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Abstract – Only 0.7% of 28,205 known New England ant specimens (1861-2011) were from Rhode Island. Consequently, apparent ant species richness of Rhode Island counties was lower than expected based on simple biogeographic models. Collections from two poorly sampled areas – Block Island and Tiverton – and from the 2013 Rhode Island Natural History Survey's BioBlitz increased Rhode Island's ant specimens by 46% and its ant species richness from 48 to 57. Both Washington and Newport Counties now have ant species richness more in line with New England-wide species-environment predictions. The extrapolated number of Rhode Island ant species is 66, but the upper bound of the 95% confidence interval is 93 species and the total species accumulation curve has not reached an asymptote. Future collection efforts should continue to add ant species to the Rhode Island list, especially if collections are targeted in the state's north and southeast regions, and its southwest pine barrens.

Introduction

The flora and fauna of the New England region – Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine – are better known than those of any other region of the United States. The combination of early European settlement, a concentration of academic institutions with taxonomic specialists and curated collections, many organizations dedicated to conservation and preservation of species, and a large cadre of dedicated amateur natural historians has yielded regular publications of regional species lists from the late 1600s (e.g., Day 1899, Henshaw 1904-1925) to the present (e.g., Ellison et al. 2012, Haines 2011). At more local scales within New England, however, there is a great deal of variation in knowledge and collection coverage of different taxonomic groups. Our regional knowledge of the New England myrmecofauna – the ants – provides a notable case in point.

Two regional summaries bracket our contemporary knowledge of the ants of New England (Ellison et al. 2012, Wheeler 1906). Wheeler (1906) listed 84 ant taxa (species, subspecies, varieties), whereas Ellison et al. (2012) listed 132 species for the six New England states. County records in 2012 ranged from only four records (and two species) in Newport County, Rhode Island to 5,475 records (66 species) in York County, Maine. Although there are four or more specimens from every county in New England, there are many gaps in town-level collections. For example, in Massachusetts, which alone accounts for 67% of the >28,000 specimen records collated by Ellison et al. (2012), there are no ant specimen records from 172 of the state's 351 towns.

Far less is known about the ant fauna of Rhode Island than the other five New England states. Wheeler (1906) listed only 12 species for Rhode Island, each represented by only a single record (except *Formica integra*, which had been collected twice by 1906), and all but two of these specimens had been collected from Providence (the other two were listed as being from Newport and Kingston). Over one hundred years later, only 195 more specimens (for a total of 208) had been recorded from Rhode Island, representing 21 of its 39 towns (Fig. 1A). These records comprised 0.7% of all the total historical specimen records (1861- 2011) known from New England and summarized by Ellison et al. (2012). However, these few Rhode Island specimens included 48 species (Fig. 1B), or 36% of the regional total. The extrapolated (Chao1) estimate of the total species richness (Chao et al. 2013) for Rhode Island in 2011 was 62, but this was assuredly an underestimate, as the cumulative number of known species for Rhode Island had shown no sign of reaching an asymptote (Fig. 1B).

Ant species richness increases from the boreal forests to the equator (e.g., Dunn et al. 2009) and, similarly, from northern to southern latitudes in New England (Gotelli and Ellison 2002); the strongest environmental factor associated with this gradient is mean annual temperature (e.g., Dunn et al. 2009, Sanders et al. 2007). Ellison et al. (2012) illustrated that county-level species richness of ants in New England could be reasonably well predicted by latitude and average annual temperature. Rhode Island is situated near the southernmost latitude of New England; the relatively low elevations, modest topography, and relatively high average annual temperatures in the state suggest that Rhode Island should have many more species than current data indicate (Fig. 2).

Here, we use three sets of new specimen records collected in 2012 and 2013 from four localities in Rhode Island to test the relationships illustrated by the regression lines in Figure 2. If the relationships shown in Figure 2 are reliable, we would predict that previously poorly-sampled counties and the southernmost extent of Rhode Island should show dramatic increases in the number of species occurrences, whereas the one previously well-sampled county – Washington

County in southwest Rhode Island – should show a smaller increase in the number of new species recorded. We also use the new data to update the species accumulation curve for Rhode Island (Fig. 1B), and provide a new estimate of the expected ant species richness for the state (Fig. 1C).

