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Habitat Selection and Dispersal of the Cobblestone Tiger Beetle (Cicindela marginipennis Dejean) along the Genesee River, New York

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Abstract.—The goal of this study was to determine ecological, behavioral and environmental factors that would facilitate a management plan for the rare cobblestone tiger beetle (*Cicindela marginipennis*). We used a mark – recapture study to document dispersal distances of the cobblestone tiger beetle along the upper Genesee River in western New York and binomial logistic regression models to compare habitat characteristics measured during occupancy surveys. Cobblestone tiger beetles occupied cobble bars with approximately twice the interior area and difference between minimum and maximum elevation, and higher shrub cover, than unoccupied cobble bars. Beetles occasionally dispersed distances greater than the maximum distance between cobble bars in our study area. In order to preserve cobblestone tiger beetles and riparian habitats along the upper Genesee River, habitats should be managed to reduce impacts from recreational activities and sand/gravel mining.

Introduction

Anthropogenic changes to natural waterways resulting in altered flow patterns and pollution can lead to loss of riverine invertebrates (Allan, 1995; SaintOurs, 2002; Bates *et al.*, 2007). Lotic inhabitants face threats from land development and agricultural practices that include changes to water temperature, pesticide concentration, nutrient regimes, storm water discharge and flow due to impoundments and irrigation practices (Allan, 1995; SaintOurs, 2002; Bates *et al.*, 2007). In New York State, loss of biodiversity and changes to riverine ecosystems are major management concerns (Pfankuch, 1975; Novak, 2006).

Tiger beetles (*Cicindela* spp.) are useful for tracking environmental change within riverine and riparian systems. They act as models for understanding, managing and conserving biodiversity and ecosystems (Rodriguez *et al.*, 1998; Pearson, 2006), as they possess all or most of the seven criteria required for bioindicator species (Pearson and Cassola, 1992). Ideally, indicator species should (1) be in a well-known and stable taxon, with species easily and reliably defined; (2) have well-understood biology and life histories; (3) be easily monitored in the field by observers with differing skill levels; (4) occur across a wide geographical range in a broad number of habitats; (5) be narrow habitat specialists and sensitive to habitat changes; (6) have distributional patterns observed in other taxa; and (7) have potential economic importance that can be used to influence scientists and politicians

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to dedicate resources to relevant studies. Studies on speciation, extinction and ecology of tiger beetles have shown their usefulness as bioindicators in understanding complex habitats and environments (Pearson, 2006). One potential indicator species of natural habitat in New York State is the cobblestone tiger beetle (*Cicindela marginipennis* Dejean), a rare species adapted to natural river disturbances that maintain its required habitat, cobble bars.

Tiger beetles are variously considered a distinct family, Cicindelidae or a subfamily within the Carabidae, and nearly 2700 species have been described worldwide; most are similar in shape, proportion and behavior, and differ primarily in size and coloration (Pearson and Cassola, 2005). In the United States, 111 species of tiger beetles occur, 40% of which are habitat specialists (Pearson and Cassola, 1992). Eight species of tiger beetles, including the cobblestone tiger beetle, have been identified as ''Species of Greatest Conservation Need'' in New York State's Comprehensive Wildlife Conservation Strategy (New York State Department of Environmental Conservation, 2006) because they are scarce, occur only in small localized areas, with identified threats to their populations (Graves and Brzoska, 1991; Novak, 2006).

In New York State, the cobblestone tiger beetle occurs in at least two watersheds and is possibly extirpated from a third watershed (NatureServe, 2009; New York Natural Heritage Program, 2010). There have been few studies on cobblestone tiger beetles and many of the specific habitat requirements and dispersal biology of the species are poorly understood.

The objectives of our study were to (1) understand the dispersal dynamics of adult cobblestone tiger beetles; (2) identify environmental variables associated with suitable habitat; (3) model habitat selection; and (4) describe important features of the beetles' natural history. Data from our study establishes a baseline for monitoring environmental change and population status of this species of management concern in riverine and riparian habitats.

METHODS

STUDY SPECIES

Cobblestone tiger beetles are rapacious predators that live on cobble bars. They are a dull olive color, 11–14 mm in length and exhibit a white band around the outside edge of the elytra. They are metallic blue-green below except for a red-orange abdomen (Graves and Brzoska, 1991; Leonard and Bell, 1999; Pearson *et al.*, 2006). Although adults are highly mobile, larval stages hunt prey from the surface of vertical tunnels in the soil and are sedentary (Nothnagle, 1995; Hoback *et al.*, 2000). Riparian tiger beetle habitats are prone to seasonal flooding (Pyzikiewicz, 2005) that help preserve heterogeneity by disturbing successional patterns and removing vegetation. Tiger beetles in these habitats have life cycles adapted to seasonal flooding (Pyzikiewicz, 2005).

