms of the dose that kills 50% of adults ($LD_{50}$), and only for honey bees, not other pollinators. International guidance to improve GM organism risk assessment is being developed under the CBD's Cartagena Protocol on Biosafety (*12*); this presents an opportunity to encourage inclusion of indirect and sublethal effects on a range of pollinator species.

There are substantial risks from movement of managed pollinators around the world (*1*). Managed pollinators, including newly domesticated species, offer opportunities to grow businesses and improve pollination services. Commercial bumble bee trade has grown dramatically, leading to invasions of *Bombus terrestris* beyond its native range and increasing the risk of disease transfer to native wild bee populations, potentially including other bee species (*13*). The issue of invasive species has been highlighted in the UN Sustainable Development Goals and the CBD's Strategic Plan for Biodiversity, which parties to the CBD are implementing in national strategies and action plans. This creates momentum and opportunity for regulators to consider limiting and better managing pollinator movement within and between countries.

### SUSTAINABLE FARMING

Agriculture is a major driver of pollinator declines, through land-use change; intensive practices, such as tillage and agrochemical use; and declines in traditional farming practices. Agriculture also provides opportunities to support wild pollinators (*1*). We propose two complementary policy objectives: (i) promote ecological intensification of agriculture (*14*) and (ii) support diversified farming systems (*15*).

Ecological intensification involves managing ecological functions, such as pollination and natural pest regulation, as part of highly productive agriculture. It can be as profitable and productive as conventional approaches at a farm level, even with up to 8% of land out of production to provide habitats that support beneficial organisms (*16*).

A major barrier to uptake of ecological intensification is uncertainty about ecological and agronomic outcomes. To tackle uncertainty, a promising option is to adjust crop insurance schemes to provide incentives, such as lower premiums or smaller loss thresholds, for farmers who take action to promote pollinators. Insurance is a key element in "climate-smart agriculture" (*17*) but has yet to be tested or adopted for more general agricultural sustainability.

Another barrier, lack of knowledge among farmers and agronomists, can be addressed by extension services. For example, national Farm Advisory Systems are obligatory for member states under the EU's Common Agricultural Policy. The extent to which these provide information relevant to ecological management could be improved.

Diversified farming systems (including some organic farms, home gardens, agroforestry, mixed cropping, and livestock systems) incorporate many pollinator-friendly practices, such as flowering hedgerows, habitat patchiness, and intercropping (*1*). Support for these systems can be achieved through financial incentives, such as European agri-environment schemes (*18*), or market-based instruments, such as certification schemes with a price premium—both used to support organic farming. In at least 60 countries, these practices and farming systems depend on indigenous and local knowledge (*2*). To secure people's ability to pursue pollinator-friendly practices, their tenures and rights to determine their agriculture policies (food sovereignty) must be recognized and strengthened (*19*).

## Ten pollinator policies

1. Raise pesticide regulatory standards.
2. Promote integrated pest management (IPM).
3. Include indirect and sublethal effects in GM crop risk assessments.
4. Regulate movement of managed pollinators.
5. Develop incentives, such as insurance schemes, to help farmers benefit from ecosystem services instead of agrochemicals.
6. Recognize pollination as an agricultural input in extension services.
7. Support diversified farming systems.
8. Conserve and restore "green infrastructure" (a network of habitats that pollinators can move between) in agricultural and urban landscapes.
9. Develop long-term monitoring of pollinators and pollination.
10. Fund participatory research on improving yields in organic, diversified, and ecologically intensified farming.

## BIODIVERSITY AND ECOSYSTEM SERVICES

Policy interest in pollinators stems largely from their role in food production (*2*). Historically, the most widely adopted policy approaches for biodiversity conservation have been to identify and protect threatened species and to create protected areas. These remain critical but are not sufficient to maintain the substantial global value of pollination services in agriculture, for two reasons. First, the spatial separations between protected areas, as well as between protected areas and croplands, are usually large relative to daily movements of most pollinators. Second, although pollinator diversity is important, the bulk of crop pollination is from relatively few common, widespread species rather than rare or threatened species (*20*). For crop pollination, the policy goal should be to secure a minimum level of appropriate habitat, with flower and nesting resources, distributed throughout productive landscapes at scales that individual pollinators can move between. This fits the definition of "green infrastructure" identified by the EU in 2013 (*21*). It involves a diverse range of land managers, with overview and coordination at regional scales. As examples, small patches of habitat on public lands might be conserved through regulation, whereas protection or restoration of habitat on private land might be achieved through incentive payments (*18*) or by encouraging voluntary action (*22*). To conserve wider pollinator diversity and functions not relevant to agriculture, this approach must be integrated within strategically planned habitat and species protection policies (*20*, *23*).

## INCREASING KNOWLEDGE

There are substantial knowledge gaps about the status of pollinators worldwide and the effectiveness of measures to protect them (*1*). Evidence is largely limited to local-scale, short-term effects and is biased toward Europe and North America. There is a need for long-term, widespread monitoring of pollinators and pollination services. Recent research funded by the U.K. government as part of the National Pollinator Strategy for England (*4*) compared ways to achieve this monitoring, with varying levels of professional and volunteer involvement (*24*).

Finally, we suggest funding research on how to improve agricultural yields in farming systems known to support pollinators. This underpins several policies in our list. It also resonates with a global focus on improving food production and food security, especially on small farms (<2 ha), which represent more than 80% of farms and farmers, and 8 to 16% of farmed land (*2, 25*). To ensure that findings are considered credible, salient, and legitimate by agricultural communities, the research should prioritize knowledge co-production and exchange between scientists, farmers, stakeholders, and policy-makers. Such approaches can be supported through national and international research funding or institutional infrastructure. ■

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25. International Food Policy Research Institute, in *2016 Global Food Policy Report* (IFPRI, Washington, DC, 2016), chap. 1.


10.1126/science.aai9226

**Ten policies for pollinators**

Lynn V. Dicks, Blandina Viana, Riccardo Bommarco, Berry Brosi, María del Coro Arizmendi, Saul A. Cunningham, Leonardo Galetto, Rosemary Hill, Ariadna V. Lopes, Carmen Pires, Hisatomo Taki and Simon G. Potts (November 24, 2016)

*Science* **354** (6315), 975-976. [doi: 10.1126/science.aai9226]

Editor's Summary

**Chamberlain, Anne**

**From:** Fish, Gary
**Sent:** Friday, December 09, 2016 11:03 AM
**To:** AF-Pesticides; Murray, Kathy; Lund, Jennifer
**Subject:** Monarch decline not linked to loss of milkweed from herbicide resistent crop culture

I found this to be quite interesting…

http://www.oikosjournal.org/search/content/linking%20the%20continental%20migratory%20cycle%20of%20the%20monarch%20butterfly%20to%20understand


OIKOS JOURNAL

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# LINKING THE CONTINENTAL MIGRATORY CYCLE OF THE MONARCH BUTTERFLY TO UNDERSTAND ITS POPULATION DECLINE


Threats to several of the world's great animal migrations necessitate a research agenda focused on identifying drivers of their population dynamics. The monarch butterfly is an iconic species whose continental migratory population in eastern North America has been declining precipitously. Recent analyses have linked the monarch decline to reduced abundance of milkweed host plants in the USA caused by increased use of genetically modified herbicide-resistant crops. To identify the most sensitive stages in the monarch's annual multi-generational migration, and to test the milkweed limitation hypothesis, we analyzed 22 years of citizen science records from four monitoring programs across North America. We analyzed the relationships between butterfly population indices at successive stages of the annual migratory cycle to assess the validity of these citizen-science data, and to address the roles of migrant population size verses temporal trends that reflect changes in habitat or resource quality. We find a sharp population decline in the first breeding generation in the southern USA, driven by the progressively smaller numbers of spring migrants from the overwintering grounds in Mexico. Monarch populations then build regionally during the summer generations.
**Contrary to the milkweed limitation hypothesis, we did not find statistically significant temporal trends in stage-to-stage population**

**relationships in the mid-western or northeastern USA.** In contrast, there are statistically significant negative temporal trends in monarch success during fall migration and re-establishment at the overwintering grounds in Mexico, suggesting that these stages contribute strongly to the decline of monarchs. **Lack of milkweed, the only host plant for monarch butterfly caterpillars, is unlikely to be driving the monarch's population decline.** Conservation efforts therefore require additional focus on the later phases in the monarch's annual migratory cycle. We hypothesize that a lack of nectar sources, habitat fragmentation, and continued degradation at the overwintering sites are critical factors.

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Inamine, H., Ellner, S. P., Springer, J. P. and Agrawal, A. A. 2016. Linking the continental migratory cycle of the monarch butterfly to understand its population decline. – Oikos doi: 10.1111/oik.03196

Documents oik-03196.pdf

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**OIK-03196**

Inamine, H., Ellner, S. P., Springer, J. P. and Agrawal, A. A. 2016. Linking the continental migratory cycle of the monarch butterfly to understand its population decline. – Oikos doi: 10.1111/oik.03196

## Supplementary material

**Table A1**: Summary of annual data used in analyses.

**Appendix 1:** Summary of analyses examining quality and potential biases in the NABA dataset.

**Appendix 2**: Summary of analyses to examine temporal change in the relationship between stages of the monarch's annual migratory cycle.

Table A1. A summary of the annual census data used in analyses. All data were compiled, normalized and smoothed from the raw data (see Methods, code provided in Dryad), except that of the last four columns beginning with Mexico.