Methods

Historical data on Rhode Island ant diversity and distribution were extracted from the ants of New England dataset (Ellison and Gotelli 2009) that were summarized in Ellison et al. (2012). New England specimens in this dataset were collected between 1861 and 2011, but Rhode Island specimens are known from ca. 1900 (undated records in Wheeler 1906; the first certain date of a Rhode Island ant specimen – the Eastern Carpenter Ant *Camponotus pennsylvanicus* − is August 22, 1906) to 2009.

New Rhode Island collections were made in 2012 and 2013 (Table 2). In 2012, we collected ants across Block Island (focused collections from 11–13 July; additional collections throughout July) and at Barton Woods and the Revolutionary War redoubt at Fort Barton in Tiverton (14 July). In 2013, ants were collected on June 7–8 at the South County Museum in Narragansett during the annual BioBlitz of the Rhode Island Natural History Survey. Block Island was chosen for sampling because it is one of the southernmost locations in New England, only seven previous specimens had been collected there (all in 1971 by Edward Goldstein), and because earlier studies of the ant fauna of New England’s off-shore islands had revealed unexpectedly high numbers of species (Goldstein 1975, Ellison 2012). Barton Woods and Fort Barton were chosen for sampling because it is in Newport County, the county for which there were the fewest historical specimen records (4) for all of Rhode Island or elsewhere in New England. Both Block Island and Barton Woods also have a range of different habitats in a small area.

On Block Island, we sampled ants at nine locations (Table 2). Habitats sampled included beaches and dunes (North Light, Clay Head, Grace's Cove Beach), wetlands (West Side Road Bog and the shoreline of Sachem Pond), deciduous forests (Clay Head, Nathan Mott Park), open fields (Turnip Farm), and anthropogenically-maintained sites (Dodge Cemetery, the grounds of The Nature Conservancy's Nature Center). Geographic coordinates of all collection locations were taken with a Garmin hand-held GPS (Garmin International, Inc., Olathe, Kansas).

At each of these locations, we slowly walked on and off trails within a 75 × 75-m area centered on the trail for at least one person-hour and collected representative workers from any ant colonies we encountered. We turned over rocks, opened up decayed logs and stumps, dug into anthills and ant mounds, and gleaned from foliage, branches, and trunks. This method of timed hand-sampling accumulates far more species than baiting or pitfall trapping (Ellison et al. 2007). We also collected four 1-L litter samples from random locations within the plot, sieved them in the field (1/8″-mesh), and collected all ants we extracted from the sieved litter.

Additional ant samples were collected as "by-catch" during a month-long (July 2012), drag-sheet survey for deer ticks conducted by Casey Finch and Patrick O'Shea (Yale School of Public Health, New Haven, Connecticut). GPS coordinates for individual drag sheets, each deployed once and checked within one hour, are given in Table 3. Any ants that accumulated on the sheets were collected and sent to us for identification.

At Barton Woods, ants were collected at the historic fort site and adjacent cemetery, and then along the "Red Trail" in five different habitats: areas dominated by nonnative plants, an upland oak-hickory woodland, the floodplain forest adjacent to Sin & Flesh Brook, the edge of a vernal pool dominated by *Sphagnum* mosses, and the mixed woodland at the northeast junction of the Red and Blue trails (Table 2). As we had done at Block Island, we searched for and collected ants by hand from nests in each habitat for approximately 1 person-hour, and then sieved four 1-L litter samples and extracted ants from the sieved litter in the field.

The Rhode Island Natural History Survey's BioBlitz occurs each year at different locations. The 2013 BioBlitz was intended to sample throughout the town of Narragansett. However, because of the simultaneous occurrence of Tropical Storm Andrea, pitfall traps were washed out, and only opportunistic samples from the Canonchet Farm property at the South County Museum were hand-collected (Table 2).

All ants were identified to species using keys in Ellison et al. (2012). As in Ellison et al. (2012), local regression analysis was done using the loess function in R version 3.0.1 (R Development Core Team 2013). Regressors used were latitude and mean annual temperature at the county centroid derived from WorldClim (Hijmans et al. 2005). The Chao1 estimator of species richness (Chao et al., in press) was computed using the species diversity module (for both rarefaction and extrapolation) in EstimateS version 9 (Colwell 2013). Raw data are available in the ants of New England dataset of the Harvard Forest data archive (http://harvardforest.fas.harvard.edu/data-archive), dataset HF147. Voucher specimens are stored in the Harvard Forest sample archive.

