Invasive *Tipula* (Diptera: Tipulidae) in Turfgrass of the Northeast United States: Geographic Distribution and Local Incidence Three Years After Detection

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ABSTRACT Two species of invasive crane flies are damaging pests of turfgrass in the Great Lakes region after their inadvertent introduction and establishment. In New York, where *Tipula paludosa* Meigen and *Tipula oleracea* L. (Diptera: Tipulidae) were first detected in 2004, baseline data on the extent of establishment is needed to monitor range expansion, make predictions about pest status, and guide management efforts. The incidence of both species was therefore addressed at two spatial scales to ascertain how widespread they were across the state and across sites of recent local establishment. Based on divergent natural history, *T. oleracea* was predicted to be more widespread both geographically and locally than *T. paludosa*. To delimit the current area of occurrence, surveys were conducted from 2004 to 2006. *T. paludosa* was detected in four counties and *T. oleracea* in 12 counties. In western New York, *T. oleracea* was established in more than a six-fold greater area than *T. paludosa*. *T. oleracea* was additionally detected on Long Island, shown to be a geographically disjunct area of establishment. To measure local incidence, putting greens and tee boxes were scouted on golf courses. Contrary to predictions, 56–97 and 22–56% of those surfaces were already infested by *T. paludosa* and *T. oleracea*, respectively, within one or two seasons after initial detection. Because damage thresholds are relatively high, scouting for the insect, rather than its injury, will promote earlier detection. Given the impact of invasive *Tipula* across diverse turf habitats, continued range expansion will have serious repercussions for regional turfgrass management.

KEY WORDS crane flies, golf courses, invasive insects, *Tipula paludosa*, *Tipula oleracea*

In all phases of biotic invasions—transport, establishment, spread, and impact (Hulme 2006)—early detection is a vital component of any preventive or mitigating response. During range expansion (spread), early detection of local populations enhances opportunities to suppress outbreaks, lessens economic and environmental consequences, and may contribute to reducing the rate of spread. Curbing and monitoring range expansion might translate to more time to divulge information on natural history, diagnosis, and decision-making, and to generate and validate intervention tactics ahead of the pest's arrival to new areas.

Two species of crane flies native to Europe, *Tipula paludosa* Meigen and *Tipula oleracea* L. (Diptera: Tipulidae), have established in at least three geographic regions of North America (Peck and Held 2007). The origin of those introductions and the trajectory of range expansion are undocumented. On the West Coast, both species were first detected in British Columbia and now occur as far south as northern California (Beirne 1971, Rao et al. 2006). On the East Coast, areas of establishment include Newfoundland, Nova Scotia, and Quebec in eastern Canada, and Michigan, New York, and Ontario in the Great Lakes region (Alexander 1962, Gelhaus 2006, Simard et al. 2006, Taschereau 2007). In New York, both species were detected for the first time in 2004 (Peck et al. 2006). Beyond that initial report, the scope of establishment is completely unknown. Baseline information on how widespread invasive *Tipula* are is essential for monitoring range expansion, making predictions about pest status, and guiding efforts to transmit information on pest management.

Larvae of both species are known as "leatherjackets" and are injurious in turfgrass and other horticultural systems. They inhabit the top layer of the soil to feed on root hairs, roots, and crowns of their hosts. Pruning and disruption of belowground portions of the plant cause damage that leads to severe thinning and extensive dieback (Vittum et al. 1999; Dawson et al. 2002; D.C.P. et al., unpublished). Larvae also reside in the thatch to feed on aboveground portions of the stems and foliage. Beyond turfgrass, there is concern about the pest status of invasive *Tipula* in other horticultural systems of the United States. Affected production crops in the Pacific Northwest include pep-

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permint, turnips, winter wheat, seedling nurseries, grass seed fields, pastures, and hayfields (Sutherland et al. 1989, LaGasa and Antonelli 2000, Rao and Gelhaus 2003, Rao and Umble 2003). A range of crops are susceptible in their native European range, including brassicas, clover, corn, lettuce, sugar beets, strawberries, turnips, pastures, and winter cereals (Blackshaw and Coll 1999).

