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ORIGINAL PAPER

Status and conservation of an imperiled tiger beetle fauna in New York State, USA

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Abstract New York has 22 documented species of tiger beetles (Coleoptera: Cicindelidae). Over half of these species are considered rare, at risk, or potentially extirpated from the state. These rare species specialize on three sandy habitat types under threat from human disturbance: beaches, pine barrens, and riparian cobble bars. In 2005, we began a status assessment of eight of New York's rarest tiger beetles, examining museum records, searching the literature, and conducting over 130 field surveys of historical and new locations. Significant findings included (1) no detections of four of the eight taxa; (2) no vehicle-free beach habitat suitable for reintroducing *Cicindela dorsalis dorsalis*; (3) *C. hirticollis* at only 4 of 26 historical locations; (4) *C. patruela patruela* at only one site statewide; and (5) *C. ancocisconensis* at only 3 of 28 de novo survey sites. Additional species that might be declining deserve our attention, as do some threats to tiger beetle habitats, like lack of beach wilderness, fire suppression in pine barrens, and river damming. Rarity in tiger beetles is a result of varying ecologies, which suggest different conservation strategies. Future inventory and documentation of tiger beetle occurrences need to take into account the metapopulation structure and imperfect detectability of these rare insects.

Keywords Tiger beetles · Cicindelidae · Rarity · Status · New York · Beach · Pine barrens · Cobble bars

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Introduction

Tiger beetles (Coleoptera: Cicindelidae) are strikingly patterned, predatory insects that have captured the attention of entomologists and collectors for centuries. Beyond their intrinsic interest, tiger beetles can serve as model organisms or indicator species to enable broad conclusions about a region or ecosystem's biodiversity (Pearson and Cassola 1992; Pearson and Vogler 2001). Tiger beetles are threatened by habitat destruction and modification, alteration of natural processes like fire and flooding, and overcollection; across the United States, approximately 15% of taxa are threatened with extinction (Pearson et al. 2006). They are strong fliers and long-distance dispersers (Pearson and Vogler 2001), but despite this mobility many species are considered at risk and many populations have declined.

As with most taxa (Loreau 1992; MacArthur 1960), tiger beetle faunas consist of a few widely distributed and abundant species and several narrowly distributed and rare species. Several northeastern U.S. states and Canadian provinces have cataloged their tiger beetle fauna in an attempt to focus conservation attention on the rarest taxa (e.g., Boyd 1978; Dunn 1981; Larochelle 1972; Sutherland 1999; Wilson and Brower 1983). In 2005, we began a status assessment of rare tiger beetles in New York State, beginning by gathering data on historical locations and conducting field surveys to those locations and new sites with suitable habitat. Tracking down historical occurrences was facilitated by a strong history of tiger beetle collection in the state (Blanchard 2006; Gordon 1939; Leng in Leonard 1928; Stamatov 1970). Despite this collection history, the overall status of the family in the state has never been assessed. Two recent volumes (Knisley and Schultz 1997; Leonard and Bell 1999) cover nearby and neighboring states and provided context for our assessment.

Table 1 Tiger beetles of New York State

Scientific name	Common name	Global status rank[a]	Subnational status rank[a]
Cicindela abdominalis	Eastern pinebarrens tiger beetle	G4	SH
Cicindela ancocisconensis	Appalachian tiger beetle	G3	S2
Cicindela dorsalis dorsalis	Northeastern beach tiger beetle	G4T2	SX[b]
Cicindela duodecimguttata	Twelve-spotted tiger beetle	G5	S5
Cicindela formosa	Big sand tiger beetle	G5	S4
Cicindela hirticollis hirticollis	Hairy-necked tiger beetle	G5	S1S2
Cicindela hirticollis rhodensis	Hairy-necked tiger beetle	G5	S1S2
Cicindela lepida	Ghost tiger beetle	G3G4	S3
Cicindela limbalis	Common claybank tiger beetle	G5	S4
Cicindela longilabris	Boreal long-lipped tiger beetle	G5	S3S4
Cicindela marginata	Margined tiger beetle	G5	S3
Cicindela marginipennis	Cobblestone tiger beetle	G2	S1S2[c]
Cicindela patruela consentanea	New Jersey pine barrens tiger beetle	G3T1T3	SH
Cicindela patruela patruela	Northern barrens tiger beetle	G3T3	S1
Cicindela punctulata	Punctured tiger beetle	G5	S5
Cicindela puritana	Puritan tiger beetle	G1G2	SNA[d]
Cicindela purpurea	Cow path tiger beetle	G5	S5
Cicindela repanda	Bronzed tiger beetle	G5	S5
Cicindela rufiventris	Eastern red-bellied tiger beetle	G5	S3
Cicindela scutellaris lecontei	Festive tiger beetle	G5T5	S5
Cicindela scutellaris rugifrons	Festive tiger beetle	G5T5	S3
Cicindela sexguttata	Six-spotted tiger beetle	G5	S5
Cicindela tranquebarica	Oblique-lined tiger beetle	G5	S5
Cicindela unipunctata	One-spotted tiger beetle	G4	SH
Tetracha virginica	Virginia big-headed tiger beetle	G5	SU