In New York State, the cobblestone tiger beetle is presently known to occur along the Genesee River in the Lake Ontario watershed and Cattaraugus Creek in the Lake Erie watershed (NatureServe, 2009; New York Natural Heritage Program, 2010). The population of cobblestone tiger beetles on the Delaware River in southeastern New York is considered extirpated (Schlesinger, 2010). The cobblestone tiger beetle is classified as a ''critically imperiled'' species in Alabama, New Jersey, New York, Pennsylvania and Vermont because of its small numbers and vulnerable habitat. It is a protected species in New Hampshire (Pyzikiewicz, 2005). It is assumed to be extirpated in Mississippi (NatureServe, 2009), but was detected for the first time in Maine in 2009 (Ward and Mays, 2010) and in southeastern

Kentucky in 2008 (Laudermilk *et al.*, 2010). The International Union for Conservation of Nature (IUCN) lists cobblestone tiger beetles as ''near threatened'' (Gimenez Dixon, 1996).

STUDY AREA

The Genesee River (Fig. 1) originates in Potter County, PA at an elevation of 683 m, and flows north for 241 km into Lake Ontario at Rochester, NY. South of Letchworth State Park, about halfway along its length, the river is a 2^{nd}- to 3^{rd}-order stream that meanders through a rural and agricultural landscape past a few towns and villages. The river's flow is fast in spring, with annual spring flooding. Mean peak water-flow measurement for 2000–2007 at Portageville, NY, within the study area, was 43 m^3/s (U.S. Geological Survey, 2010). The river is generally wide and shallow as it winds back and forth across a floodplain approximately 1.6 km wide. North of Portageville, the Genesee River enters Letchworth State Park. There are three major falls at the south end of the park and the Mt. Morris Dam, completed in 1954, at the north end of the park. The gorge cut by the river has rock walls rising up to 170 m above the river.

Large cobble bars are deposited at bends in the river and as islands. These are frequently scoured by spring flooding and their locations may shift from year to year. Cobble bars typically consist of boulders, cobbles, pebbles and sand; they have wide areas with and without vegetation (Novak, 2006). Soil types adjacent to the river include alluvial deposits, loam, silt loam, gravelly silt loam, loamy-skeletal (variety of components), gravelly loam, silty clay loam, fine sandy loam and bedrock (USDA - Natural Resources Conservation Service, 2009). The Genesee River carries a high, naturally occurring silt and sediment load, as the soils throughout the upper Genesee River valley are highly erodible and some areas in the drainage have steep stream banks.

Extensive agricultural use and land development contribute to silt and sediment loading. Point sources of pollution are inadequately maintained or failing on-site septic systems and salt storage and application for deicing (Bureau of Watershed Assessment and Research, Division of Water, 2003). Channelization for flood control and irrigation within some Genesee River tributaries and the lack of riparian vegetation further degrade water quality (Bureau of Watershed Assessment and Research, Division of Water, 2003).

Portions of the Genesee River from Belfast, NY to Letchworth State Park were surveyed for cobblestone tiger beetles by the New York Natural Heritage Program (NYNHP) between 2000 and 2002 as part of a biodiversity inventory of Letchworth State Park and subsequent, rare animal surveys south of the park (New York Natural Heritage Program, 2010). Seventeen cobble bars occupied by tiger beetles were identified during these surveys.

DISPERSAL STUDY

During the summer of 2008, we used two series of three cobble bars located south of Letchworth State Park for our studies of adult cobblestone tiger beetle dispersal patterns. In the first series of cobble bars, the largest cobble bar was an old riverbed that remained dry throughout the summer. The second cobble bar was located approximately 171 m upstream of the largest cobble bar. The third cobble bar, often inaccessible to us during the high water levels of the summer, was approximately 80 m downstream of the largest cobble bar. The second series of cobble bars was located approximately 24 km upstream (south) of the first series. The largest cobble bar had been actively mined for gravel during 2002 and perhaps in prior years. The second cobble bar in this series was located approximately 46 m upstream of the largest cobble bar, while the third cobble bar was 164 m upstream of the second.