Results

We accumulated 108 new specimen records (nests + samples from litter) from Block Island, 61 new specimen records from Tiverton, and 11 new specimen records from the South County

Museum. These 180 records increased the total number of specimen records for Rhode Island by 46%, and added nine new species to the current list of Rhode Island ants (Table 1; Figs. 2A, 2B).

On Block Island, we collected 18 species. All seven of the species collected by Goldstein in 1971 (*Tapinoma sessile, Lasius alienus, Lasius neoniger, Aphaenogaster rudis, Crematogaster cerasi*, *Myrmica americana*, and *Tetramorium caespitum*) were re-collected in 2012, along with 11 others (Table 1). Six of these − *Lasius pallitarsis, Aphaenogaster fulva, Monomorium emarginatum*, *Myrmica punctiventris,* an undescribed species of *Myrmica* (denoted *Myrmica* sp. AF-scu), and *Solenopsis molesta* − were new records for Washington County. Of these six species, all but *Monomorium emarginatum* and *Myrmica americana* (both previously collected in Providence) also were new state records. Of additional note, only one of Block Island's known ants is nonnative (the Pavement Ant, *Tetramorium caespitum*). The European Fire Ant (*Myrmica rubra*), which has been collected from the mainland coastal city of Newport, has not yet been found on Block Island. Curiously, despite the abundance of dead trees, downed limbs, and firewood, we found no carpenter ants (*Camponotus* species) on Block Island. Several long-time island residents and local naturalists also reported never having seen carpenter ants on Block Island.

At Fort Barton and in Barton Woods, we collected 22 species, but did not find the two species previously collected in the county (*Dolichoderus plagiatus* and *Myrmica rubra*). Therefore, all of these 22 species (Table 1) were new county records for Newport County. Three species were new state records (*Formica neogagates*, *Lasius nearcticus*, and *Stenamma impar*), and three others had been collected previously in Rhode Island only during the previous days' sampling on Block Island (*Aphaenogaster fulva*, *Myrmica punctiventris,* and *Solenopsis molesta*).

Among the 11 species collected during the 2013 BioBlitz at the South County Museum (Table 1), two were new state and Washington County records (*Aphaenogaster picea*, *Myrmica incompleta*).

Based on all Rhode Island collection records available to us through June 2013, we now estimate that there are 66 ant species in the state with a 95% confidence interval = [59 – 93]. Including the new collection data in the regression analyses predicting number of ant species per county as a function of latitude ($F_{1,65} = 9.87$, $P = 0.003$) or mean annual temperature ($F_{1,65} = 12.12$, $P = 0.0009$) brought Washington County and Newport County more in line with expectation with the rest of New England (the residual sums of squares decreased by 5% in both cases with the inclusion of the new collection data), but did not significantly change the shape of the relationship between these variables and ant species richness (Fig. 2).

Discussion

Targeted field collecting of ants in Rhode Island yielded new state and county records and supported a regression model relating county-level ant species richness to geographic and climatic variables. These results suggest that additional collecting focused on historically under-sampled areas in Rhode Island, as well as elsewhere in New England, can rapidly increase our knowledge of the region's myrmecofauna.

Five days of ant collecting nearly doubled the number of Rhode Island ant specimens (from 208 to 388), increased the number of ant species known from the state by nearly 20% (from 48 to 57), and increased the expected number of Rhode Island ant species from 62 to 66 while decreasing the uncertainty (width of the confidence interval) of that estimate by 25% (Fig. 2). However, the current upper limit of the 95% confidence interval is 93 species and the species accumulation curve shows no sign of reaching an asymptote (Fig. 1B), so these results imply that future collection efforts will almost assuredly continue to add ant species to the Rhode Island list relatively quickly. It is also noteworthy that only two nonnative ants – *Myrmica rubra* and *Tetramorium caespitum* – are currently known from Rhode Island. Other temperate-zone nonnatives are likely to be found in urban areas (cf. Pećarević et al. 2010), and tropical tramps are likely to be found in houses, greenhouses, and commercial buildings that are heated year-round (Ellison et al. 2012). Searching for ants in these "non-traditional" settings – urban areas and indoors – could easily detect nonnative species in Rhode Island.

