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Seasonal and habitat abundance and distribution of some forensically important blow flies (Diptera: Calliphoridae) in Central California

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ABSTRACT

Seasonal and habitat calliphorid abundance and distribution were examined weekly for two years (2001–2003) in Santa Clara County, California, using sentinel traps baited with bovine liver. Of the 34,389 flies examined in three defined habitats (rural, urban, and riparian), 38% of the total catch represented *Compsomyiops callipes* (Bigot) and 23% represented *Phormia regina* (Meigen). Other flies collected in this survey included *Calliphora vomitoria* (Linnaeus), *Calliphora latifrons* (Hough), *Lucilia sericata* (Meigen), *Lucilia cuprina* (Wiedemann), and *Lucilia mexicana* (Macquart), which is a new record for the area. Multivariate MANOVA and ANOVA ($P \leq 0.05$) analysis indicate significant seasonal habitat preference for all fly species examined. This information may be used to identify potentially forensically important fly species within Santa Clara County, California.

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1. Introduction

Most forensic entomologists agree that calliphorid flies are currently the most forensically important of all insects; however, research for this fly family is limited to regions where there are only a few active forensic entomologists such as Florida [1], Hawaii [2,3], Indiana [4,5], Michigan [6], South Carolina [7], Tennessee [8], Texas [9], West Virginia [10], Germany [11,12], and British Columbia [13–15]. Moreover, while some calliphorids are established worldwide, evidence indicates that abundance and distribution varies with respect to season, geography, and habitat [13,16]. These differences mean that general successional and life history studies may be of some use to forensic entomologists, but accurate time of colonization (TOC) or post mortem interval (PMI) estimation is dependent upon intimate knowledge of the immediate community makeup, specific successional patterns, and life histories of forensically important flies common in the area of the crime [4,17,18].

Over the years, we have been requested by law enforcement agencies and medical examiners in Santa Clara County to identify and collect insects from human remains. It has become apparent that the calliphorid diversity, abundance, and distribution in this region are different from other areas and poorly studied [19]. The most definitive calliphorid studies in California come from James [20] and Whitworth [21]. James [20] conducted a survey of the blowflies of California by tabulating museum specimens. This survey revealed 16 species found within or bordering Santa Clara County (Alameda County, San Mateo County and Santa Cruz County) (Table 1). While this work gives insight as to which species were present in California at the time, it relied upon historical collections of fly specimens and did not focus on those of forensic importance. Whitworth [21] updated the keys for the identification of Calliphoridae, and referenced James [20] for distribution data within California. Whitworth's work focused on the reclassification of several calliphorid species, but did not address the specific forensic importance, distribution, or abundance of species within California.

Thus, the objectives of this study were twofold: (1) survey the forensically important calliphorid community of Santa Clara county in particular and the San Francisco Bay Area in general, and (2) determine calliphorid habitat distribution and abundance.

2. Materials and methods

2.1. Field trapping

Commercial fly traps (Rescue! Fly Trap, Sterling International, Inc.) (Fig. 1) were baited with 6 oz. fresh, food-grade beef liver, and covered with 8 oz. of fresh water. Gruner et al. [1] found that aerial capture of adult specimens accurately predicted carrion-colonizing species. Results of these methods were also compared to forensic entomology cases in Santa Clara County, and found to mimic those species present on bodies. It was therefore determined that adult trapping is an effective method to predict forensically important species of Calliphoridae.

Traps were placed in three habitat types where human remains were often found within Santa Clara County (Lt. Eric Sills, San Jose Police Department, personal

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Table 1
Species checklist of calliphorid flies by James [20] and those collected in the current study.