[a] Definitions of natural heritage global and state ranks are in the Appendix

[b] Federally and state listed as threatened

[c] Federally listed as a species of concern

[d] Federally listed as threatened

Twenty-two species of tiger beetles have been reported from New York State (NatureServe 2010). Three of these species each have two recognized subspecies that occur in New York, for a total of 25 tiger beetle taxa (Table 1). In our status assessment, we focus on eight of the rarest taxa, providing historical data; recent survey information; conservation issues; research, inventory, and monitoring needs; and changes in conservation status ranks. As habitat descriptions and conservation issues are shared among taxa that occur in the same ecosystem type, the species accounts are grouped accordingly. Cicindela hirticollis is treated as one taxon because historical accounts often did not distinguish between the two subspecies.

Study area and methods

New York State occupies nearly 130,000 km^2 in a diverse region of the northeastern United States (Fig. 1). The state stretches from the Atlantic Ocean at the southeast to the Great Lakes of Ontario and Erie at its western border. Its elevations range from sea level to 1,629 m and its annual precipitation ranges from approximately 75–125 cm annually. New York's geology is highly varied and the state contains multiple types of substrates suitable for breeding by tiger beetles.

Field surveys and incidental observations were our primary method of documenting the current distribution of New York's rare tiger beetles. While several species had recent records between 1980 and 2005, the majority of our survey effort took place from 2005 to 2009, when we conducted over 130 field surveys (defined as unique combinations of sites and dates) throughout the state. Our main focus was to revisit historical occurrences, but in addition, we conducted de novo searches for most of the taxa. The combination of those two field approaches provided a strong foundation on which to base assessments of conservation status by answering two important questions: (1)

Fig. 1 Location of New York State within North America

Is the species still found in places it once occupied? and (2) Is the species present in locations not previously known or has its distribution expanded? For this paper, we used information from both kinds of field surveys to help determine the conservation status of each species.

We divided records and surveys into two periods: historical (before 1980) and current (1980 and after). This division allowed us to look at changes between the two periods. The use of museum and other historical data has been recommended as a powerful method of determining changes in distribution (Shaffer et al. 1998), and tiger beetles in particular have been singled out for this kind of historical comparison because of their long history of collection (Pearson and Cassola 2007). We compiled historical data from Natural Heritage records, museum specimens, and published literature.

The great challenge of attempting visits to historical locations gleaned from museum specimens and the literature is that these locations are often described imprecisely or broadly (e.g., "New York City"). However, many were described precisely enough to enable the use of remote sensing tools, such as aerial photography and satellite imagery (Mawdsley 2008), to determine appropriate areas to survey. This analysis was simpler for some habitat types than for others. For example, remote sensing readily informed us whether a beach was present, but less readily whether a stretch of stream had suitable substrate for tiger beetles. (Of course, the simple presence of a beach did not indicate suitable habitat for rare tiger beetles, because habitat suitability also depended on beach structure and human use, which are less easily determined without groundtruthing.) Therefore, in some cases, remote analysis demonstrated that suitable habitat was no longer present, and no follow-up field visits were needed, while in other cases the range of options for field work was simply narrowed down.

Field surveys were conducted during the known flight seasons of adult beetles (Gordon 1939; Pearson et al. 2006) on warm ($\sim$21° C), sunny days from 0900 to 1800 h. Trained observers walked areas of suitable habitat and used close-focusing binoculars and insect nets to observe or capture beetles encountered. These "presence-absence" surveys were not designed to estimate abundances, but we did conduct rough counts. Site surveys were typically conducted only once, although some sites were surveyed multiple times.

We summarized survey efforts by reporting the number of historical locations surveyed and the number determined to be occupied, as well as the number of current locations surveyed and occupied. For a variety of reasons, absence cannot necessarily be inferred from nondetection of an adult beetle; this topic is discussed further below. However, adult tiger beetles are conspicuous, and observers were experienced, so we believe that detectability was very high. We did not have the data to calculate detectability or occupancy parameters for these species.

