Appendix A

Species Listing PROPOSAL Form:

Listing Endangered, Threatened, and Special Concern Species in Massachusetts

Scientific name: *Satyrium acadica*

Current Listed Status (if any): None

Common name: Acadian Hairstreak

Proposed Action:

__X__ Add the species, with the status of: Threatened

_____ Remove the species

_____ Change the species' status to: _____

Change the scientific name to: _____

Change the common name to: _____

(Please justify proposed name change.)

Proponent's Name and Address:

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Association, Institution or Business represented by proponent: Massachusetts Division of Fisheries & Wildlife

Proponent's Signature: Garry Kessler, Michael W. Nelson Date Submitted: March 1, 2023

Please submit to: Natural Heritage & Endangered Species Program, Massachusetts Division of Fisheries & Wildlife, 1 Rabbit Hill Road, Westborough, MA 01581

Justification

Justify the proposed change in legal status of the species by addressing each of the criteria below, as listed in the Massachusetts Endangered Species Act (MGL c. 131A) and its implementing regulations (321 CMR 10.00), and provide literature citations or other documentation wherever possible. Expand onto additional pages as needed but make sure you address all of the questions below. The burden of proof is on the proponent for a listing, delisting, or status change.

(1) Taxonomic status. Is the species a valid taxonomic entity? Please cite scientific literature.

- Acadian Hairstreak (*Satyrium acadica*) is a valid taxonomic entity (Glassberg 2017, p. 90), (Cech and Tudor 2005, p.108), (Brock and Kaufman 2003, pp. 98-99).

(2) Recentness of records. How recently has the species been conclusively documented within Massachusetts?

- Listed here are all the observation records from the last two years.

  6/29/22 - Williamstown, 4 individuals, Kessler
  7/3/22 - Joint Base Cape Cod, 5 individuals, Kessler, et al.
  7/6/22 - Williamstown, 3 individuals, Rosenstein

  6/28/21 - Joint Base Cape Cod, 3 individuals, Trimble
  7/5/21 - Joint Base Cape Cod, 2 individuals, Kessler, Trimble
  7/10/21 - Joint Base Cape Cod, 4 individuals, Kessler, Trimble, et al.
  7/20/21 - Williamstown, 1 individual, Zaremba

(3) Native species status. Is the species indigenous to Massachusetts?

- Yes (Stichter 2014).

(4) Habitat in Massachusetts. Is a population of the species supported by habitat within the state of Massachusetts?

- Yes (Stichter 2014).
- See 2021 and 2022 records listed above under (2) Recentness of records.

(5) Federal Endangered Species Act status. Is the species listed under the federal Endangered Species Act? If so, what is its federal status (Endangered or Threatened)

- No, *S. acadica* is not listed under the federal Endangered Species Act.

(6) Rarity and geographic distribution.

(a) Does the species have a small number of occurrences (populations) and/or small size of populations in the state? Are there potentially undocumented occurrences in the state, and if so, is it possible to estimate the potential number of undocumented occurrences?

- The species is currently known from only 2 occurrences in the state, one in Williamstown and one on Joint Base Cape Cod. Both occurrences are currently estimated to be small with observations of less than 10 individuals per visit.

  There could be undocumented populations in the state. Potential habitat containing host plants (native willow, *Salix* spp.) is common. However, suitable habitat must also include nearby nectar sources. Acadian Hairstreak is also reported to be ant-attended, which may limit otherwise suitable habitat (Cech and Tudor 2005, p.108).

  In the past two years (2021-2022) Garry Kessler and volunteers from the Massachusetts Butterfly Club surveyed sites either known to have had Acadian Hairstreaks in the past, or with high potential for Acadian Hairstreaks based on the habitat. Surveys were conducted in over 40 towns across the state. These surveys documented occurrences (populations) at only two locations out of all the locations surveyed. Searches of numerous locations with potential habitat and "historical" populations failed to document (or re-document) this species. See "Massachusetts Butterfly Club Acadian hairstreak survey records, 2021 - 2022," attached below after the Comments section.

(b) What is the extent of the species' entire geographic range, and where within this range are Massachusetts populations (center or edge of range, or peripherally isolated)? Is the species a state or regional endemic?

- *S. acadica* is a northern species ranging from British Columbia east to Nova Scotia; south to Idaho, Colorado, the upper Midwest, Maryland, and New Jersey (Lotts & Naberhaus 2021).

The species is not a state or regional endemic.

Massachusetts is near the southeastern edge of its range. Declines have been reported to our south in northern New Jersey as well as Connecticut (Stichter 2014). In Pennsylvania and Rhode Island, it is ranked S2S3 or "imperiled" (NatureServe 2022). In Massachusetts the current NatureServe rank is S4 and should be updated.

(7) <u>Trends.</u>

(c) Is the species decreasing (or increasing) in state distribution, number of occurrences, and/or population size? What is the reproductive status of populations? Is reproductive capacity naturally low? Has any long-term trend in these factors been documented?

- The species is decreasing in state distribution / number of occurrences (Stichter 2014).

Of the 41 towns "historically" hosting Acadian Hairstreaks referenced by Stitcher (2014), only two currently known occurrences remain, Joint Base Cape Cod (JBCC) and Williamstown. Based on the loss of occurrences throughout the state, Acadian hairstreak is declining in Massachusetts. For the remaining two occurrences, it is difficult to estimate trends (Breed et al. 2012). The observed numbers have been small, less than 5 per survey for Williamstown and a maximum of 43 in 2011 for JBCC, but typically less than 10 individuals per survey.

The data series for JBCC:

7/3/22 – 5 individuals
7/10/21 – 4 individuals
7/5/21 – 2 individuals
6/28/21 – 3 individuals
7/4/20 – 0 individuals
7/17/19 – 2 individuals
7/26/17 – 4 individuals
7/3/16 – 10 individuals
7/8/14 – 6 individuals
2011 – 43 individuals
7/17/10 – 3 individuals
7/15/10 – 3 individuals

Williamstown:

7/6/22 – 3 individuals
6/29/22 – 4 individuals
7/20/21 – 1 individual
7/23/16 – 1 individual
2012 – 1 individual
7/3/99 – 1 individual
7/2/98 – 1 individual

(8) <u>Threats and vulnerability.</u>

(d) What factors are driving a decreasing trend, or threatening reproductive status in the state? Please identify and describe any of the following threats, if present: habitat loss or degradation; predators, parasites, or competitors; species-targeted taking of individual organisms or disruption of breeding activity.

- The following factors have been observed at various "historical" sites and appear to have contributed to possible extirpation at those sites.

    1) Animal browse of willow, especially by deer, moose, or rabbit. Willow browse was observed at the small Mason Gravel pit reclamation site in Princeton. Animal browse of New Jersey Tea (*Ceanothus americanus*), a high value nectar source, has also been observed at Horn Pond Mountain in Woburn.

    2) Detrimental clearing of willow under powerlines or in wet meadows as part of routine maintenance to keep fields open. Clearing under powerlines probably contributed to the apparent extirpation at Horn Pond Mountain in Woburn. Changes to the mowing regime probably contributed to the apparent extirpation at the Pittsfield site ("site-p1" in the attached data).

    3) Development eliminated sites at the South Weymouth Naval Air Station (condominiums) and Dauphinais Park in Grafton (solar farm).

    4) Of the two remaining known occurrences, the most significant threat at the Williamstown site is illicit collecting due to the small size of the population. The site is protected by a conservation organization and the meadow is managed so as to mow only sections of the field in a given year. Ecology staff is aware of the butterfly and its current status in Massachusetts and at this site.

    5) The known occurrence at Joint Base Cape Cod is under a powerline and therefore subject to periodic vegetation clearing. The Natural Resources manager for the Base is aware of the occurrence of the butterfly and its status in Massachusetts and on the Base. State listing would give the population additional MESA protection at this site.

    6) Climate change is a long-term threat to northern butterfly species such as the Acadian Hairstreak and it does appear that this species is declining in the southern portion of its range (Breed et. al. 2012). While climate change may be a contributing factor to the decline of Acadian hairstreak in Massachusetts, there are other documented threats that have compounded this decline.

    7) Invasive species are also a concern. It is not known if Gray Willow (*Salix cinerea*), an introduced, invasive species, is a larval host plant for the butterfly. Gray Willow is not present at the Williamstown site. More work is needed at the Joint Base Cape Cod to determine if Gray Willow is a threat there.

    8) Russian-olive (*Elaeagnus angustifolia*) is a threat at the Williamstown site, but it is being controlled. Russian-olive also threatened the Dauphinais site in Grafton before the solar array eradicated habitat at the site.

(e) Does the species have highly specialized habitat, resource needs, or other ecological requirements? Is dispersal ability poor?

- Acadian Hairstreak is a wet meadow specialist, often in a riparian setting, and is dependent upon native willows for reproduction. Nearby nectar sources for adults are also required. Milkweed (*Asclepias* spp.) and New Jersey Tea (*Ceanothus americanus*) are particularly valued. The butterfly does not usually fly far from its host plants and populations are usually localized.

  Acadian Hairstreak has been reported to be ant-attended (Cech and Tudor 2005). Specifics of this relationship require additional research.

Conservation goals.

What specific conservation goals should be met in order to change the conservation status or to remove the species from the state list? Please address goals for any or all of the following:

(a) State distribution, number of occurrences (populations), population levels, and/or reproductive rates

- Currently the Acadian Hairstreak is only known from one occurrence in the southeastern part of the state and a second occurrence in the northwest corner of the state. The butterfly was once found throughout most of the state, though localized to areas of suitable habitat.

