Journal of Medical Entomology Advance Access published July 17, 2015

FORENSIC ENTOMOLOGY

Seasonal and Geographic Variation in Biodiversity of Forensically Important Blow Flies (Diptera: Calliphoridae) in New Jersey, USA

L. M. WEIDNER,[1,2] D. E. JENNINGS,[3] J. K. TOMBERLIN,[4] AND G. C. HAMILTON[1]

J. Med. Entomol. 1–10 (2015); DOI: 10.1093/jme/tjv104

ABSTRACT Determining the time of colonization of human or other animal remains by blow flies (Diptera: Calliphoridae) can play an important role in criminal investigations. However, blow fly presence in a given area is strongly influenced by abiotic and biotic variables such as temperature and habitat. We wanted to assess the biodiversity of adult blow flies in New Jersey, USA, where very little is known about these taxa. Toward that end we collected adult blow flies biweekly from traps baited with bovine liver and placed across three regions in New Jersey over a 2-yr period (2011–2013). We collected and identified 9,257 adult calliphorids, comprising six genera and 12 species. Blow fly assemblages composed of these species varied by season, but community composition did not vary among regions within a given season. Three species, *Lucilia coeruleiviridis* (Macquart), *Lucilia sericata* (Meigen), and *Phormia regina* (Meigen) comprised 88.5% of all adult blow flies collected (42.6, 25.9, 20.0%, respectively). Combining all regions, the dominant species for both spring and summer was *L. coeruleiviridis* comprising 35.1% of all adults caught in spring and 64.1% in summer. *P. regina* was the dominant species in fall, totaling 40.1% of all adults caught and *Calliphora vicina* (Robineau-Desvoidy) was the dominant species for winter, totaling 44.8% of all adults caught. Our findings provide the first assessment of blow fly communities in New Jersey, and these results can be applied to surrounding states where data are severely lacking for forensic application.

KEY WORDS forensic entomology, community composition, *Lucilia coeruleiviridis*, *Lucilia sericata*, *Phormia regina*

One of the most important instances in which insects can benefit criminal investigations is the determination of the time of colonization of human or animal remains by blow flies (Diptera: Calliphoridae), which can subsequently be used to predict a minimum postmortem interval (m-PMI) when assuming colonization after death or that larvae did not migrate from another food source to the corpse (Greenberg 1991, Amendt et al. 2004). However, the presence of a specific blow fly species in a given area is influenced by many abiotic and biotic variables such as temperature and habitat. Knowing which species are present in particular areas is vital, as this information can be used to determine the m-PMI or be indicative of movement of the remains (Catts and Goff 1992). Consequently, surveys of adult blow flies are important, as they provide a reliable record of their potential community composition and species abundance at a given point in time.

Although the development time of blow fly larvae is commonly used in determining when insect colonization occurred, understanding patterns of blow fly adult arrival to carcasses can also help in this determination, and potentially that of body placement (Mohr and Tomberlin 2014). Mohr and Tomberlin (2014) found that when investigating blow fly adult arrivals to swine carcasses, time of day was a significant predictor of the dominant blow fly species in Texas, across seasons. Because of the different temperature ranges and environmental conditions associated with seasons, blow fly arrival to a carcass can be profoundly influenced by these divisions of the year.

Seasons have long been known to affect blow fly species abundance and community composition such that cooler temperatures during fall and winter result in lower blow fly abundance, and warmer temperatures during spring and summer result in increased blow fly numbers (Deonier 1940, Cruickshank and Wall 2002, Tenorio et al. 2003, Gruner et al. 2007, Sabanoğlu and Sert 2010, Brundage et al. 2011, Benbow et al. 2013, Mohr and Tomberlin 2014). In addition to season, geographic location can also influence blow fly communities. For example, some species such as *Cynomya*

[1] Department of Entomology, Rutgers, The State University of New Jersey, 93 Lipman Drive, New Brunswick, NJ 08901.
[2] Corresponding author, e-mail: laurenmweidner@gmail.com.
[3] Department of Entomology, University of Maryland, 4112 Plant Sciences Bldg., College, Park, MD 20742.
[4] Department of Entomology, Texas A & M University, TAMU 2475, College Station, TX, 77843.

cadaverina Robineau-Desvoidy, *Calliphora vomitoria* (L.), and *Lucilia sericata* (Meigen) are widespread throughout the USA while other species such as *Lucilia mexicana* Maquart and *Calliphora graham* Aldrich are typically found in distinct geographic locations in the USA (south and west, respectively; Whitworth 2006, Marshall et al. 2011).

Presently, very little is known about blow fly distribution and diversity in the northeastern USA (such as New Jersey), as most studies have focused on the southern, Mid-western, and western USA including Arizona (Deonier 1942), Virginia (Tabor et al. 2004), Louisiana (Watson and Carlton 2005), Texas (Tenorio et al. 2003, Mohr and Tomberlin 2014), Michigan (Tarone and Foran 2006, Zurawski et al. 2009), and California (Brundage et al. 2011). New Jersey is environmentally diverse with regional variation in human population densities and environment characteristics. For example, the northwest corner of New Jersey is categorized as the Ridge and Valley ecoregion and moving southeast throughout the state there are also Northeastern Highlands, Northern Piedmont, Middle Atlantic Coastline Plain, and Atlantic Coastal Pine Barren ecoregions (Woods et al. 2007). Such diversity in habitats allows for various blow fly species to be present (Hall 1948, Richards and Goff 1997, Anderson 2011, Tomberlin and Benbow 2015).

The objective of this study was to identify the blow fly species found in New Jersey as well as their abundance and community composition across regions and seasons. The adult blow flies collected in these traps were analyzed because previous studies have shown that adults collected in traps baited with bovine liver were a valid approach to survey forensically important Calliphoridae (Brundage et al. 2011). Because factors such as temperature and habitat are known to influence blow fly activity and distribution (Gruner et al. 2007, Sabanoğlu and Sert 2010, Brundage et al. 2011), we hypothesized that community composition, species richness, and diversity would be significantly different across different geographical regions and season. These findings can be used to aid in criminal investigations locally and in the surrounding area.