One reason for alarm about the spread of these invasives in the eastern United States is that the potentially susceptible landscapes are vast. In New York state alone, there are 1.4 million ha of managed turf in the form of home lawns, golf courses, athletic fields, parks, and related landscapes (NASS 2004). Most turf and forage grass species seem to be acceptable hosts for larvae (Pesho et al. 1981), and crane fly infestations may have an impact across the full spectrum of grass species and management scenarios. Among production systems, this would include sod farms, pastures, and hayfields. In northern Ireland, for example, pasture yield increased 74% after larval control (Blackshaw 1985).

Certain diverging aspects of biology and behavior lead us to believe that the spread of invasive *Tipula* across New York will be species specific. For example, female *T. paludosa* mate and lay most of their full complement of eggs the first night they emerge (Coulson 1962), whereas female *T. oleracea* will lay eggs over a period of 3–17 d after emergence (Laughlin 1958). Gravid *T. paludosa* are also extremely poor fliers because of their low wing to abdomen length ratio (Rennie 1916), whereas gravid *T. oleracea* are capable fliers supported by a higher ratio (Laughlin 1967). *T. paludosa* is univoltine, with adult flights in the autumn (Jackson and Campbell 1975), whereas *T. oleracea* has flights in spring and autumn and is probably bivoltine (Blackshaw and Coll 1999). These differences may translate to a higher rate of potential range expansion in *T. oleracea* compared with *T. paludosa.* In contrast, increased dispersal means that *T. oleracea* may build up local populations at a slower rate than *T. paludosa.* More precise information on variation in natural history is therefore relevant not only to the selection and timing of interventions for pest management, but to gauging the rate of range expansion, local outbreak potential, and overall pest status.

To understand the scope of invasive *Tipula* establishment in New York 3 yr after their first detection, we address their occurrence at two spatial scales. To ascertain how widespread the insects were across the state, our first objective was to gauge the current known geographic distribution of each species and thereby establish a baseline for monitoring future range expansion. To ascertain how widespread the insects were at sites of local establishment, our second objective was to describe the incidence of each species across newly infested golf courses and thereby measure the extent of establishments within those landscapes. Based on species-specific attributes, we predicted that *T. oleracea* would be more widespread both locally and geographically than *T. paludosa.*

Materials and Methods

Geographic Distribution. We obtained locality data from specimens collected at or around turf sites across New York state from 2004 to 2006. All identifications were based on adult specimens preserved in 70% ethyl alcohol, a subsample of which was reared from field-collected larvae. Determinations were made according to features summarized in Peck et al. (2006). The specific differentiation of *T. paludosa* and *T. oleracea* depended on ventral spacing between the eyes, number of antennal segments, male genitalia, and female wing-to-abdominal length ratio (Coe et al. 1950, Den Hollander 1975, LaGasa and Antonelli 2000). Identifications based on other life stages were not made because there are currently no reliable morphological characters to distinguish between the two invasive species (Humphreys et al. 1993).

Data reported in Peck et al. (2006), collected from 2004 to early 2005, showed both species to be present across an area that encompassed the western half of New York state, extending east from Buffalo to Syracuse. To build on this initial assessment and better define the boundaries of each species' range, additional delimiting surveys were conducted in late 2005 and 2006 along three main corridors. Two north–south corridors extended from Buffalo southwest to the Pennsylvania border (along the east shore of Lake Erie), and from Syracuse north to the Canadian border (along the east shore of Lake Ontario) and south through the Finger Lakes to the Pennsylvania border. A west–east corridor extended from Syracuse along the Erie Canal corridor toward Albany. In light of the detection of *T. oleracea* on Long Island in spring 2006 (Peck et al. 2006), this west–east corridor extended into geographic regions intermediate to western New York and Long Island, so data could be gathered to help ascertain whether Long Island represented a separate introduction and establishment, or whether the species occurred across the state.