Species	Current study	James [20]			
		Santa Clara Co.	Alameda Co.	San Mateo Co.	Santa Cruz Co.
Calliphora grahami		×	×	×	×
Lucilia elongata				×	
Lucilia silvarum		×	×	×	
Lucilia thatuna		×	×		
Calliphora livida		×		×	×
Calliphora terraenovae			×	×	
Calliphora vicina			×	×	×
Calliphora vomitoria	×	×	×	×	×
Cochliomyia macellaria		×	×		
Calliphora latifrons	×	×	×	×	×
Compsomyiops callipes	×	×	×	×	×
Lucilia cuprina	×	×		×	
Lucilia mexicana	×				
Lucilia sericata	×	×	×		
Phormia regina	×	×	×	×	×
Pollenia rudis	×	×	×	×	×

communication). These areas were defined as follows: (1) on city streets or in private homes and yards (urban areas); (2) along local waterways or along the banks of rivers or streams (riparian areas); and (3) in sparsely populated foothills (rural areas).

Collected specimens were also analyzed by season. Seasons were defined based on average temperatures local temperatures: winter (December, January and February); spring (March, April and May); summer (June, July and August); and fall (September, October, and November).

A total of twelve sentinel traps (four within each habitat) were hung from trees, approximately 2 m above ground, at least 1.6 km apart to discourage inter-trap competition. All traps were checked weekly from January 24, 2001 through February 28, 2003, and bait was replaced during each check. Captured flies were preserved in 70% isopropyl alcohol and eventually dried and pinned. Due to the overwhelming number of flies attracted to the traps, it was decided that only those species in the family Calliphoridae would be included in the study. Vouchers are preserved and stored in the J. Gordon Edwards Entomology Museum at San Jose State University. Calliphorids included in the current study were identified to be species using published keys by James, Whitworth and McAlpine [20–22], and identifications verified by the curator of the J. Gordon Edwards Entomology Museum, Dr. J. Gordon Edwards.

Fig. 1. Commercial fly trap.

Data were analyzed using a two-way multivariate analysis of variance (MANOVA, $P \leq 0.05$) (SPSS Inc., Chicago, IL) to determine species composition changes with habitat and/or season. A significant habitat effect indicated species composition changes were dependent on habitat type, whereas a significant interaction between habitat and season indicated that habitat changes in species composition depend upon season.

3. Results

Over the two-year period, 40,404 calliphorid specimens were collected. However trapping methods caused damage to a number of specimens, limiting identification to 34,389 flies. There was no significant difference in either total numbers of specimens trapped or in species composition between individual traps in any given area, or between seasons. The data for each habitat and each season was therefore pooled for further analysis. Eight species were identified: *Compsomyiops callipes* (Bigot), *Phormia regina* (Meigen), *Lucilia sericata* (Meigen), *Lucilia mexicana* (Macquart), *Lucilia cuprina* (Wiedemann), *Calliphora vomitoria* (Linnaeus), *Calliphora latifrons* (Hough), and *Pollenia rudis* (Fabricus). *L. mexicana* represents a new species record for Santa Clara County (Table 1). Furthermore, *P. rudis* was excluded from further analysis as immature stages are earthworm parasites and not considered a fly of forensic importance.

In summarizing the total fly catch over two years, flies were most abundant in spring and summer when trap numbers during these seasons represented 65% of the total numbers of flies captured, and least abundant in fall and winter when trap numbers were 35% of the total trap number. With respect to habitat, the majority of flies were caught in rural traps (46%), followed by riparian traps (35%), and urban traps (19%).

A much clearer picture emerges when individual species are examined in different habitats over the seasons. With the exception of *P. regina*, all other species showed that season significantly impacted habitat abundance and distribution (Table 2).

For example, *C. callipes* numbers were relatively low in fall and winter and higher in spring and summer. Although this species could be found throughout the year in riparian habitats it appeared to favor rural areas in the spring and summer, while urban areas continued to exhibit minimal abundance (Fig. 2). *C. latifrons* was most abundant in winter, and showed the highest preference for urban habitats. Its numbers fell dramatically after winter and it appears to have shifted towards rural habitats during spring and summer (Fig. 2). *C. vomitoria* exhibited stable habitat preferences throughout the year as it favored rural habitats over riparian habitats, and riparian habitats over urban habitats (Fig. 2). It was least common during winter and fall and most abundant during

Table 2
Two-way multivariate analysis of variance for examining effects of habitat (urban, rural, and riparian) and season (spring, summer, fall, and winter) on abundance of *C. callipes*, *L. sericata*, *L. mexicana*, *L. cuprina*, *C. vomitoria*, *C. latifrons*, and *P. regina*.