Materials and Methods

Study Sites. Six sites across New Jersey were surveyed for blow flies over a 2-yr period (September 2011–August 2013; Fig. 1). Sites were categorized into three regions (north, central, and south) based on a combination of quantitative similarities in latitude, elevation, and population density and qualitative assessment of land use; the closest adjacent sites were ~24 km apart, and the most distant sites were separated by 164 km. Distance between traps in each site ranged from 51–1,717 m, site elevation ranged from 14.3–256.9 m, and population density varied from ~116–1,012 persons per square kilometer (ppsk; U.S. Census Bureau 2010). The north region consisted of sites in Branchville, NJ (41° 10′18.38″ N, 74° 50′42.21″ W) and Pittstown, NJ (40° 33′32.19″ N, 74° 57′35.38″ W), and was composed primarily of hardwood forest and open farmland at a mean (± SE) elevation of 217.7 ± 15.3 m and a population density ranging from 111–116 ppsk. The central region consisted of sites in New Brunswick, NJ (40° 28′45.44″ N, 74° 25′44.69″ W) and Princeton, NJ (40° 20′27.46″ N, 74° 39′04.36″ W) at a mean elevation of 27.5 ± 2.9 m and a population density ranging from 630–1012 ppsk. Lastly, the south region consisted of sites in Cream Ridge, NJ (40° 07′00.48″ N, 74° 31′18.04″ W) and Chatsworth, NJ (39° 42′52.16″ N, 74° 30′40.45″ W) and had a high concentration of pine forests and sandy farmlands located at a mean elevation of 19.9 ± 2.5 m and a population density ranging from 217–519 ppsk.

Collection Technique. A preliminary experiment was conducted for 5 mo (April through to August 2011) to determine the appropriate length of time to leave out the baited traps. We found that ~7.2–30.3 accumulated degree days (ADD; Base-10°C) was a sufficient length of time to capture adults, eggs, and larvae of initial colonizers. This base temperature was chosen because it is a commonly used value in blow fly development, especially with warmer month species, which make up the majority of this collection; this temperature was held constant throughout the 2-yr period for comparison purposes (Deonier 1940, Wall et al. 1992). Four baited traps were deployed at each of the six sites biweekly for a length of 1–7 d, averaging 16.5 ± 0.9 ADD (Base-10°C).

Each trap consisted of a Ziploc Double Zipper Heavy Duty Freezer Gallon Bag (26.8 by 27.3 cm^2; S.C. Johnson & Son Inc., Racine, WI) with a plastic cone trap taken from a RESCUE! Disposable Fly Trap (Model # FTD-DB12, Sterling International, Inc. Spokane, WA) and held in place with binder clips. Within each trap ~50–60 g bovine liver was added on top of half a paper towel. Liver was obtained from Bringhurst Meats in southern New Jersey. Each trap was suspended from a tree branch in order to reduce the risk of predation. Trap heights ranged from 1.45–2.45 m, with an average height (± SE) of 1.83 ± 0.10 m. When the traps were collected, the plastic cone top was removed; the bag was sealed and taken back to the laboratory in New Brunswick, New Jersey. For each trap, we recorded if it contained adults, larvae, and eggs.

Identification. Adult identifications were made based on morphological characteristics using the keys of Whitworth (2006), Marshall et al. (2011) and Jewiss-Gaines et al. (2012). Voucher specimens were sent to Dr. Terry Whitworth at Washington State University for verification and voucher specimens were also deposited into the Rutgers University Entomological Museum located on Cook Campus, New Brunswick, New Jersey.

Data Analysis. Blow fly communities were analyzed both by region and season. Seasons were defined by the calendar year and temperature (Table 1); spring (March–May), summer (June–August), fall (September–November), and winter (December–February). We were interested in examining if temperature differed by region and season. Temperature values were not normally distributed and could not be appropriately transformed; therefore, Kruskal–Wallis

Fig. 1. Map of New Jersey with labeled study sites.

Table 1. The mean temperature (°C) and mean precipitation (cm) for each region when traps were in the field from 2011–2013 (±SE)

Month	North		Central		South	
	Avg. temp.	Avg. ppt.	Avg. temp.	Avg. ppt.	Avg. temp.	Avg. ppt.
Jan.	1.15 ± 0.81	0.47 ± 0.15	3.57 ± 0.67	0.36 ± 0.12	4.41 ± 0.80	0.47 ± 0.13
Feb.	−1.09 ± 0.45	0.12 ± 0.05	2.78 ± 0.54	0.16 ± 0.05	2.10 ± 0.57	0.18 ± 0.06
Mar.	7.08 ± 1.15	1.25 ± 0.75	8.94 ± 1.12	0.22 ± 0.09	7.92 ± 0.92	0.20 ± 0.07
April	10.08 ± 0.76	0.09 ± 0.04	12.17 ± 0.73	0.08 ± 0.05	11.25 ± 0.78	0.06 ± 0.04
May	16.11 ± 0.87	0.33 ± 0.09	17.65 ± 0.91	0.38 ± 0.10	17.13 ± 0.93	0.19 ± 0.06
June	19.67 ± 0.75	1.21 ± 0.43	21.21 ± 0.70	0.60 ± 0.31	21.25 ± 0.81	0.28 ± 0.09
July	22.88 ± 0.44	0.43 ± 0.24	24.54 ± 0.52	0.69 ± 0.39	23.36 ± 0.59	0.30 ± 0.13
Aug.	21.49 ± 0.39	0.19 ± 0.10	23.30 ± 0.33	0.48 ± 0.28	22.58 ± 0.43	0.10 ± 0.09
Sept.	18.04 ± 0.70	1.35 ± 0.40	21.31 ± 0.56	0.66 ± 0.23	20.75 ± 0.84	0.61 ± 0.22
Oct.	12.47 ± 0.63	0.20 ± 0.10	13.72 ± 0.56	0.16 ± 0.10	12.66 ± 0.54	0.14 ± 0.07
Nov.	5.33 ± 0.64	0.05 ± 0.03	7.09 ± 0.65	0.04 ± 0.03	6.34 ± 0.65	0.05 ± 0.03
Dec.	1.45 ± 0.53	0.54 ± 0.19	4.70 ± 0.56	0.52 ± 0.14	4.84 ± 0.55	0.63 ± 0.21

one-way analyses of variance (ANOVA) were conducted to determine regional and seasonal differences, followed by a Wilcoxon Rank-Sum test when Kruskal–Wallis results were statistically significant ($P < 0.05$).