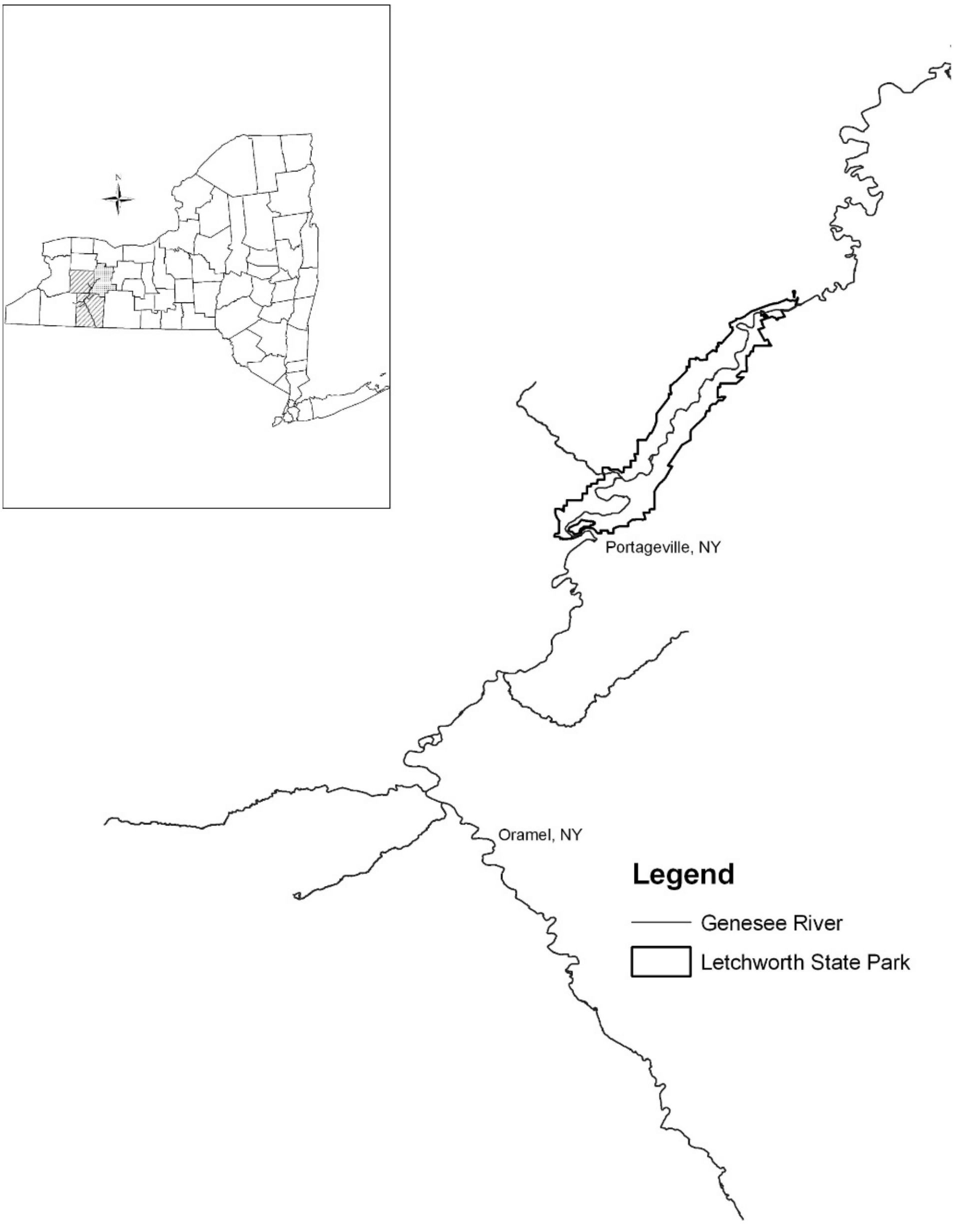

FIG. 1.—Study area on Genesee River, New York for 2008 and 2009

Mixtures of trees, shrubs and forbs covered the inland side of all cobble bars. During the 2009 field season, we conducted the dispersal study only on this second series of cobble bars and we added a fourth cobble bar, 34 m south of the third.

The flight period for cobblestone tiger beetles in New York begins in late Jun. and continues through early Aug. (Gordon, 1939). In 2008, we sighted the first cobblestone tiger beetle on 2 Jul., and began mark – recapture work on 5 Jul., with 20 marking periods between 5 Jul. and 13 Aug. In 2009, the first sighting occurred on 23 Jun. and mark – recapture work began on 29 Jun., with 17 marking periods between 29 Jun. and 13 Aug. Cobblestone tiger beetles usually were captured with a 38-cm diameter flexible net. Ovipositing females were not captured. We spent approximately 4 h per cobble bar visit in 2008 ($\bar{x}$ = 4.4 h) and 2009 ($\bar{x}$ = 3.9 h), walking each cobble bar from access point to end in a serpentine pattern until the area had been completely searched. We sexed each captured beetle, and marked it with a unique number written dorsally on the elytra with a Sharpie® oil-based extra-fine-point pen. Beetles were released immediately after marking at their capture point and we saw no indication of ink fading on marks of recaptured beetles. Ground temperatures were taken at each capture point. Elevation and x-y coordinates were obtained using a Garmin eTrex Legend® or Venture® global positioning unit. Ambient and ground temperatures were taken using a Physitemp BAT-12 Microprobe Thermometer or a Radio Shack Indoor/Outdoor Thermometer with Hygrometer (Model: 63-1032).

Distance between cobble bars (nearest_cb), cobble bar area (area), perimeter-to-area ratio (perim/area) and cobblestone tiger beetle dispersal distances between initial marking point and recapture point were calculated using ArcGIS 9.3 software (Bates *et al.*, 2006).

HABITAT SURVEYS

We conducted a systematic survey of ground cover on 40 cobble bars in 2009. We estimated ground cover (gravel, rocks and vegetation) percentages within 1 m^2 sample plots randomly placed along 100 m transect lines located at approximately 50 m intervals. Placement of the transect lines depended on size and shape of the cobble bar. Vegetation was identified by type (forbs, grasses, shrubs) and substrate was identified by categories: (1) boulders (>25 cm), (2) cobbles (6–25 cm), (3) pebbles (0.4–6 cm) and (4) small grains (<0.4 cm). Ground cover was measured between mid-Jul. and mid-Aug. We used Braun-Blanquet coverage classes for substrate and vegetation cover: (1) 0–5%, (2) 6–25%, (3) 26–50%, (4) 51–75% and (5) 76–100% (Elzinga *et al.*, 1998).