| YEAR | Spring South | Midwest | Northeast | Truncated Midwest | Truncated Northeast | Cape May | Peninsula Point | Fall South | Mexico [1] | Change in monarch population estimate (Mexico) [2] | Average adoption of HT corn & soybean [3] | Change in HT adoption [2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | NA | 153.365 | 39.425 | 53.258 | 34.591 | 544.6 | NA | NA | 6.23 | NA | 0 | 0 |
| 1994 | NA | 226.537 | 59.704 | 210.537 | 39.124 | 839.8 | NA | NA | 7.81 | 1.58 | 0 | 0 |
| 1995 | NA | 35.737 | 43.021 | 34.37 | 35.147 | 248.5 | NA | NA | 12.61 | 4.8 | 0 | 0 |
| 1996 | NA | 102.151 | 37.713 | 61.293 | 32.97 | 503.6 | 104.411 | NA | 18.19 | 5.58 | 5 | 5 |
| 1997 | NA | 230.106 | 108.253 | 149.485 | 70.155 | 919.6 | 254.429 | NA | 5.77 | -12.42 | 10.5 | 5.5 |
| 1998 | NA | 104.858 | 40.951 | 47.686 | 25.308 | 403.1 | 63.514 | NA | 5.56 | -0.21 | 26.5 | 15.95 |
| 1999 | NA | 255.704 | 104.118 | 126.978 | 45.144 | 2849.2 | 287.665 | NA | 8.97 | 3.41 | 32 | 5.3 |
| 2000 | NA | 149.817 | 80.296 | 73.162 | 32.814 | 250.7 | 259.48 | NA | 3.83 | -5.14 | 30.5 | -1.4 |
| 2001 | NA | 307.803 | 90.546 | 141.428 | 34.372 | 658.4 | 421.751 | NA | 9.36 | 5.53 | 38 | 7.5 |
| 2002 | NA | 166.007 | 21.381 | 62.175 | 8.54 | 276.8 | 317.842 | 35 | 7.54 | -1.82 | 43 | 5 |
| 2003 | NA | 193.017 | 41.897 | 103.476 | 17.272 | 392.3 | 466.94 | 110.833 | 11.12 | 3.58 | 48 | 5 |
| 2004 | NA | 58.672 | 16.049 | 33.361 | 9.238 | 74 | 92.053 | 28.25 | 2.19 | -8.93 | 52.5 | 4.5 |
| 2005 | 44.629 | 163.33 | 58.997 | 89.566 | 20.206 | 538.2 | 401.245 | 56.734 | 5.91 | 3.72 | 56.5 | 4 |
| 2006 | 77.268 | 338.107 | 265.467 | 162.687 | 120.702 | 1743.4 | 56.64 | 133.614 | 6.87 | 0.96 | 62.5 | 6 |
| 2007 | 72.977 | 266.017 | 179.67 | 159.438 | 90.476 | 746 | 129.424 | 64.362 | 4.61 | -2.26 | 71.5 | 9 |
| 2008 | 51.261 | 170.119 | 132.027 | 76.062 | 57.147 | 265.8 | 320.048 | 24.262 | 5.06 | 0.45 | 77.5 | 6 |
| 2009 | 75.296 | 185.16 | 88.072 | 84.44 | 43.095 | 281.2 | 177.383 | 183.774 | 1.92 | -3.14 | 79.5 | 2 |
| 2010 | 29.595 | 306.761 | 95.789 | 156.473 | 51.278 | 1026.5 | 624.553 | 58.829 | 4.02 | 2.1 | 81.5 | 2 |
| 2011 | 34.3 | 140.353 | 80.143 | 76.412 | 35.492 | 681.73 | 108.428 | 171.66 | 2.89 | -1.13 | 83 | 1.5 |
| 2012 | 20.861 | 169.584 | 178.336 | 89.023 | 114.551 | 1222.26 | 121.686 | 62.798 | 1.19 | -1.7 | 83 | 0 |
| 2013 | 10.31 | 41.939 | 16.801 | 17.153 | 6.524 | 112.73 | 42.462 | 37.39 | 0.67 | -0.52 | 89 | 6 |
| 2014 | 21.129 | 99.009 | 46.367 | 64.998 | 16.011 | 393.9 | 652.844 | 53.21 | 1.13 | 0.46 | 91.5 | 1.5 |

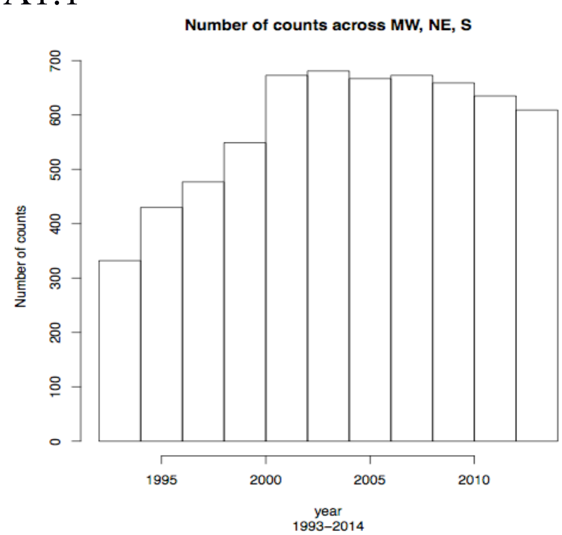
[1]http://assets.worldwildlife.org/publications/768/files/original/REPORT_Monarch_Butterfly_colonies_Winter_2014.pdf?1422378439. For a YEAR N, the Mexico population corresponds to the butterflies overwintering from N to N+1.
[2]the change given in year N represents the change from Year N-1 to N. [3]http://www.ers.usda.gov/media/185551/biotechcrops_d.html

# Appendix 1

**Summary of analyses examining quality and potential biases in the NABA dataset**.

Here we examine potential biases and quality issues common in citizen science datasets [1]. While there are some shortcomings, several lines of evidence and past studies [e.g. 2] suggest that this is a reliable dataset and it is appropriate for our analyses. First, we compared our complete population indices with truncated indices that only included sampling dates that had consistent data cross all years. The truncated dataset constitutes a very small portion (20-25%) of the original dataset, yet we see very high correlations between the two (Pearson's $r$ in Midwest: 0.88; Northeast: 0.94). Second, to address the potential for missing data early in the season, we plotted the yearly counts for the Midwest and Northeast to ensure that censuses captured a temporal increase in butterfly abundance in late spring. Third, we addressed the relationship between sampling effort and butterfly counts by transforming party hours to test for sampling effort biases common in citizen science datasets [1]. Fourth, we used Ripley's $K$ function [3] to assess whether the count data show a temporal bias of increased clustering over years. Finally, the potential for additional spatial biases in sampling are addressed in Results and Discussion in the main article.

A1.1

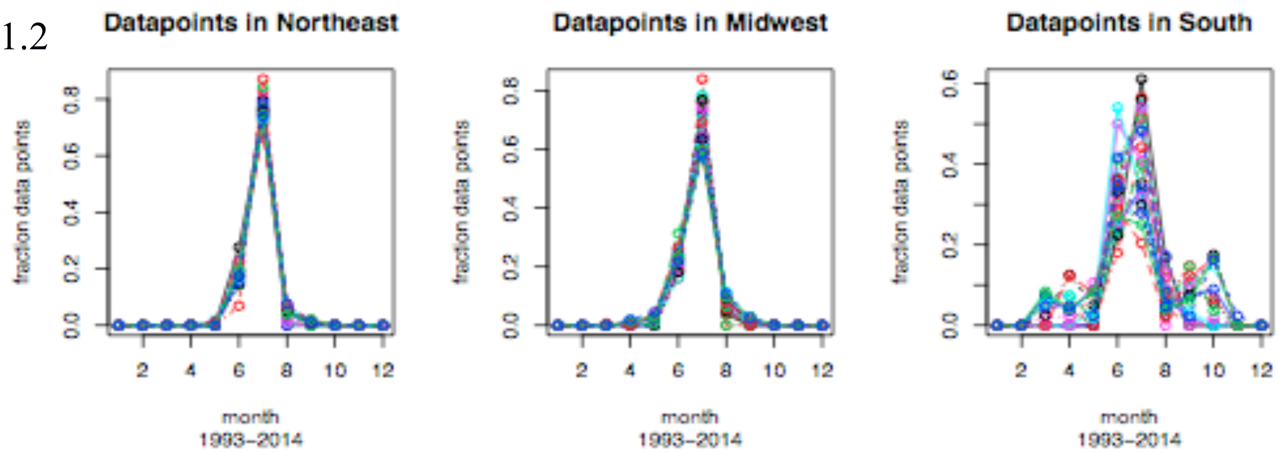



**Description of NABA dataset**. The North American Butterfly Association (NABA) has compiled butterfly counts from participating citizens across North America since 1975. The counts are taken from various locations throughout the year and the data includes the number of observed monarchs, the location (latitude and longitude), date, number of observers, number of parties (groups of observers), and the total hours spent.

The dataset goes back to 1975 initially as July 4th counts (led by the Xerces Society for Invertebrate Conservation, later acquired by NABA), but the number of sampling dates has been increasing every year, with samples taken more widely throughout the year. The number of counts gradually increased over the years and substantial number of counts were reported 1993-2014 (mean of 290 counts per year across the USA, see Fig A1.1). Furthermore, these years correspond to the data available on the overwintering population in Mexico from the surveys by the WWF.

While the counts originally took place on 4 July, participants started to collect data more widely throughout the year. Figure A1.2 shows the fraction of data points (each colored line represents a year) taken in each month. Northeast and Midwest are concentrated while South has wider sampling range. The two to three key breeding generations during the summer occur in the Midwest and Northeast regions. Although our earliest and latest NABA samples from these regions (across the 22 years in the dataset) were taken from 27 March and 3 October, respectively, on average there are ~74% of counts in July, with fewer samples in June (~20%) and August (~5%). These months correspond to the peak abundance and breeding period of monarchs [4] (also see Fig 3B). We used 27 March to 3 October to capture all the information available on the breeding populations. While these intervals are large, they again capture the regional dynamics (Fig. 3B); a smaller subset of the dataset corresponding to the maximum of each peak (and with equal sampling effort across years) is highly correlated with the full dataset (see Section 1 below).

A1.2



It is important to note that intense sampling does not necessarily correspond to high butterfly counts. As a case in point, the mean relative population size index of the monarchs in the south is lower in the summer compared to spring and fall (Fig. 3B), even though the number of samples are much higher in the summer than either season. Below we address potential issues with varying sampling intensity.

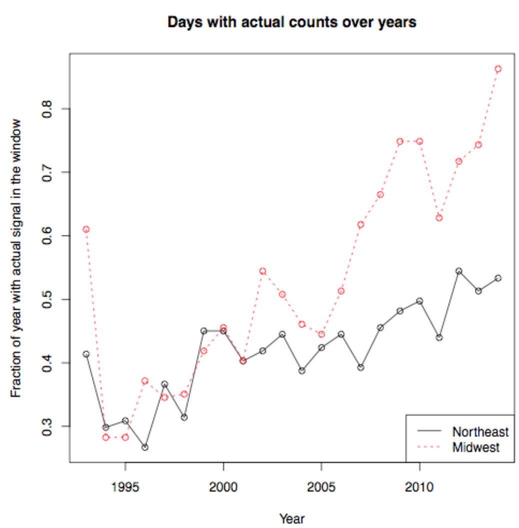
**1. Moving average over large spatial and temporal scale: Will varying intensity cause bias in moving average?**

NABA data points are collected in various locations throughout the USA, with different years of coverage. Furthermore, we see varying sampling intensity within a year. Not surprisingly, we see no obvious population dynamics pattern at fine spatial and temporal scales in the dataset. In order to focus on the appropriate scale that reflects continental population dynamics, we use a moving average (i.e., kernel estimation using uniform function) over 7-day windows. For each observed count within a region, let $i$ be the day of year, and $y_i$ the observed number of monarchs per party hour. Then, the averaged abundance assigned to day $j$ for the specified region is

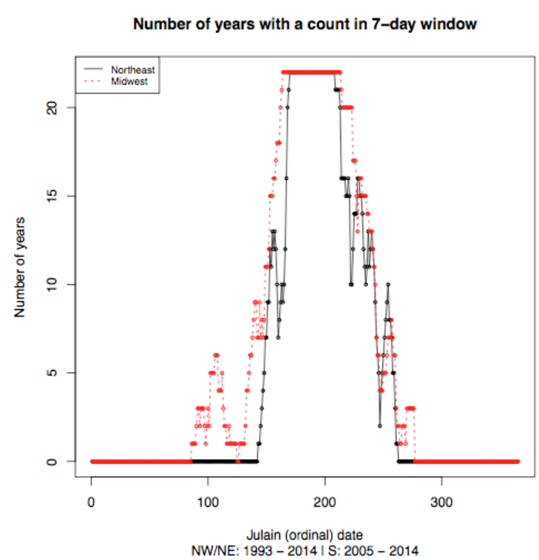
$$\bar{y}_j = \frac{1}{n_j}\left(\sum_{i=j-3}^{j+3} y_i\right)$$

where $n_j$ is the number of counts that occurred during the 7-day window. If there are several counts on one day, they are both included in the sum. Conversely, a day without any counts within the 7-day window is assigned value 0.