We then calculated the relative abundance, species richness, and Shannon diversity index (H) for each season based on region. For the same reason described above, Kruskal–Wallis one-way ANOVA were conducted to determine regional and seasonal differences in the relative abundance of the seven most common species by trap (those comprising > 1% of the total collection), followed by a Wilcoxon Rank-Sum test when Kruskal–Wallis results were statistically significant ($P < 0.05$). Species richness however, was approximately normally distributed and therefore one-way ANOVA were performed to determine regional and seasonal differences, followed by a Tukey HSD when the ANOVA results were statistically significant ($P < 0.05$). Diversity values were not normally distributed and therefore were analyzed using the same method as relative abundance. Prior to analyzing species composition, rare taxa (those comprising <1% of the total collection) and any sample collection period where the total collection consisted of zero or a single individual were removed. Blow fly community composition (based on counts) was initially analyzed using nonmetric multidimensional scaling (NMDS). Additionally we used multi-response permutation procedures (MRPP) with Bonferroni corrections for multiple pairwise comparisons (McCune and Grace 2002), followed by indicator species analysis (ISA) which followed the general methods of Dufrene and Legendre (1997). An indicator value displays the taxon or taxa that are considered the best predictor of that season with a value of 0 showing no indication and a value of 100 showing perfect indication. Analyses were conducted using R 3.1.2 (R Core Team 2014) and JMP 10 (SAS Institute Inc. 2012).

Results

Species Richness and Diversity. A total of 9,257 blow fly specimens were collected and identified to species. These specimens consisted of 12 species across six genera (Table 2). The central region had the highest total number of adult blow flies captured during the survey (4,688), followed by the southern (3,330) and northern (1,239) regions. There was a significant difference in temperatures between seasons ($H = 682.60$, $df = 3$, $P < 0.001$), but there were no significant differences in regional temperatures in fall ($H = 5.13$, $df = 2$, $P = 0.077$) or spring ($H = 3.27$, $df = 2$, $P = 0.194$). Significant differences were found between regional temperatures in summer ($H = 9.83$, $df = 2$, $P = 0.007$) and winter ($H = 46.46$, $df = 2$, $P < 0.001$). Summer temperatures from the south region were not significantly different compared to the central or north region ($P > 0.05$). However, significant differences in temperatures were present in the summer between the north and central region ($P = 0.002$) with central being warmer. In the winter, there were no significant differences in temperature between the central and south region ($P > 0.05$) while the north region was significantly colder in comparison to both the central region ($P < 0.001$) and the south region ($P < 0.001$). The central region had the highest number of blow flies collected in the spring and fall, while the south region had the highest number of blow flies collected in the summer and winter. Although the central region had higher temperatures in the summer, it also had higher precipitation averages.

Table 2. Total number and percentage of Calliphoridae species collected in New Jersey from September 2011 through August 2013

Genus	Species	Total collected	Percent (%)
Calliphora	*vomitoria*	201	2.2
	vicina	392	4.2
	livida	207	2.2
Phormia	*regina*	1855	20.0
Lucilia	*sericata*	2400	25.9
	coeruleiviridis	3943	42.6
	illustris	43	0.5
	silvarum	1	<0.1
Cochliomyia	*macellaria*	5	0.1
Pollenia	*rudis*	31	0.3
	pediculata	62	0.7
Cynomya	*cadaverina*	117	1.3

Relative abundance was compared across each region based on season and it was determined that species composition varied among each region for each season (Fig. 2). Along with abundance, dominant species varied across region during each season. The dominant species in the north region during spring were *Calliphora livida* Hall (34.4%), *C. vicina* (17.7%), and *Calliphora vomitoria* (L.) (21.8%), the central region consisted of *Lucilia coeruleiviridis* (Macquart) (17.9%), *Lucilia sericata* (Meigen) (23.2%), and *Phormia regina* (36.5%), and the south region was predominantly *L. coeruleiviridis* (70.0%). During summer, *L. coeruleiviridis* (66.0%) and *P. regina* (15.8%) were dominant in the north, *L. coeruleiviridis* (29.0%) and *L. sericata* (62.3%) in central, and *L. coeruleiviridis* (91.5%) in south. In the fall, *P. regina* (59.3%) was dominant in the north, *L. sericata* (51.1%) and *P. regina* (36.1%) in central, and *L. coeruleiviridis* (39.3%) and *P. regina* (45.8%) in south. Lastly, in winter *C. vicina* (100%) was dominant in the north, *P. regina* (27.4%) and *C. vicina* (45.5%) in central, and *C. vicina* (37.5%), *C. vomitoria* (25.0%), and *Cynomya cadaverina* (Robineau-Desvoidy) (31.3%) in south (Fig. 2).

Blow fly species richness did not differ significantly between regions ($F = 1.188$, $df = 2$, $P = 0.328$), but did differ significantly between seasons ($F = 25.001$, $df = 3$, $P < 0.001$). Species richness was highest in the spring for all regions but did not differ significantly from summer or fall ($P > 0.05$). Winter had significantly lower richness compared to spring ($P < 0.001$), summer ($P < 0.001$), and fall ($P = 0.003$; Fig. 3). There was no significant difference in diversity between regions ($P > 0.05$) or seasons ($P = 0.052$). Although there were larger numbers collected during the summer, ($n = 557$, $n = 1{,}643$, $n = 2{,}044$, north, central, and south respectively) and more species overall, two species accounted