Defining the boundaries of geographic distribution meant that sites where *T. paludosa* and *T. oleracea* could be considered absent were equally important as those where they were detected. To report most confidently on localities where they had not yet established, guidelines were applied to standardize and reduce the chance of missing an infestation. The criterion for absence was a golf course survey where adults or pupal exuviae could not be found on any of 10–15 putting greens or tee boxes located across eight or more different fairways on the golf course. Exuviae were relatively easy to spot protruding from the surface of short-mown playing surfaces and, once detected, a sweep net was used to search for adults in the surrounding area and verify their species identity. In addition, the golf course was scouted during a window of time in spring or autumn when adults were known to be actively emerging in other areas.

Finally, locality data from any other sources were also included, such as state parks and residential lawns, and other confirmed sites provided by collaborators, among them extension agents, golf course superinten-

Table 1. Incidence of invasive crane flies soon after initial detection on select golf courses over the spring (*T. oleracea*) and fall (*T. oleracea* and *T. paludosa*) adult flight periods

Species	Site[a]	First confirmation	Survey timing	Putting greens and tee boxes infested (%)	*n*
T. paludosa	Hyde Park GC, Niagara Falls, NY	Spring 2005[b]	Fall 2005 (26 Sept., 26 Oct.)	97.2	36
			Fall 2006 (19 Sept.)	85.4	48
	Niagara Falls CC, Lewiston, NY	Fall 2004[b]	Fall 2004 (11 Oct.)	56.5	46
			Fall 2005 (6 Oct.)	36.1	36
			Fall 2006 (20 Sept.)	17.6	68
T. oleracea	Battle Island GC, Fulton, NY	Fall 2005	Fall 2005 (28 Sept.)	22.9	35
	Big Oak GC, Geneva, NY	Spring 2006	Spring 2006 (5, 11 May)	54.5	55
	Elms GC, Sandy Creek, NY	Spring 2006[c]	Spring 2006 (10 May)	22.2	18
	Geneva CC, Geneva, NY	Spring 2006	Spring 2006 (5, 11 May)	40.7	27
	Penfield CC, Penfield, NY	Spring 2006	Spring 2006 (26 April; 1, 22 May)	56.5	23
	Willowbrook CC, Lockport, NY	Spring 2005[b]	Spring 2005 (24 May, 9 June)	38.3	60

[a] CC, country club; GC, golf course.
[b] Probably detected by course superintendent one to two seasons before confirmation by investigators.
[c] Not detected in a detailed survey in fall 2005.

dents, lawn care service providers, and private consultants.

Local Incidence. To ascertain how widespread infestations were around sites of recent establishment, we measured the local incidence of invasive *Tipula* in golf course landscapes. We chose golf courses for three reasons, the foremost that invasive *Tipula* were first detected in this management system. Second, establishments are probably detected earlier on golf courses than other turf systems because visual standards on playing surfaces mean superintendents are motivated to monitor for new pest threats. Finally, putting greens and tee boxes represent discrete units for measuring and quantifying the extent of infestations.

Surveys were conducted across eight golf courses in western New York, two with establishments of *T. paludosa* and six with *T. oleracea* (Table 1). The specific courses were selected based on our opportunity to initiate monitoring soon after invasive *Tipula* were first detected. This was usually the same season they were confirmed at the golf course. At that point, there was no information on the scope of the infestation other than a positive species identification. On each golf course, 18–68 putting greens and tee boxes were surveyed during the seasonal windows of adult emergence. Surveys were conducted before tee boxes were mowed, either early in the day before cutting or on days when maintenance did not occur. Each site was scored as infested or uninfested based on whether larvae, pupae, pupal exuviae, or adults were recovered from the playing surface. The primary detection method, however, was the presence of pupal exuviae, and as mentioned above, species identity was confirmed through adult collections.