  Reintroduction of the butterfly to sites from which it has disappeared should be considered. However, because the butterfly is ant-attended the best candidates for this are the most recently occupied sites.

  The Pittsfield site (site-p1) is private property and discussion with the property owner, who is sympathetic to the butterfly, would be required.

  Reintroduction at Horn Pond Mountain, Woburn is possible. However, willow and New Jersey Tea under the powerline would need to be protected.

(b) Amount of protected habitat and/or number of protected occurrences

- Potential for purchase and protection of additional lands, such as the Pittsfield site (site-p1) could be investigated.

(c) Management of protected habitat and/or occurrences

- There are currently two known occurrences in Massachusetts. Both are known to the property managers and management practices on both properties are conducted so as to preserve the Acadian Hairstreak populations and their habitat. At the Williamstown site future management includes as a goal enhancement of the Acadian Hairstreak population at that site.

  At both sites the primary management activity is to explicitly maintain native willow and nearby nectar sources. At the Williamstown site there is an invasive control plan along the periphery of the habitat to exclude Russian-olive.

  At both sites there is periodic clearing of woody species, including willow. This should be done so as to clear only a portion of the willow in any given year, so that a portion remains untouched in that year. The untouched portion of the willow may be cut in a subsequent year.

Literature cited, additional documentation, and comments.

Breed, G.A., S. Stichter, and E.E. Crone. 2012. Climate-driven changes in northeastern US butterfly communities. *Nature Climate Change* 3, 142-145.
(attached below Comments section)

Brock, J.P., and K. Kaufman. 2003. *Butterflies of North America*. Houghton Mifflin, New York, New York. 383 pp.

Cech R., and G. Tudor. 2005. *Butterflies of the East Coast*. Princeton University Press, Princeton, New Jersey. 345 pp.

Glassberg, J. 2017. *A Swift Guide to Butterflies of North America*. Princeton University Press, Princeton, New Jersey. 420 pp.

Lotts, K., and T. Naberhaus, coordinators. 2021. Butterflies and Moths of North America. https://www.butterfliesandmoths.org/species/Satyrium-acadica (Version 09/07/2022).

Stichter, S. 2014. The Butterflies of Massachusetts https://www.butterfliesofmassachusetts.net/acadian%20hairstreak.htm (Version 11/12/2014). (attached below Comments section)

Additional Documentation:

Massachusetts Butterfly Club records for Acadian Hairstreak 1991 – 2019
(attached below Comments section)

Massachusetts Butterfly Club Acadian Hairstreak survey records, 2021 – 2022
(attached below Comments section)

Comments:

- Garry Kessler has been observing nature and butterflies for more than 50 years. He has contributed to various organizations and publications including:

  Memberships:

  Massachusetts Butterfly Club, Acadian Hairstreak Survey, Lead Investigator
  National Butterfly Association, member
  Westborough Conservation Commission, 2011 –
  Westborough Community Land Trust, past President
  Open Space Committee of Westborough, past chairman

  Contributor:

  deMaynadier, P.R. Butler, and H. Wilson. 2015. Maine Butterfly Survey (2006-2015). https://mbs.umf.maine.edu/.

  Kricher, J. 2020. *Peterson Reference Guide to Bird Behavior*. Mariner Books, Boston, Massachusetts. 360 pp.

  Nature Notes series, Westborough News and later Westborough Community Advocate, 2004-2022.

  Shumway, S.W. 2008. *Naturalist's Guide to the Atlantic Seashore*. Globe Pequot Press, Guilford, Connecticut. 240 pp.

Acadian Survey effort: 2021

6/23/21 - Went to Hanover and Pembroke to check hairstreak habitats today. No habitat left...what a shame. Cassie
6/26/21 - East Branch Ware R., Rte 62 / Wheeler Rd., Princeton, mostly cloudy, 80 degrees, Found small patch of black willow. Heavily browsed. S.Cloudywing, ETB, Ringlet, Kessler
6/26/21 - Moose Hill Farm, Sharon, 2 hours, 10 species of butterflies but no hairstreaks...yet. Cassie
6/28/21 - Looked at Adams Farm, Walpole and the traditional Milford powerline.....nice and warm, lots of flowers, no hairstreaks. Cassie
6/28/21 - northern part of Camp Edwards Sandwich, and found 3 Acadian Hairstreaks. Trimble
x/xx/21 - Dauphinais Park, Grafton, (overgrown and no longer active, Price)
6/30/21 - Horn Pond Mtn. Woburn, no acadian hairstreaks, Rosenstein
7/1/21 - Warren Woods, powerline by High School, below dam Ashland SP, no habitat, Ashland, 77 degrees, mostly cloudy, Ashland, Kessler
7/4/21 - Holliston powerline, Fiske St., Whitney St., Washinton St (Sherborn), didn't find habitat, 4 wood nymph, mostly sunny, mid-60 after rain, Kessler
7/5/21 - Williams Land, Harvard, 11:00am-1:25pm. 73 degrees, partly cloudy, no hairstreaks, Newton
7/5/21 - North Worcester County / Wachusett, no hairstreak, Cassie
7/5/21 - Noquochoke, Dartmouth, lots of striped hairstreak, no Acadian, Griffith
7/5/21 - JBCC, 2 Acadian hairstreak, Gibbs Rd., 71 - 74, mostly overcast, Kessler
7/6/21 - Noquochoke, Dartmouth, striped hairstreak, coral hairstreak, no Acadian, sunny, low 90s, Newton, Kessler
7/6/21 - ~200 New Plainville Rd., New Bedford, mtn. mint almost in bloom, no butterflies, mostly overgrown w/Autumn Olive, sunny, low 90s, Newton, Kessler
7/6/21 - Arlington Great Meadow, Lexington. via Sheila Road, sunny, 84, 2-3PM, Edwards, Coral, no Acadian, Rosenstein, Mosco
7/7/21 - 2.5 hours at Adams Farm, Walpole this morning, lots of nectar, no hairstreaks, Cassie
7/7/21 - Martin Burns, Newburyport, 1 gray hairstreak, no acadians, 85-90+, humid, Zaremba
7/x/21 - Pittsfield, site-p1, no hairstreaks, week of 7/1, Anonymous
7/10/21 - JBCC, 4 Acadian, Range Golf, 2 Oak hairstreaks, 70-73, solid overcast, 20 species overall, Group: Haugh, Mosco, Newton, Zaremba, Griffith, Kessler, McCumber, Trimble
7/10/21 - Williamstown, site-w1, 11:15 until 2:45 under full sun, no Acadians, Callahan
7/11/21 - Weymouth, Old Naval Air Station, south of Delahunt Pkwy, great habitat, lots of nectar and willow, wet, boots, sun and clouds, no acadians, 1 gray hairstreak, Kessler
7/11/21 - Milford, Hopedale, 25 species, no hairstreak, Cassie
7/14/21 - 278 Salem St., Wilmington, RR tracks north to RR intersection, good nectar, 1 summer azure, no hairstreak, overcast, 70s, Kessler
7/14/21 - Horn Pond Mtn, NJ tea in bloom at bottom of hill, 4 Juniper hairstreak up top, no other hairstreak, 80, overcast, Kessler,
7/11/21 - Pittsfield, site-p1, 2 locations, visited on 2 days, know locations 2-3 years prior, no Acadians, Hurley, +3 others, 2nd visit
7/15/21 - Hop Brook, Fernside Rd., Lee, 1 Baltimore checkerspot, no hairstreaks, limited nectar, wet, lots of willow, mid-70s, sunny, Kessler
7/15/21 - Schenob Brook Fen, S Undermountain Rd., Sheffield, lots of nectar and butterflies, no hairstreaks, will and shrubby cinquefoil wetland, 80s, sunny, Kessler
7/15/21 - Crane Mngmt Area, Falmouth, some willow, lots of gray, edwards, banded hairstreak, no Acadian, Griffith,
7/15/21 - Fannie Stebbins and Bark Haul Road, Longmeadow, mid-80s, hazy sun, gentle breezes, no hairstreak, Coleman,

7/16/21 - Cassie, summary, spots checked or rechecked, no acadian hairstreak found at any location
Hanover, Rte. 53
Sharon, Moose Hill Farm and power line……two times

Milford, traditional powerline….two times
Lamson Road fields, Foxboro….several times
Blackstone Valley 4JBC….Hopedale and Milford
No. Worcester Co. 4JBC…..Clinton, etc. (new spots)
Adams Farm, Walpole…..three times (new spot)

7/16/21 - Horn Pond Mtn., Woburn, 1 Gray hairstreak, 1 Coral hairstreak, 3 Juniper hairstreak, 1 Viceroy, no Acadian hairstreak, 90, sunny, humid, Kessler
7/16/21 - Pittsfield, site-p2, and Canoe Meadows Pittsfield, no acadian hairstreak, in either locaction, Callahan