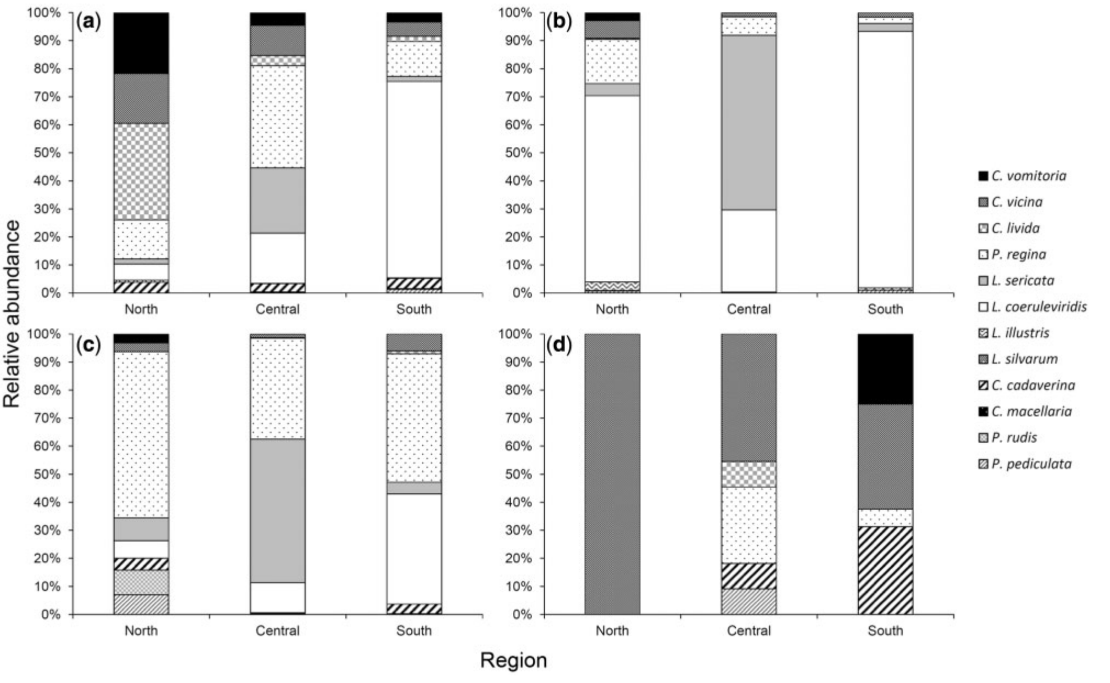

Fig. 2. Relative abundance on overall totals of blow flies in each region (north, central, south) based on season. Shown are (a) spring populations ($n = 395$, $n = 1,137$, $n = 888$, respectively), (b) summer populations ($n = 557$, $n = 1,643$, $n = 2,044$, respectively), (c) fall populations ($n = 285$, $n = 1,897$, $n = 382$, respectively), and (d) winter populations ($n = 2$, $n = 11$, $n = 16$, respectively).

for more than 60% of all blow flies collected in those regions; *L coeruleiviridis* (66.0%) in north, *L. sericata* (62.3%) in central and *L. coeruleiviridis* (91.5%) in south.

Community Assemblage. The global model of blow fly communities indicated a significant difference among regions, but the Bonferroni adjusted *P*-values from the pairwise comparisons did not identify any significant differences between central and north (MRPP: $A = 0.020$, $P = 0.108$), central and south (MRPP: $A = 0.021$, $P = 0.099$), and north and south (MRPP: $A = < -0.001$, $P = 1.000$; Fig. 4a). However, blow fly communities differed between fall and spring (MRPP: $A = 0.035$, $P = 0.012$), fall and summer (MRPP: $A = 0.078$, $P = 0.006$), spring and summer (MRPP: $A = 0.108$ $P = 0.006$), spring and winter (MRPP: $A = 0.081$, $P = 0.006$) and summer and winter (MRPP: $A = 0.141$, $P = 0.006$), while no difference was found between fall and winter communities (MRPP: $A = 0.024$, $P = 0.378$; Fig.4b). Multiple species were shown to be indicators of spring (with *C. livida* being the strongest), and the only indicator for summer was *L. coeruleiviridis* with no indicator species found for fall and winter (Table 3). Only one regional indicator species was found, which was *L. sericata* for the central region (Table 3).

Calliphora vomitoria, *C. vicina*, *C. livida*, *P. regina*, *L. sericata*, *L. coeruleiviridis*, and *C. cadaverina* were the seven most common (>1% of total collection) blow flies species during the present study (Table 2). All of these species had significant differences in their relative abundance between seasons, while *P. regina*, *L. sericata*, and *L. coeruleiviridis* had significant differences between regions as well (Table 4). *Calliphora vomitoria* and *C. livida* had differences between spring and all other seasons, while *P. regina* had differences between all seasons excluding fall and spring (Table 4). *Lucilia sericata* populations differed significantly between central, north and south regions during spring (23.2, 1.8, and 1.8%, respectively), summer (62.3, 4.3, and 2.8%, respectively) and fall (51.1, 8.1, and 4.2%, respectively) collections (Table 4). *Lucilia coeruleiviridis* had larger populations in the south region in comparison to north and central during spring (70.1, 5.8, and 17.9%, respectively), summer (91.5, 66.4, and 29.34%, respectively), and fall (39.3, 6.32, and 10.8%, respectively). However, abundance only differed significantly between the north and central and north and south regions.

Discussion

The present study is the first to examine blow fly communities continuously for 2 yr in New Jersey. Using traps baited with bovine liver, a total of 12 blow fly species were collected across the state. *Lucilia coeruleiviridis*, *L. sericata*, and *P. regina* were the dominant blow fly species found, totaling 88.5% of capture, 42.6, 25.9, and 20.0% of capture, respectively. Blow fly communities were shown to differ in comparisons between all seasons, with the exception of fall and winter. In general these findings were consistent with previous