We calculated conservation status ranks (S-ranks; Appendix) for rare tiger beetles using NatureServe's Element Rank Calculator, version 2.0 (NatureServe 2009). This methodology for assigning S-ranks is based on a process developed by NatureServe (Faber-Langendoen et al. 2009; Master et al. 2009) that is in use by Natural Heritage programs and Conservation Data Centers in North and South America. It is closely related to the International Union for the Conservation of Nature (2001, 2003) system; the factors assessed and breakpoints between categories are similar, and the assessed statuses can be cross-walked (Master et al. 2009; Appendix). The rank calculator is a spreadsheet into which the user inputs information on rarity, trends, and threats, each of which has several components (e.g., range extent, area of occupancy, population size, number of occurrences, short-term trend, long-term trend, and threat impact [itself calculated through a series of steps]). The calculator then performs a series of algorithms based on pre-defined or user-defined parameter weights to generate an S-rank. The calculator was built to accommodate missing data and to accept a great deal of uncertainty. For tiger beetles, population size was not available and trend information was patchy.

Results and species status assessments

Of New York's eight rarest tiger beetles, only four (50%) have been detected since 1980, and two of these have either one or two known locations in the state (Table 2). Thus, four (16%) of New York's 25 taxa are likely extirpated from the state, and an additional four (16%) are considered imperiled or critically imperiled. Accounts of these eight beetles follow, grouped into three main habitat types.

Beach tiger beetles

Northeastern beach tiger beetle (Cicindela dorsalis dorsalis)

Cicindela dorsalis dorsalis was formerly distributed along many of Long Island's barrier beaches (Fig. 2), but it appears to have been entirely extirpated by around 1950 (Stamatov 1972). The only known extant population in the Northeast is at Martha's Vineyard, Massachusetts, and this population has been studied intensely (e.g., Nothnagle and Simmons 1990), with additional studies of populations in Virginia and Maryland (e.g., Knisley et al. 1987) providing a good understanding of the species' habitat needs.

Nearly all historical locations for *C. d. dorsalis* in New York have been surveyed in the past 20 years, with no detections of the species recorded. Even though some of the few remaining sites are remote islands, it is highly unlikely that this species will be discovered again in New York. Recent surveys have strengthened the notion that not only is the species extirpated from New York, but that unless management of ocean beaches changes, it will never return. Beach stabilization for erosion control, the primary agent of habitat destruction for *C. d. dorsalis* (Blanchard 2006; Hill and Knisley 1993a; Knisley et al. 2005; Nothnagle and Simmons 1990; Stamatov 1972; U.S. Fish and Wildlife Service 2009), would be very challenging to reverse, both physically and politically. Not all beaches have been stabilized, but even on those where natural processes of wave action and erosion are allowed to continue, there are other threats. Nearly all beaches surveyed had significant vehicle traffic, which most experts (Blanchard 2006; Hill and Knisley 1993a; Knisley et al. 2005; Nothnagle and Simmons 1990; Stamatov 1972; U.S.Fish and Wildlife Service 2009) agree is another chief cause of decline for this species and beach tiger beetles more generally (Arndt et al. 2005). Vehicles are currently allowed on most of Long Island's beaches. If managers of beaches are willing to restrict some destructive forms of recreation, and leave some beaches in a wild state, then certain beaches with intact structure and natural processes might once again be suitable habitat for *C. d. dorsalis.* Admittedly, however, it is hard to offer too much encouragement regarding reintroduction. The one attempt at reintroduction of this species (Knisley et al. 2005) apparently has failed (U.S. Fish and Wildlife Service 2009). In addition, with global climate change threatening coastal ecosystems (Parry et al. 2007), it might be a difficult restoration project to sell to land managers and the public—if the beaches themselves could disappear in 50 years, why attempt to reintroduce the native fauna? These questions, nonetheless, deserve serious discussion in planning and management of New York's State Parks and federal lands like Gateway National Recreation Area and Fire Island National

Table 2 Surveys for rare *Cicindela* spp. in New York State, USA and NatureServe conservation status ranks (Appendix)

Species	Historical locations surveyed	Historical locations occupied	Current locations surveyed	Current locations occupied	Calculated subnational status rank
Beach tiger beetles					
C. dorsalis dorsalis	21	0 (0%)	10	0 (0%)	SX
C. hirticollis	26	4 (15%)	22	10 (45%)	S1S2
Pine barrens tiger beetles					
C. abdominalis	2	0 (0%)	0	N/A	SH
C. patruela consentanea	5	0 (0%)	1	0 (0%)	SH
C. patruela patruela	4	0 (0%)	5	1 (20%)	S1
C. unipunctata	3	0 (0%)	0	N/A	SH
Riparian tiger beetles					
C. ancocisconensis	6	1 (17%)	41	16 (39%)	S2
C. marginipennis	1	0 (0%)	2	2 (100%)	S1S2

Historical locations were documented before 1980 and not since; current locations include de novo survey sites and those documented with the species' presence from 1980 onward