Opportunities to involve citizen-scientists, such as the annual BioBlitz of the Rhode Island Natural History Survey, also are likely to pay off with new state records and the concomitant excitement generated by such discoveries. We encourage future structured collecting and educational BioBlitzes to focus attention on poorly-collected towns and counties: there are fewer than 10 records each from Bristol and Kent Counties, and only 15 from Providence County. These counties have habitats ranging from urban to rural and wooded to open, all of which could yield new species records for the state. New records can be added to our database through the Ants of New England website: http://NEants.net. We note that we were unable to assess relationships between species richness and habitat type in Rhode Island because most of the historical specimen labels lacked habitat data. As we accumulate more data, however, we will be able to better assess these relationships as we have done for the broader New England region (Ellison 2012, Ellison et al. 2012).

The new data from Rhode Island also strengthened our confidence in relatively simple regression models that predict ant species richness from easy-to-measure variables such as latitude and mean annual temperature (Fig. 2). The other Rhode Island counties are still “outliers” in these species-environment spaces (grey circles in Fig. 2), again emphasizing that targeted ant collecting in northern and southeastern Rhode Island (i.e., the un-sampled towns in Fig. 1) should be a priority. At the same time, even though Washington County is comparatively well-sampled, the vast majority of the historical specimens are from around the University of Rhode Island’s Kingston campus (solid triangle in Fig. 1A), and after our 2012 collecting forays, more than half of the total specimens are from Block Island. Other habitats in Washington County include pine barrens and extensive wetlands, both of which have unique ants. Pine barrens in particular have very diverse ant assemblages (Boyd and Marucci 1979), and have more ant species than any other habitat in New England (Ellison et al. 2012). In short, there is still much to learn about the Rhode Island myrmecofauna, and there are many opportunities to contribute to biodiversity studies right here in the northeast.

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Table 1. Checklist of the ants of Rhode Island. Species names in **bold** were listed in Wheeler (1906). Superscripts indicate new state records since the publication of Ellison et al. (2012): [†]Collected on Block Island (Washington County), July 2012; [‡]Collected at Barton Woods, Tiverton (Newport County), July 2012; ***Collected at the South County Museum, Narragansett (Washington County) during the 2013 Rhode Island Natural History Survey BioBlitz.

	County				
	Bristol	Kent	Newport	Providence	Washington
AMBLYOPONINAE					
Stigmatomma pallipes (Haldeman, 1844)		√			
PONERINAE					
Ponera pennsylvanica Buckley, 1866			√		√
DOLICHODERINAE					
Dolichoderus plagiatus (Mayr, 1870)			√		√
Dolichoderus pustulatus Mayr, 1886					√
Tapinoma sessile (Say, 1836)				√	√
FORMICINAE					
Camponotus americanus Mayr, 1862					√
Camponotus castaneus (Latreille, 1802)					√
Camponotus chromaiodes Bolton, 1995					√
Camponotus nearcticus Emery, 1893			√	√	
Camponotus novaeboracensis (Fitch, 1855)	√			√	√
Camponotus pennsylvanicus (DeGeer, 1773)	√	√	√	√	√
Formica argentea Wheeler, 1902					√
Formica dolosa Buren, 1944				√	√
Formica exsectoides Forel, 1886					√
Formica impexa Wheeler, 1905		√			√
Formica incerta Buren, 1944					√
Formica integra Nylander, 1856				√	√
[‡]*Formica neogagates* Viereck, 1903			√		
Formica obscuriventris Mayr, 1870		√			√
Formica pallidefulva Latreille, 1802			√		√
Formica pergandei Emery, 1893		√			√
Formica querquetulana Kennedy & Dennis, 1937					√
Formica subaenescens Emery, 1893			√		√
Formica subintegra Wheeler, 1908			√	√	