To determine the number of plots required to sample vegetation and substrate adequately, we selected a mid-sized cobble bar for presampling from among the ones visited in 2008. During the presample we randomly placed 1-m^2 plots along transects; ground cover data were analyzed using a sequential sampling graph, plotting running mean and standard deviation. We determined the representative number of sample plots from the point where the curves began to smooth out (Elzinga *et al.*, 1998). We then used a ratio of 0.006 plots/ 100 m^2 of cobbles to determine the number of sample plots on each cobble bar (range: 4–90).

Habitat models were based on the presence or absence of cobblestone tiger beetles as determined by a minimum of three visits per site. The cobble bars we used for these habitat surveys were between Oramel and Fillmore, NY, and within Letchworth State Park (Fig. 1). This area was selected because cobblestone tiger beetles had been detected on some of the cobble bars in surveys done by the NYNHP between 2000 and 2002 (New York Natural Heritage Program, 2010). We divided the section of the Genesee River between Oramel – Fillmore into three smaller sections (Oramel – Caneadea, Caneadea – Houghton and Houghton – Fillmore) based on river access points and time required for travel between cobble bars. Each section contained at least nine accessible cobble bars. The stretch of cobble bars within Letchworth State Park was between Lee's Landing and St. Helena river access points. We made visits to cobble bars by kayak between 5 Jul. and 7 Sept. and each trip began at approximately 10:00 and ended by 17:00. We did not make kayak trips on days when it rained or when water levels were unsafe. We surveyed 40 cobble bars for cobblestone

TABLE 1.—Ground cover factors and factor loadings generated by Principal Component Analysis for cobblestone tiger beetles (*Cicindela marginipennis*) along the Genesee River, NY in 2009

	I	II	III
Eigenvalue	2.6	1.3	1.0
Proportion of total variance explained	36.5	18.4	14.9
Cumulative variance explained	36.5	54.9	69.7
Variables[1]			
Boulders	0.7	0.4	0.2
Cobbles	−0.5	−0.8	−0.1
Pebbles	−0.8	−0.2	0.1
Small Grains	−0.1	0.9	0.0
Shrubs	0.1	−0.1	−0.8
Forbs	0.8	−0.2	0.1
Grasses	0.2	0.0	0.6

[1] Only components with eigenvalues > 1.0 are shown

tiger beetles and noted the presence of other tiger beetle species (*Cicindela ancocisconensis* and *C. repanda*). If a cobblestone tiger beetle was sighted, or when the entire cobble bar had been searched, we moved to the next cobble bar.

MODELING HABITAT USE

We used model selection techniques to evaluate relationships between habitat variables and the presence of cobblestone tiger beetles. We converted substrate and vegetation variables from Braun-Blanquet coverage classes to median percent values for each class. To reduce multicollinearity, we used a *t*-test for equality of means to evaluate independent samples (SPSS, 2008) and Pearson's correlation test to evaluate correlations between habitat variables and Principal Component Analysis (PCA) to combine boulders, cobbles, pebbles, small grains, forbs, grasses and shrubs into three components with eigenvalues ≥1.0. The three components accounted for 70% of the total variance in the data set. We interpreted the components by examining loadings of the original variables (Table 1) (SPSS, 2008). Cobble bars with many boulders and forbs and few pebbles scored high on the first axis (I), cobble bars with many small grains and few cobbles scored high on the second axis (II) and cobble bars scoring high on the third axis (III) contained few shrubs and some grasses. We used a *t*-test for equality of means to determine significant differences in variables between cobble bars with and without cobblestone tiger beetles. We used chi-square tests to test for differences in the sex ratio of captured beetles. If necessary, variables were transformed using z-scores in order to meet normal distribution requirements.

We used binary logistic regression to model effects of predictor variables on cobble bar occupancy. Response variable for the models was presence or absence of cobblestone tiger beetles on a cobble bar. Main effect covariates included PCA components (I, II and III), perim/area, difference between minimum and maximum elevations (diff_elev), area and nearest_cb. We created a series of models and compared them using a process described by Gjerdrum *et al.* (2005). Akaike's Information Criterion, corrected for small sample sizes (AIC_c), was used to determine fitness of each model (Burnham and Anderson, 2002) and models were ranked according to ΔAIC_c. We also calculated AIC_c weights for each model, which assisted in assessing evidence favoring a model (Burnham and Anderson, 2002). At each step in our selection process, we sequentially removed the predictor variable with the highest P-value > 0.05. We built nine models *a priori* based on our understanding of tiger

TABLE 2.—Mark – recapture data by sex for cobblestone tiger beetles (*Cicindela marginipennis*) along the Genesee River, NY for 2008 and 2009

Year	Activity	Male	Female	Unknown	Total
2008	Marked	53	59	2	114
	Recaptured	6	2	—	8
2009	Marked	56	86	3	145
	Recaptured	5	11	—	16
TOTAL	Marked	109	145	5	259
	Recaptured	11	13	—	24[1]

[1] Recaptures includes one beetle recaptured three times

beetle biology and riverine ecosystems. The most complex model included all predictors, plus five two-way interactions (diff_elev*perim/area, diff_elev*area, PCA I*PCA III, PCA II*PCA III and PCA I*PCA II), two three-way interactions (area*diff_ elev*perim/area and PCA I*PCA II*PCA III), and one four-way interaction (PCA I*PCA II*PCA III*perim/area). We considered models with ΔAIC_c values < 2.0 to be most meaningful (Burnham and Anderson, 2002). We set $\alpha = 0.05$ and summary statistics are reported as mean $\pm$ 1 SE unless otherwise noted.