7/16/21 - Oct. Mtn. and Williamstown: 21 species, no acadians, sunny, 70s-80s, Callahan
7/18/21 - Blackstone Corridor Count, Warren Brook, Upton, no acadian since 2008, Dodd
7/20/21 - 113 Mechanic St, Upton, powerline, too flooded for me, unable to check the area, Kessler
7/20/21 - Fessenden Fields, powerline, Sherborn, parking are closed, unable to check the area, Kessler
7/20/21 - Barber Res., fields and powerline, some willow, sunny, 85+, little activity, no acadian, Kessler
Note: Barber Res., Sherborn, area previously checked by Newton, 1st week of July, no acadian.
7/20/21 - Savoy Mtn., Savoy, no acadians, 1 coral HS, 80s, sunny, Callahan
7/20/21 - Barber Res., Sherborn, powerline south, no acadians, 85+, sunny, Rosenstein
7/6/21 - Barber Res., Sherborn, powerline south, no acadians, 85+, sunny, Rosenstein
7/10/21 - Wilbraham Power Lines, off Tinkham Road, across the street from Fountain Park, no acadians, Partly cloudy, 73, very humid, Desmarais
7/18/21 - Bruuer Pond, Wilbraham, no acadians, Cloudy, 85, very humid, Desmarais
7/20/21 - Williamstown, site-w1, sunny, 80s, 1 worn Acadian hairstreak, Zaremba
7/21/21 - October Mtn, 80s, sunny, no acadian, Zaremba
7/22/21 - October Mtn, 70s, sunny, no acadian, Kessler
7/22/21 - Pittsfield, site-p1, 70s, sunny, no acadian, Kessler
7/22/21 - Williamstown, site-w1, sunny, 70s, no Acadian hairstreak, Rosenstein
7/24/21 - Bruuer Pond, Wilbraham, no acadians, partly cloudy, 80, very humid, good nectar and willow, Desmarais
7/27/21 - Salvation Army Thrift Store Parking lot, 310 Russell St, Hadley, no acadians, sunny, 85, very humid, good nectar and willow, Desmarais

Acadian Survey effort: 2022

6/22/22 - Arlington's Great Meadows - Edwards HS, no Acadian, looked in the historic spot - Mosco
6/24/22 - Sherborn powerline from Fessenden Field to Brook St. including the Dopping Brook marsh. Sunny 70s. Did not find Acadian habitat - Kessler
6/24/22 - Upton, Mechanic St., Willow Brook, sunny 70s, looked at the historic site, good habitat, swamp milkweed not in bloom, maybe next week - worth another look, Kessler
6/26/22 - Sherborn powerline from Barber Reservation to Osprey tower. Sunny, mid 80s. Almost no willow, no butterflies - Kessler
6/28/22 - Rockland, South Weymouth Naval Air Station, sunny 70s, Looked like willow was cut late last year, 1 Baltimore checkerspot, no Acadian hairstreak - Kessler
6/29/22 - Pittsfield, Canoe Meadow, sunny 70s, willow did not look eaten, no Acadians - Kessler
6/29/22 - Pittsfield, site-p3, sun and clouds 70s, didn't see willow, lots of milkweed, no Acadians - Kessler
6/29/22 - Williamstown, site-w1, sun and clouds 70s, willow and milkweed, 4 Acadians - Kessler
6/29/22 - Dalton, Legion Pond, sunny 70s, willow, no Acadians - Kessler
6/29/22 - Pittsfield, site-p2, sunny and clouds 70s, willow and milkweed, no Acadians - Kessler
6/29/22 - Pittsfield, site-p1, sunny 70s, willow and some milkweed, no Acadians - Kessler
6/30/22 - Upton, Mechanic St., Willow Brook, sunny high 70s, looked at the historic site, good habitat, some swamp milkweed starting to bloom, no Acadians - Kessler
7/3/22 - JBCC, overcast changing to sunny 70s-80s, 5 Acadians - McCumber, Newton, Griffith, Mosco, Zaremba, Kessler
7/3/22 - Woburn, Horn Pond Mtn, no Acadians, only hairstreak seen: 1 coral hs, lots of clearing etc. by power company - Hoople, et.al.
7/4/22 - Upton, Mechanic St., Willow Brook, sunny high 70s, looked at the historic site, good habitat, 65% of the swamp milkweed in bloom, no Acadians - Kessler
7/6/22 - Windsor, Moran Wildlife Mgmt Area, low 70s, light breeze, clouds and sun, lots of willow, little milkweed nearby, no Acadian hairstreaks, the site is not known to have had Acadian hairstreaks - Kessler
7/6/22 - Williamstown, site-w1, sun and clouds 70s, 3 Acadians - Rosenstein
7/7/22 - Woburn, Horn Pond Mtn, sunny hi-70s to 80, no Acadians, very few hairstreaks at all, where are all the Edward's hairstreak - Murray
7/x/22 - Dalton, Legion Pond, no Acadians - Hurley

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Massachusetts Butterfly Club records for Acadian hairstreak (*Satyrium acadica*) 1991-2019

Note: there were no sighting reports for *S. acadica* in 2020.

date	qty	location
22-Jun-91	1	WORCESTER
14-Jul-91	1	WORCESTER
03-Jul-92	1	WORCESTER
11-Jul-92	3	WALPOLE
18-Jul-92	1	WORCESTER
19-Jul-92	1	WORCESTER
26-Jul-92	1	WORCESTER
02-Aug-92	1	WORCESTER
05-Jul-93	2	STERLING
05-Jul-93	2	WORCESTER
11-Jul-93	5	WALPOLE
25-Jul-93	1	WORCESTER
02-Jul-94	1	HOLLISTON
02-Jul-94	7	EASTON
02-Jul-94	1	WORCESTER
04-Jul-94	3	STERLING
04-Jul-94	6	WORCESTER
13-Jul-94	5	SAVOY
22-Jul-94	1	SAVOY
22-Jul-94	1	FLORIDA
30-Jun-95	1	SHERBORN
01-Jul-95	2	HAMPDEN
08-Jul-95	1	CONCORD
09-Jul-95	6	ZNC FOXBORO
12-Jul-95	11	ZNC NORTHERN BERKSHIRE
15-Jul-95	4	ZNC LOWER PIONEER
15-Jul-95	2	NORTHBOROUGH
15-Jul-95	2	WEST BOYLSTON
16-Jul-95	1	ZNC CENTRAL BERKSHIRE
16-Jul-95	14	ZNC BRISTOL
21-Jul-95	1	ZNC SOUTHERN BERKSHIRE
27-Jul-95	2	SAVOY
29-Jun-96	1	ZT CLINTON/STERLING
08-Jul-96	2	BOSTON
20-Jul-96	1	ZT CLINTON/STERLING
06-Jul-97	1	LEXINGTON GREAT MEADOWS
19-Jul-97	3	TAUNTON

21-Jun-98	1	GRAFTON
28-Jun-98	1	FRAMINGHAM
02-Jul-98	1	WILLIAMSTOWN
10-Jul-98	1	HOLLISTON
12-Jul-98	1	ZNC NORTHERN WORCESTER
12-Jul-98	1	LEXINGTON
12-Jul-98	1	PITTSFIELD
15-Jul-98	1	SAVOY
03-Jul-99	1	WILLIAMSTOWN SITE-W1
03-Jul-99	7	ZNC FOXBORO
04-Jul-99	2	GRAFTON DAUPHINAIS PARK
04-Jul-99	1	NORTHBRIDGE
05-Jul-99	1	ZT CLINTON/STERLING
05-Jul-99	3	WEST BOYLSTON
08-Jul-99	1	UXBRIDGE
11-Jul-99	5	ZNC NORTHERN WORCESTER
24-Jul-99	2	PITTSFIELD
24-Jul-99	2	ZNC CENTRAL BERKSHIRE
05-Jul-00	2	WOBURN
13-Jul-00	1	NORTHAMPTON FLORENCE
04-Jul-01	4	MILFORD
04-Jul-01	5	MILFORD PL
22-Jul-01	6	PITTSFIELD
03-Jul-02	1	WOBURN HORN POND MOUNTAIN
13-Jul-02	1	WOBURN HORN POND MOUNTAIN
13-Jul-02	2	BLACKSTONE
21-Jul-02	19	PITTSFIELD
09-Jul-03	1	WEYMOUTH NAVAL AIR STATION
12-Jul-03	4	ZNC BLACKSTONE VALLEY
12-Jul-03	1	ZNC SOUTHERN BERKSHIRE
15-Jul-03	1	SHREWSBURY PL
20-Jul-03	34	PITTSFIELD
20-Jul-03	35	ZNC CENTRAL BERKSHIRE
27-Jun-04	6	WOBURN HORN POND MOUNTAIN
28-Jun-04	4	WOBURN HORN POND MOUNTAIN
30-Jun-04	5	WOBURN HORN POND MOUNTAIN
01-Jul-04	16	WOBURN HORN POND MOUNTAIN
02-Jul-04	8	WOBURN HORN POND MOUNTAIN
09-Jul-04	103	PITTSFIELD
11-Jul-04	1	ZNC NORTHERN BERKSHIRE
11-Jul-04	1	ZT MOUNT GREYLOCK