A1.3




A1.4

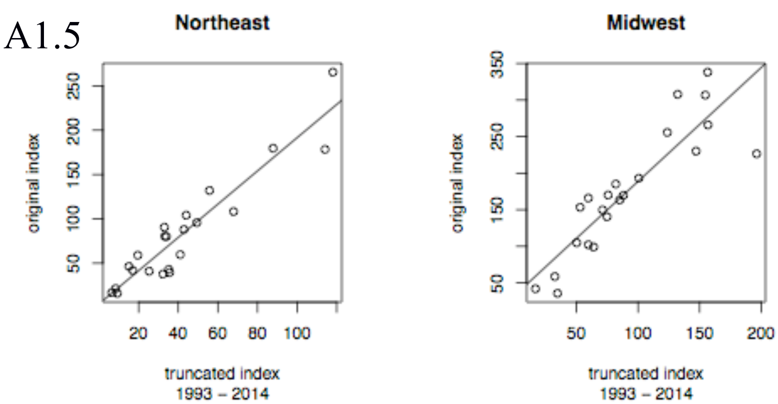



Varying sampling intensity may bias our index, because clustered missing data results in 0, and therefore lowers the index compared to widely sampled years. For example, Figure A1.3

shows the fraction of days in NE and MW where there was at least one data point within each 7-day window; the number of samples increases over time. This varying sampling intensity could bias our results, leading to non-decreasing population index over years. We do not believe this is the case for Spring South, where the population index is decreasing over time; any increase in sampling effort over time would counteract the observed decline. The concern lies in Midwest and Northeast, however, where we see a largely stable population index across years despite decreasing abundance in Mexico. We therefore focus on these two regions for the rest of this Appendix.

To assess this potential bias, we constructed a truncated dataset for each region where the averaged days consistently included a count, across all 22 years; that is, we focused on days where $n_j > 0$ across all years (See Fig A1.4 for corresponding dates; the figure shows, for each date, the number of years with a data point in the 7-day window). We summed the indices from these days and compared them to the total Midwest and Northeast population indices derived by our methods.

A1.5

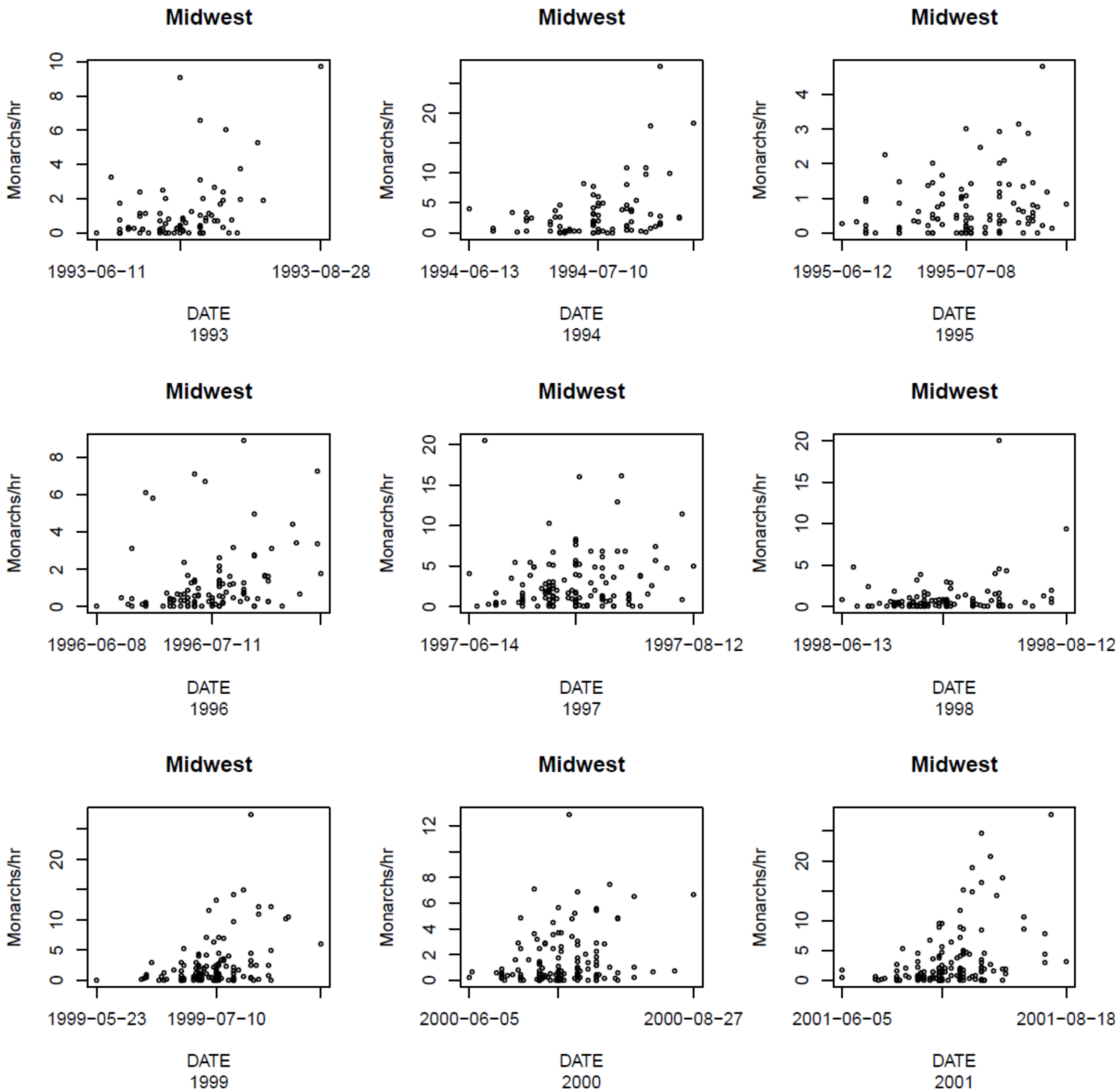


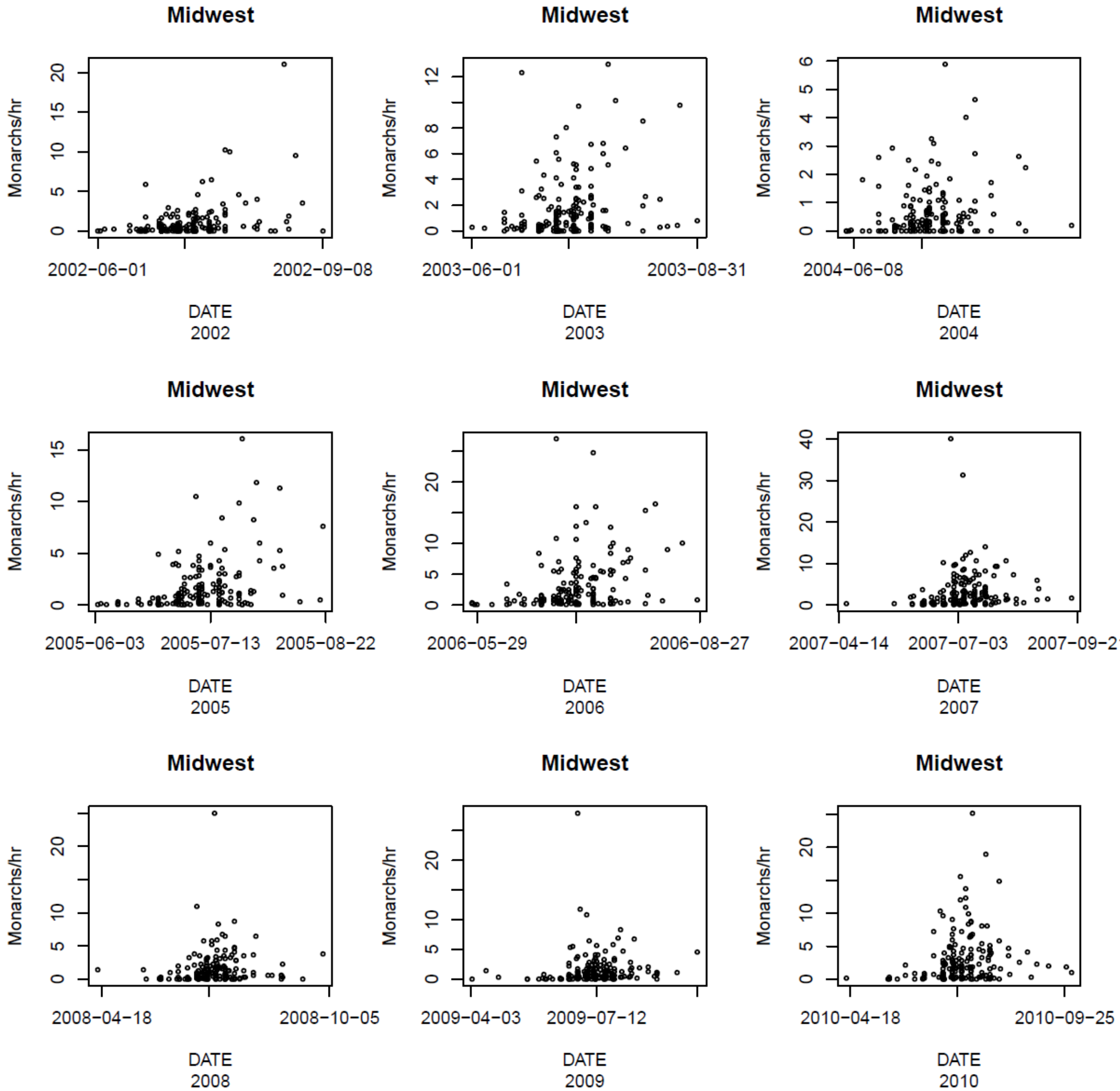

This reduced the dataset to samples taken from 13 June - 1 Aug. Importantly, this truncated index is not impacted by varying sampling intensity across years because sampling intensity has been fixed (no days without counts). Our complete yearly index was highly correlated with this truncated index (n = 22, Midwest Pearson's r = 0.88, p < 0.001; Northeast Pearson's r = 0.94, p < 0.001; see Fig. A1.5). Furthermore, analyses of linkages between regions and declines were qualitatively the same if we used the yearly index or the truncated index (data provided in Table A1). We therefore conclude that varying sampling intensity across years is not affecting the population indices. Accordingly, to utilize the most available information, we include the complete index from March through October for the main analyses.