RESULTS

DISPERSAL (MARK – RECAPTURE)

In 2008 and 2009, we marked 259 cobblestone tiger beetles. We marked a greater proportion of females than males (df = 1, $\chi^2 = 5.1$, P = 0.02) over the two summers (Table 2). In 2008, there was no significant difference in proportion of males (n = 53) to females (n = 59) marked ($\chi^2 = 0.32$, df = 1, P = 0.57), whereas a significantly larger proportion of females (n = 86) than males (n = 56) was marked in 2009 ($\chi^2 = 6.34$, df = 1, P = 0.01). Five beetles of undetermined sex were not used in this analysis.

During the 2 y, we recaptured 21 of 259 marked beetles. In 2008, eight individual cobblestone tiger beetles were recaptured (Table 3). One male was recaptured 322 m from his original capture point. Other recapture distances ranged from 0 to 123 m. In 2009, 13 individual cobblestone tiger beetles were recaptured. One male was recaptured three times over 21 d at distances from 6 to 68 m from his marking site. One beetle was observed to move between cobble bars in 2008, whereas four did so in 2009. Means for recapture distances did not differ significantly between years or sex (year: $t = 0.59$, df = 21, P = 0.56; sex: $t = 0.76$, df = 21, P = 0.46), nor did time between captures (year: $t = 1.00$, df = 21, P = 0.33; sex: $t = 0.77$, df = 21, P = 0.45) (Table 4). Recaptured cobblestone tiger beetles occasionally traveled distances greater than the maximum distance between adjacent cobble bars in the study area (beetles: = 133 m, range 0–481 m; nearest_cb: = 53 m, range 11–203 m).

Between 2000 and 2002, cobblestone tiger beetles were found on 17 cobble bars examined during the NYNHP survey on the Genesee River from Belfast through Letchworth State Park (New York Natural Heritage Program, 2010). In 2008 and 2009, we found cobblestone tiger beetles on six of 14 NYNHP cobble bars; three of their cobble bars were inaccessible in 2008 and 2009. Within Letchworth State Park, we surveyed five of the seven NYNHP cobble bars with cobblestone tiger beetles in 2000–2002. Of these five, only one (LL6) had cobblestone tiger beetles detected in 2008 and 2009. Although cobblestone tiger beetles were not found on the majority of the NYNHP cobble bars in 2008 and 2009, we

TABLE 3.—2008 and 2009 Recapture distances and time between marking and recapture for individual cobblestone tiger beetles (*Cicindela marginipennis*)

Year	Sex	Location[1]	Distance (m)[2]	Time between marking and recapture (d)
2008	F	P1	123	6
2008	F	R1	112	5
2008	M	P1	34	3
2008	M	P1	113	3
2008	M	R1 – R2	322	24
2008	M	P1	12	2
2008	M	P1	0	2
2008	M	R2	15	5
2009	F	R1	5	23
2009	F	R1	74	23
2009	F	R2 – R1	481	21
2009	M	R1	6	1
2009	M	R1	5	68
2009	M	R1	21	58
2009	M	R1	21	1
2009	F	R1	3	1
2009	F	R1	0	5
2009	F	R1	17	5
2009	F	R1	15	6
2009	F	R0 – R1	366	21
2009	M	R0 – R1	362	13
2009	F	R2	54	2
2009	F	R2 – R1	458	4

[1] Cobble bar identifier. Two locations (R0 – R1) indicate movement between cobble bars from original capture point to recapture point

[2] Distance from original capture point

found them on 17 other cobble bars. In 2009, we also found three occupied cobble bars where cobblestone tiger beetles had not been detected in 2008.

HABITAT USE

In 2009, we detected cobblestone tiger beetles on 23 of 40 surveyed cobble bars. Area, perimeter-to-area ratio, elevational difference and shrub cover differed significantly between occupied and unoccupied cobble bars (Table 5); occupied cobble bars had about twice the area and difference between minimum and maximum elevation, and higher shrub cover, than unoccupied cobble bars. Difference in percent boulder cover and distance to the nearest cobble bar also approached statistical significance, with occupied bars tending to have lower boulder cover and occurring nearer to other cobble bars. Shrub cover was significantly higher on occupied cobble bars, although cover for all vegetation types on surveyed bars was generally less than 10% (Table 5).

Seven predictor variables (area, diff_elev, perim/area, nearest_cb, and PCA components I, II and III) were used to develop habitat models for predicting cobblestone tiger beetle presence (Table 6). The model with perim/area alone had the strongest fit, with all other models having ΔAIC_c values ≥ 3.0. Cobblestone tiger beetles tended to occur on cobble bars with smaller perimeter-to-area ratio (*i.e.*, cobble bars with more center area and less edge).