18-Jul-04	55	ZNC CENTRAL BERKSHIRE
10-Jul-05	1	ZT MOUNT GREYLOCK
12-Jul-05	2	WOBURN HORN POND MOUNTAIN
12-Jul-05	3	GRAFTON DAUPHINAIS PARK
12-Jul-05	7	ZNC SOUTHERN BERKSHIRE
15-Jul-05	5	WOBURN HORN POND MOUNTAIN
16-Jul-05	3	ZNC BLACKSTONE VALLEY
17-Jul-05	134	ZNC CENTRAL BERKSHIRE
19-Jul-05	12	ZNC BRISTOL
24-Jul-05	36	ZC BERKSHIRE
01-Jul-06	2	WOBURN HORN POND MOUNTAIN
08-Jul-06	3	WOBURN HORN POND MOUNTAIN
09-Jul-06	30	ZNC CENTRAL BERKSHIRE
11-Jul-06	1	ZNC SOUTHERN BERKSHIRE
16-Jul-06	30	ZNC CENTRAL BERKSHIRE
04-Jul-07	4	WOBURN HORN POND MOUNTAIN
06-Jul-07	5	ZNC SOUTHERN BERKSHIRE
08-Jul-07	1	ZNC NORTHERN BERKSHIRE
12-Jul-07	18	PITTSFIELD
15-Jul-07	53	ZNC CENTRAL BERKSHIRE
17-Jul-07	6	PITTSFIELD
04-Jul-08	8	PITTSFIELD
05-Jul-08	8	WOBURN HORN POND MOUNTAIN
06-Jul-08	1	ZNC NORTHERN WORCESTER
11-Jul-08	2	ZNC SOUTHERN BERKSHIRE
13-Jul-08	2	ZNC BLACKSTONE VALLEY
19-Jul-08	32	ZNC CENTRAL BERKSHIRE
03-Jul-09	2	WOBURN HORN POND MOUNTAIN
04-Jul-09	10	WOBURN HORN POND MOUNTAIN
05-Jul-09	1	PITTSFIELD
05-Jul-09	8	WOBURN HORN POND MOUNTAIN
10-Jul-09	3	WOBURN HORN POND MOUNTAIN
18-Jul-09	24	ZNC CENTRAL BERKSHIRE
21-Jun-10	1	WOBURN HORN POND MOUNTAIN
22-Jun-10	1	WOBURN HORN POND MOUNTAIN
25-Jun-10	1	WOBURN HORN POND MOUNTAIN
26-Jun-10	12	PITTSFIELD
26-Jun-10	3	WOBURN HORN POND MOUNTAIN
27-Jun-10	1	WOBURN HORN POND MOUNTAIN
17-Jul-10	12	ZNC CENTRAL BERKSHIRE
09-Jul-11	1	ZNC NORTHERN BERKSHIRE
09-Jul-11	1	CHESHIRE
16-Jul-11	12	ZNC CENTRAL BERKSHIRE

23-Jun-12	1	WOBURN HORN POND MOUNTAIN
23-Jun-12	1	WOBURN
23-Jun-12	1	CANTON GREAT BLUE HILL
24-Jun-12	24	PITTSFIELD
26-Jun-12	1	WOBURN HORN POND MOUNTAIN
02-Jul-12	3	WOBURN HORN POND MOUNTAIN
14-Jul-12	1	ZNC NORTHERN BERKSHIRE
21-Jul-12	1	ZNC CENTRAL BERKSHIRE
29-Jun-13	3	WOBURN HORN POND MOUNTAIN
29-Jun-13	11	PITTSFIELD
02-Jul-13	1	WOBURN HORN POND MOUNTAIN
20-Jul-13	14	ZNC CENTRAL BERKSHIRE
28-Jun-14	31	PITTSFIELD
19-Jul-14	18	ZC BERKSHIRE
19-Jul-14	20	ZNC CENTRAL BERKSHIRE
27-Jun-15	1	WOBURN HORN POND MOUNTAIN
02-Jul-15	1	ZC BERKSHIRE
05-Jul-15	6	MASHPEE
10-Jul-15	27	PITTSFIELD
18-Jul-15	47	PITTSFIELD
22-Jun-16	1	ZC BERKSHIRE
24-Jun-16	8	PITTSFIELD
07-Jul-16	2	WOBURN HORN POND MOUNTAIN
08-Jul-16	3	PRINCETON MOUNT WACHUSETTS
17-Jul-16	11	ZNC CENTRAL BERKSHIRE
23-Jul-16	1	ZNC BRISTOL
23-Jul-16	4	WILLIAMSTOWN SITE-W1
30-Jun-17	11	PITTSFIELD
13-Jul-17	1	HARVARD WILLIAMS LAND
15-Jul-17	19	ZNC CENTRAL BERKSHIRE
29-Jun-18	3	PITTSFIELD
01-Jul-18	13	ZC BERKSHIRE
04-Jul-18	1	PRINCETON MOUNT WACHUSETTS
07-Jul-18	1	PITTSFIELD
14-Jul-18	8	ZNC CENTRAL BERKSHIRE
04-Jul-19	1	ZC BERKSHIRE
13-Jul-19	3	ZNC CENTRAL BERKSHIRE

The Butterflies of Massachusetts

18 Acadian Hairstreak *Satyrium acadica* (W. H. Edwards, 1862)

Photo: Woburn, Massachusetts, H. Hoople 7-1-2011

The Acadian is a rather special hairstreak. Unlike our more common *Satyrium* hairstreaks, Coral, Edwards', Banded, and Striped, which are forest, forest-edge, or dry scrub dwellers, the Acadian is associated with shrubby willows in open wet meadows and streamsides. It was probably one of the earliest re-colonizers of New England during the post-glacial Pleistocene. Today it is a northerly species only, lacking the southeastern U.S. distribution shown by most of our other *Satyrium* hairstreaks (maps in Opler and Krizek 1984; Cech and Tudor 2005). A recent study suggests it is declining in Massachusetts due to climate change (Breed *et al*. 2012). Its notable decline further south, at its former southern limit in New Jersey (Gochfeld and Berger 1997: 149) may be due to climate warming as well as habitat loss.

Acadian Hairstreak was apparently not common, and perhaps even rare, at the turn of the century here, even though one might think it would have benefited from an

increase in willows during the agricultural era. Scudder cites hardly any New England locations for it, in contrast to the Banded, Striped, Edwards', and Coral Hairstreaks. He had specimens from only two Massachusetts areas, Williamstown and Cape Cod, which he himself had taken around thickets fringing streams (1889: 901). He did list it as "known to occur in Essex County" (Scudder 1872), but cites no specimens. T. W. Harris does not mention Acadian, nor did he have any specimens in his 1822-1850 collection (*Index*). In fact, there are no 19th century Massachusetts specimens in the Harvard Museum of Comparative Zoology. Maynard (1886) wrote that he had "two specimens of this rare species before me which were taken in the vicinity of Boston, but I have never met with it living, in fact it does not appear to be at all common anywhere."

Thirty years later, Farquhar (1934) adds only Amherst (C.S. Minot; specimen is at Boston Univ.) to Scudder's list of Massachusetts locations. Root and Farquhar (1948) list no specimens in their review of the Andover region, and Jones and Kimball (1943) do not list it for Martha's Vineyard or Nantucket.

Acadian Hairstreak may actually have become more common in the 1960's and 1970's, judging from specimen and Lepidoperists' Society records, although it may be simply that hitherto unknown colonies were discovered. Records begin the 1960's for both Berkshire and Middlesex counties. For the Berkshires there are five 1961 specimens from Mt. Greylock (no collector listed) at the Smithsonian. In 1962, S. A. Hessel found a colony in Egremont (MCZ 3 specimens; Yale 2 specimens); and O. R. Taylor found specimens in Richmond (Yale). There is also a 1971 specimen from Worthington (Smithsonian, no collector), and a 1976 specimen from Windsor (R. P. Webster, McGuire). In 1980 R. Wendell Sr. took specimens from a colony in Pittsfield, and in 1995 he found one in Adams.

In the southern Berkshires D. Wagner and others found Acadian Hairstreak at Sheffield's Schenob Brook Fen in 1993 and in Ashley Falls in 1996 (specimens at UConn), and there is a 1982 Sheffield specimen at Yale (D. S. Dodge). In the Connecticut River valley, Patrick Carey reported in 1975 that Acadian was "fairly common in fresh condition in a dry field near the CATY tower in South Hadley on June 30" (Lep Soc. Seas. Sum. and Corresp., 1965-1975). In addition, there are several 1985 specimens from Amherst, Amethyst Brook Cons. Area (P. Savage, R. P. Webster, McGuire).

For eastern Massachusetts the 1960 specimens begin with one from Acton, dated 1962 (Charles. G. Oliver, Yale); subsequently in 1965-66 Oliver collected about eleven Acadian Hairstreak specimens in Acton and west Acton (Yale), and two in Littleton (1966, McGuire; 1970, MCZ). Oliver listed Acadian in 1967 as one of three hairstreaks, the others being Banded and Striped, which were common in dry old fields on *Asclepias* in the Acton area (LSSS 1967). A bit further south, in Ashland, M. G. Douglas found four specimens in 1963 (McGuire), and W. D. Winter found at least one specimen in Westwood in 1969

(MCZ). Daryll Willis also reported Acadian Hairstreak in 1973 and 1974 in the Holliston-Sherborn-Framingham area, saying that he took 12 specimens in 1973 (LSSS 1973, 1974).

North of Boston in the 1970's, Robert Robbins found a colony of Acadian Hairstreak in Woburn, in the vicinity of Horn Pond Mountain. He took seven specimens in 1975 and 1976 (Smithsonian). And south of Boston, in the 1980's Mark Mello discovered a colony near New Bedford (earliest specimen 1984, Mello collection). This colony was monitored for several year through the Xerxes Counts; 11 were counted in 1987, 40 in 1989, and 16 in 1990 (see below for later reports).

Host Plants and Habitat

Acadian Hairstreak's larval hosts are many willows, including black willow (*nigra*), pussy willow (*Salix discolor*), silky willow (*Salix sericea*), and beaked willow (*Salix bebbiana*) (Scott 1986), all of which are native to, and found in, every county in Massachusetts (Dow Cullina *et al.*, 2011). The 1995-99 Connecticut Atlas found eggs or larvae on black willow in the wild in that state (O'Donnell *et al.* 2007).