**2. Census of early season butterflies**

To address the potential for missing data early in the season, we plotted the yearly counts for the Midwest and Northeast to ensure that censuses captured a temporal increase in butterfly abundance in late spring. Namely, we were concerned that scarce sampling in some years could have missed some of the early migrating butterflies. In order to check that the incoming butterflies are all taken into account, we plotted the raw counts (i.e. before smoothing via moving average) for the Midwest and Northeast (Fig. A1.6). Throughout the panels, the seasonal data sets consistently begin with a low count (~ 0 monarchs per hour) early in the breeding season, and the values typically increase over time. This suggests that counts began each year early enough to capture the timing of monarch arrival (which is somewhat variable across years). Given the consistent sampling coverage within the time of high monarch abundance each year, we are confident that our indices capture both the migrants and the breeding populations in Midwest and Northeast.

A1.6 (pages 8-13)

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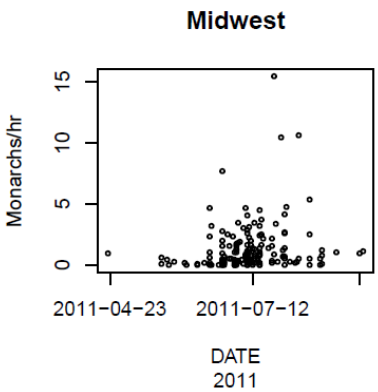
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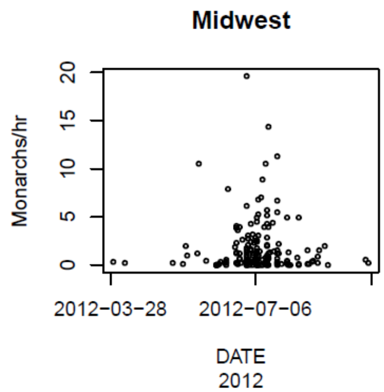
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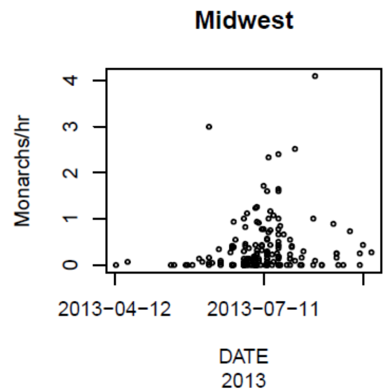
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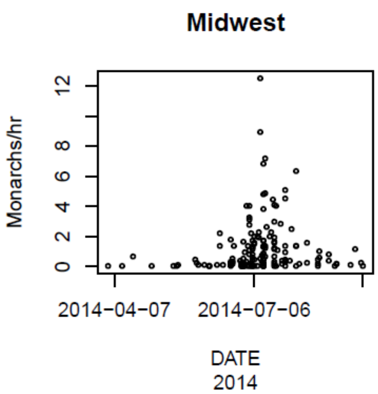
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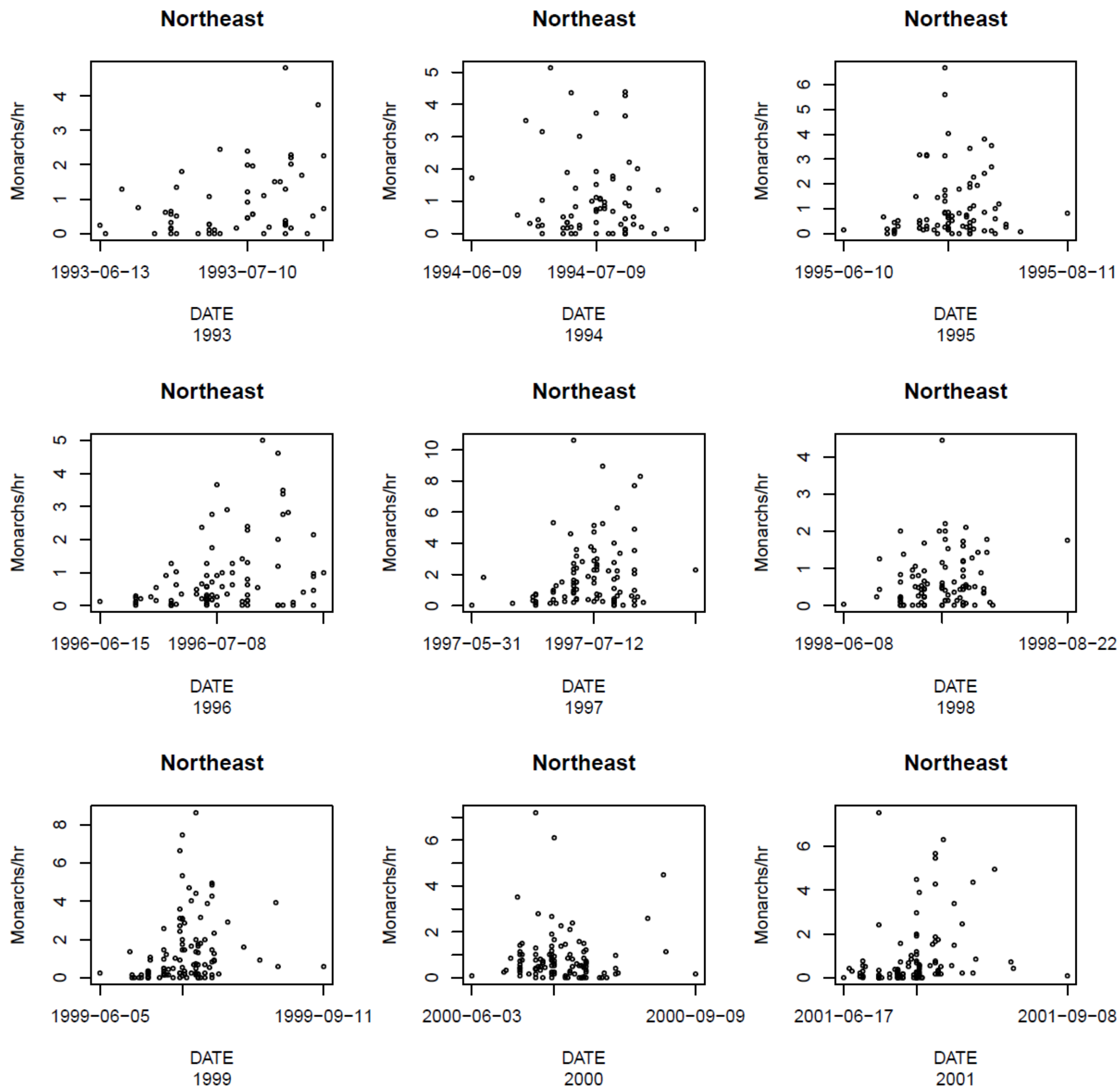
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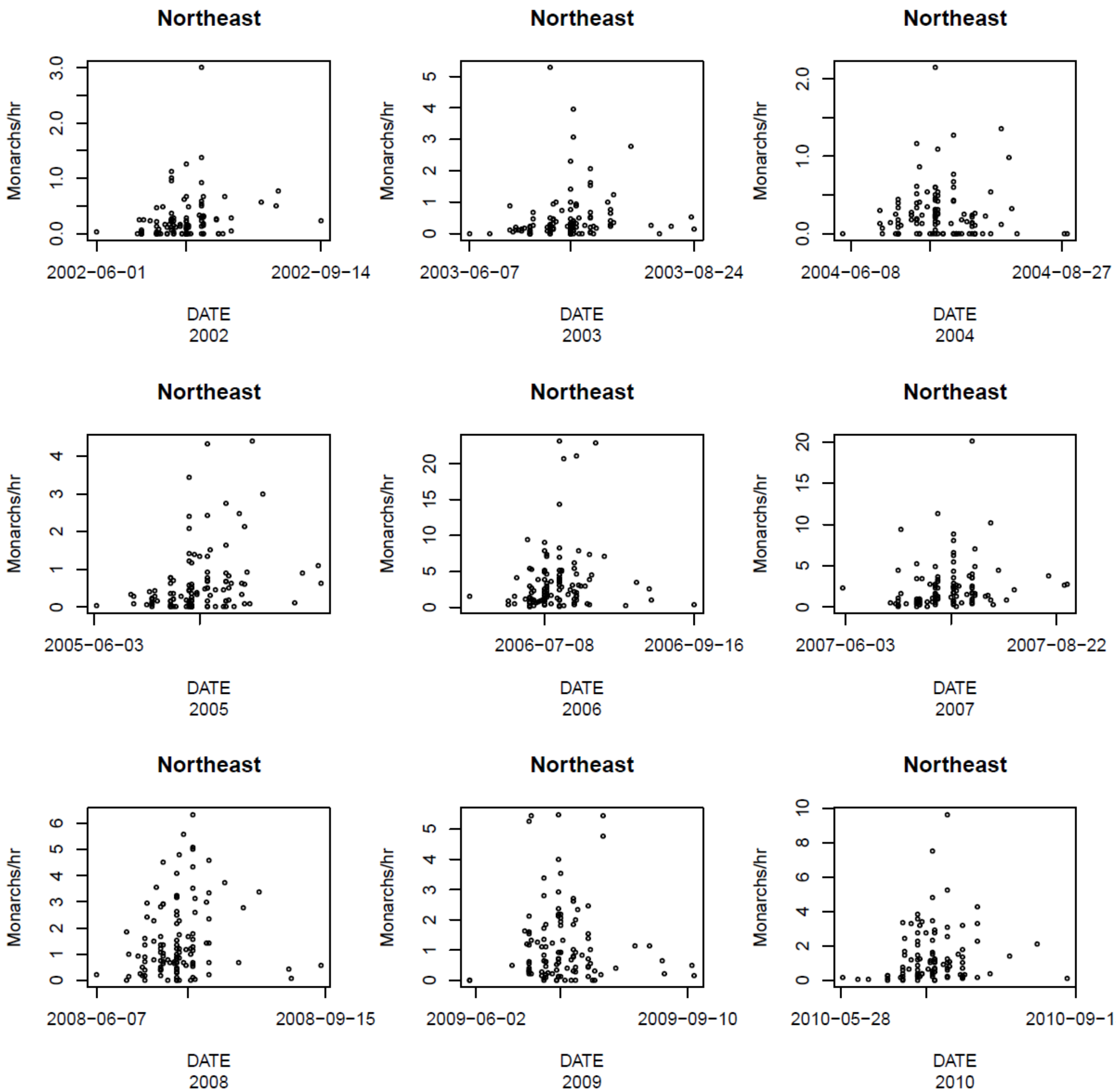
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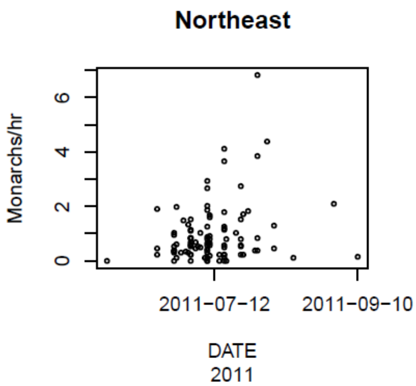
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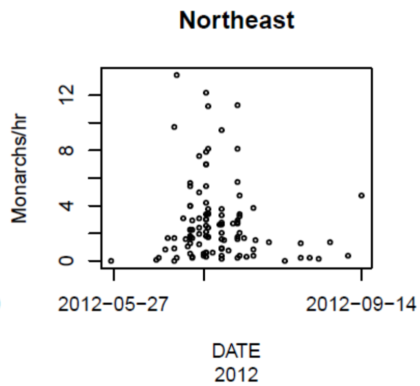
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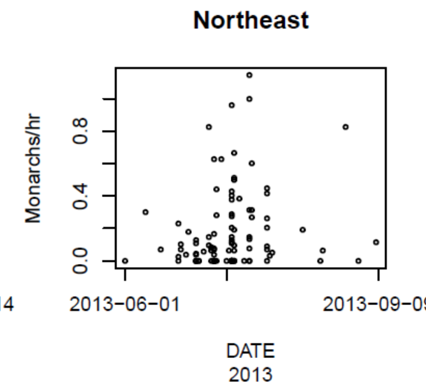
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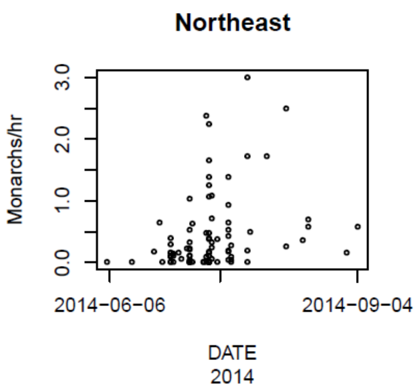
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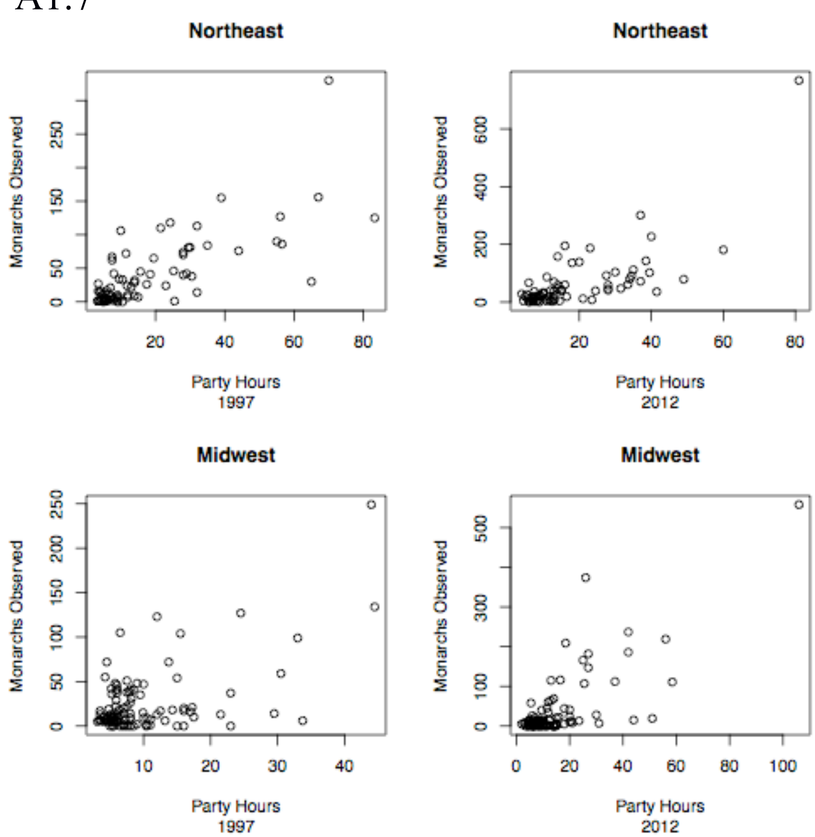
## 3. Are their biases in monarch censuses due to varying party hours?