Results

Geographic Distribution. Based on at least one positive identification from a total of 27 locality entries, *T. paludosa* was detected in four counties and 11 municipalities (Table 2). In 2004, it was originally reported from two counties (Erie and Niagara). Two more counties were added in 2005 (Monroe and Ontario),

Table 2. Occurrence of *T. paludosa* and *T. oleracea* in New York based on collections conducted from 2004 to 2006

Species	County	Yr first detected	Municipalities where detected	No. localities by habitat[a]		
				GC	HL	PK
T. paludosa	Erie	2004	Amherst, Orchard Park, Williamsville	2	2	0
	Monroe	2005	Penfield, Pittsford, Rochester	4	12	0
	Niagara	2004	Lewiston, Lockport, Niagara Falls, Youngstown	4	0	2
	Ontario	2005	Victor	1	0	0
T. oleracea	Erie	2006	Collins	1	0	0
	Livingston	2006	Lima	1	0	0
	Monroe	2005	Penfield, Pittsford, Spencerport	4	0	0
	Nassau	2006	New Hyde Park	0	1	0
	Niagara	2004	Lockport, Niagara Falls, Youngstown	4	0	0
	Onondaga	2006	Baldwinsville, Cicero, Manlius, Marcellus	4	0	0
	Ontario	2006	Canandaigua, Geneva	3	0	0
	Oswego	2005	Fulton, Sandy Creek	2	0	0
	Seneca	2006	Ovid, Seneca Falls	2	0	0
	Suffolk	2006	Babylon[b], Riverhead	0	2	0
	Wayne	2006	Lyons	1	0	0
	Wyoming	2006	Varysburg	1	0	0

[a] GC, golf course; HL, home lawn; PK, park.
[b] Recovered from a trap used to monitor for exotic bark beetles.

and none were added in 2006. Pooling data collected over all 3 yr, *T. paludosa* was collected from two parks, 11 golf courses, and 14 residential home lawns. Eleven of those home lawns were individual residences in a single municipality (Pittsford, NY).

Based on positive identification from a total of 26 locality entries, *T. oleracea* was detected in 12 counties and 23 municipalities (Table 2). In 2004, it was originally reported from one of the same counties as *T. paludosa* (Niagara). Two more counties were added in 2005 (Monroe and Oswego), and nine counties were added in 2006 (Erie, Livingston, Nassau, Onondaga, Ontario, Seneca, Suffolk, Wayne, Wyoming). Pooling data collected over all 3 yr, *T. oleracea* was collected from 23 golf courses and two residential home lawns. The most notable addition in 2006 was the detection of *T. oleracea* at two residences and one additional site on Long Island. One report was made by a home owner in New Hyde Park, NY (Nassau Co.) because of nuisance swarms of adults after spring emergence. The second residential report was based on a single individual caught in Riverhead, NY (Suffolk Co.) during the autumn emergence. In addition, a single female was recovered from an exotic bark beetle trap in Babylon, NY (Suffolk Co.) that was included in a survey conducted by the Cooperative Agricultural Pest Survey of New York (det. E. R. Hoebeke, Cornell). Both species co-occurred at five localities (all golf courses) situated in five municipalities and two counties (Niagara and Monroe).

In western New York, all localities fell within the Great Lakes Ecoregion, one of seven ecoregions that occur in the state based on boundaries defined by The Nature Conservancy with respect to similarities in soil, physiography, climate, hydrology, geology, and vegetation (Sotomayor 2004) (Fig. 1). The most outlying locality (*T. oleracea*, Collins, NY, Erie Co.) was at the boundary with the Western Allegheny Plateau and the High Allegheny Plateau ecoregions. All localities outside of western New York were from Long Island within the North Atlantic Coast Ecoregion.

Based on the detection criteria, 22 localities situated in 21 municipalities and 14 counties were recorded as sites where invasive *Tipula* were absent. For the spring and fall flight periods, mean date of those surveys was 18 May (range, 5 May–8 June; $n = 10$) and 23 September (range, 12–30 September; $n = 14$), respectively. The timing of those surveys coincided with the windows of emergence at localities of known presence. For *T. paludosa,* mean date of collection was 23 September (range, 1 September–11 October; $n = 33$). For *T. oleracea,* mean dates of collection were 17 May (range, 24 April–1 July; $n = 19$) and 20 September (range, 1–29 September; $n = 7$).

