



Targeted Sampling Increases Knowledge and Improves Estimates of Ant Species Richness in Rhode Island

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1 **Targeted Sampling Increases Knowledge and Improves Estimates of Ant Species Richness**
2 **in Rhode Island**

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

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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

50 specimens had been collected from Providence (the other two were listed as being from Newport
51 and Kingston). Over one hundred years later, only 195 more specimens (for a total of 208) had
52 been recorded from Rhode Island, representing 21 of its 39 towns (Fig. 1A). These records
53 comprised 0.7% of all the total historical specimen records (1861- 2011) known from New
54 England and summarized by Ellison et al. (2012). However, these few Rhode Island specimens
55 included 48 species (Fig. 1B), or 36% of the regional total. The extrapolated (Chao1) estimate of
56 the total species richness (Chao et al. 2013) for Rhode Island in 2011 was 62, but this was
57 assuredly an underestimate, as the cumulative number of known species for Rhode Island had
58 shown no sign of reaching an asymptote (Fig. 1B).

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

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

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

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Methods

79 Historical data on Rhode Island ant diversity and distribution were extracted from the ants of
80 New England dataset (Ellison and Gotelli 2009) that were summarized in Ellison et al. (2012).
81 New England specimens in this dataset were collected between 1861 and 2011, but Rhode Island
82 specimens are known from ca. 1900 (undated records in Wheeler 1906; the first certain date of a
83 Rhode Island ant specimen – the Eastern Carpenter Ant *Camponotus pennsylvanicus* – is August
84 22, 1906) to 2009.

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

95 historical specimen records (4) for all of Rhode Island or elsewhere in New England. Both Block
96 Island and Barton Woods also have a range of different habitats in a small area.

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

103 At each of these locations, we slowly walked on and off trails within a 75×75 -m area
104 centered on the trail for at least one person-hour and collected representative workers from any
105 ant colonies we encountered. We turned over rocks, opened up decayed logs and stumps, dug
106 into anthills and ant mounds, and gleaned from foliage, branches, and trunks. This method of
107 timed hand-sampling accumulates far more species than baiting or pitfall trapping (Ellison et al.
108 2007). We also collected four 1-L litter samples from random locations within the plot, sieved
109 them in the field (1/8"-mesh), and collected all ants we extracted from the sieved litter.

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

115 At Barton Woods, ants were collected at the historic fort site and adjacent cemetery, and then
116 along the "Red Trail" in five different habitats: areas dominated by nonnative plants, an upland
117 oak-hickory woodland, the floodplain forest adjacent to Sin & Flesh Brook, the edge of a vernal

118 pool dominated by *Sphagnum* mosses, and the mixed woodland at the northeast junction of the
119 Red and Blue trails (Table 2). As we had done at Block Island, we searched for and collected
120 ants by hand from nests in each habitat for approximately 1 person-hour, and then sieved four 1-
121 L litter samples and extracted ants from the sieved litter in the field.

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

127 All ants were identified to species using keys in Ellison et al. (2012). As in Ellison et al.
128 (2012), local regression analysis was done using the loess function in R version 3.0.1 (R
129 Development Core Team 2013). Regressors used were latitude and mean annual temperature at
130 the county centroid derived from WorldClim (Hijmans et al. 2005). The Chao1 estimator of
131 species richness (Chao et al., in press) was computed using the species diversity module (for
132 both rarefaction and extrapolation) in EstimateS version 9 (Colwell 2013). Raw data are
133 available in the ants of New England dataset of the Harvard Forest data archive
134 (<http://harvardforest.fas.harvard.edu/data-archive>), dataset HF147. Voucher specimens are stored
135 in the Harvard Forest sample archive.

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Results

138 We accumulated 108 new specimen records (nests + samples from litter) from Block Island,
139 61 new specimen records from Tiverton, and 11 new specimen records from the South County

140 Museum. These 180 records increased the total number of specimen records for Rhode Island by
141 46%, and added nine new species to the current list of Rhode Island ants (Table 1; Figs. 2A, 2B).