TABLE 4.—Cobblestone tiger beetle (*Cicindela marginipennis*) dispersal by distance and time between captures, and by year and sex

Variable	Year	Sex	n	Mean[1]	SE[1]	Minimum	Maximum	Range	95% Confidence interval for mean: Lower bound	95% Confidence interval for mean: Upper bound
Distance (m)	2008	Female	2	117.8	5.3	112	123	11	107.3	128.3
		Male	6	82.6	50.6	0	321	321	−16.7	181.8
		Total	8	91.4	37.5	0	322	322	17.8	164.9
	2009	Female	10	147.3	63.9	0	481	481	22.1	272.5
		Male	5	103.0	65.8	6	362	356	−25.9	231.9
		Total	15	132.5	46.8	0	481	481	40.8	224.3
	Total	Female	12	142.4	52.8	0	481	481	38.8	245.9
		Male	11	91.8	38.7	0	362	362	16.0	167.7
		Total	23	118.2	32.9	0	481	481	53.7	182.7
Time between captures (d)	2008	Female	2	5.5	0.5	5	6	1	4.5	6.5
		Male	6	6.7	3.7	2	25	23	−0.6	13.9
		Total	8	6.4	2.7	2	25	23	1.1	11.7
	2009	Female	10	11.1	3.0	1	23	22	5.8	16.4
		Male	5	8.2	3.9	1	21	20	0.6	15.8
		Total	15	10.1	2.3	1	23	22	5.6	14.7
	Total	Female	12	10.2	2.6	1	23	22	5.1	15.2
		Male	11	7.4	2.6	1	25	24	2.4	12.4
		Total	23	8.8	1.8	1	25	24	5.3	12.3

[1] Means and standard error (SE) for distances (m) between original marking point and recapture point and time (d) between initial capture and recapture by year and sex

NATURAL HISTORY

We observed cobblestone tiger beetles in 2008 between 2 Jul. and 7 Sept., and in 2009 between 23 Jun. and 3 Sept., with a peak season in Jul. and early Aug. (Fig. 2). We rarely encountered them before 10:00 or after 17:00, and then only on warm sunny days. Occasionally, one or two beetles were seen during light rain, but they soon disappeared when precipitation began to form puddles. Ambient air temperatures on dispersal study days ranged from 18.8 C to 32.7 C ($\bar{x}$ = 26.9 C), whereas ground temperatures ranged from 21.5 C to 46.4 C ($\bar{x}$ = 32.3 C). On hot days, beetles often were observed in areas of moist substrate near the river's edge.

Cobblestone tiger beetles were observed with the gregarious and more common bronzed tiger beetles (*Cicindela repanda*) and the more elusive Appalachian tiger beetle (*C. ancocisconensis*). For the 40 cobble bars surveyed in 2009, bronzed tiger beetles occupied 37 and Appalachian tiger beetles occupied 10. Cobblestone and bronzed tiger beetles were detected near the river's edge and in sandy patches scattered among cobbles, whereas Appalachian tiger beetles occurred closer to vegetation on the inland edge of cobble bars.

Cobble bars occupied by cobblestone tiger beetles were located along the river's edge and at bends in the river. Only one of these cobble bars was an island that was occasionally isolated from the shoreline by storm events and high water levels. We did not observe cobblestone tiger beetles on cobble bars completely isolated from the shoreline. Occupied cobble bars were likely to have some area above high water levels. Areas of sand or other small grains were located downstream of the vegetation. Most of the occupied cobble bars were covered with loosely packed cobbles. These cobble bars had few boulders at the

TABLE 5.—Cobblestone tiger beetle (*Cicindela marginipennis*) habitat characteristics for occupied and unoccupied cobble bars along Genesee River, NY, for 2009. **Bold** indicates significant P-values (α = 0.05)

	All cobble bars		Beetles present		Beetles absent		T-test for equality of means		
Predictor variable	Mean[1]	SE[1]	Mean	SE	Mean	SE	*t*	df	P
Area (m^2)	10,585	1423	13,572	2038	6543	1451	2.62	38	**0.01**
Perimeter to area ratio	0.09	0.01	0.06	0.00	0.12	0.02	3.51	18	**0.00**
Elev. difference (m)	21.7	2.96	28.0	4.43	13.0	2.36	2.99	32	**0.01**
Nearest cobble bar (m)	54	6.54	44	7.02	68	11.51	1.91	38	0.06
Boulders (%)	5.5	1.14	3.7	0.30	8.0	2.56	1.69	16	0.11
Cobbles (%)	67.5	2.86	69.3	3.16	65.2	5.39	0.71	38	0.48
Pebbles (%)	34.2	2.35	35.6	2.52	32.4	4.40	0.67	38	0.51
Small grains (%)	40.5	3.27	39.1	3.90	42.4	5.71	0.50	38	0.62
Forbs (%)	9.4	1.107	9.1	1.05	9.9	2.13	0.34	38	0.74
Grasses (%)	4.5	0.46	4.2	0.41	4.9	0.94	0.70	22	0.49
Shrubs (%)	3.7	0.26	4.1	0.38	3.1	0.30	2.21	38	**0.03**
PCA I[2]	0.00	0.16	−0.10	0.16	0.14	0.32	0.74	38	0.46
PCA II[2]	0.00	0.16	−0.09	0.17	0.13	0.29	0.68	38	0.50
PCA III[2]	0.00	0.16	−0.28	0.18	0.38	0.25	2.14	38	**0.04**