These willows, especially black and pussy, are widespread in Massachusetts, so the scarcity of the butterfly today is somewhat surprising, and may have to do more with climate or some other aspect of habitat, such as the availability of nearby nectar sources or the presence of suitable ants. The butterfly is almost always associated with willow-bordered wetlands, such as wet meadows and streamsides, but may often be found on flowers at nearby, drier sites, such as a dry rocky hilltop in Woburn (see photo above). Nectar sources include milkweeds, dogbane, and New Jersey tea.

Relative Abundance Today

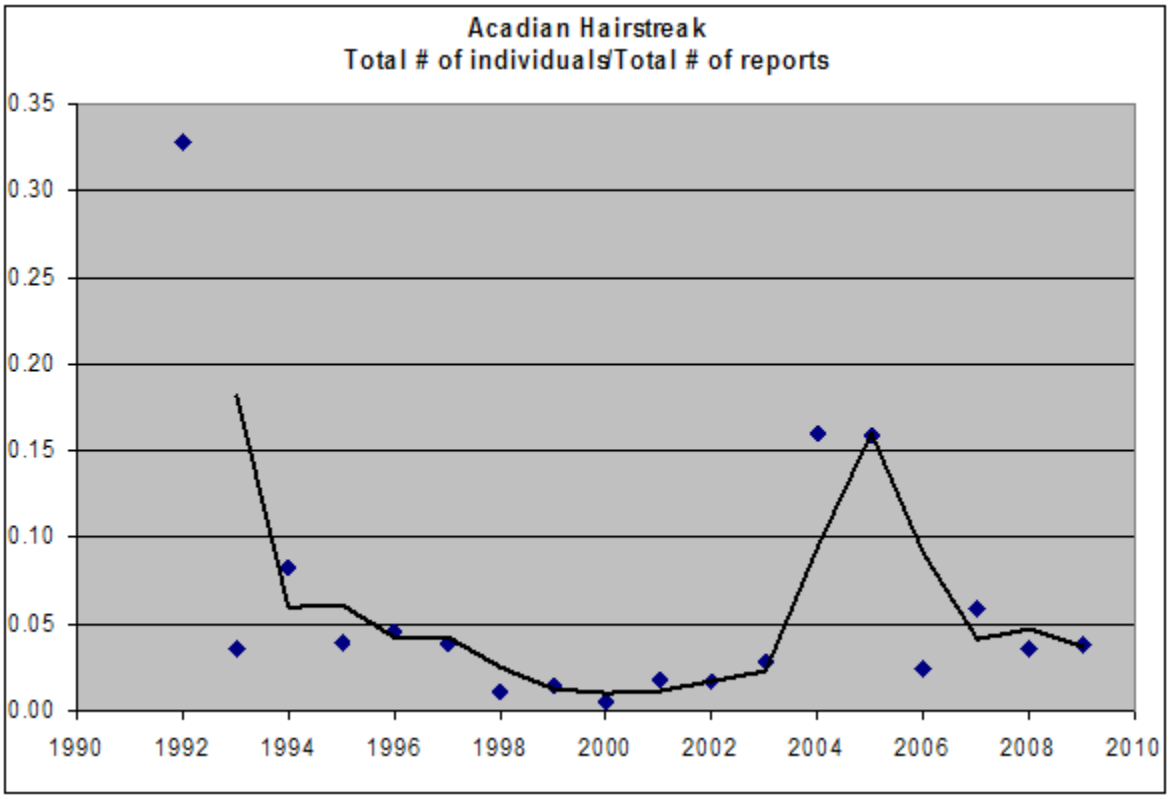
Both MBC and earlier Atlas records rank Acadian Hairstreak as Uncommon (Table 5). The Atlas found it in 30 out of 723 blocs searched.

Acadian Hairstreak may be declining in Massachusetts, or at least is subject to great population fluctuations at its few known locations. Chart 18 shows an overall decline between 1992 and 2009. This result depends greatly on the high index reading for 1992, which mainly reflects high counts at the two best-known colonies: New Bedford area (41) and Pittsfield (26). Then in succeeding years numbers at both colonies dropped, but showed a resurgence in 2004 and 2005.

A separate analysis of the same 1992-2010 MBC data, which used list-length rather than number of trips as a proxy for effort, and did not rely on counts of individual butterflies, found a statistically significant 82.5% decline over these years. In that study, Acadian Hairstreak had the second largest decline among all Massachusetts

species in detection probability. It, Aphrodite Fritillary and Atlantis Fritillary are the three species with the greatest declines. All are northern-based species (Breed *et al*., 2012).

Chart 18: MBC Sightings per Total Trip Reports 1992-2009

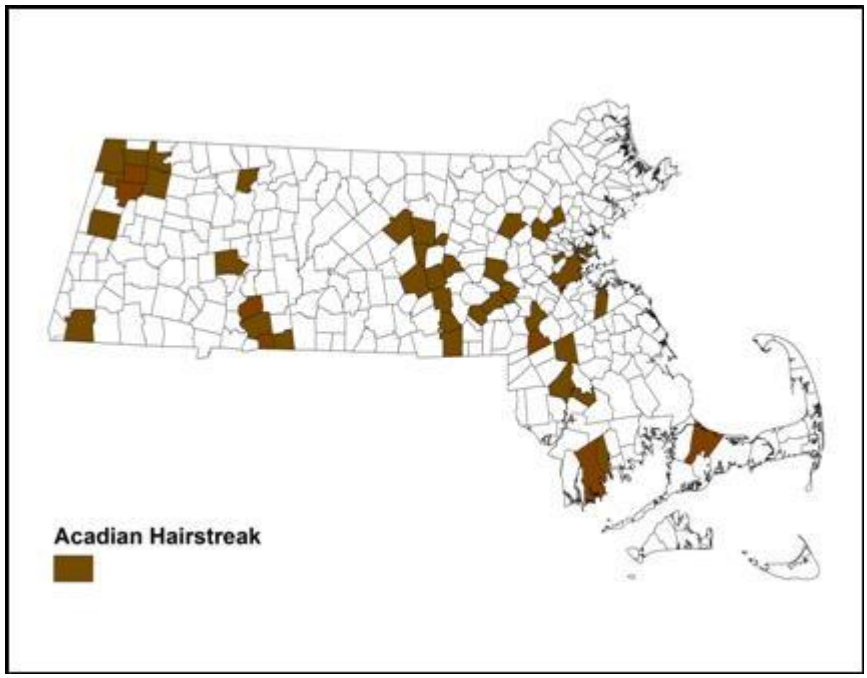


The number of individuals per total trip reports shown in Chart 18, as well as the number of sightings per total trip reports containing that species (chart not shown), both show the same pattern: a marked increase in 2004 and 2005, and a downward trend 2005-2009.

A decline in 2008 and 2009 from the highs of 2004 and 2005 is also evident in calculations of percentage decline from prior years. In 2007 the average number of Acadians per report of that species increased 43% compared to the average for preceding years back to 1994. But in 2008 and 2009 the average declined 25% and 19% respectively, compared to prior years. The number of reports of this species also declined in each of these three years compared to prior years. The declines are especially notable in contrast to the increases for Coral Hairstreak (Nielsen, Season Summary, MB 2008-2010, Nos. 30, 32, 34).

State Distribution and Locations

Map 18: BOM-MBC Sightings by Town, 1992-2013



In 22 years of MBC records 1992-2013, Acadian Hairstreak was found in 41 out of 351 towns (Map 18). The map shows three main areas for Acadians: the Berkshires, the Connecticut River valley, and from the Worcester area through eastern and southeastern Massachusetts. This hairstreak was not been found in these years in Essex County or on Martha's Vineyard or Nantucket.

Both Map 18 and the earlier MAS Atlas show Acadian Hairstreak well-distributed in central, southern and northern Berkshire County, as one would expect from the historical record. On the Central Berkshire NABA Counts, Acadian Hairstreak has been found in good numbers nearly every year from 1992-2011; a high count of 134 was reported 7/17/2005, and the next highest total was 53 in 2007. But there were only 26 in 2009, 12 in 2010, 10 in 2011, 1 in 2012 (but 24 two weeks earlier), and 14 in 2013, so numbers appear to be declining. The Southern Berkshire NABA Counts found Acadian every year 2003-2008 in small numbers, but did not report it in 2009, 2010, 2011, 2012 or 2013. The Northern Berkshire NABA Counts found Acadians in very small numbers in 1994, 1995, 2004, 2007, 2011 (including Mt. Greylock), and 2012 (1, Williamstown, B. Zaremba and P. Weatherbee). From Count data, numbers in the Berkshires, as in the state as a whole (Chart 18), seem to be in a downward phase.

For the Connecticut River Valley, contemporary records are few, and mostly from the 1990's. The latest are Greenfield (1, 7/7/2001, Central Franklin NABA), Northampton (1, 7/13/2000, T. Gagnon), and the Springfield area (4, 7/15/1995, and 1, 7/15/1999, Lower Pioneer Valley NABA). There are no records for "the valley" more recent than these. There are two records from Chicopee Westover Air Base (M. Mello, 7/2/1994; T. Gagnon 6/22/1996), and earlier reports from East Longmeadow and Hampden.