A potential problem with citizen science datasets is variation in survey effort and its non-linear effect on counts (Link and Sauer 1999). As indicated in the Material and methods, each NABA count was normalized by dividing the number of observed monarchs by the party hours [5-7]. In some areas of citizen science analysis, as with Christmas bird counts, additional statistical methods have been used to account for potential spatial and temporal effort biases [1, 8]. For example, the number of organisms found may saturate with observation hours. These methods are used to correct for the saturating nature of count data with respect to hours spent. This bias would only appear when effort values are particularly high. Figure A1.7 shows representative graphs (from year 1997 and 2012) of how the number of observed monarchs changes with party hours for the count in both Northeast and Midwest. Specifically, we focused on July (the most intensely sampled month) under the assumption that the population size is more or less the same within a region over a month. We do not see a saturating relationship between sampling effort and butterfly observations. Similar results hold for other years.

In order to further test our dataset, we transformed our party hours to see if it affected the analyses [8, 9]. We re-ran our analyses using counts standardized by the square root of party hours (a simple method of transformation suggested by Link et al. 2006), and the patterns remain the same. Using sqrt(effort) and re-calculating the annual indices, comparisons of the transformed to the original indices yielded $R^2$ values of 0.95 to 0.99 (with the intercepts not being significantly different from zero). Thus, given the linear relationship between effort and monarch counts, the lack of an effect of further transforming the data, and to align with previous analyses [5-7], we maintain using the count data standardized by party hours.

A1.7



**4. Do census points cluster more over the years?**

If patches of suitable monarch habitat are disappearing (in particular, due to loss of milkweed), then it is conceivable that NABA citizen science counts in later years were done in the few remaining patches, leading to an upward bias in population indices and masking a decline in the total regional population. To test for this possibility, we asked if NABA count locations show increasing spatial clustering in later years, which would occur if the counts are being done in a smaller number of locations. We used Ripley's *K* function [3], a standard measure of clustering in spatial statistics, to quantify the clustering of count locations in each year. Ripley's *K* function calculates the number of neighboring data points present within concentric circles around a focal sampling location, as the radius/distance increases. These values are averaged over all the sampling locations present in the data set for that year. We used Mercator projection (*mapproj* library in R) of sampling locations (given as latitude and longitude in the NABA data set) and Ripley's isotropic correction estimate of *K* (*spatstat* library in R).

The patterns are consistent across years in both Northeast and Midwest regions (Fig. A1.8, different colors and lines correspond to different years), and do not differ substantially across years. More importantly, we do not see any trends in the *K* function with respect to year (Fig. A1.9) at any spatial scale. This implies that the count locations do not cluster more over time. We conclude that geographic clustering of monarch sampling is not increasing over time, and is therefore not a source of temporal bias in the NABA dataset.

Figure A1.8

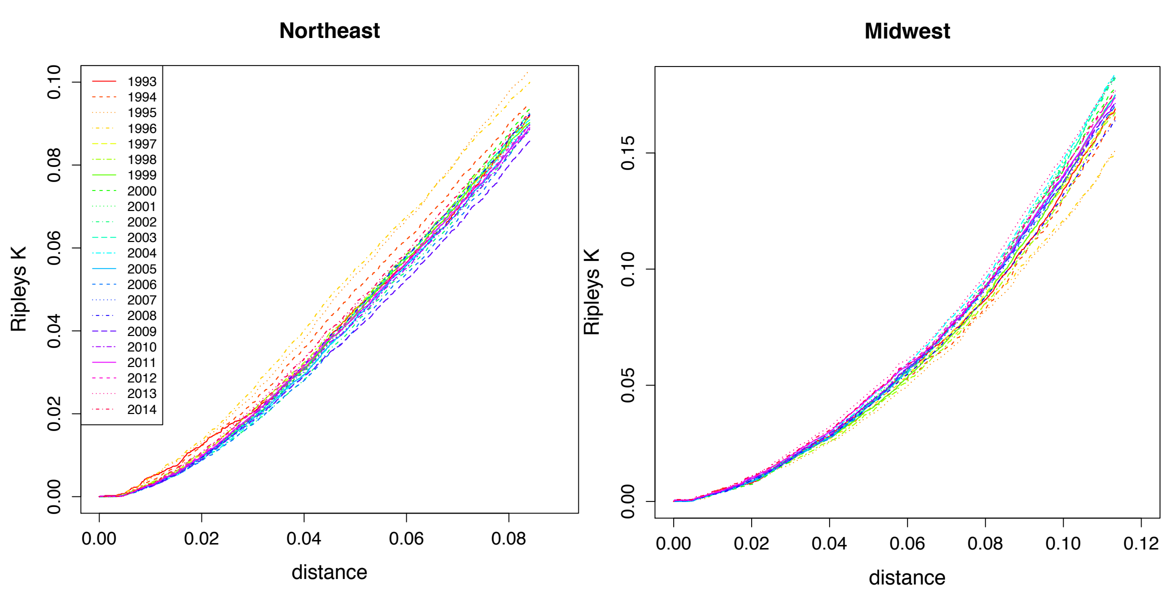



**Figure A1.8.** Ripley's K function for the spatial locations of NABA population counts in each year.

Figure A1.9

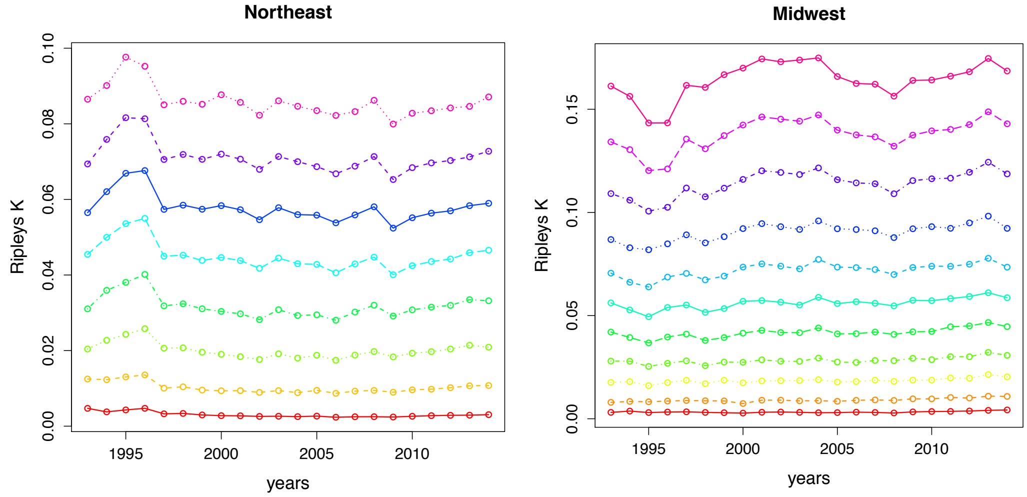



**Figure A1.9.** Ripley's K function as a function of year for the Northeast and Midwest regions. The different colors and lines correspond to distances 0.01, 0.02, …, 0.11 from bottom to top.