Species	Habitat		Season		Habitat × season	
	F	*P*	*F*	*P*	*F*	*P*
C. callipes	27.55	<**0.001**	12.044	<**0.001**	5.257	<**0.001**
L. sericata	21.386	<**0.001**	7.396	<**0.001**	5.179	<**0.001**
L. mexicana	0.202	0.817	13.406	<**0.001**	4.378	<**0.001**
L. cuprina	14.301	<**0.001**	7.025	<**0.001**	2.916	**0.009**
C. vomitoria	32.39	<**0.001**	14.723	<**0.001**	8.164	<**0.001**
C. latifrons	5.497	**0.005**	6.523	<**0.001**	7.344	<**0.001**
P. regina	12.159	<**0.001**	7.468	<**0.001**	1.969	0.07

the spring and summer. *L. sericata* is the first of two fly species to show consistent preference for urban habitats although it is found in high numbers in rural areas in the spring and summer. *L. sericata* abundance is low in the winter and builds its numbers over the following seasons until it peaks in the fall (Fig. 2). *L. cuprina* also showed preference for urban habitats and was similar to *L. sericata* in habitat preference throughout all seasons although its numbers peaked in spring and summer (Fig. 2). *L. mexicana* exhibited overall low abundance but exhibited definite seasonal and habitat preferences: abundance was lowest during winter months, and it preferred riparian habitats. However, as abundance increased, preferences shifted towards rural habitats in spring and summer before switching to urban areas in the fall (Fig. 2). *P. regina* did not show a significant habitat/season interaction; thus, habitat preference was not due to seasonal effects ($F_{[6,312]} = 1.969$, $P = 0.070$). However, *a priori* statistics using two-way ANOVA to analyze seasons and locations independent of one another showed *P. regina* significantly preferred warm seasons (spring and summer) over cool seasons (fall and winter) ($F_{[1,312]} = 8.921$, $P = 0.003$) However, it did not show any significant preference between spring and summer ($F_{[1,312]} = 1.083$, $P = 0.299$) or fall and winter ($F_{[1,312]} = 0.079$, $P = 0.779$). *P. regina* also significantly preferred riparian and rural to urban areas ($F_{[1,312]} = 5.813$, $P = 0.016$) with over 7000 individuals collected in these areas, versus 383 collected in urban areas over the total two year survey period. More individuals were consistently collected in riparian habitats ($N = 4138$) than rural ($N = 3371$), and statistical analysis showed a significant preference for riparian habitats over rural habitats ($F_{[1,312]} = 29.797$, $P < 0.001$) (Table 2 and Fig. 2).

Given the significant changes between season and habitat, these data may be used to predict the probable occurrence of species during a given season in a given habitat (Table 3).

4. Discussion

Habitat diversity in the Bay Area may allow for high calliphorid diversity. However, only seven separate species were collected and identified during this study. This differs with a species diversity study [20] that surveyed calliphorid collections throughout California, and reported 15 calliphorid species present in and around Santa Clara County. Eight of the species present in a previous survey [20], *Calliphora grahami* (Aldrich), *Lucilia thatuna* (Shannon), *Lucilia elongata* (Shannon), *Lucilia silvarum* (Meigen), *Calliphora livida* (Hall), *Calliphora terraenovae* (Macquart), *Calliphora vicina* (Robineau-Desvoidy) and *Cochliomyia macellaria* (Fabricus) were not encountered during this study (Table 1). A previous study [20] reveals that three species are not found on carrion and therefore not considered forensically important. *L. elongata*, *L. silvarum*, and *L. thatuna* are all known parasites of frogs and toads, and while *L. elongata* has been described as a facultative parasite of mammals, no medico-legal cases featuring this species have been reported.