For the central towns around the Quabbin Reservoir, MBC, like the Atlas, has no Acadian records, although it seems likely the species would occur there. For the Worcester area, and to the east and south of Worcester, MBC, like the Atlas, does have records, but these are nearly all from the 1990's and are of low numbers (1-2 per report). The most recent record is from 2008: 2 found on the Blackstone Valley NABA Count. This Count reported 2 to 3 Acadians each year 2001 through 2005 (e.g. Grafton Dauphinais Park 3, 7/12/2005, D. Price), but has not reported any Acadian Hairstreaks 2009-2013.

In Norfolk and upper Bristol County (southeastern Massachusetts), the Foxboro NABA Count reported Acadians regularly 1992-2000, before the Count was discontinued. Some specific towns from this Count area are Walpole, 5 on 7/11/1993, T. Dodd; Easton, 7, 7/2/1994, B. Cassie; Taunton, 3, 7/19/1997, B. Cassie; and Milford power line, 5, on 7/4/2001, R. Hildreth. The latter is the latest report from this area.

In southern Bristol County Acadian Hairstreak does still occur in a well-known colony near New Bedford (54 individuals counted 7/17/1994; but 12 on 7/19/2005). This colony was reported from the 1980s through 2005 (see above), but none were reported between 2005 and 2012, despite searches, because the colony declined markedly as a result of a well-intentioned wetland restoration project. But finally, in 2012, a dozen Acadian Hairstreaks were re-located at that site (July 6, 2012, M. Mello), nectaring on dogbane and narrow-leaved mountain mint. There is also another small colony in the Dartmouth area, from which one was reported on 7/8/2012, M. Mello. MBC records do not show Acadian Hairstreak to be “common” in Bristol County, as the Connecticut Atlas put it; MBC and NABA records refer solely to these two small colonies.

For Essex County, MBC does not have any Acadian records, and there are apparently none since 1990, when the MAS Atlas found it in Beverly (7/14/1990, T. French), Haverhill (7/4/1989, T. French), and Reading (7/8/1989, S. Goldstein). These areas should be re-checked.

The only report from Cape Cod is from Sandwich, Massachusetts Military Reservation, where a recent survey (7/16/2011, E. Nielsen and P. Trimble) found 43

Acadian Hairstreaks amid many Edwards' and Banded. This area is closed to the public. This is the first report of Acadian Hairstreak from Cape Cod since Scudder's day (the Atlas did not find it on the Cape), and this colony ought to receive monitoring and protection.

Acadian has not been reported from Martha's Vineyard or Nantucket by MBC or the Atlas or other sources (Pelikan 2002; LoPresti 2011). Jones and Kimball (1943) do not list it as present historically on these islands.

NOTE TO COLLECTORS: Due to its uncommon and possibly declining status here, collectors should refrain from taking specimens of this butterfly. Some locations have been omitted from the discussion above to deter amateur collecting.

Broods and Flight Period

All of our *Satyrium* hairstreaks have a single flight mainly in July, and the Acadian is no exception. Peak reports are usually the second week in July (http://www.naba.org/chapters/nabambc/flight-dates-chart.asp). However, in the warm spring/summer of 2012 the peak numbers at the Pittsfield colony were recorded on June 24, and declined after that (T. Gagnon, pers. com.).

Earliest Sightings: In the 23-year period 1991-2013, the five earliest "first reports" in MBC records are 6/21/2010 Woburn, R. and S. Cloutier; 6/21/1998 Grafton D. Price and D. Small; 6/22/1991 Worcester BMB, T. Dodd; 6/23/2012 Woburn, S. Moore *et al*.; 6/27/2004 Woburn, M. Rines. The first sighting date in 2013 was 6/29/2013 Pittsfield, T. Gagnon.

Flight Time Advancement: A century ago Scudder wrote that this butterfly "generally appears about the 10-15 July, although it sometimes occurs as early as the very end of June" (1899: 902). The geographical latitude to which Scudder was referring is not clear, but usually included Massachusetts. Given that Acadian Hairstreak's first appearance in Massachusetts is now usually in the third or fourth week of June, one might suspect that its flight period had advanced since Scudder wrote.

Analysis of BOM-MBC and Atlas sight data 1986-2012 shows that Acadian Hairstreak has advanced its flight date about 8 to 10 days over this time period (Williams *et al.* 2014). All ten elfins and hairstreaks examined had advanced flight dates somewhat, with elfins advancing more than hairstreaks. An earlier study at Boston University, which looked at Atlas and MBC sighting data for 1986-2009, did not find that Acadian Hairstreak had advanced its flight time over that time period (Polgar *et al.* 2013), but addition of newer data revised the analysis. Polgar *et al.* also

showed that, like most elfins and hairstreaks, Acadian Hairstreak emergence times were highly responsive to average temperatures in the two months preceding emergence.

Latest Sightings: In the 23-year period 1991-2013, the five latest MBC "last observation" dates are 8/12/1992 Easton, L. Lovell; 7/27/1995 Savoy D. Potter; 7/26/1997 Pittsfield T. Tyning *et al.*; 7/25/1993 Worcester BMB T. Dodd; and 7/24/2005, Berkshire Co., B. Benner.

Scudder's rather vague flight ending date was "until the end of the first week in August, perhaps longer" (1899: 902). In all of 23 years, MBC records contain only two sighting in August, that from Easton noted above, and 8/2/1992, Worcester BMB, T. Dodd. Scudder's dates may be meant to include localities further south of Massachusetts.

Outlook

The Acadian Hairstreak's center of gravity is northern damp meadows; it is most secure in the northern mid-continent areas of the U.S. and Canada. In the east, it reaches the southern edge of its range in Pennsylvania and New Jersey, and it is vulnerable in these areas, where climate warming may induce a withdrawal westward and northward.

Two studies indicate that Acadian Hairstreak is declining here, and it has already undergone a decline in New Jersey. Despite repeated searches, it has not been seen there since 2006, and is now under state review (Wander and Wander, 2009). Acadian Hairstreak may also be declining in Connecticut. In the 1990-95 Connecticut Atlas, there were only 19 project specimens, compared to 41 pre-project specimens. Also, it appeared to be gone from some former areas in the eastern part of the state. In Rhode Island, Acadian is ranked S2S3 or “imperilled” (NatureServe 2010).

Acadian Hairstreak is listed here as a Species of Conservation Concern in Massachusetts. It is already scarce on the southeastern plain, and if climate warms further, we could see a range contraction northward and westward, and contraction to higher elevations, in the state (Table 6). Climate warming appears to be the main threat, but urban/suburban development, forest re-growth, pesticide spraying, and indiscriminate collecting can also adversely affect this species. Very few of the known colonies are on protected land.

The four largest known Acadian Hairstreak colonies-- Sandwich Mass. Military Reservation, New Bedford, Woburn, and Pittsfield --should be protected from development, should be monitored yearly, and should be managed to deter forest

succession and preserve host plant willows. Searches need to be undertaken to locate and protect the lesser-known breeding areas in the northern Berkshires. Acadian Hairstreak's 2010 NatureServe rank is S4 in Massachusetts, but this needs review given the indications of decline here.

Climate-driven changes in Northeastern US butterfly communities

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Climate-driven changes in northeastern US butterfly communities

Greg A. Breed[1]*, Sharon Stichter[2] and Elizabeth E. Crone[1]

Climate warming is expected to change the distribution and abundance of many species[1–3]. Range shifts have been detected in a number of European taxa for which long-term government-initiated or organized-survey data are available[4–8]. In North America, well-organized long-term data needed to document such shifts are much less common. Opportunistic observations made by citizen scientist groups may be an excellent alternative to systematic surveys[9]. From 1992 to 2010, 19,779 butterfly surveys were made by amateur naturalists in Massachusetts, a geographically small state located at the convergence of northern and southern bioclimatic zones in eastern North America. From these data, we estimated population trends for nearly all butterfly species (100 of 116 species present) using list-length analysis[10,11]. Population trajectories indicate increases of many species near their northern range limits and declines in nearly all species (17 of 21) near their southern range limits. Certain life-history traits, especially overwintering stage, were strongly associated with declines. Our results suggest that a major, climate-induced shift of North American butterflies, characterized by northward expansions of warm-adapted and retreat of cold-adapted species, is underway.

Climate warming has demonstrably altered the distribution and phenology of numerous plant and animal species[1–3]. Although a large and growing number of case studies have shown population-level effects of climate change, most of these examples come from unusually well-studied systems, such as government-organized or government-funded monitoring programmes in Europe[4–8]. There is an urgent need to know whether these trends extend into other geographical areas.

Natural history observations by amateurs have the potential to document the distribution and abundance of species in places where systematically collected monitoring data do not exist. Many amateur organizations are now holding decades-long data sets of the occurrence and abundance of species[9,12,13]. However, sampling effort is often poorly controlled in citizen-collected data and until recently these data have not been widely used because they have been considered unreliable. As efforts have unfolded to properly organize and archive amateur observations, their use by the scientific community is becoming mainstream[9]. Effort control and reliability remain an issue, but, because of their potential wide coverage, the development of robust statistical methods to analyse citizen science data is an active area of research.

We used list-length analysis[10,11], a new analytical approach for citizen-collected observations, to analyse population trends of butterflies observed in Massachusetts by the Massachusetts Butterfly Club (MBC) between 1992 and 2010 (Supplementary Fig. S4 and Table S1). List-length analysis uses the number of species reported in a particular outing as a proxy for observation effort. Though list-length analysis was originally intended to control for effort, it controls for all factors that affect detectability on a particular day (see Supplementary Information for complete methods). Effort and weather are the most important day-to-day factors affecting detection probability, but phenology is also strongly reflected in list length, and list length implicitly controls for this effect as well (see the Supplementary Information for further discussion). After controlling for list length, the residual detectability can be used as an index of abundance and changes in detectability used to estimate changes in abundance though time[10,11].