The distribution boundaries were defined in Fig. 1 with respect to the position of sites where each species was present and absent. The resulting range maps reveal that *T. paludosa* is limited to western New York, centered around the greater Buffalo and Rochester metropolitan areas. Because of the lack of intervening positive sites, these are depicted as disjunct areas of establishment. Overall, this area is estimated to cover 3,881 km^2, or 2,786 in Buffalo and 1,095 in Rochester.

In contrast, *T. oleracea* occurred in two geographic regions: western New York and Long Island. In western New York, the area was estimated to encompass 23,122 km^2, nearly 6 times greater than that of *T. paludosa.* Along the Erie Canal and Interstate 90 corridor, it occurred as far east as Manlius, NY (Onondaga Co.), including the Syracuse, NY, metropolitan area. Along the eastern shore of Lake Ontario, it was detected as far north as Sandy Creek, NY (Oswego Co.); in the Finger Lakes area as far south as Ovid, NY (Seneca Co.); and along the eastern shore of Lake Erie as far south as Collins, NY (Erie Co.). The Long Island distribution encompassed another 8,834 km^2 for a total estimated distribution of 31,956 km^2. Long Island is depicted as a disjunct area of establishment because of the absence of *T. oleracea* in several intervening areas. This includes five localities in the eastern Erie Canal and Mohawk River corridor within the eastern arm of the Great Lakes Ecoregion, three in the northern end of the Lower New England-Northern Piedmont Ecoregion, two in the High Allegheny Plateau and two in the Western Allegheny Plateau.

Local Incidence. Within one to two seasons after the first detection of invasive *Tipula* on golf courses, 22–97% of putting greens and tee boxes were already infested (Table 1). Based on pooled data, infestation rates by *T. paludosa* and *T. oleracea* were 54.3 and 40.8%, respectively. Because of its limited geographic distribution, the incidence of *T. paludosa* was only assessed at two golf courses, both situated in the northwest corner of western New York. After monitoring over three consecutive seasons at Niagara Falls CC, the infestation rate declined from 2004 to 2006 (56, 36, and 18%). Monitored over two seasons at Hyde Park GC, the infestation rate was high in 2005 and 2006 (97 and 85%). Because of its more widespread geographic distribution, the incidence of *T. oleracea* was monitored over single seasons, but in sites located throughout western New York. The mean incidence of infestations across those six golf courses was 39% (range, 22–56%).

Discussion

The scope of invasive *Tipula* establishment in New York was addressed at two spatial scales, and this establishes baseline information that will be useful for monitoring future changes in the status of these invasives in the Great Lakes region and the eastern United States. Results reveal that *T. oleracea* is much more widespread geographically than *T. paludosa* but not more widespread locally. This supports one original prediction, stemming from differences in natural history, that *T. oleracea* would occur over a broader geographic area of New York state than *T. paludosa.* It does not support a second prediction, however, that the incidence of *T. oleracea* around sites of recent establishment also would be greater. The different outcomes at two spatial scales should be taken into