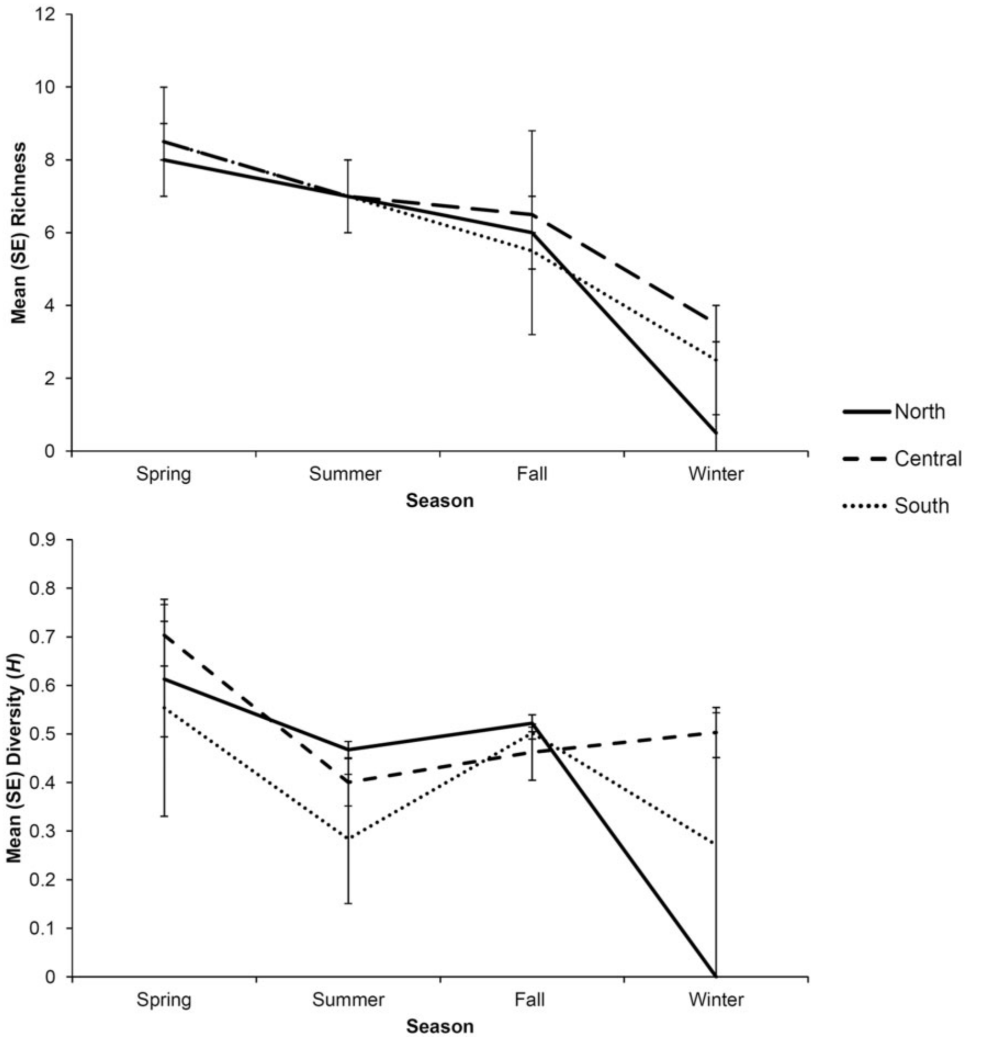

Fig. 3. Mean (SE) species richness (a) and mean (SE) species diversity (b) across season and region.

studies, such that higher totals of blow flies were collected in warmer months (summer and spring) than in cooler months (fall and winter; Fig. 2).

We found that four species (*C. livida*, *C. vomitoria*, *C. vicina*, and *C. cadaverina*) were strong indicators of spring, while one species (*L. coeruleiviridis*) was a strong indicator of summer. *Calliphora* spp. are considered cooler month species and can be found colonizing remains in large numbers in fall, winter, and spring, depending on the geographic location (Watson and Carlton 2005, Mohr and Tomberlin 2014, Matuszewski et al. 2010). Hall (1948) stated that *C. vicina* has a Holarctic distribution and is abundant in March and April, specifically in the Midwest. Less work has been conducted on *C. livida*, but Hall (1948) classified this species as having a Nearctic distribution and being found in the central USA in April and May. *Calliphora vomitoria* and *C. cadaverina* are also commonly found in early spring and late fall, consistent with the findings of the present study (Hall 1948, Schroeder et al. 2003). *Lucilia* spp. are typically considered a summer month species often being collected in June through August in the USA (Hall 1948, Greenberg 1973, Tomberlin and Adler 1998, Brundage et al. 2011). Schroeder et al. (2003) only collected *L. sericata* from human remains from May to October in Germany, while Benbow et al. (2013) determined *L. coeruleiviridis* was a significant indicator of the fresh stage of decomposition of swine carrion during summer (July) and autumn (November) in Ohio.

Phormia regina was present in all four seasons, but most prevalent in the fall, with 1,028 individuals (40.1% of the total for that season) when combining all three regions studied. Brundage et al. (2011) found *P. regina* to be a dominant blow fly species in California and also collected adults during all four seasons. *Lucilia sericata* was a dominant species (>20% of adults collected) in the central region of New Jersey in all seasons excluding winter, with the greatest numbers during the summer and fall, similar to the findings of