142 On Block Island, we collected 18 species. All seven of the species collected by Goldstein in
143 1971 (*Tapinoma sessile*, *Lasius alienus*, *Lasius neoniger*, *Aphaenogaster rudis*, *Crematogaster*
144 *cerasi*, *Myrmica americana*, and *Tetramorium caespitum*) were re-collected in 2012, along with
145 11 others (Table 1). Six of these – *Lasius pallitarsis*, *Aphaenogaster fulva*, *Monomorium*
146 *emarginatum*, *Myrmica punctiventris*, an undescribed species of *Myrmica* (denoted *Myrmica* sp.
147 AF-scu), and *Solenopsis molesta* – were new records for Washington County. Of these six
148 species, all but *Monomorium emarginatum* and *Myrmica americana* (both previously collected in
149 Providence) also were new state records. Of additional note, only one of Block Island’s known
150 ants is nonnative (the Pavement Ant, *Tetramorium caespitum*). The European Fire Ant (*Myrmica*
151 *rubra*), which has been collected from the mainland coastal city of Newport, has not yet been
152 found on Block Island. Curiously, despite the abundance of dead trees, downed limbs, and
153 firewood, we found no carpenter ants (*Camponotus* species) on Block Island. Several long-time
154 island residents and local naturalists also reported never having seen carpenter ants on Block
155 Island.

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

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

166 Based on all Rhode Island collection records available to us through June 2013, we now
167 estimate that there are 66 ant species in the state with a 95% confidence interval = [59 – 93].
168 Including the new collection data in the regression analyses predicting number of ant species per
169 county as a function of latitude ($F_{1,65} = 9.87$, $P = 0.003$) or mean annual temperature ($F_{1,65} =$
170 12.12 , $P = 0.0009$) brought Washington County and Newport County more in line with
171 expectation with the rest of New England (the residual sums of squares decreased by 5% in both
172 cases with the inclusion of the new collection data), but did not significantly change the shape of
173 the relationship between these variables and ant species richness (Fig. 2).

174

175 Discussion

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

181 Five days of ant collecting nearly doubled the number of Rhode Island ant specimens (from
182 208 to 388), increased the number of ant species known from the state by nearly 20% (from 48 to
183 57), and increased the expected number of Rhode Island ant species from 62 to 66 while
184 decreasing the uncertainty (width of the confidence interval) of that estimate by 25% (Fig. 2).
185 However, the current upper limit of the 95% confidence interval is 93 species and the species

186 accumulation curve shows no sign of reaching an asymptote (Fig. 1B), so these results imply that
187 future collection efforts will almost assuredly continue to add ant species to the Rhode Island list
188 relatively quickly. It is also noteworthy that only two nonnative ants – *Myrmica rubra* and
189 *Tetramorium caespitum* – are currently known from Rhode Island. Other temperate-zone
190 nonnatives are likely to be found in urban areas (cf. Pećarević et al. 2010), and tropical tramps
191 are likely to be found in houses, greenhouses, and commercial buildings that are heated year-
192 round (Ellison et al. 2012). Searching for ants in these “non-traditional” settings – urban areas
193 and indoors – could easily detect nonnative species in Rhode Island.

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

206 The new data from Rhode Island also strengthened our confidence in relatively simple
207 regression models that predict ant species richness from easy-to-measure variables such as
208 latitude and mean annual temperature (Fig. 2). The other Rhode Island counties are still

209 “outliers” in these species-environment spaces (grey circles in Fig. 2), again emphasizing that
210 targeted ant collecting in northern and southeastern Rhode Island (i.e., the un-sampled towns in
211 Fig. 1) should be a priority. At the same time, even though Washington County is comparatively
212 well-sampled, the vast majority of the historical specimens are from around the University of
213 Rhode Island’s Kingston campus (solid triangle in Fig. 1A), and after our 2012 collecting forays,
214 more than half of the total specimens are from Block Island. Other habitats in Washington
215 County include pine barrens and extensive wetlands, both of which have unique ants. Pine
216 barrens in particular have very diverse ant assemblages (Boyd and Marucci 1979), and have
217 more ant species than any other habitat in New England (Ellison et al. 2012). In short, there is
218 still much to learn about the Rhode Island myrmecofauna, and there are many opportunities to
219 contribute to biodiversity studies right here in the northeast.