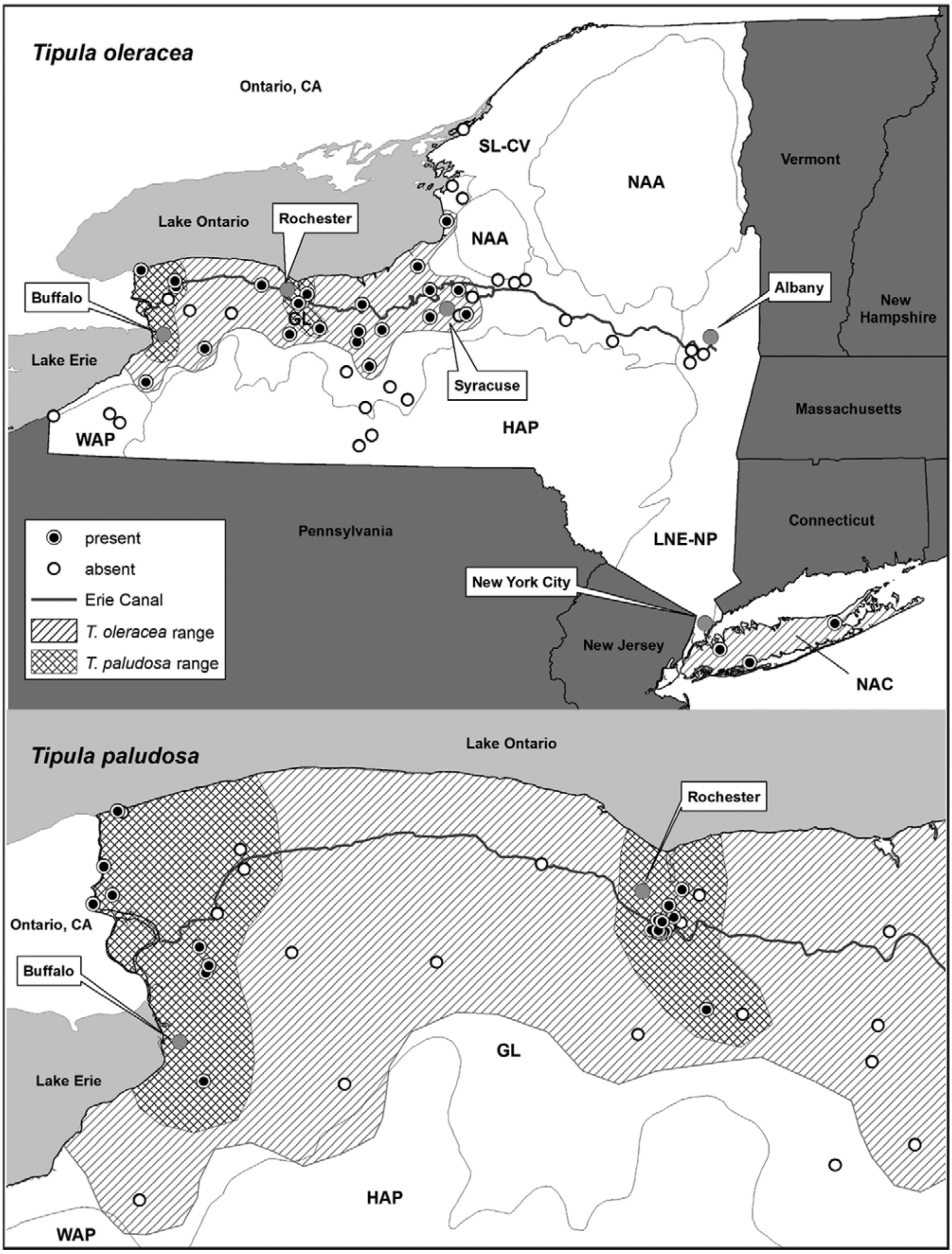

Fig. 1. Known localities and estimated distribution of *T. paludosa* and *T. oleracea* in New York state with respect to ecoregion, based on field collections made from 2004 to 2006. Ecoregions are Great Lakes (GL), High Allegheny Plateau (HAP), Lower New England-Northern Piedmont (LNE-NP), Northern Appalachian/Acadian (NAA), North Atlantic Coast (NAC), St. Lawrence-Champlain Valley (SL-CV), and Western Allegheny Plateau (WAP).

account when making predictions about differences in pest status between the two species.

At a broad geographic scale, the evidence gathered in this study supports the idea that *T. oleracea* is more widespread than *T. paludosa.* In western New York, where the original detections were made in 2004, the estimated distribution of *T. oleracea* (23,122 km^2) is nearly 6 times greater than *T. paludosa* (3,881 km^2). Moreover, across this region *T. paludosa* was not detected outside the greater Buffalo and Rochester areas (Fig. 1), raising the question as to whether it occurs very broadly at all and whether there might have been two original points of establishment. Beyond western New York, *T. oleracea* was additionally detected on Long Island, represented by three localities in Nassau and Suffolk counties. The absence of both species from all sites surveyed in the intervening regions between western New York and Long Island matches the idea of a divided range. Although it was impossible to ensure that some populations did not go undetected, the overall concurrence between the position and number of localities is strong support for a disjunct distribution, which could be explained by two separate geographic establishments for *T. oleracea* in New York.