Formica subsericea Say, 1836		√	√	√
Lasius alienus (Foerster, 1850)	√	√	√	√
Lasius claviger (Roger, 1862)			√	√
Lasius interjectus Mayr, 1866				√
Lasius latipes (Walsh, 1963)			√	
[‡]*Lasius nearcticus* Wheeler, 1906		√		
Lasius neoniger Emery, 1893				√
[†]*Lasius pallitarsis* (Provancher, 1881)				√
Lasius speculiventris Emery, 1893				√
Lasius umbratus (Nylander, 1846)		√	√	√
Nylanderia parvula (Mayr, 1870)				√
Prenolepis imparis (Say, 1836)				√
Myrmicinae				
Aphaenogaster fulva Roger, 1863		√		√
****Aphaenogaster picea (Wheeler, 1908)***				√
Aphaenogaster rudis (s.l.) Enzmann, 1947		√		√
Aphaenogaster treatae Forel, 1886				√
Crematogaster cerasi (Fitch, 1855)	√			√
Crematogaster lineolata (Say, 1836)			√	√
Monomorium emarginatum DuBois, 1986			√	√
Monomorium viridum Brown, 1943				√
Myrmecina americana Emery, 1895		√		
Myrmica americana Weber, 1939			√	√
***Myrmica incompleta* Provancher, 1881				√
[†,‡,*]*Myrmica punctiventris* Roger, 1863		√		√
Myrmica rubra (Linnaeus, 1758)		√		
[†]*Myrmica* sp. AF-scu				√
Myrmica sp. AF-smi		√		√
[†,‡]*Solenopsis molesta* (Say, 1836)		√		√
[‡]*Stenamma impar* Forel, 1901		√		
Temnothorax curvispinosus (Mayr, 1866)		√		√
Temnothorax longispinosus (Roger, 1863)		√		√
Temnothorax schaumi (Roger, 1863)				√
Tetramorium caespitum (Linnaeus, 1758)		√		√

Table 2. Rhode Island localities sampled during 2012 and 2013. Coordinates are decimal degrees North and West.

Location	Latitude	Longitude	Number of specimens	Number of species
Block Island				
North Light	41.22756	−71.57577	2	2
Clay Head	41.20857	−71.56125	15	9
Grace’s Cove Beach	41.18295	−71.60278	11	7
Sachem Pond	41.18216	−71.58499	8	8
West Side Road Bog	41.18105	−71.58492	3	3
The Nature Conservancy Office	41.16969	−71.55807	4	3
Nathan Mott Park	41.16907	−71.58424	15	7
Turnip Farm	41.16816	−71.59193	32	11
Dodge Cemetery	41.16640	−71.59641	1	1
Fort Barton and Barton Woods				
Edge of vernal pool	41.62698	−71.19828	5	4
Upland oak-hickory woodland	41.62654	−71.19550	6	4
Floodplain forest	41.62628	−71.19471	11	8
Cemetery wall	41.62562	−71.20684	1	1
Redoubt tower	41.62537	−71.20695	19	11
Mixed woodland	41.62537	−71.19629	19	10
Area of nonnative plants	41.62498	−71.20541	5	4
South County Museum				
Canonchet Farm	41.43858	−71.46060	13	13

Table 3. Coordinates (decimal degrees) of locations on Block Island where individual drag sheets were deployed and from which ant by-catch was collected.