Population trends of butterflies in Massachusetts indicate strong climate-driven changes in abundance. Trends in abundance were estimable for 100 of the 116 butterfly species reported (Supplementary Table S2), 21 of which were northern species, defined as those with ranges centred north of Boston (41.78° N, 70.50° W). Northern species were significantly overrepresented in declining species (permutation test $p = 0.0003$). Of the 21 northern species, 17 were declining, one was increasing and three did not show significant trends through time (Fig. 1 and Supplementary Table S3). Regional trends in abundance corroborate the presence of climate-driven trends. We divided Massachusetts into five subregions based on environmental conditions (Fig. 2). All regions of the state have warmed significantly in the past 100 years (Supplementary Fig. S10). Northern species, however, were less likely to be declining in cooler, higher-altitude regions, but were strongly declining in warmer, lower-altitude regions (Fig. 2). Higher regions probably still contain cooler microclimates, which could allow cold-adapted species to increase their altitude and remain in an appropriate climate envelope[14–16].

Furthermore, we identified species that had recently expanded their ranges by comparing our species list with the *Massachusetts Butterfly Atlas* (MBA; ref. 17), compiled between 1986 and 1990. Of the 100 estimated population trajectories, 14 were from species that were very rare or not reported in the atlas (four or fewer reports). Of these, 12 have southerly ranges, one has a northerly range and one is near its range core. The species with a northerly range was the only one in decline, whereas the 12 with southerly ranges were all increasing. Many of these growing populations are new to the state and represent invasions from the south (Fig. 1). Declining northern species are being replaced by warm temperate and subtropical species such as the giant swallowtail (*Papilio cresphontes*) and zabulon skipper (*Poanes zabulon*)[18]. Permutation tests indicate that this pattern of increase by historically (1980s) rare southern species is highly significant ($p = 0.0003$).

In contrast to climate change, butterfly population trends did not seem to be systematically related to habitat or landscape change. We found no evidence ($p > 0.1$) that host-plant rarity,

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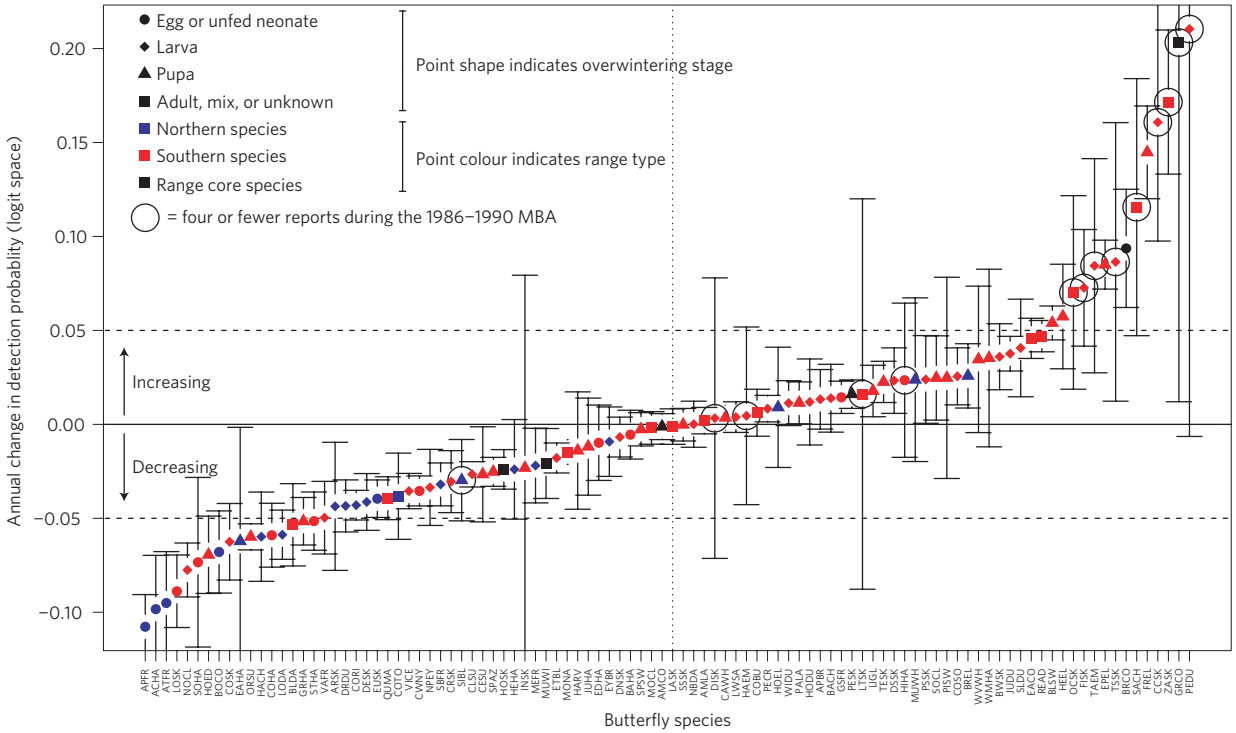

Figure 1 | Population trajectories with 90% confidence intervals for butterfly species in Massachusetts, with range type (northerly versus southerly, symbol colour) and overwintering stage (symbol shape) superimposed. Species that were rare or not present in the 1986–1990 MBA are circled. The solid horizontal line denotes the zero-population-growth estimate and the vertical dotted line separates declining species with negative growth estimates (to its left) from increasing species (to its right). Population changes for each species as a percentage of the 1992 population are shown in Supplementary Table S3; the species performing least well represent about an 85% decline over the 18-year time series.

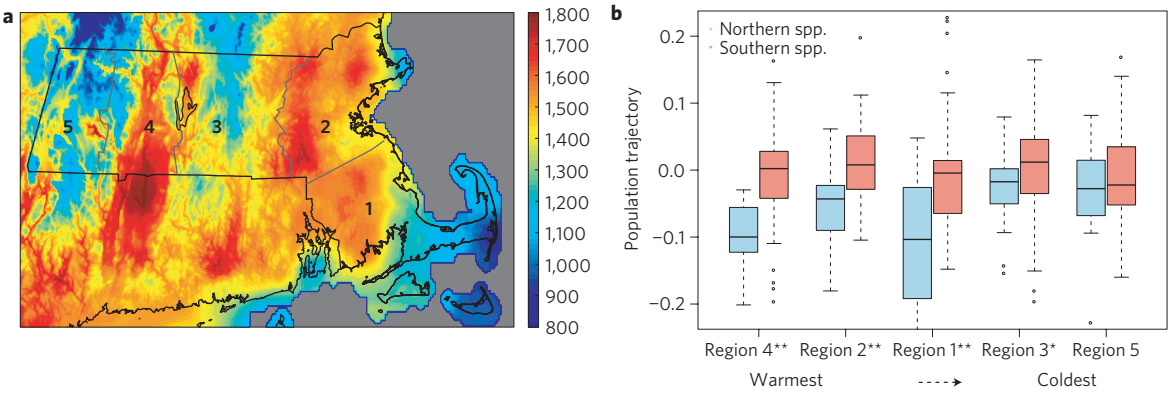

Figure 2 | Regional analysis. Region 1: Cape Cod/Long Island terminal moraines and Narragansett/Bristol Lowland; region 2: Metro Boston; region 3: Worcester Plateau; region 4: Connecticut River Valley; region 5: Berkshire Mountains. **a**, Regional divisions superimposed over a state map of 30-year mean 15 °C degree days. The colour scale indicates annual accumulated degree days above 15 °C (data from ref. 29). **b**, Northerly distributed butterflies are declining much faster in warmer regions of Massachusetts (**regions 1,2,4: $p = 0.0055$, $p = 0.0053$, $p < 0.0001$, respectively). *Region 3, which is cooler and higher, had only marginally significant declining trends in northerly species ($p = 0.0530$) and region 5, which is mountainous and much cooler, had no trend ($p = 0.4346$). The open circles are outliers.

degree of host plant or habitat specialization, or the kinds of habitat preferred, had any relationship to the pattern of decline (see Supplementary Figs S6 and S7), suggesting that climate and not habitat alteration is driving broad patterns of community change. Landscape changes and habitat destruction have probably affected some species, but it is difficult to attribute the community-wide pattern of decline in cold-adapted species and invasion and growth of warm-adapted species to any mechanism other than climate warming. Furthermore, changes in abundance do not seem to be strongly associated with phylogeny. For example, although two of the three most rapidly declining species were from the genus *Speyeria*, another *Speyeria* species (*Speyeria cybele*) is increasing in abundance.