The remaining five species, *C. grahami*, *C. livida*, *C. terraenovae*, *C. macellaria* and *C. vicina* are all intimately associated with carrion and time of colonization or post mortem interval estimation [1,10,11,23,24]. However, none were encountered during this survey, and several factors may be associated with this phenomenon: trapping methods may have been insufficient to attract these species, as they may only be attracted to large carrion, and small liver traps were used; species may not be present in sufficient numbers within the county to be encountered during a survey of this nature; local populations may have migrated away from the county or became extinct in the years since James' survey due to population growth, climate change, or introduced interspecies competition; or specimens captured may have fallen into the 12.96% category left unidentifiable due to trapping methods. Further studies are needed to determine if these species are present in the immediate area using more intensive, localized trapping.

The effects of habitat and season on Calliphoridae are well documented [16]. Each species exhibits a unique set of seasonal adaptations allowing it to exploit resources in a variety of habitats. These adaptations vary greatly between species, and within species found in distinct areas, and may account for a species' ability to coexist in areas with closely related and similarly adapted species. Until recently, *C. callipes* has not been considered forensically important in entomological literature, and therefore has not been studied in terms of seasonal distribution [19]. This survey shows that *C. callipes* prefers the warmest months, and was most abundant during the hottest months in mostly rural and riparian habitats. Additionally, *L. mexicana* is found in low numbers overall; it is present in rural and riparian habitats in spring and summer, and urban habitats in fall. The remaining flies examined have extensive geographical ranges and have been studied previously so we can summarize and compare their habitat and seasonal preferences. *C. latifrons* is found in all environments throughout the year in all habitats which is in agreement with Anderson's study [14]. *C. vomitoria* is found primarily in rural areas in spring and summer, which is also in agreement with previous studies [14,25]. Both *L. sericata* and *L cuprina* are found primarily in urban habitats from spring through fall and our data for *L. sericata* agree with those of Tomberlin [7], Anderson [14], and Schroeder et al. [25]. Finally, *P. regina* is found primarily in the spring and summer months which is in agreement with previous studies [7,25]; however, Anderson [14] found this species common in both rural and urban habitats while we found it predominantly in riparian and rural habitats (Table 3 and Fig. 2).

While abiotic factors such as seasonal climate may account for the abundance and distribution in which a particular species may be found, species interaction may restrict available ranges and result in resource partitioning. As species diversity rises, resource competition drives niche partitioning, with each species exploiting habitats within a given area. When looking at these habitats and the flies in the area, interesting patterns emerge. For example, Both *L. serricata* and *L. cuprina* are known to complete their life cycles on either refuse or carrion, and are therefore uniquely adapted to urban and rural habitats, which they appear to inhabit. However, as introduced species they cannot tolerate cold winters and probably do not compete well in riparian and rural habitats with *C. callipes*. On the other hand, the native *C. callipes* only feeds on carrion and is rare in urban settings: even when more common *L. sericata* and *L. cuprina* are scarce in the winter. Thus, *C. callipes* is probably well adapted to thrive in rural areas but not urban areas where the *Lucilia* species can thrive. *C. latifrons* is also indigenous and found year round in all habitats; however, it appears to suffer from competition from other flies. Common in urban areas during