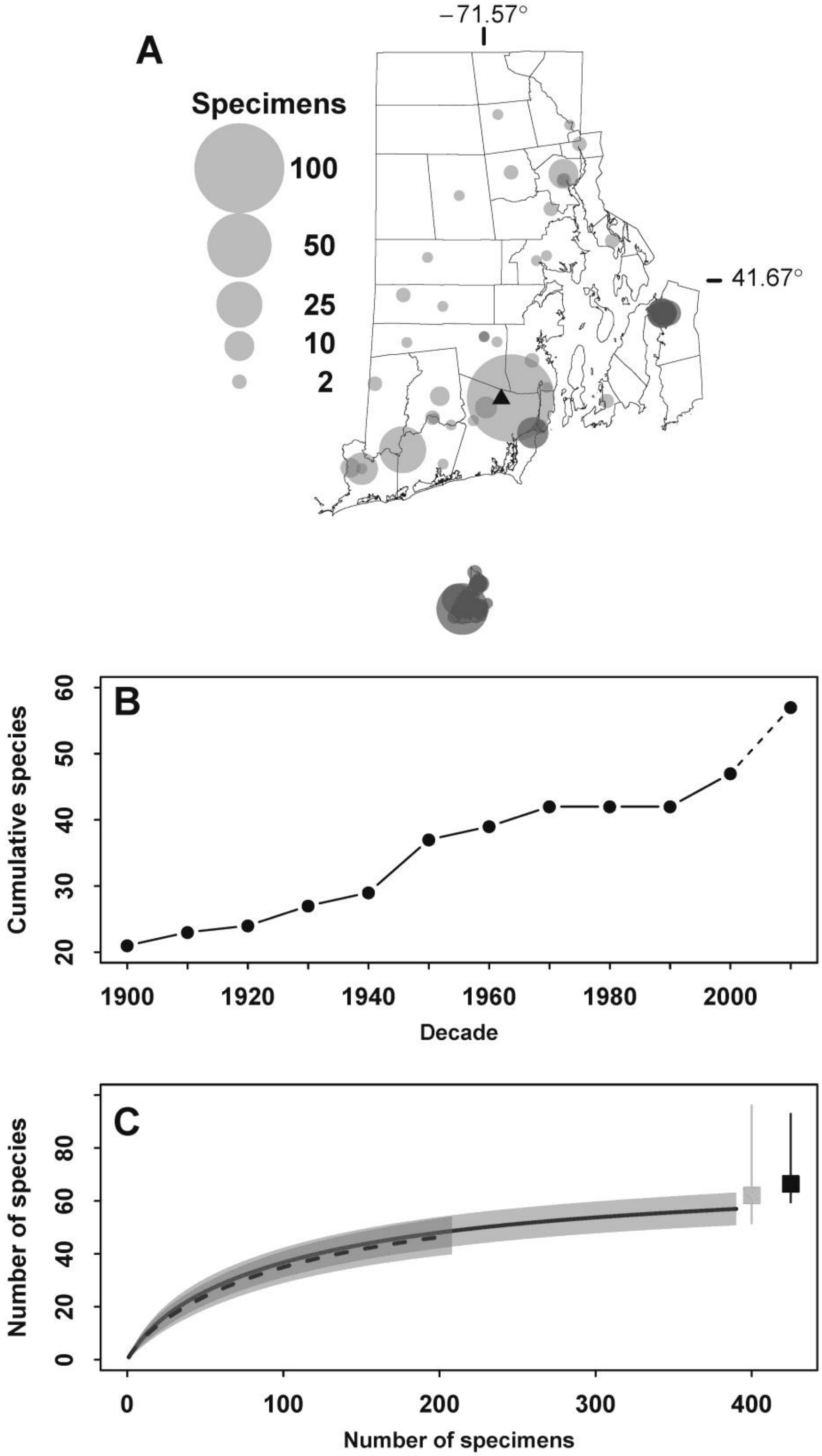
Latitide	**Longitude**	**Number of specimens**	**Number of species**
41.15649	-71.6070	2	2
41.15812	-71.58926	3	3
41.15824	-71.56432	2	2
41.15904	-71.55457	1	1
41.17593	-71.56686	1	1
41.17702	-71.59243	2	2
41.17793	-71.54173	1	1
41.17796	-71.56474	1	1
41.18596	-71.58641	1	1
41.18952	-71.56837	1	1
41.20129	-71.56573	1	1
41.20254	-71.56388	3	3
41.20740	-71.55980	1	1
41.20761	-71.56600	1	1
41.20796	-71.56068	1	1
41.21600	-71.56100	1	1
41.58240	-71.56432	1	1

Figure Legends

Figure 1. Collection frequency, species accumulation curve, and rarefaction and extrapolation curves of the ants of Rhode Island. **A** – Map of Rhode Island, showing numbers of specimens collected in each town through 2013; the geographic coordinates in the margins indicate the geographic center of the state. Light gray circles indicate numbers of specimens collected in each town, and dark gray circles indicate 2012−2013 collections. The solid triangle indicates the location of the University of Rhode Island and Block Island is at the bottom of the map. **B** – Decadal species accumulation curve for Rhode Island ants. The dotted line connects the historical specimen records (ca. 1900−2009) to the 2012−2013 collections. **C** – Rarefied species accumulation curves as a function of the number of specimens collected for historical specimen records (dotted line) and all specimen records through 2013 (solid line). Each curve shows the expected number of species for a given number of specimens collected, and the limits of the shaded areas around the curves are the 95% confidence bounds for each curve based on 100 randomizations. The solid squares to the right of the curves give the predicted species richness (gray – historical data; black – all data including 2012 and 2013 data); the vertical lines are the 95% confidence intervals of these predictions based on the Chao1 estimator (Chao et al., in press).

Figure 2. Relationships between ant species richness per county in New England and either (**A**) latitude or (**B**) mean annual temperature at the county centroid derived from WorldClim (Hijmans et al. 2005). White symbols are pre-2012 data from New England counties not in Rhode Island; pre-2012 data from Rhode Island counties are indicated by solid gray symbols; and new data for Washington and Newport Counties are shown in solid black symbols. The lines (dashed gray – historical relationship; solid black – based on new data)

are the best-fit local regressions through all of the data. Figure modified from Fig. 6.6 of Ellison et al. (2012).