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226 the Future” program), Casey Finch, and Patrick O’Shea (Yale School of Public Health), who
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283 the Boston Natural History Society 7(7):1-24.

284

285 Table 1. Checklist of the ants of Rhode Island. Species names in **bold** were listed in Wheeler
 286 (1906). Superscripts indicate new state records since the publication of Ellison et al. (2012):
 287 †Collected on Block Island (Washington County), July 2012; ‡Collected at Barton Woods,
 288 Tiverton (Newport County), July 2012; *Collected at the South County Museum,
 289 Narragansett (Washington County) during the 2013 Rhode Island Natural History Survey
 290 BioBlitz.

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

<i>Formica subsericea</i> Say, 1836		√	√	√
<i>Lasius alienus</i> (Foerster, 1850)	√	√	√	√
<i>Lasius claviger</i> (Roger, 1862)			√	√
<i>Lasius interjectus</i> Mayr, 1866				√
<i>Lasius latipes</i> (Walsh, 1963)			√	
[‡] <i>Lasius nearcticus</i> Wheeler, 1906		√		
<i>Lasius neoniger</i> Emery, 1893				√
[†] <i>Lasius pallitarsis</i> (Provancher, 1881)				√
<i>Lasius speculiventris</i> Emery, 1893				√
<i>Lasius umbratus</i> (Nylander, 1846)		√	√	√
<i>Nylanderia parvula</i> (Mayr, 1870)				√
<i>Prenolepis imparis</i> (Say, 1836)				√

Myrmicinae

<i>Aphaenogaster fulva</i> Roger, 1863		√		√
* <i>Aphaenogaster picea</i> (Wheeler, 1908)				√
<i>Aphaenogaster rudis</i> (s.l.) Enzmann, 1947		√		√
<i>Aphaenogaster treatae</i> Forel, 1886				√
<i>Crematogaster cerasi</i> (Fitch, 1855)	√			√
<i>Crematogaster lineolata</i> (Say, 1836)			√	√
<i>Monomorium emarginatum</i> DuBois, 1986			√	√
<i>Monomorium viridum</i> Brown, 1943				√
<i>Myrmecina americana</i> Emery, 1895		√		
<i>Myrmica americana</i> Weber, 1939			√	√
* <i>Myrmica incompleta</i> Provancher, 1881				√
^{†,‡,*} <i>Myrmica punctiventris</i> Roger, 1863		√		√
<i>Myrmica rubra</i> (Linnaeus, 1758)		√		
[†] <i>Myrmica</i> sp. AF-scu				√
<i>Myrmica</i> sp. AF-smi		√		√
^{†,‡} <i>Solenopsis molesta</i> (Say, 1836)		√		√
[‡] <i>Stenamamma impar</i> Forel, 1901		√		
<i>Temnothorax curvispinosus</i> (Mayr, 1866)		√		√
<i>Temnothorax longispinosus</i> (Roger, 1863)		√		√
<i>Temnothorax schaumii</i> (Roger, 1863)				√
<i>Tetramorium caespitum</i> (Linnaeus, 1758)		√		√

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293 Table 2. Rhode Island localities sampled during 2012 and 2013. Coordinates are decimal degrees
 294 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

295

296

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

299

Latitude	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

300

301 **Figure Legends**

302 Figure 1. Collection frequency, species accumulation curve, and rarefaction and extrapolation
303 curves of the ants of Rhode Island. **A** – Map of Rhode Island, showing numbers of
304 specimens collected in each town through 2013; the geographic coordinates in the margins
305 indicate the geographic center of the state. Light gray circles indicate numbers of specimens
306 collected in each town, and dark gray circles indicate 2012–2013 collections. The solid
307 triangle indicates the location of the University of Rhode Island and Block Island is at the
308 bottom of the map. **B** – Decadal species accumulation curve for Rhode Island ants. The
309 dotted line connects the historical specimen records (ca. 1900–2009) to the 2012–2013
310 collections. **C** – Rarefied species accumulation curves as a function of the number of
311 specimens collected for historical specimen records (dotted line) and all specimen records
312 through 2013 (solid line). Each curve shows the expected number of species for a given
313 number of specimens collected, and the limits of the shaded areas around the curves are the
314 95% confidence bounds for each curve based on 100 randomizations. The solid squares to
315 the right of the curves give the predicted species richness (gray – historical data; black – all
316 data including 2012 and 2013 data); the vertical lines are the 95% confidence intervals of
317 these predictions based on the Chao1 estimator (Chao et al., in press).