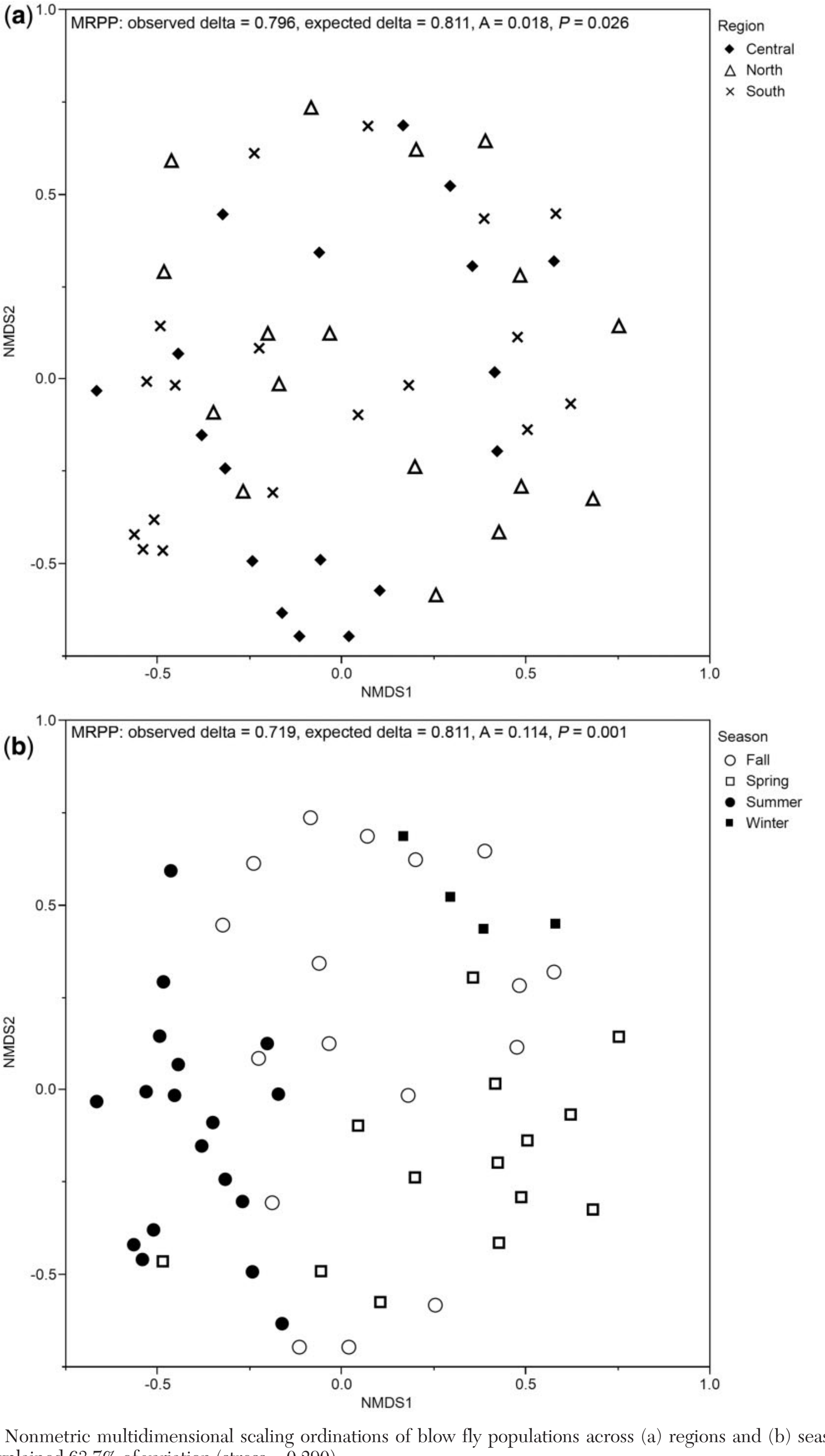

Fig. 4. Nonmetric multidimensional scaling ordinations of blow fly populations across (a) regions and (b) seasons. This ordination explained 63.7% of variation (stress = 0.290).

Anderson and VanLaerhoven (1996), Tomberlin and Adler (1998), and Brundage et al (2011). Due to the high numbers collected in the central region (2,257) compared to the north (54) or south (89) during this entire study, there may be a preference for this species in areas with higher population densities, which could support the observation that *L. sericata* favors a more urbanized environment (Isiche et al. 1992, Anderson 2000, Hwang and Turner 2005, Brundage et al. 2011). Although *L. coeruleiviridis* was a dominant species in all three regions of New Jersey, it was particularly abundant in summer, when it had larger populations in the southern region in comparison to north and central. *Lucilia coeruleiviridis* was the most abundant blow fly species captured during the present survey, and has been the dominant species collected from pig carcasses in Florida (Gruner et al. 2007), Virginia (Tabor et al. 2004), and West Virginia (Joy et al. 2006). Although this species is common along the eastern coast of the USA, little research has been conducted on their biology and development due to their difficulty to maintain more than the initial generation in laboratory conditions (Weidner et al. 2014).

Of the 12 species collected during the present survey, 10 were collected across all three regions; however, *L. silvarum* (Meigen) and *Cochliomyia macellaria* (F.) were collected in only one region. We collected only one individual of *L. silvarum,* which was found during the summer in northern New Jersey. While it was considered a forensically important species, *L. silvarum* is known more for parasitizing frogs and other amphibians (Marshall et al. 2011). *Cochliomyia macellaria* was another rare species in this survey, with five individuals collected during the fall in the central region. *Cochliomyia macellaria* is a facultative parasite and is found to be a common colonizer of remains in the southern USA (Byrd and Butler 1996, Boatright and Tomberlin 2010, Mohr and Tomberlin 2014, Owings et al. 2014).

Table 3. Indicator species for season or region in New Jersey

Group	Species	Indicator value	*P* value
Season			
Spring	*Calliphora livida*	86.96	0.001
	Calliphora vomitoria	77.40	0.001
	Calliphora vicina	56.77	0.013
	Cynomya cadaverina	51.66	0.012
Summer	*Lucilia coeruleiviridis*	64.69	0.008
Region			
Central	*Lucilia sericata*	73. 05	0.001

An indicator value and *P* value are provided for each species.

Although there were no significant differences in diversity between seasons, diversity decreased from spring to summer in all three regions as the dominant species accounted for more than 60% of all adults collected; *L. coeruleiviridis* in the north and south region and *L. sericata* in the central region. Diversity then decreased through fall and winter, with the exception of the central region. The northern region had two adults of one species, *C. vicina*, collected. This is most likely due to the mean temperatures being significantly lower than other regions potentially leading to blow flies there being less active. During the winter months of this study (December–February) the mean temperature for when the traps were in the field did not exceed 5°C, and during this time 29 adults were collected, signifying their potential importance in m-PMI determination in colder months in northeastern USA.

Among the collected blow fly adults in winter, there were four *P. regina*. This observation is of interest because Deonier (1942) found that when the average monthly temperature dropped below 10°C the activity of *P. regina* was restricted and reduced. Additionally, Nabity et al. (2006) found that *P. regina* completed development at a minimum temperature of 14°C, and their data showed that a minimum threshold value ranged from 12.2–14.0°C. The differences seen in this study compared to past literature could potentially be due to genetic differences in the populations (Tarone and Foran 2006, Gallagher et al. 2010, Tarone et al. 2011, Jordaens et al. 2013, Owings et al. 2014). The mean temperature for when the traps were out during the winter months in this present study did not exceed 5°C, and although this does not provide evidence for development of *P. regina*, it does suggest that further work is warranted on the development of this species at lower temperatures in the northeastern USA.