Past studies of climate-induced changes in species distribution have widely shown lower-latitude species expanding into higher latitudes[4–6,8]. Range retractions have been documented, but not nearly as well[7,19]. Nearly all of the past studies have relied on changes in the occupancy of survey grid cells. Unlike expansions into previously unoccupied territory, retreating species may occupy lower-latitude range margins long after warming has occurred. These areas, however, will be increasingly marginal, and sensitive populations that remain present will decline. Populations may

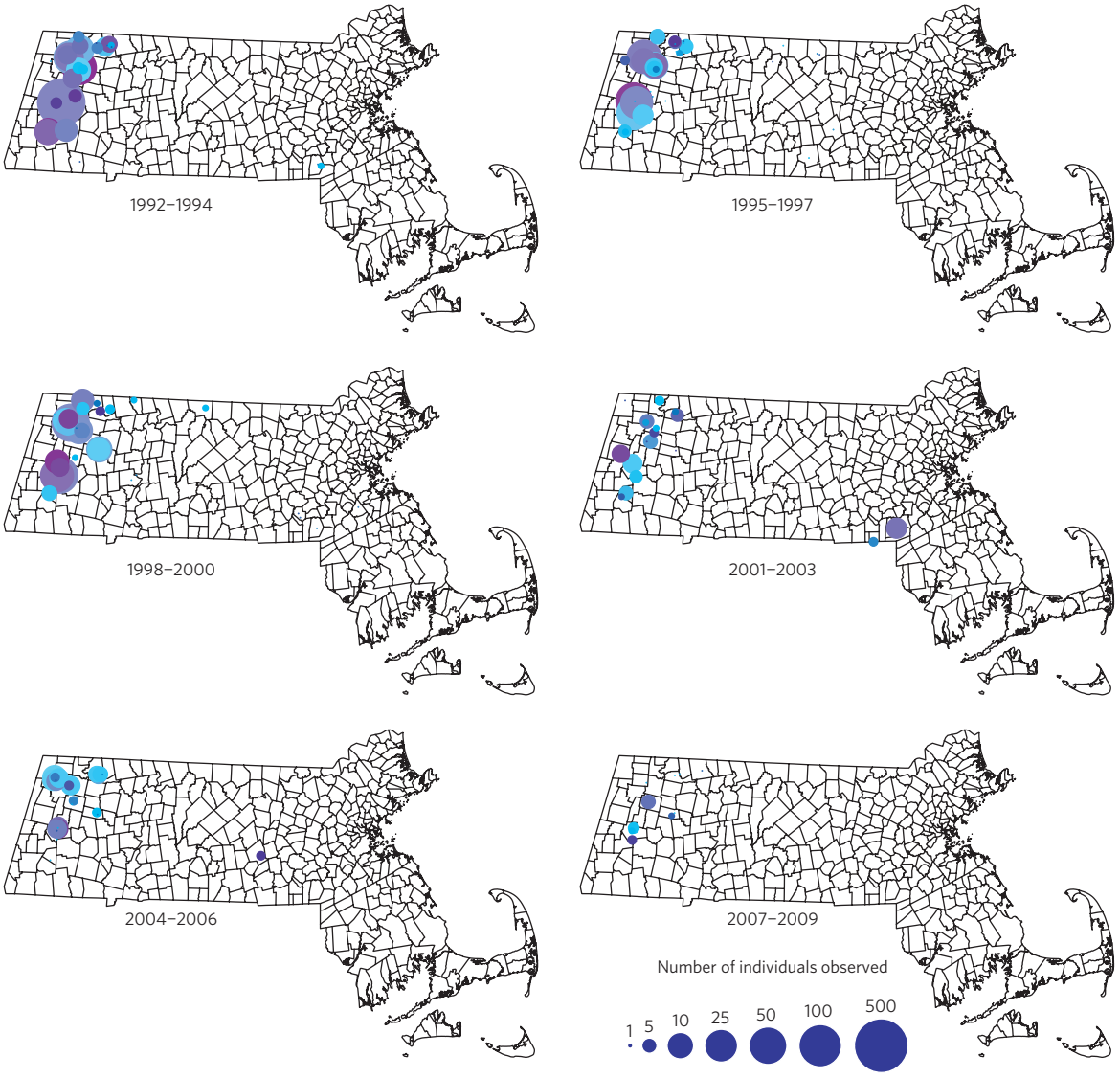

Figure 3 | Raw MBC reports for the atlantis fritillary (*Speyeria atlantis*), which is near its southern range limit in Massachusetts. Hue of each report is randomly offset so that overlapping reports are more visible. The size of the circles represents the number of individuals reported. Circle size is log scaled so that large reports do not overwhelm the map.

decline slowly or quickly and extinction may become certain in slowly declining species well before it actually occurs—a climate-induced extinction debt[19,20]. In other words, analyses of static distribution maps are likely to underestimate range retractions, whereas our approach using estimates of population trends provides much greater insight into why, and how fast, ranges are retracting or expanding.

As well as demonstrating widespread changes in butterfly communities, our results indicate that differences among species are partly predictable from life-history traits. Species that overwintered as eggs or unfed neonate larvae were highly overrepresented in declining species ($p = 0.0008$), with many of the fastest-declining species having this life-history trait (Fig. 1). Overwintering eggs and neonates are probably more susceptible to dehydration if summers, autumns and winters become warmer, dryer and with less snow cover, as they have very limited water and energy reserves and cannot actively augment them before diapause. To a lesser degree, butterflies that are obligately univoltine were also significantly over-represented in declining species ($p = 0.0117$, see Supplementary Fig. S5). One previous study tested for life-history correlates of range expansions[8]. They found that habitat availability and motility, but not overwintering stage, explained rates of poleward expansion. Life-history traits may help to predict species' responses to climate change, but our data suggest that different life-history traits are likely to be associated with range expansions versus retractions. Life-history limitations have been experimentally shown to limit butterfly range changes in response to climate change[21,22]. Finally, mechanisms of climate change affecting overwintering mortality may be more complex than a simple warming or desiccation effect. Others have suggested that macroclimatic warming may cause microclimatic cooling through earlier bud burst and foliage growth, which cools larvae by shading and transpirative cooling, slowing larval growth in species that overwinter as larvae and mature in the spring[23].

Our results have implications for conservation policy in changing environments. In the twentieth century, habitat loss was widely cited as the leading cause of species endangerment and extinction[24,25]. Here, climate seems to be the strongest driver of population trends. Formally listing species as threatened or endangered in political units (that is, states) that are on the very edge of their climate envelope could direct funding to habitat management that has little to do with the probable long-term survival of the species.

For example, in Massachusetts, the frosted elfin (*Callophrys irus*), a southern species at its northern range margin, receives formal protection by the state. Our analysis reveals this species to be one of the fastest-growing populations in the state, with an estimated 1,000% increase since 1992 (Figs 1 and Supplementary Fig. S9 and Table S3). This trend may be owing to habitat management in response to its conservation status, but it may also be that the climate in Massachusetts has become more favourable. At the same time, two of the state's historically common and conspicuous summer butterflies, the atlantis and aphrodite fritillaries (*Speyeria atlantis* and *Speyeria aphrodite*) have declined by nearly 90% since 1992, remain unprotected and continue to decline (Figs 1 and 3). Conservation agencies should not use our results to infer that all southern species are safe nor that all northern species are doomed to extinction. However, understanding mechanisms of population decline could improve management practices and limit potentially costly efforts that will have little influence on species conservation.

Our results highlight the power of data collected by amateur naturalist organizations such as the MBC (refs 12,13). They are part of a growing number of important findings derived from observations made by citizens, including range changes, changes in phenology and the spread of invasive species and diseases[9]. Citizen science data and the further development of analytical techniques for these data can fill key gaps in our knowledge of species' responses to climate change. With appropriate analytical methods, these data will be increasingly important for detecting climate-induced changes in plant and animal communities worldwide.

Methods

Data were collected from 1992 to 2010 by the MBC and included a total of 19,779 observation trips, each one producing a list of species observed (Supplementary Table S1). Data were sufficient to estimate population trends for 100 of the 116 species observed in the state. We excluded some species owing to taxonomic realignments or changes in how the MBC reported certain taxa. Two species, the Milbert's tortoiseshell (*Aglais milberti*) and little yellow (*Pyrisitia lisa*), were excluded because their populations exhibited major outbreaks in the middle of the time series, not reflective of overall population trends. Most excluded species were simply observed too rarely to reliably estimate population trends (Supplementary Table S2).

Species lists were analysed using list-length analysis[10,11]. This method fits a three-parameter logistic regression and makes the simple assumption that the more species that are reported in a particular outing, the greater the observation effort. Adding the list-length parameter to the regression accounts for observer effort[10,11]. The other two parameters were the intercept (overall detectability) and change in detectability through time, the slope of which is a robust estimate of population trajectory. The model was fit in a Bayesian framework using the free software package WinBUGS. The model was run in two independent chains, updated 20,000 times, used a burn-in of 10,000, a thin of five and vague priors for all parameters. All diagnostics, including Rhat values, pD (effective number of parameters) and chain mixing indicate good convergence for all species we report. Life-history traits for all species in the MBC database were gathered and cross-checked from numerous published accounts[26–28]. Species were considered northerly if more than 50% of their published range was north of the city of Boston (41.78° N, 70.50° W) and were considered southerly if more than 50% of their published range was south of that line (Supplementary Fig. S1). Furthermore, we drew on records from the 1986–1990 MBA, a five-year intensive survey programme, to identify species that had recently invaded the state[17]. To assess the impact of life-history traits, we ranked species based on their estimated population trajectory, then used simple permutation tests (1,000,000 permutations) to see if particular traits were clumped in a higher-than-random chance in increasing or decreasing population trajectories.

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Author contributions

E.E.C. and G.A.B. conceived the analysis. G.A.B. coded and implemented the analysis and created all figures. G.A.B. and E.E.C. wrote the manuscript. S.S. collected, organized and maintained the MBC observations database, provided help in understanding how the data were collected and archived, and provided feedback on earlier drafts.

Additional information

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to G.A.B.

Competing financial interests

The authors declare no competing financial interests.