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

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

326

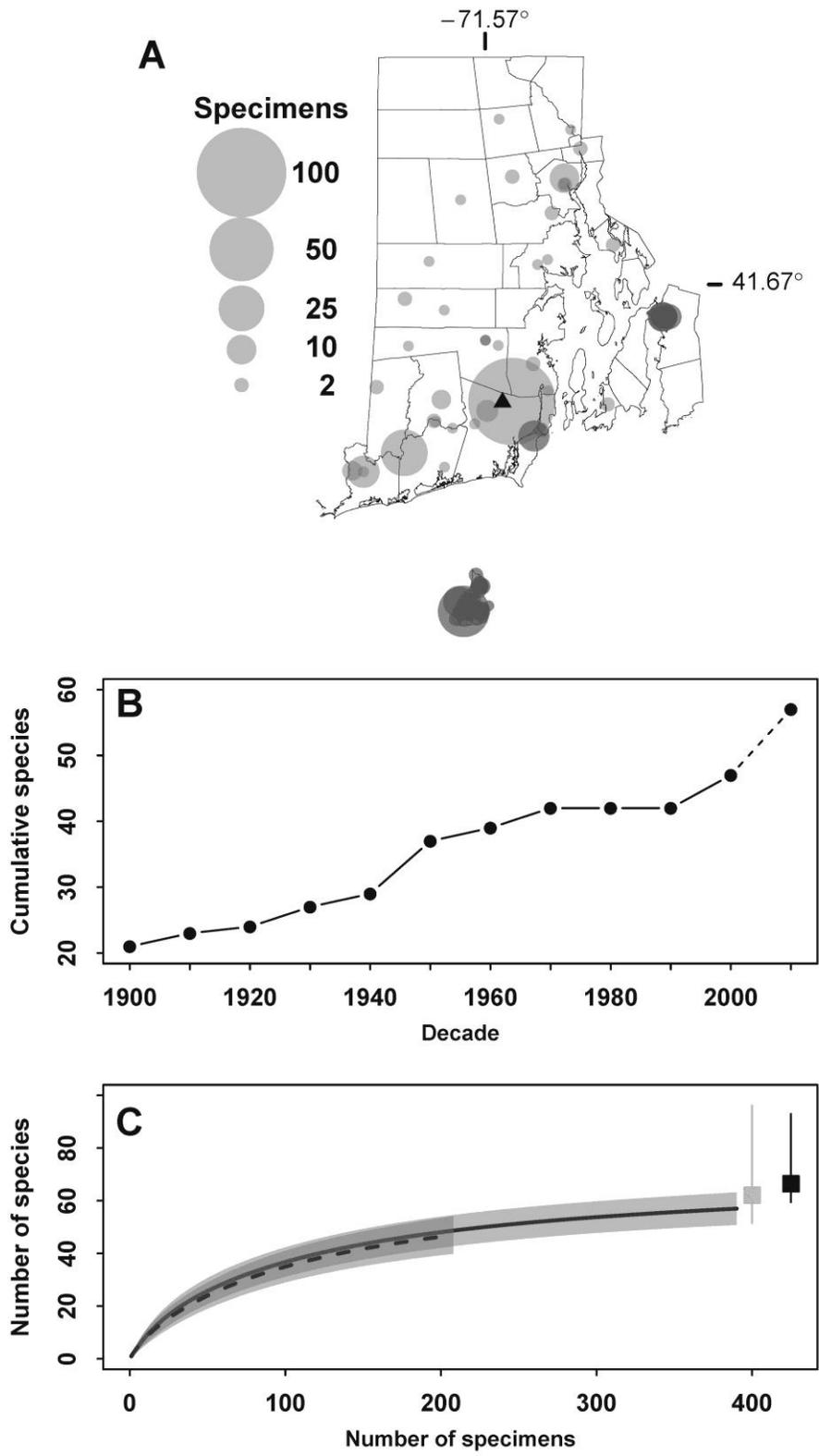
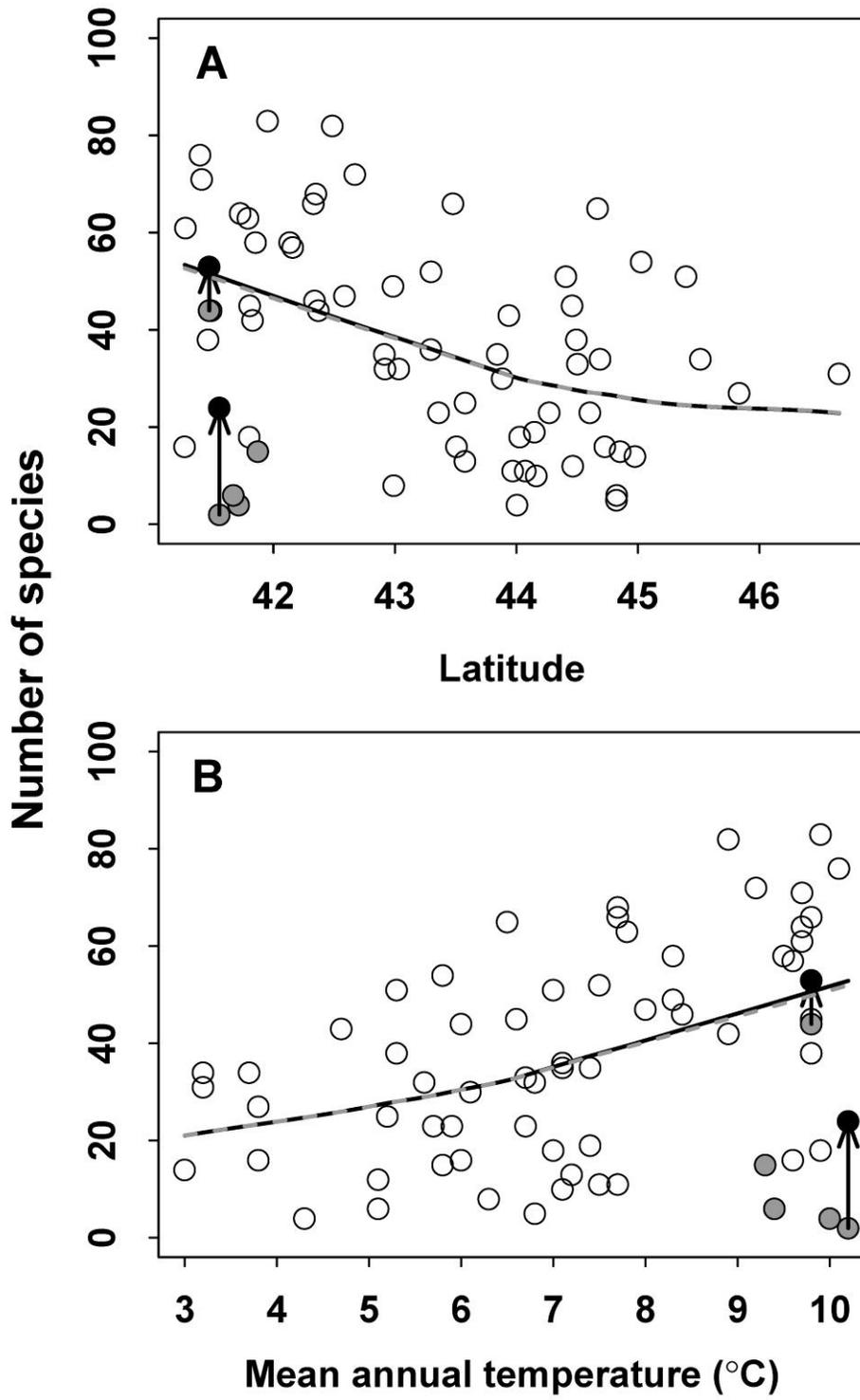


Figure 1



330

331

Figure 2