A
Specimens
100
50
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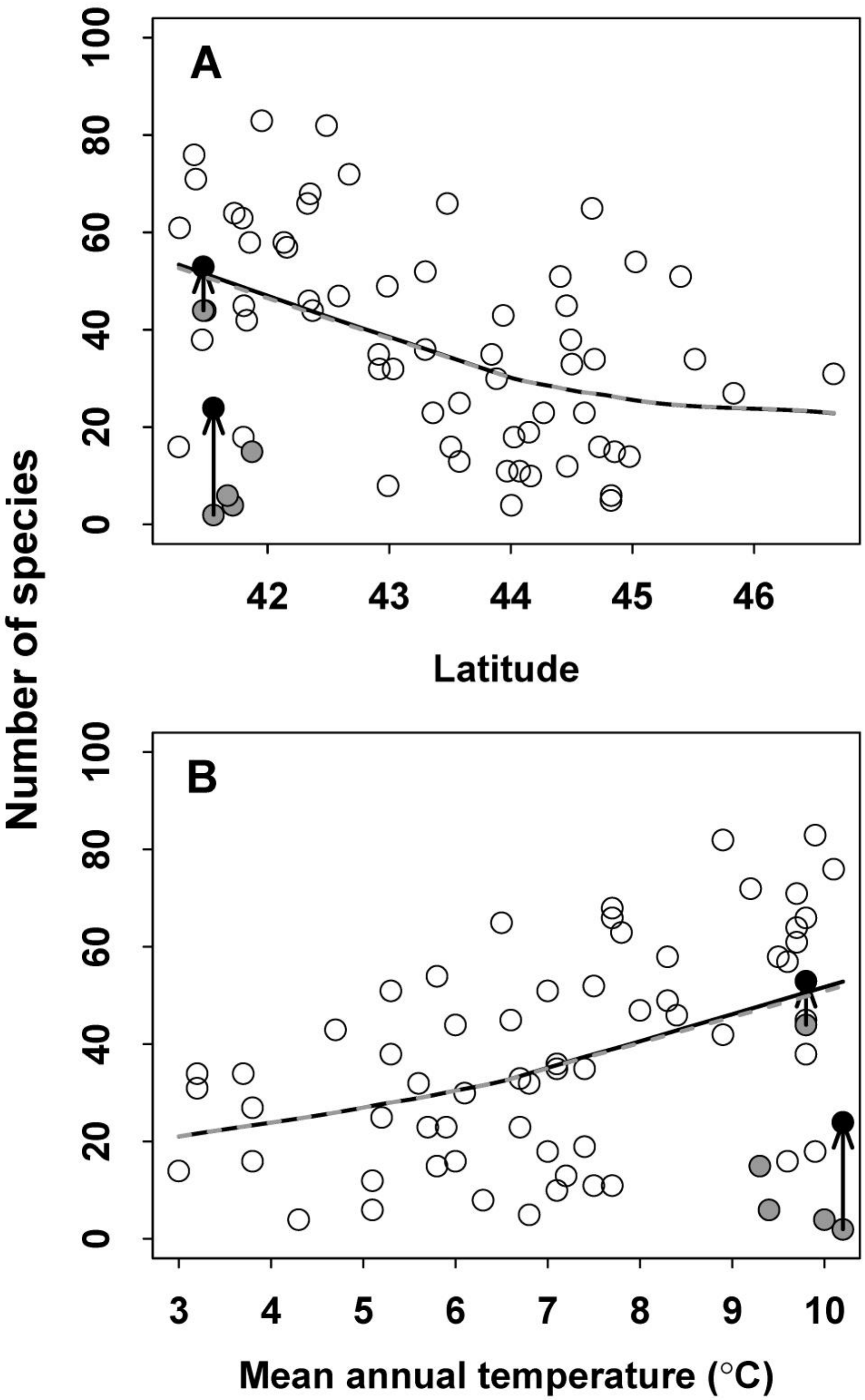
10
2
−71.57°
41.67°
B
Cumulative species
20
30
40
50
60
1900
1920
1940
1960
1980
2000
Decade
C
Number of species
0
20
40
60
80
0
100
200
300
400
Number of specimens

Figure 1


A
Number of species
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20
0
42
43
44
45
46
Latitude
B
3
4
5
6
7
8
9
10
Mean annual temperature (°C)

Figure 2