The range maps constructed for *T. paludosa* and *T. oleracea* depict a highly conservative baseline estimate of species distribution through the end of 2006 (Fig. 1). Tracking changes to these current boundaries in the future will help measure range expansion. These baseline distribution data show all western New York localities to fall within boundaries of the Great Lakes Ecoregion. Monitoring priorities should include the eastern arm of that ecoregion, between Syracuse and Albany. Beyond that, the prevalence of invasive *Tipula* in coastal areas, along waterways and at lower elevations means that other physiogeographic corridors for natural range expansion could include the eastern shore of Lake Ontario northeast toward the St. Lawrence-Lake Champlain Ecoregion, the eastern and southern shores of Lake Erie toward Pennsylvania, and from Long Island toward the Hudson River Valley of the Lower New England/Northern Piedmont Ecoregion. Furthermore, Long Island may be the gateway for *T. oleracea* to New England, New Jersey, and the coastal areas of the Mid-Atlantic, parallel to its purported spread from British Columbia south to California (Umble and Rao 2004).

Despite behaviors that match a greater dispersive capacity, *T. oleracea* was not more widespread across recently infested turf than *T. paludosa.* Within one or two seasons after first detection on golf courses, *T. paludosa* and *T. oleracea,* respectively, had already infested 56–97 and 22–56% of the putting greens and tee boxes. It may be that the relatively longer oviposition period and flight capability of gravid *T. oleracea* (Laughlin 1958, 1967) are not relevant enough to influence its local incidence. Alternatively, it may be that local colonization was essentially complete by the time infestations were detected.

Regardless, one implication is that our current ability to detect incipient populations and new establishments may be poor. This is evidenced by the lack of injury on the surveyed areas during most of the golf course surveys. Injury thresholds in residential home lawns are from 160 to 270 larvae per m^2 (Antonelli and Campbell 1989). Healthy turf is thereby able to support high densities before injury expression. On golf course roughs and fairways, this could greatly delay the detection of a local establishment and allow local populations to expand substantially. The same would likely not be true for injury to putting greens, which would not go undetected for long given the extremely low tolerance thresholds. Scalping caused by larvae to those surfaces has emerged as a major class of damage in New York (D.C.P. et al., unpublished), but it was only sparsely observed on the courses where the surveys were conducted. Because of this cryptic nature, improved monitoring techniques would help turf managers identify infestations earlier and thereby have more success in mitigating the severity of outbreaks. Just as important as injury recognition will be approaches to detect the insect itself, such as pupal exuviae on short-mown turf as used here, or adults during emergence flights or larvae through soil extractions and disclosing solutions. Therefore, scouting for the insect, rather than its injury, will promote earlier detection because of the relatively high damage thresholds.

The last invasive insect to threaten turfgrass of the Northeast United States was the European chafer, *Rhizotrogus majalis* (Razoumowsky), which arrived in 1940 and coincidentally first established in western New York (Gambrell et al. 1942). Today, it remains one of the most troublesome turf-infesting insects across the state. Based on their pest status in the Pacific Northwest and observations to date in New York, the establishment of *T. paludosa* and *T. oleracea* also will have serious repercussions for turfgrass management in the Northeast. Since 2004, impact in New York has taken the form of root injury and die-off in residential lawns and golf course fairways, scalping injury on putting greens, nuisance swarms of adults in suburban settings, and damage due to the activities of vertebrate predators (D.C.P. et al., unpublished). Predictions about pest status in areas where both species co-occur must take into account the information on regional and local distribution reported here as well as outbreak potential, injury and habitat preferences. Whether *T. paludosa* and *T. oleracea* have diverging habitat preferences is currently unknown, much less what those preferences might be in the face of turf management regimes. Future studies designed to assess habitat vulnerability to invasion (Lonsdale 1999, Barney et al. 2005) will be important for predicting which environments are most favorable for crane fly establishment and development.

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