One limitation of the present study is that for logistical reasons baits were used instead of an entire carcass. The olfactory cues released from bovine liver will likely

Table 4. Regional and seasonal differences between the relative abundance on the dominant blow fly species using Kruskal–Wallis one-way ANOVAs and Wilcoxon Rank-Sum tests

Species	Kruskal–Wallis		Wilcoxon								
			Region			Season					
	Region	Season	C v N	C v S	N v S	Sp v Su	Sp v Fa	Sp v Wi	Su v Fa	Su v Wi	Fa v Wi
C. vomitoria	1.95 (0.377)	**51.57 (<0.001)**	–	–	–	**<0.001**	**<0.001**	**<0.001**	ns	ns	ns
C. vicina	3.19 (0.203)	**11.02 (0.012)**	–	–	–	ns	ns	**0.005**	ns	**0.007**	ns
C. livida	3.11 (0.211)	**65.44 (<0.001)**	–	–	–	**<0.001**	**<0.001**	**<0.001**	ns	ns	ns
P. regina	**7.79 (0.020)**	**48.52 (<0.001)**	**0.006**	ns	ns	**0.003**	ns	**<0.001**	**<0.001**	**<0.001**	**<0.001**
L. sericata	**47.03 (<0.001)**	**44.89 (<0.001)**	**<0.001**	**<0.001**	**0.017**	**0.040**	ns	**<0.001**	ns	**<0.001**	**<0.001**
L. coeruleiviridis	**9.35 (0.009)**	**112.31 (<0.001)**	**0.023**	ns	**0.005**	**<0.001**	**0.048**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
C. cadaverina	3.00 (0.223)	**47.01 (<0.001)**	–	–	–	**<0.001**	**0.005**	**<0.001**	**<0.001**	ns	**0.030**

C, central; N, north; S, south; Sp, spring; Su, summer; Fa, fall; Wi, winter; ns, not significant ($P > 0.05$); numbers in bold signify significant values.

not be as extensive or strong (due to size) as an entire carcass. Although bovine liver is commonly used in baited traps (Anderson 2000, Brundage et al. 2011, Berg and Benbow 2013), it may not be sufficient to attract all forensically important blow fly species. For example, preliminary work examining blow fly colonization on piglet carcasses conducted in New Brunswick, NJ, collected adults of a species not captured in the present study, *Protophormia terraenovae* (Robineau-Desvoidy) (L.M.W unpublished data). Therefore we suggest that bait choice should be carefully considered when examining blow fly communities, and future work on forensically important insect taxa should consider the use of pig carcasses.

In conclusion, our results provide baseline data regarding blow fly communities in New Jersey, and these data could be used as a reference in the northeastern USA where information on blow fly diversity is lacking. Further, because the present study was conducted over multiple years we were able to assess possible seasonal variation in community composition. This information along with the environmental data provided, should help to facilitate the wider use of blow flies in forensic investigations in New Jersey and surrounding states.

Acknowledgments

We would like to thank M.A. Maki for her assistance in the field and laboratory during this study and T. Whitworth for verifying the identification of specimens. We would also like to thank the Lindley G. Cook 4-H Camp, Clifford E. & Melda C. Snyder Research and Extension Farm, The Grounds Department at Princeton University, Rutgers Fruit and Ornamental Research Extension Center, and the Philip E. Marucci Center for Blueberry and Cranberry Research and Extension for allowing us access and permission to use their property in conducting this study.

References Cited

Amendt, J., R. Krettek, and R. Zehner. 2004. Forensic entomology. Naturwissenschaften 91: 51–65.

Anderson, G. S. 2000. Minimum and maximum development rates of some forensically important Calliphoridae (Dipter). J. Forensic Sci. 45: 824–832.

Anderson, G. S. 2011. Comparison of decomposition rates and faunal colonization of carrion in indoor and outdoor environments. J. Forensic Sci. 56: 136–42

Anderson, G. S., and S. L. VanLaerhoven. 1996. Initial studies on insect succession on carrion in Southwestern British Columbia. J. Forensic Sci. 41: 61–625.

Benbow, M. E., A. J. Lewis, J. K. Tomberlin, and J. L. Pechal. 2013. Seasonal necrophagous insect community assembly during vertebrate carrion decomposition. J. Med. Entomol. 50: 440–450.

Berg, M. C., and M. E. Benbow. 2013. Environmental factors associated with *Phormia regina* (Diptera: Calliphoridae) oviposition. J. Med. Entomol. 50: 451–457.

Boatright, S. A., and J. K. Tomberlin. 2010. Effects of temperature and tissue type on the development of *Cochliomyia macellaria* (Diptera: Calliphoridae). J. Med. Entomol. 47: 917–923.

Brundage, A., S. Bros, and J. Y. Honda. 2011. Seasonal and habitat abundance and distribution of some forensically important blow flies (Diptera: Calliphoridae) in Central California. Forensic Sci. Int. 212: 115–120.

Byrd, J. H., and J. F. Butler. 1996. Effects of temperature on *Cochliomyia macellaria* (Diptera: Calliphoridae) development. J. Med. Entomol. 33: 901–905.

Catts, E. P. and M. L. Goff. 1992. Forensic entomology in criminal investigations. Annu. Rev. Entomol. 37: 253–272.

Cruickshank, I., and R. Wall. 2002. Population dynamics of the sheep blowfly *Lucilia sericata:* seasonal patterns and implications for control. J. App. Ecol. 39: 493–501.

Deonier, C. C. 1940. Carcass temperatures and their relation to winter blowfly populations and activity in the Southwest. J. Econ. Entomol. 33: 166–170.

Deonier C. C. 1942. Seasonal abundance and distribution of certain blowflies in southern Arizona and their economic importance. J. Econ. Entomol. 35: 65–70.

Dufrene, M., and P. Legendre. 1997. Species assemblages and indicator species: The need for a flexible asymmetrical approach. Ecol. Monogr. 67: 345–366.

Gallagher, M. B., S. Sandhu, and R. Kimsey. 2010. Variation in developmental time for geographically distinct populations of the common green bottle fly, *Lucilia sericata* (Meigen). J. Forensic Sci. 55: 438–442.

Greenberg, B. 1973. Flies and disease, vol. 2. Biology and disease transmission. Princeton University Press, Princeton, NJ.

Greenberg, B. 1991. Flies as forensic indicators. J. Med. Entomol. 28: 565–577.

Gruner, S. V., D. H. Slone, and J. L. Capinera. 2007. Forensically important Calliphoridae (Diptera) associated with pig carrion in rural north-central Florida. J. Med. Entomol. 44: 509–515.