# Appendix 2

## Statistical analyses to examine temporal change in the relationship between stages of the annual migratory cycle

In the following series of analyses, we investigated the relationship between population size at one stage of the annual migratory cycle (DONOR region, independent variable) and the next time step (RECIPIENT region, dependent variable). To address temporal change in these relationships, we considered YEAR and the DONOR×YEAR interaction as additional covariates. YEAR was entered as a numerical covariate because we are interested in directional trends over time. Because the change in YEAR is small relative to its mean, DONOR and DONOR×YEAR are strongly collinear. To remove this, we centered YEAR about its mean. We considered the following models:

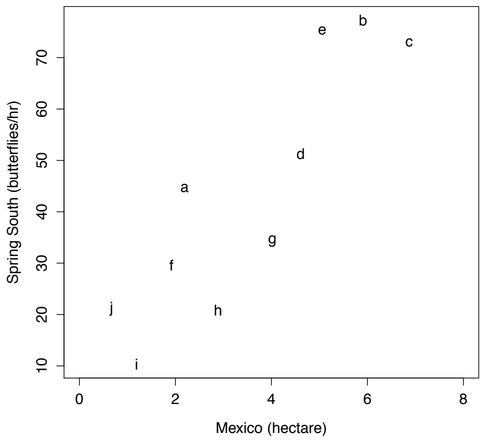
- Model 1: RECIPIENT ∼DONOR + YEAR + DONOR*YEAR
- Model 2: RECIPIENT ∼DONOR + DONOR*YEAR
- Model 3: RECIPIENT ∼DONOR
- Model 4: RECIPIENT ∼DONOR*YEAR
- Model 5: RECIPIENT ∼DONOR + YEAR
- Model 6: RECIPIENT ∼YEAR + DONOR*YEAR
- Model 7: RECIPIENT ∼YEAR

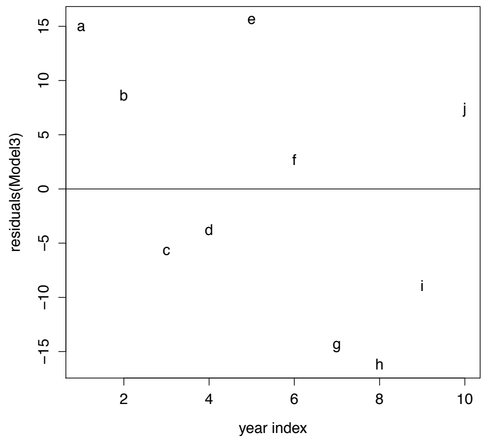
For each DONOR-RECIPIENT pair, we plot the relationship between regions or between region and year, with the letters on the plot indicating chronological order (a = first year of census, etc.). The table next to the graph shows the $\Delta$AIC value for each model, relative to the lowest AIC value.

We performed stepwise model selection based on AIC values [10], and also F-tests to evaluate the statistical significance of terms by a comparison of nested models with and without the term. We performed both backward and forward selection to check for consistency between these approaches. In backward selection, we started with the full model (Model 1) and sequentially eliminated the non-significant term (if any such exist) that resulted in the largest improvement in AIC, stopping when all terms are significant. In forward selection, we started with either DONOR (Model 3) or YEAR (Model 7), whichever had the stronger univariate correlation with the dependent variable, and sequentially added the term that gave the largest improvement in AIC, stopping when the added term was not statistically significant.

The table below each plot summarizes backward and forward model selection. The entries under **Model Comparison** in each row show the significance of that covariate, based on an $F$-test against a model with that term dropped (for Backward selection) or added (for Forward selection). The AIC of the modified model (with a term added or dropped) is also given. If an outlier was detected, the table reflects the analyses after it was removed.

# 1 Mexico to Spring South




| | df | ΔAIC |
|---|---|---|
| Model 1 | 5 | 1.36 |
| Model 2 | 4 | 0.00 |
| Model 3 | 3 | 2.86 |
| Model 4 | 3 | 6.94 |
| Model 5 | 4 | 0.56 |
| Model 6 | 4 | 8.30 |
| Model 7 | 3 | 8.98 |

| | **Model** | **AIC** | **Model comparison** | | |
|---|---|---|---|---|---|
| Backward | | | Mexico | YEAR | Mexico*YEAR |
| 1 | Mexico + YEAR + Mexico*YEAR | 50.38 | **AIC=57.32, p=0.03** | AIC=49.02, p=0.55 | AIC=49.58, p=0.42 |
| 2 | ***Mexico + Mexico*YEAR*** | 49.02 | **AIC=55.95, p=0.02** | | AIC=51.88, p=0.07 |
| Forward | | | | | |
| 3 | Mexico | 51.88 | | AIC=49.58, p=0.09 | AIC=49.02, p=0.07 |
| 2 | ***Mexico + Mexico*YEAR*** | 49.02 | | AIC=50.38, p=0.55 | |

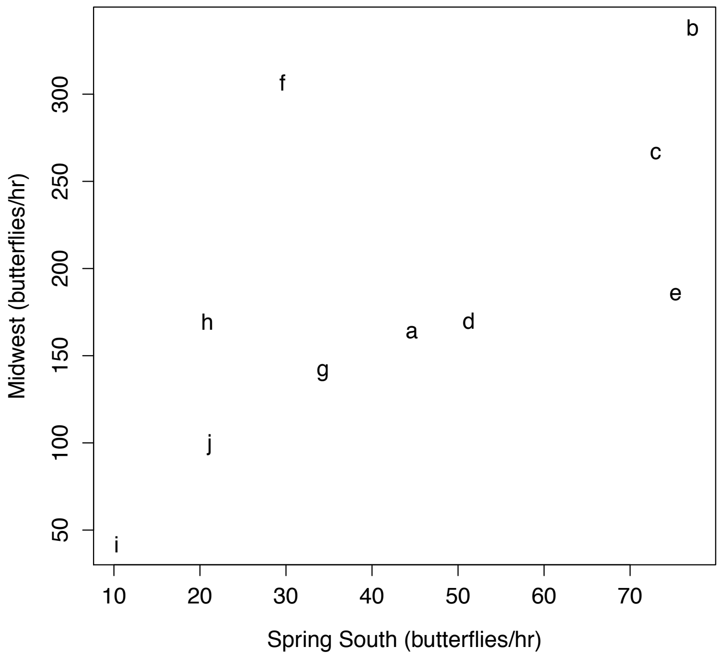
Backward and Forward model selection both lead to Model 3,

$$\text{Spring South} \sim \text{ Mexico}$$

AIC favors the addition of Mexico*YEAR (Model 2), but the $F$-test shows that this term is only marginal ($\mathbf{p} = 0.07$) and the residuals from Model 3 (plotted above) do not show any visible pattern over time.

*Conclusion:* The overwintering populations in Mexico predict Spring South populations. There is marginal evidence for a small decrease in the slope of this relationship over time.

## 2 Spring South to Midwest




| | df | ΔAIC |
|---|---|---|
| Model1 | 5 | 3.32 |
| Model2 | 4 | 1.43 |
| Model3 | 3 | 0.00 |
| Model4 | 3 | 0.70 |
| Model5 | 4 | 1.35 |
| Model6 | 4 | 2.40 |
| Model7 | 3 | 0.54 |

| | **Model** | **AIC** | **Model comparison** | | |
|---|---|---|---|---|---|
| Backward | | | Spring South | YEAR | Spring South*YEAR |
| 1 | Spring South + YEAR + Spring South*YEAR | 91.2 | AIC=90.28, p=0.44 | AIC=89.30, p=0.81 | AIC=89.22, p=0.91 |
| 5 | Spring South + YEAR | 89.22 | AIC=88.42, p=0.38 | AIC=87.87, p=0.51 | |
| 3 | ***Spring South*** | 87.87 | **AIC=91.30, p=0.04** | | |
| Forward | | | | | |
| 3 | ***Spring South*** | 87.87 | | AIC=89.22, p=0.51 | AIC=89.30, p=0.54 |

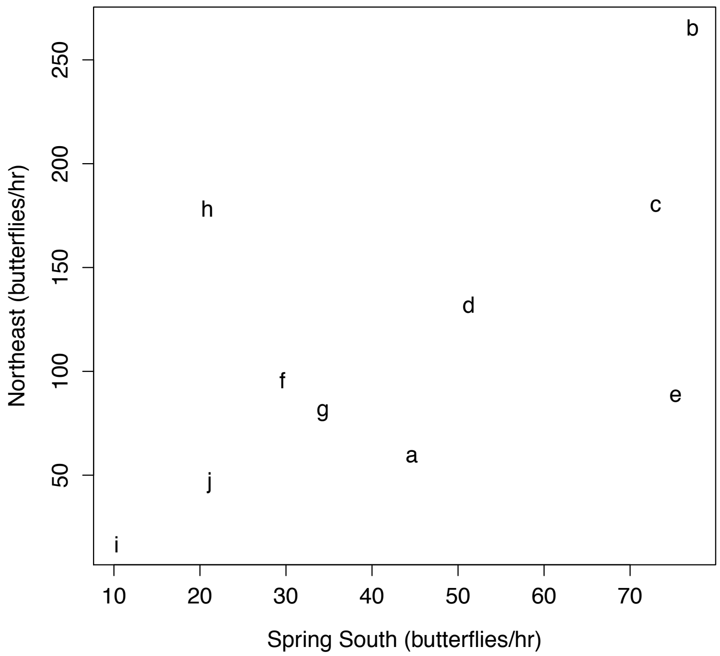
Forward selection, Backward selection, and AIC all lead to Model 3,

$$\text{Midwest} \sim \text{Spring South}$$

with the donor region as the only significant predictor ($p < 0.05$).

*Conclusion:* Monarch populations in Spring South significantly predict those in the Midwest. There is no evidence for a temporal trend in this relationship.

# 3 Spring South to Northeast




| | df | ΔAIC |
|---|---|---|
| Model1 | 5 | 2.29 |
| Model2 | 4 | 1.35 |
| Model3 | 3 | 0.00 |
| Model4 | 3 | 0.24 |
| Model5 | 4 | 1.98 |
| Model6 | 4 | 1.70 |
| Model7 | 3 | 1.87 |

| | **Model** | **AIC** | **Model comparison** | | |
|---|---|---|---|---|---|
| Backward | | | Spring South | YEAR | Spring South*YEAR |
| 1 | Spring South + YEAR + Spring South*YEAR | 87.03 | AIC=86.44, p=0.38 | AIC=86.09, p=0.44 | AIC=86.72, p=0.33 |
| 2 | Spring South + Spring South*YEAR | 86.09 | AIC=84.98, p=0.45 | | AIC=84.74, p=0.52 |
| 3 | ***Spring South*** | 84.74 | AIC=87.35, p=0.06 | | |
| Forward | | | | | |
| 3 | ***Spring South*** | 84.74 | | AIC=86.72, p=0.92 | AIC=86.09, p=0.52 |

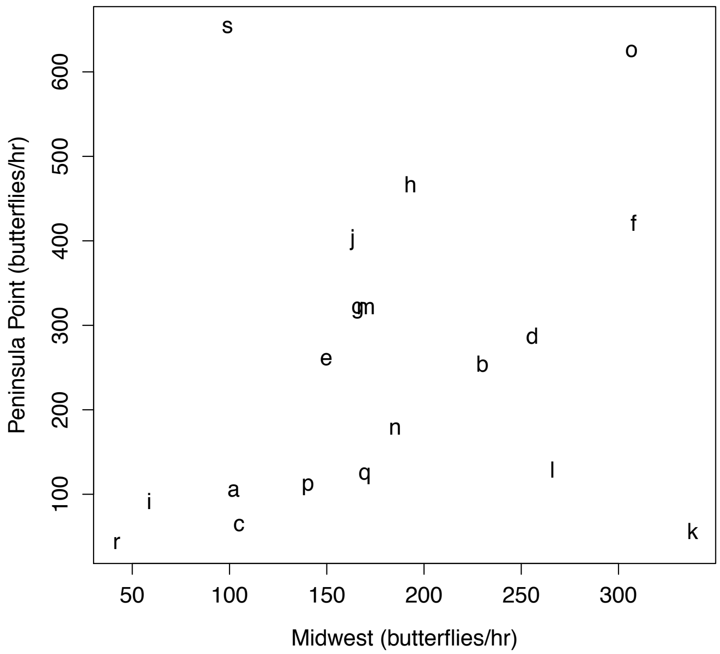
Forward selection, Backward selection, and AIC all lead to Model 3,

$$\text{Northeast} \sim \text{Spring South}$$

with the donor region as the marginally significant predictor ($p = 0.06$).