[1] Habitat predictor variables with mean and standard error (SE) for total (n = 40), present (n = 23) and absent (n = 17) with T-test results for differences between Present and Absence means

[2] PCA I - Boulders/Pebbles/Forbs, PCA II - Cobbles/Small grains and PCA III - Shrubs/grasses

TABLE 6.—Habitat models for cobblestone tiger beetles (*Cicindela marginipennis*) for 2009 with AIC_c corrected for small sample sizes. Models ranked relative to best-fit model, based on ascending ΔAIC_c values

Model variables	Model summary −2 log likelihood	AIC_c	Δ AIC_c	AIC_c sum of likelihood	AIC_c weight
A,1	37.1	44.4	0.0	1.0	0.8
A,1,2	37.2	48.0	3.6	0.2	0.1
A,1,2,3	36.8	51.1	6.8	0.0	0.0
A,1,2,3,4,5,6,7	26.2	54.5	10.1	0.0	0.0
A,1,2,3,4,5,6,7,8	25.1	57.4	13.0	0.0	0.0
A,1,2,3,4,5,6,7,8,9,10	32.9	63.1	18.7	0.0	0.0
A,main effects (1,2,3,4,8,9,11)[+]	23.5	65.0	20.6	0.0	0.0
A,1,2,3,4,5,6,7,8,9,10,11,12,13,14	20.4	84.0	39.6	0.0	0.0
A,1,2,3,4,5,6,7,8,9,10,1112,13,14,15	20.4	91.1	46.8	0.0	0.0

[+] Main effects model uses the covariate and factor main effects but no interaction effects

Model variables are as follows:

(A) Intercept, (1) Perim/area, (2) PCA I, (3) Area, (4) Diff_elev, (5) Diff_elev * Perim/area, (6) Area * Diff_elev, (7) Area * Diff_elev * Perim/area, (8) Nearest_cb, (9) PCA III, (10) PCA I * PCA III, (11) PCA II, (12) PCA I * PCA II, (13) PCA I * PCA II * PCA III, (14) Perim/area * PCA I * PCA II * PCA III, (15) PCA II * PCA I

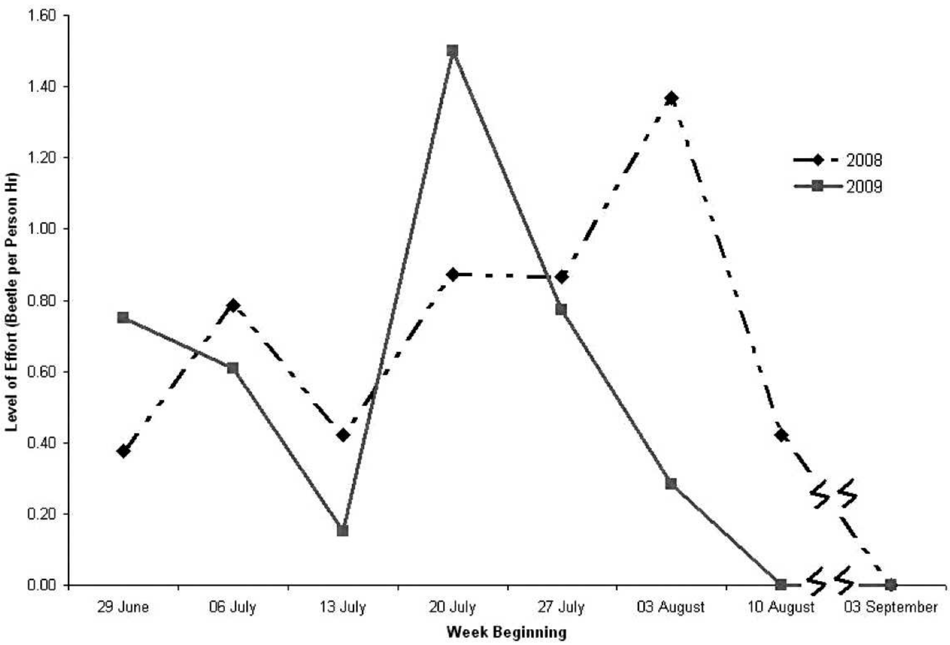

FIG. 2.—Cobblestone tiger beetles captured per unit effort along the Genesee River, NY. In 2008, the first observation occurred on 2 Jul. and the last on 8 Sept.; in 2009 the first observation occurred on 23 Jun. and the last on 3 Sept.

upstream end and sand/silt areas downstream. Other arthropods, such as spiders, spider wasps and ants, were always present on occupied cobble bars.