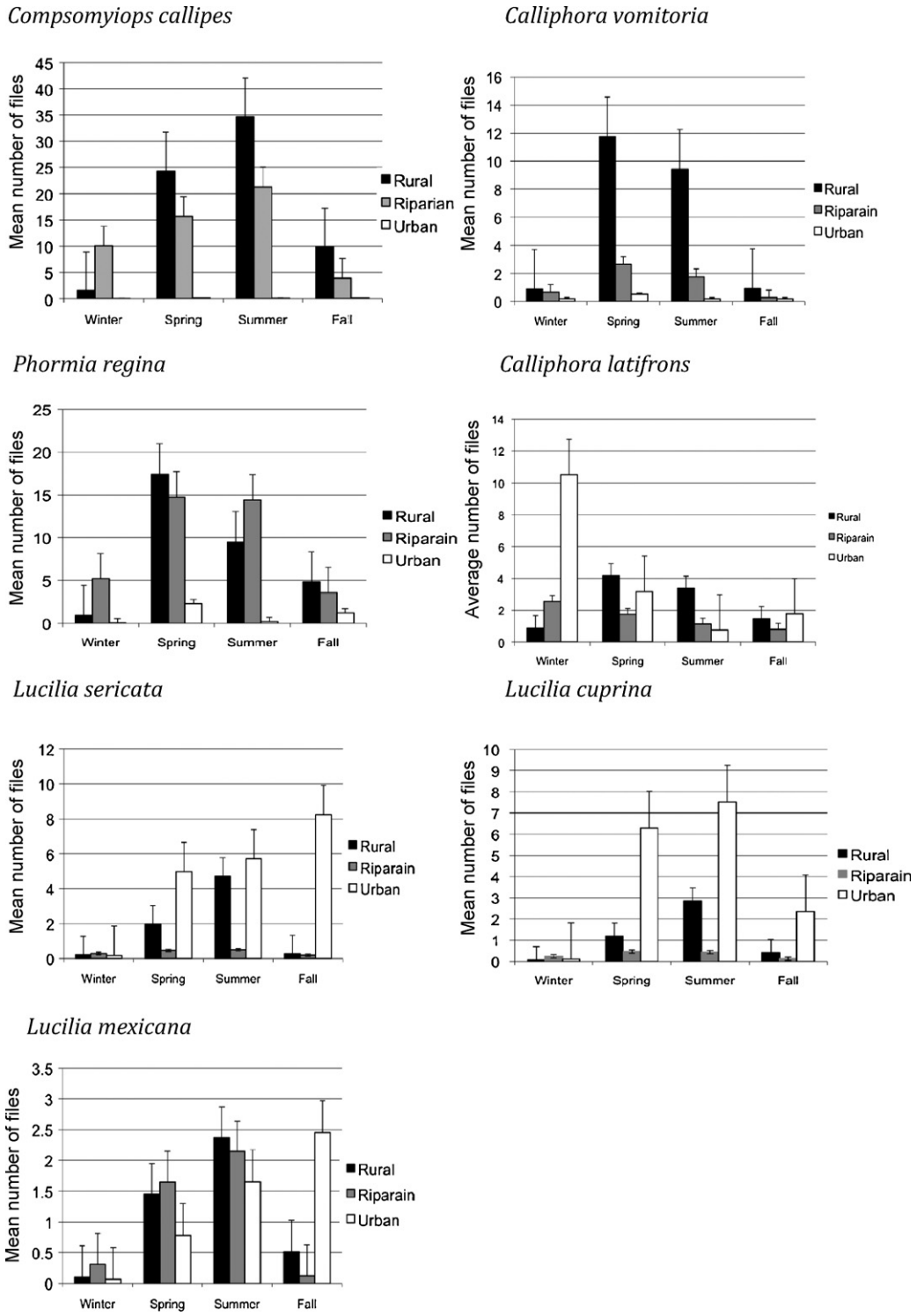

Fig. 2. Distribution and abundance of species by habitat and season. Bars indicate the mean number of each species collected in all traps in each habitat during each season. Data from individual traps and seasons were combined to illustrate distribution and abundance trends over the two-year study.

the winter, it may not be able to compete with increasing *Lucilia* numbers from spring to fall, and migrates to rural and riparian habitats where it prefers smaller carrion such as birds and rodents [21]. Finally, the least encountered fly, *L. mexicana* showed significant shifts in habitats over the seasons. It was found primarily in rural/riparian habitats in spring and summer and in urban habitats in the fall. As a relatively new fly in the area, *L. mexicana* may have trouble competing with already established species, and may prefer riparian areas simply because those flies that are of greatest competition do not prefer those habitats during a given portion of the season.

Byrd and Castner [26] consider *C. vomitoria*, *L. cuprina*, *L. sericata*, and *P. regina* as the most important flies in medico-legal cases. Our data agree with this premise, as these four species are commonly found in Santa Clara County and the San Francisco Bay Area in general. For example, *P. regina* was the second most abundant fly, comprising about 23% of our total trap count. However, a previous study [19] suggests that other species have

Table 3
Expected species composition by habitat and season.