*Conclusion:* Monarch populations in Spring South marginally predict that in the Northeast. There is no evidence for a temporal trend in this relationship.

# 4 Midwest to Peninsula Point




| | df | Δ AIC |
|---|---|---|
| Model1 | 5 | 3.87 |
| Model2 | 4 | 1.99 |
| Model3 | 3 | 0.00 |
| Model4 | 3 | 4.46 |
| Model5 | 4 | 1.93 |
| Model6 | 4 | 6.05 |
| Model7 | 3 | 4.37 |

| | **Model** | **AIC** | **Model comparison** | | |
|---|---|---|---|---|---|
| Backward | | | Midwest | YEAR | Midwest*YEAR |
| 1 | Midwest + YEAR + Midwest*YEAR | 186.29 | AIC=188.47, p=0.08 | AIC=184.40, p=0.77 | AIC=184.35, p=0.83 |
| 5 | Midwest + YEAR | 184.35 | AIC=186.78, p=0.06 | AIC=182.41, p=0.82 | |
| 3 | ***Midwest*** | 182.41 | **AIC=184.87, p<0.05** | | |
| Forward | | | | | |
| 3 | ***Midwest*** | 182.41 | | AIC=184.35, p=0.82 | AIC=184.40, p=0.91 |

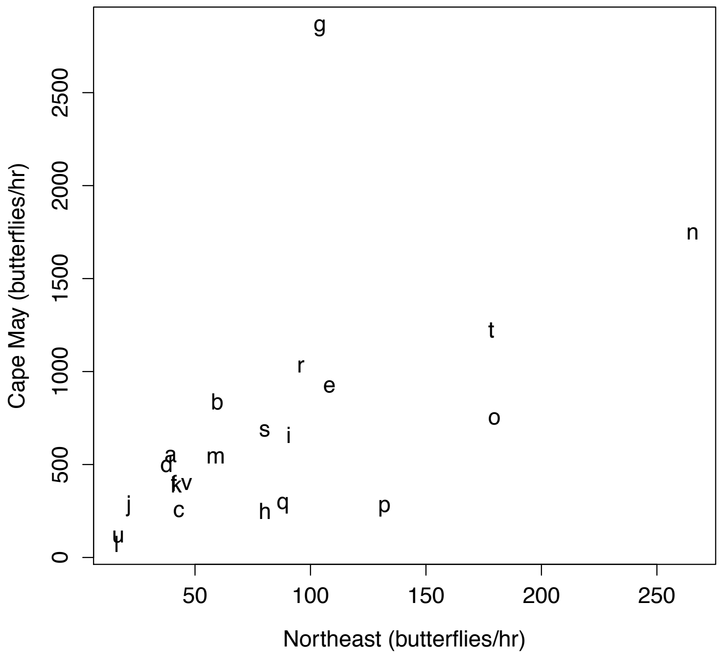
Forward selection, Backward selection, and AIC all lead to Model 3,

$$\text{Peninsula Point} \sim \text{Midwest}$$

With an outlier (2014: Midwest = 98.8, Peninsula Point = 652.8; Studentized residual >3.1) included, Midwest is not a significant predictor ($p$ = 0.26). However with an outlier removed, Midwest becomes a significant predictor ($p <$ 0.05). The model selection table reflects the analysis after the outlier was removed.

*Conclusion:* Without an outlier, Midwest monarch populations significantly predict fall migrants through Peninsula Point, and we do not see any signatures of change in the slope over time.

# 5 Northeast to Cape May




| | df | ΔAIC |
|---|---|---|
| Model1 | 5 | 2.55 |
| Model2 | 4 | 1.24 |
| Model3 | 3 | 0.00 |
| Model4 | 3 | 18.60 |
| Model5 | 4 | 0.62 |
| Model6 | 4 | 16.45 |
| Model7 | 3 | 21.21 |

| | **Model** | **AIC** | **Model comparison** | | |
|---|---|---|---|---|---|
| Backward | | | Northeast | YEAR | Northeast*YEAR |
| 1 | Northeast + YEAR + Northeast*YEAR | 236.29 | **AIC=250.20, p<0.001** | AIC=234.98, p=0.46 | AIC=234.36, p=0.81 |
| 5 | Northeast + YEAR | 234.36 | **AIC=254.96, p<0.0001** | AIC=233.74, p=0.28 | |
| 3 | ***Northeast*** | 233.74 | **AIC=253.10, p<0.0001** | | |
| Forward | | | | | |
| 3 | ***Northeast*** | 233.74 | | AIC=234.36, p=0.28 | AIC=234.98, p=0.43 |

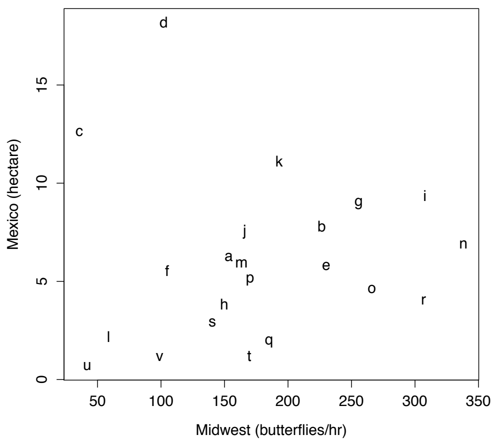
Without an outlier (1999: Northeast = 104.1, Cape May = 2849.2; Studentized residual 8.420), Forward selection, Backward selection, and AIC all lead to Model 3,

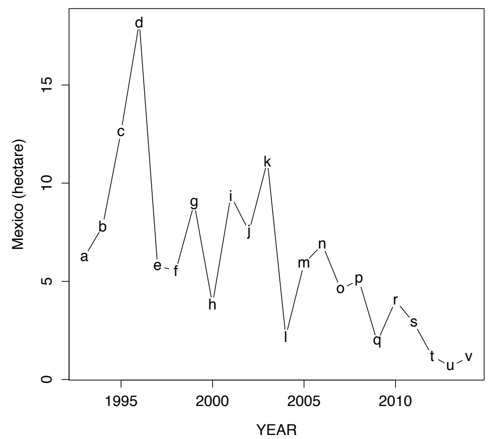
$$\text{Cape May} \sim \text{Northeast}$$

When the outlier is included, however, we see marginally significant effect ($p = 0.09$) of the interaction term (Model 2) with negative slope. The model selection table reflects the analysis after the outlier was removed.

*Conclusion:* Northeast monarch populations predict Cape May, and the weak evidence for a temporal trend was due to a single outlier.

# 6 Midwest to Mexico




| | df | ΔAIC |
|---|---|---|
| Model1 | 5 | 0.53 |
| Model2 | 4 | 7.24 |
| Model3 | 3 | 12.80 |
| Model4 | 3 | 7.17 |
| Model5 | 4 | 0.00 |
| Model6 | 4 | 0.45 |
| Model7 | 3 | 0.09 |

| | **Model** | **AIC** | **Model comparison** | | |
|---|---|---|---|---|---|
| Backward | | | Midwest | YEAR | Midwest*YEAR |
| 1 | Midwest + YEAR + Midwest*YEAR | 39.56 | AIC=39.49, p=0.22 | **AIC=46.27, p<0.01** | AIC=39.04, p=0.28 |
| 5 | Midwest + YEAR | 39.04 | AIC=39.12, p=0.19 | **AIC=51.84, p<0.001** | |
| 7 | ***YEAR*** | 39.12 | | **AIC=51.21, p<0.001** | |
| Forward | | | | | |
| 7 | ***YEAR*** | 39.12 | AIC=39.04, p=0.19 | | AIC=39.49, p=0.24 |

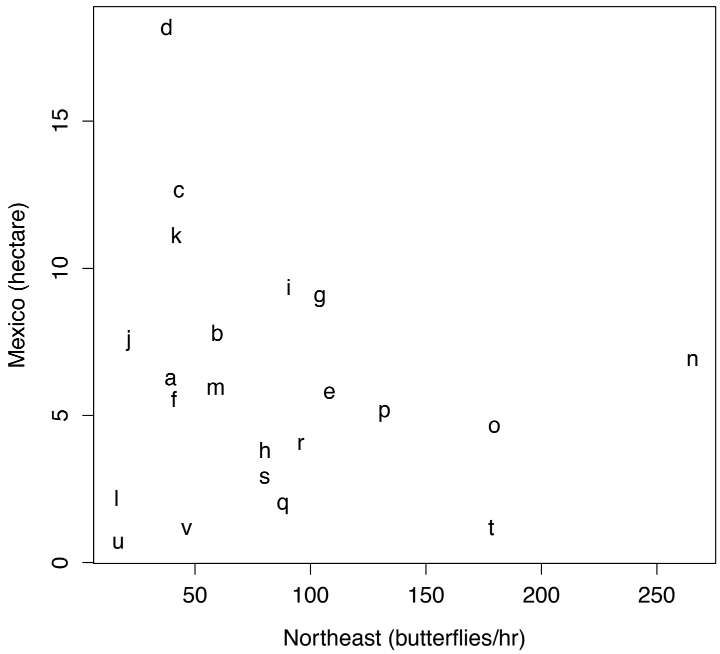
Forward and Backward model selection both lead to Model 7,

$$\text{Mexico} \sim \text{YEAR}$$

AIC favors the addition of Midwest (Model 5), but this term is not significant ($p = 0.19$). We had the same result with and without an outlier (1996: Midwest = 102.15, Mexico = 18.19; Studentized residual = 3.93). The model selection table reflects the analysis after the outlier was removed.

*Conclusion:* YEAR is an important predictor of the Mexican overwintering population, and neither Midwest nor the interaction shows statistical significance.