DISCUSSION

Cobblestone tiger beetles dispersed up to 481 m, far exceeding the maximum distance between surveyed cobble bars, and they sometimes moved between cobble bars. In comparison, *Cicindela puritana* disperse up to 2.7 km (Omland, 2004), whereas *C. dorsalis dorsalis* were recaptured up to 24 km from their marking site (Knisley and Schultz, 1997). We did not observe cobblestone tiger beetles traveling to this extent, but they moved between cobble bars in both upstream and downstream directions, consistent with general dispersal patterns of aquatic insects (Smith *et al.*, 2009). The ability to travel distances greater than those between adjacent cobble bars was a strong indicator of the beetles' ability to colonize other cobble bars. In 2009, we found an increase in the number of occupied cobble bars, which indicated possible colonization since the initial 2000–2002 surveys and the 2008 survey. Sightings of single cobblestone tiger beetles on some surveyed cobble bars may have been transitory beetles

The annual adult activity period of cobblestone tiger beetles in western NY began in late Jun., with the emergence of adults, and continued through Sept., an activity pattern similar to that of cobblestone tiger beetles in West Virginia (Allen and Acciavatti, 2002). Gordon (1939) listed the flight period in New York from late Jun. through the middle of Aug. Boyd (1978) gave 4–25 Jul. as the peak period for cobblestone tiger beetles in New Jersey with occasional sightings as early as May.

Cobblestone tiger beetles were more likely to occur in habitat patches with greater interior area and elevational relief, and few boulders. We found tiger beetles only on cobble bars on the shoreline, not on islands as described by Boyd (1978) and Dunn and Wilson (1979). We also found them throughout occupied cobble bars and not restricted to the upstream end of cobble islands or sandy beaches, in contrast to Boyd (1978), Dunn and Wilson (1979), and Leonard and Bell (1999). We observed them in areas of mixed-size cobbles and patchy vegetation, not just in areas of tightly packed cobbles; they also occurred close to the river's edge in areas of moist or wet sand and silt.

We found differences in the number of sites with cobblestone tiger beetles between the 2000–2002 NYNHP surveys and those in 2008–2009. We did not find cobblestone tiger beetles on eight of the originally occupied NYNHP cobble bars, six of which were in Letchworth State Park. Whether these were true changes in occupancy or artifacts of sampling effort is uncertain. However, beetle patch occupancy probably has changed over the years. With summer high-water events and the Genesee River's natural load of silt and sediments, cobble bars change from boulder and cobble deposits to areas supporting increased vegetation growth, especially within Letchworth State Park. Mt. Morris dam, built for flood control in the 1950s, holds back high water flows to allow for a controlled release of water downstream leaving cobble bars submerged for longer periods. Cobble bars with dense vegetation and fewer open areas were less likely to have cobblestone tiger beetles. Three previously occupied cobble bars were located between the dam and the St. Helena access point, where the gorge opens up and the river widens. These cobble bars had increased silt deposits and had become covered in vegetation. Research on *Cicindela hirticollis* along rivers in California (Knisley and Fenster, 2005) and *C. abdominalis* from the Virginia pine barrens (Knisley and Hill, 1992) suggests that vegetation increases and loss of open areas may help cause the local decline of these tiger beetles. Likewise, the decreased velocity of the Genesee River above the Mt. Morris dam and associate levels of higher siltation and increased vegetation growth may have yielded habitat unsuitable for cobblestone tiger beetles.

Human disturbance could also be a cause of local extinctions of cobblestone tiger beetles. Habitat disturbance by off-road vehicles and heavy foot traffic were major factors in the decline of *Cicindela dorsalis* on Northeastern beaches and *C. oregona* along an Arizona stream (Schultz, 1988). The Genesee River within Letchworth State Park has become a favorite destination for river rafters and kayakers. A previously occupied cobble bar at Lee's Landing (LL2) has seen an increase in traffic as buses deposit river tour participants at this access point for river tours. Substrate compaction resulting from this increase in human traffic has possibly removed suitable areas for cobblestone tiger beetle larval burrows.

Cobblestone tiger beetles are ideal candidates to aid in monitoring overall riparian health along the upper Genesee River, and the use of bioindicator species can be helpful in reducing the amount of time and cost required for inventory (Carroll and Pearson, 1998). The beetles, although highly adapted to natural river disturbances such as seasonal flooding and ice scouring, appear to be sensitive to anthropomorphic changes leading to increased vegetation and reduction of open areas. Their sessile larvae, restricted to burrows, have a narrower range of microhabitats than do adults, and seem to tolerate fewer changes, especially in soil composition, soil moisture and temperatures (Rodriguez *et al.*, 1998).

In order to preserve cobblestone tiger beetles and riparian habitats along the upper Genesee River, habitats should be managed to reduce impacts from recreational activities (canoeing/kayaking and off-road vehicles) and sand/gravel mining. Monitoring cobble bars for the presence of cobblestone tiger beetles should take place when they are most active—

in late morning through mid-afternoon when ambient temperatures are the highest, and from early Jul. through early Aug. Presence/absence surveys should continue on presently occupied cobble bars, with further surveys made to evaluate cobblestone tiger beetle presence on feeder stream cobble bars and unsurveyed cobble bars and islands in the Genesee River. Future research should include identification of cobblestone tiger beetle larvae, which have not been described (Leonard and Bell, 1999) and the effect of anthropomorphic disturbance on their habitats.

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