	Urban	Rural	Riparian
Winter	*Calliphora latifrons* (94.42%) *Calliphora vomitoria* (1.81%)	*Compsomyiops callipes* (39.06%) *Phormia regina* (27.97%) *Calliphora vomitoria* (18.84%) *Calliphora latifrons* (6.69%) *Lucilia sericata* (3.19%)	*Compsomyiops callipes* (52.71%) *Phormia regina* (27.85%) *Calliphora latifrons* (11.90%) *Calliphora vomitoria* (2.80%)
Spring	*Lucilia cuprina* (34.52%) *Lucilia sericata* (27.23%) *Calliphora latifrons* (17.53%) *Phormia regina* (12.49%) *Lucilia mexicana* (4.27%)	*Compsomyiops callipes* (41.99%) *Phormia regina* (39.35%) *Calliphora vomitoria* (7.10%) *Calliphora latifrons* (4.64%) *Lucilia mexicana* (4.40%)	*Compsomyiops callipes* (33.76%) *Phormia regina* (19.66%) *Calliphora vomitoria* (18.95%) *Calliphora latifrons* (18.80%) *Lucilia sericata* (4.99%)
Summer	*Lucilia cuprina* (46.28%) *Lucilia sericata* (35.11%) *Lucilia mexicana* (10.17%) *Calliphora latifrons* (4.73%)	*Compsomyiops callipes* (51.05%) *Phormia regina* (34.54%) *Lucilia mexicana* (5.13%) *Calliphora vomitoria* (4.26%)	*Compsomyiops callipes* (51.80%) *Phormia regina* (14.21%) *Calliphora vomitoria* (14.10%) *Lucilia sericata* (7.06%) *Calliphora latifrons* (5.04%) *Lucilia cuprina* (4.25%)
Fall	*Lucilia sericata* (50.18%) *Lucilia mexicana* (14.95%) *Lucilia cuprina* (14.36%) *Calliphora latifrons* (10.84%) *Phormia regina* (7.39%)	*Compsomyiops callipes* (43.60%) *Phormia regina* (39.47%) *Calliphora latifrons* (8.89%) *Calliphora vomitoria* (3.07%)	*Compsomyiops callipes* (53.94%) *Phormia regina* (26.22%) *Calliphora latifrons* (8.06%) *Calliphora vomitoria* (5.08%) *Lucilia mexicana* (2.83%)

equal if not more importance in this area. Our data supports this idea, revealing a clear abundance of demonstrated forensically important species. *C. callipes* is a species not prevalent in other regions studied but is abundant year-round in our area. Most importantly it made up 38% of the total fly trap count and appears to be the most common fly in the county. Together, these two species make up over 60% of all flies collected in the county and have been most commonly encountered when we have examined human remains [19]. This abundance information, taken with other biological information about particular fly species, will help investigators identify potentially forensically important species of Calliphoridae for study. Hence, our study affirms that local surveys are critical in identifying what species are present in various areas, and therefore, what species can be expected to be most important in a medico-legal case.