Hall, D. G. 1948. The blowflies of North America. Thomas Say Foundation, vol. IV. Entomological Society of America, College Park, MD.

Hwang, C., and B. D. Turner. 2005. Spatial and temporal variability of necrophagous Diptera from urban to rural areas. Med. Vet. Entomol. 19: 379–391.

Isiche, J., J. E. Hillerton, and F. Nowell. 1992. Colonization of mouse cadaver by flies in southern England. Med. Vet. Entomol. 6: 168–170.

Jewiss-Gaines, A., S. A. Marshall, and T. L. Whitworth. 2012. Cluster flies (Calliphoridae: Polleninae: *Pollenia*) of North America. Can. J. Arth. Identification 19: 1–19.

Jordaens, K., G. Sonet, Y. Braet, M. De Meyer, T. Backeljau, F. Goovaerts, L. Bourguignon, and S. Desmyter. 2013. DNA barcoding and the differentiation between North American and West European *Phormia regina* (Diptera, Calliphoridae, Chrysomyinae. ZooKeys 365: 149–174.

Joy, J. E., N. L. Liette, and H. L. Harrah. 2006. Carrion fly (Diptera: Calliphoridae) larval colonization of sunlit and shaded pig carcasses in West Virginia, USA. Forensic Sci. Int. 164: 183–192.

Marshall, S. A., T. Whitworth, and L. Roscoe. 2011. Blow flies (Diptera: Calliphoridae) of eastern Canada with a key to Calliphoridae subfamilies and genera of eastern North America, and a key to the eastern Canadian species of Calliphorinae, Luciliinae, and Chrysomyiinae. Can. J. Arth. Identification 11: 1–93.

Matuszewski, S., D. Bajerlein, S. Konwerski, and K. Szpila. 2010. Insect succession and carrion decomposition in selected forests of Central Europe. Part 1: Pattern and rate of decomposition. Forensic Sci. Int. 194: 85–93.

McCune, B., and J. B. Grace. 2002. Analysis of ecological communities. MjM Software Design, Gleneden Beach, OR.

Mohr, R. M., and J. K. Tomberlin. 2014. Environmental factors affecting early carcass attendance by four species of blow flies (Diptera: Calliphoridae) in Texas, USA. J. Med. Entomol. 51: 702–708.

Nabity, P. D., L. G. Higley, and T. M. Heng-Moss. 2006. Effects of temperature on development of *Phormia regina* (Diptera: Calliphoridae) and use of developmental data in determining time intervals in forensic entomology. J. Med. Entomol. 43: 1276–1286.

Owings, C. G., C. Spiegelman, A. M. Tarone, and J. K. Tomberlin. 2014. Developmental variation among *Cochliomyia macellaria* Fabricius (Diptera: Calliphoridae) populations from three ecoregions of Texas, USA. Int. J. Legal Med. 128: 709–717.

R Development Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. (http://www.R-project.org) (accessed 27 February 2015)

Richards, E. N., and M. L. Goff. 1997. Arthropod succession on exposed carrion in three contrasting tropical habitats on Hawaii Island, Hawaii. J. Med. Entomol. 34: 328–339.

Sabanoğlu, B., and O. Sert. 2010. Determination of Calliphoridae (Diptera) fauna and seasonal distribution on carrion in Ankara Province. J. Forensic Sci. 55: 1003–1007.

SAS. 2012. JMP version 10. SAS Institute, Inc. Cary, NC.

Schroeder, H., H. Klotzbach, and K. Püschel. 2003. Insects' colonization of human corpses in warm and cold season. Legal Med. 5: S372–S374.

Tabor, K. L., C. C. Brewster, and R. D. Fell. 2004. Analysis of the successional patterns of insects on carrion in southwest Virginia. J. Med. Entomol. 41: 785–795.

Tarone, A. M., and D. R. Foran. 2006. Components of developmental plasticity in a Michigan population of *Lucilia sericata* (Diptera: Calliphoridae). J. Med. Entomol. 43: 1023–1033.

Tarone, A. M., C. J. Picard, C. Spiegelman, and D. R. Foran. 2011. Population andtemperature effects on *Lucilia sericata* (Diptera: Calliphoridae) body size and minimum development time. J. Med. Entomol. 48: 1062–1068.

Tenorio, F. M., J. K. Olson, and C. J. Coates. 2003. Decomposition studies, with a catalog and descriptions of forensically important blow flies (Diptera: Calliphoridae) in central Texas. Southwest. Entomol. 28: 37–45.

Tomberlin, J. K. and P. H. Adler. 1998. Seasonal colonization and decomposition of rat carrion in water and on land in an open field in South Carolina. J. Med. Entomol. 35: 704–709.

Tomberlin, J. K., and M. E. Benbow. 2015. Forensic Entomology: International Dimensions and Frontiers. CRC Press, Baco Raton, FL.

U.S. Census Bureau. 2010. State and county quickfacts. (http://quickfacts.census.gov/qfd/states/34000.html) (accessed 27 February 2015)

Wall, R., N. French, and K. L. Morgan. 1992. Effects of temperature on the development and abundance of the sheep blowfly *Lucilia sericata* (Diptera: Calliphoridae). Bull. Entomol. Res. 82: 125–131.

Watson, E. J., and C. E. Carlton. 2005. Insect succession and decomposition of wildlife carcasses during fall and winter in Louisiana. J. Med. Entomol. 42: 193–203.

Weidner, L. M., J. K. Tomberlin, and G. C. Hamilton. 2014. Development of *Lucilia coeruleiviridis* (Diptera: Calliphoridae) in New Jersey, USA. Fla. Entomol. 97: 849–851.

Whitworth, T. 2006. Keys to the genera and species of blow flies (Diptera: Calliphoridae) of America north of Mexico. Proc. Entomol. Soc. Wash. 108: 689–725.

Woods, A. J., J. M. Omernik, and B. C. Moran. 2007. Level III and IV ecoregions of New Jersey. US Environmental Protection Agency, NJ.

Zurawski, K. N., M. E. Benbow, J. R. Miller, and R. W. Merritt. 2009. Examination of nocturnal blow fly (Diptera: Calliphoridae) oviposition on pig carcasses in mid-Michigan. J. Med. Entomol. 46: 671–679.

Received 1 March 2015; accepted 27 June 2015.