# 7 Northeast to Mexico




| | df | ΔAIC |
|---|---|---|
| Model1 | 5 | 3.63 |
| Model2 | 4 | 7.93 |
| Model3 | 3 | 13.37 |
| Model4 | 3 | 6.75 |
| Model5 | 4 | 1.93 |
| Model6 | 4 | 1.64 |
| Model7 | 3 | 0.00 |

| | **Model** | **AIC** | **Model comparison** | | |
|---|---|---|---|---|---|
| Backward | | | Northeast | YEAR | Northeast*YEAR |
| 1 | Northeast + YEAR + Northeast*YEAR | 56.05 | AIC=54.06, p=0.91 | **AIC=60.35, p=0.03** | AIC=54.35, p=0.62 |
| 6 | YEAR + Northeast*YEAR | 54.06 | | **AIC=59.16, p=0.01** | AIC=52.42, p=0.58 |
| 7 | ***YEAR*** | 52.42 | | **AIC=64.26, p<0.001** | |
| Forward | | | | | |
| 7 | ***YEAR*** | 52.42 | AIC=54.35, p=0.81 | | AIC=54.06, p=0.58 |

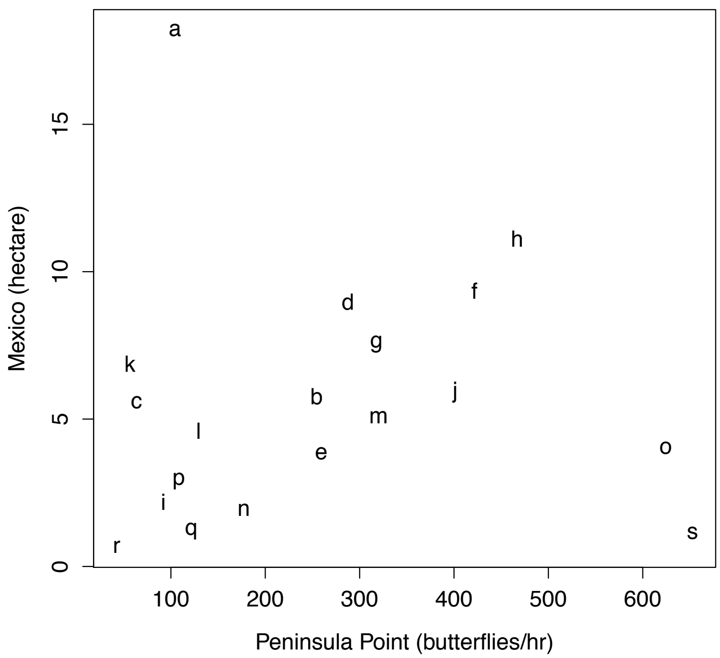
Forward selection, Backward selection, and AIC all lead to Model 7,

$$\text{Mexico} \sim \text{YEAR}$$

where YEAR is the only significant predictor ($p < 0.001$).

*Conclusion:* YEAR is an important predictor of the Mexican overwintering population, and neither Northeast nor the interaction shows statistical significance.

# 8 Peninsula Point to Mexico




| | df | ΔAIC |
|---|---|---|
| Model1 | 5 | 1.49 |
| Model2 | 4 | 0.00 |
| Model3 | 3 | 16.48 |
| Model4 | 3 | 9.55 |
| Model5 | 4 | 5.06 |
| Model6 | 4 | 8.29 |
| Model7 | 3 | 6.70 |

| | **Model** | **AIC** | **Model comparison** | | |
|---|---|---|---|---|---|
| Backward | | | Peninsula Point | YEAR | Peninsula Point*YEAR |
| 1 | Pen Point + YEAR + Pen Point*YEAR | 26.63 | **AIC=33.43, p=0.01** | AIC=25.14, p=0.54 | **AIC=30.20, p=0.04** |
| 2 | ***Pen Point + Pen Point*YEAR*** | 25.14 | **AIC=34.69, p<0.01** | | **AIC=41.62, p<0.001** |
| Forward | | | | | |
| 3 | Pen Point | 41.62 | | **AIC=30.2, p<0.001** | **AIC=25.14, p<0.001** |
| 2 | ***Pen Point + Pen Point*YEAR*** | 25.14 | | AIC=26.63, p=0.54 | |

With an outlier included, Forward selection, Backward selection, and AIC all lead to Model 7,

$$\text{Mexico} \sim \text{ YEAR}$$

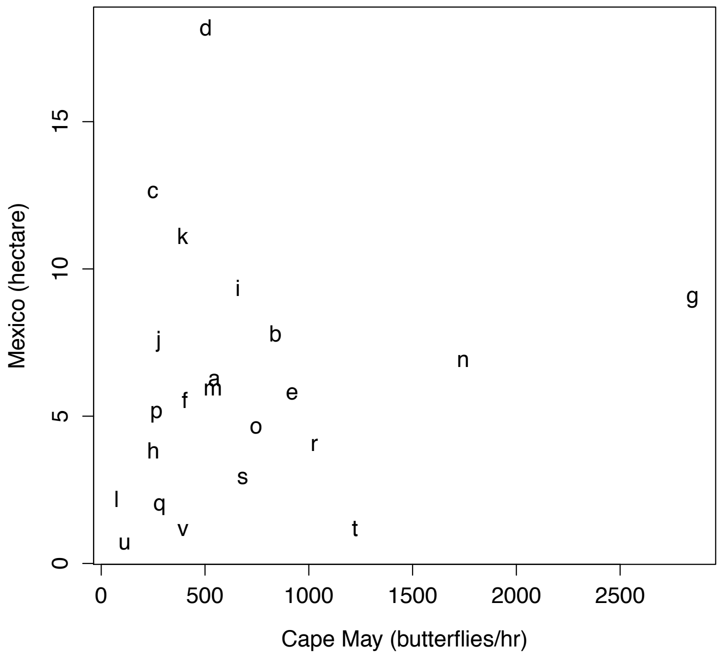
However when an outlier (1996: Peninsula Point = 104.4, Mexico = 18.19; Studentized residual = 4.41) is removed, Forward selection, Backward selection, and AIC all lead to Model 2,

$$\text{Mexico} \sim \text{Pen Point} + \text{Pen Point*YEAR}$$

with a negative coefficient for the interaction term ($p<$ 0.001) and significant donor region ($p<$ 0.01). The model selection table reflects the analysis after the outlier was removed.

*Conclusion:* With an outlier remove, Peninsula Point predicts Mexico and the relationship changes over time (i.e. the slope decreases over time). This effect cannot be explained by declining milkweed.

## 9 Cape May to Mexico




| | df | ΔAIC |
|---|---|---|
| Model1 | 5 | 3.34 |
| Model2 | 4 | 9.35 |
| Model3 | 3 | 13.50 |
| Model4 | 3 | 7.35 |
| Model5 | 4 | 1.75 |
| Model6 | 4 | 1.81 |
| Model7 | 3 | 0.00 |

| | **Model** | **AIC** | **Model comparison** | | |
|---|---|---|---|---|---|
| Backward | | | Cape May | YEAR | Cape May*YEAR |
| 1 | Cape May + YEAR + Cape May*YEAR | 55.76 | AIC=54.23, p=0.54 | **AIC=61.76, p=0.01** | AIC=54.17, p=0.57 |
| 5 | Cape May + YEAR | 54.17 | AIC=52.42, p=0.65 | **AIC=65.92, p<0.001** | |
| 7 | ***YEAR*** | 52.42 | | **AIC=64.26, p<0.001** | |
| Forward | | | | | |
| 7 | ***YEAR*** | 52.42 | AIC=54.17, p=0.65 | | AIC=54.23, p=0.69 |

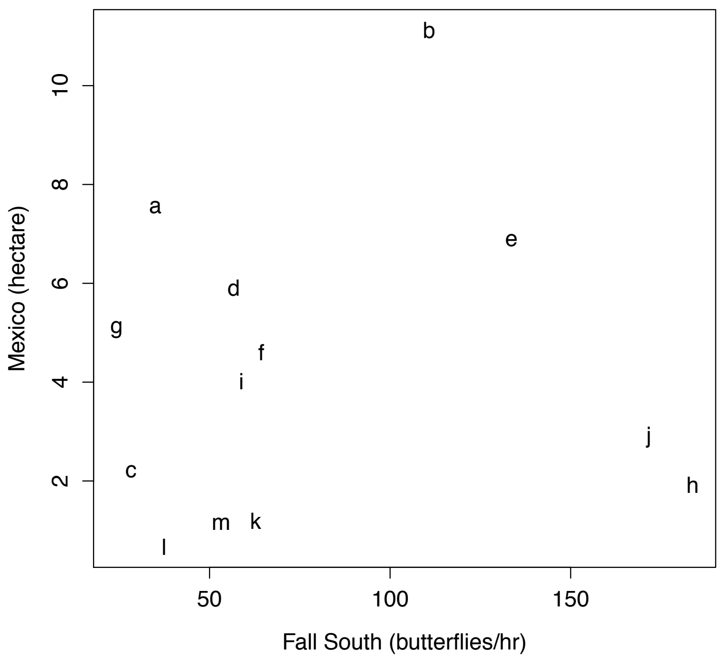
Forward selection, Backward selection, and AIC all lead to Model 7,

$$\text{Mexico} \sim \text{YEAR}$$

where YEAR is the only significant predictor ($\mathbf{p} < 0.001$).

*Conclusion*: YEAR is an important predictor of the Mexican overwintering population, and neither Cape May nor the interaction shows statistical significance.

## 10 Fall South to Mexico




| | df | Δ AIC |
|---|---|---|
| Model1 | 5 | 1.55 |
| Model2 | 4 | 0.00 |
| Model3 | 3 | 16.90 |
| Model4 | 3 | 0.58 |
| Model5 | 4 | 5.83 |
| Model6 | 4 | 1.91 |
| Model7 | 3 | 4.48 |

| | **Model** | **AIC** | **Model comparison** | | |
|---|---|---|---|---|---|
| Backward | | | Fall South | YEAR | Fall South*YEAR |
| 1 | Fall South + YEAR + Fall South*YEAR | 16.56 | AIC=16.92, p=0.21 | AIC=15.01, p=0.59 | **AIC=20.84, p<0.05** |
| 2 | Fall South + Fall South*YEAR | 15.01 | AIC=15.59, p=0.17 | | **AIC=31.90, p<0.001** |
| 4 | ***Fall South*YEAR*** | 15.59 | | | **AIC=29.99, p<0.001** |
| Forward | | | | | |
| 7 | YEAR | 19.49 | AIC=20.84, p=0.49 | | AIC=16.92, p=0.07 |
| 6 | ***YEAR + Fall South*YEAR*** | 16.92 | AIC=16.56, p=0.21 | | |

AIC leads to Model2, but backward selection shows that Fall South is not significant under the $F$-test. Forward selection shows that the interaction term is marginally significant even when YEAR is included in the model. Taken together, we infer that

$$\text{Mexico} \sim \text{Fall South*YEAR}$$

is the best model.

*Conclusion:* Interaction term is an important predictor of the Mexican overwintering population, and neither Fall South nor YEAR shows statistical significance.

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