References

[1] S.V. Gruner, D.H. Slone, J.L. Capinera, Forensically important Calliphoridae (Diptera) associated with pig carrion in rural North-Central Florida, J. Med. Entomol. 44 (2007) 509–515.
[2] M. Early, M.L. Goff, Arthorpod succession patterns in exposed carrion on the island of Oahu, Hawwaiian-Islands, USA, J. Med. Entomol. 23 (1986) 520–531.
[3] E.N. Richards, M.L. Goff, Arthropod succession on exposed carrion in three contrasting tropical habitats on Hawaii Island, Hawaii, J. Med. Entomol. 34 (1997) 328–339.
[4] E.P. Catts, Problems in estimating the postmortem interval in death investigations, J. Agric. Entomol. 9 (1992) 245–255.
[5] N.H. Haskell, D.G. Mcshaffrey, D.A. Hawley, R.E. Williams, J.E. Pless, Use of aquatic insects in determining submersion interval, J. Forensic Sci. 34 (1989) 622–632.
[6] K.N. Zurawski, M.E. Benbow, J.R. Miller, R.W. Merritt, Examination of nocturnal blow fly (Diptera: Calliphoridae) oviposition on pig carcasses in Mid-Michigan, J. Med. Entomol. 46 (2009) 671–679.
[7] J.K. Tomberlin, P.H. Adler, Seasonal colonization and decomposition of rat carrion in water and on land in an open field in South Carolina, J. Med. Entomol. 35 (1998) 704–709.
[8] K.G. Schoenly, N.H. Haskell, R.D. Hall, J.R. Gbur, Comparative performance and complementarity of four sampling methods and arthropod preference tests from human and porcine remains at the Forensic Anthropology Center in Knoxville, Tennessee, J. Med. Entomol. 44 (2007) 881–894.
[9] F.M. Tenorio, J.K. Olson, C.J. Coates, Decomposition studies, with a catalog and descriptions of forensically important blow flies (Diptera: Calliphoridae) in Central Texas, SouthWest. Entomol. 28 (2003) 37–45.
[10] J.E Joy, N.L. Liette, H.L. Harrah, Carrion fly (Diptera: Calliphoridae) larval colonization of sunlit and shaded pig carcasses in West Virginia, USA, Forensic Sci. Int. 164 (2006) 183–192.
[11] M. Benecke, Six forensic entomology cases: description and commentary, J. Forensic Sci. 43 (1998) 797–805.
[12] J. Amendt, R. Krettek, C. Niess, R. Zehner, H. Bratzke, Forensic entomology in Germany, Forensic Sci. Int. 113 (2000) 309.
[13] G.S. Anderson, The use of insects in death investigations: an analysis of forensic entomology cases in British Columbia over a five year period, Can. Soc. Forensic Sci. J. 28 (1995) 277–292.
[14] G.S. Anderson, S.L. Vanlaerhoven, Initial studies on insect succession on carrion in Southwestern British Columbia, J. Forensic Sci. 41 (1996) 617–625.
[15] S.L. Vanlaerhoven, G.S. Anderson, Insect succession on buried carrion in two biogeoclimatic zones of British Columbia, J. Forensic Sci. 44 (1999) 32–43.

[16] C. Hwang, B.D. Turner, Spatial and temporal variability of necrophagous Diptera from urban to rural areas, Med. Vet. Entomol. 19 (2005) 379–391.
[17] L.E.O. Braack, Community dynamics of carrion-attendant arthropods in tropical African woodland, Oecologia 72 (1987) 402–409.
[18] J.H. Byrd, J.L. Castner, Forensic Entomology: The Utility of Arthropods in Legal Investigations, CRC Press, Boca Raton, 2001.
[19] J.Y. Honda, A. Brundage, C. Happy, S.C. Kelly, J. Melinek, New records of carrion feeding insects collected on human remains, Pan-Pac. Entomol. 84 (2008) 29–32.
[20] M.T. James, The blowflies of California, Bull. Calif. Insect Survey 4 (1955) 1–34.
[21] T. Whitworth, Keys to the genera and species of blow flies (Diptera: Calliphoridae) of America, North of Mexico, Proc. Entomol. Soc. Wash. 108 (2006) 689–725.
[22] J.F. McAlpine, Manual of Nearctic Diptera, Ottawa (1981).
[23] J.F. Wang, C. Hu, Y.C. Chen, J.X. Min, J.T. Li, Chronometrical morphology of *Aldrichina grahami* and its application in the determination of postmortem interval, Acta Entomol. Sin. 45 (2002) 265–270.
[24] G.D. De Jong, J.W. Chadwick, Decomposition and arthropod succession on exposed rabbit carrion during summer at high altitudes in Colorado, USA, J. Med. Entomol. 36 (1999) 833–845.
[25] H. Schroeder, H. Klotzbach, K. Puschel, Insects' colonization of human corpses in warm and cold season, Legal Med. 5 (2003) S372.
[26] J.H. Byrd, J.L. Castner, N. Inc, Forensic Entomology: The Utility of Arthropods in Legal Investigations, second ed., CRC Press, Boca Raton, 2010.