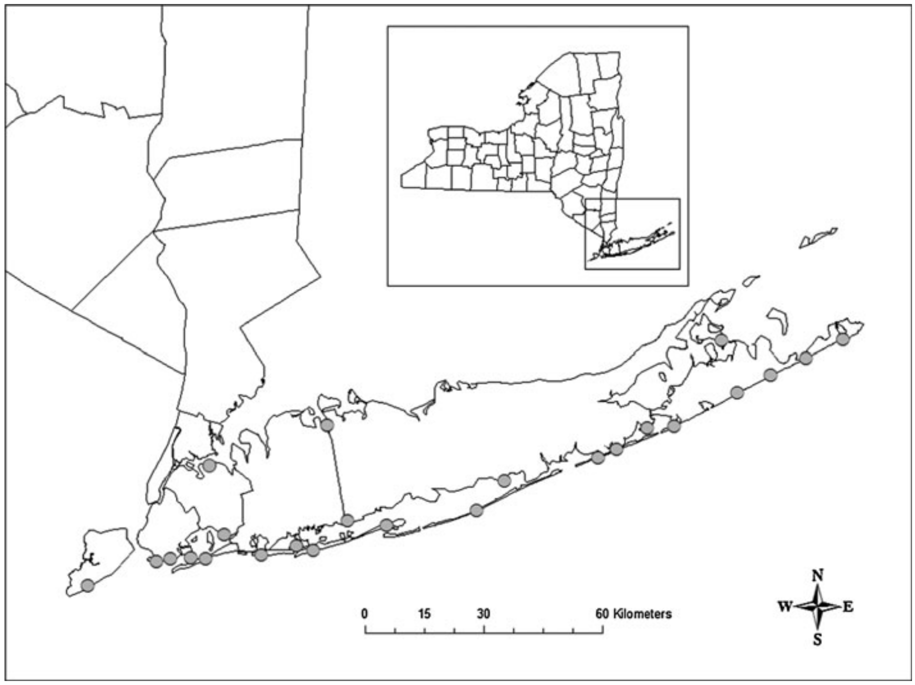

Fig. 2 Former distribution of *Cicindela dorsalis dorsalis* on Long Island, New York. *Gray circles* represent approximate historical locations. County boundaries are shown

Seashore, as the majority of potentially suitable habitat remaining falls under federal and state jurisdiction.

Hairy-necked tiger beetle (Cicindela hirticollis)

Clearly the tiger beetle with the best common name, the hairy-necked tiger beetle (*C. hirticollis*) has several facets of its natural history in common with the federally listed *C. d. dorsalis*, including dependence on beaches with intact structure and processes and vulnerability to devastation of larval burrows from vehicular traffic. Not surprisingly, the two species' historical distributions overlapped considerably. However, *C. hirticollis* has managed to survive in more locations and on more altered beaches than has *C. dorsalis*. In part this may result from their one-year life cycle, compared to the two-year life cycle of *C. dorsalis*; this quicker larval development means less time spent in the vulnerable larval burrow (Simmons 2008). In addition, *C. hirticollis* is not restricted to the U.S. coast, occurring nearly nationwide on the sandy shores of large inland lakes and rivers. In New York, in addition to historical and extant occurrences on Long Island, *C. hirticollis* was found on a 30-km undeveloped and unmotorized beach/dune system along eastern Lake Ontario in 2001 and at Lake Champlain in 1998. The range map in Pearson et al. (2006) shows the range of *C. hirticollis* extending along the Lake Ontario and Lake Erie shores. We have not found documentation of populations on Lake Erie in New York and Natural Heritage Program surveys of several beaches there in the 1990s and early 2000s failed to locate this species.

Despite its greater tolerance for habitat alteration and recreational activities, *C. hirticollis* appears to be a declining species. Blanchard (2006) found the species at 3 (19%) of 16 sites he surveyed, and reported having found it previously at Shelter Island and Jones Beach. Simmons (2008) found the species at 2 (22%) of 9 sites (Fire Island and Shelter Island) in 2008 and notably not at Jones Beach. Mawdsley (2010) found the species at 5 (24%) of 21 sites surveyed (including two on Shelter Island as previously noted). We did not find the species at the previously documented location on Lake Champlain, but discovered a new occurrence farther south. We found the species at 3 (60%) of 5 sites surveyed on the eastern Lake Ontario shore, all within the 30-km beach/dune system. All in all, the species was found at 4 (15%) of approximately 26 historical locations (the number is approximate because of the vague location descriptions of some older specimens), and is now known statewide from 14 locations (Fig. 3). Two locations discovered in 2010, close to known locations, are not included in these tallies.

Survey results suggest a steep decline in this species' historical distribution, and while the beetles persist at some sites in good numbers (Lake Ontario, Plum Island), habitat is limited for this species and often highly compromised by recreation where it exists. As is the case for *C. dorsalis*, management that recognizes the value of the wild beach is necessary for the persistence of this species in the long term. Many subspecies of *C. hirticollis* have undergone considerable decline, resulting primarily from alterations of natural hydrology (Brust et al. 2005). Flooding caused by

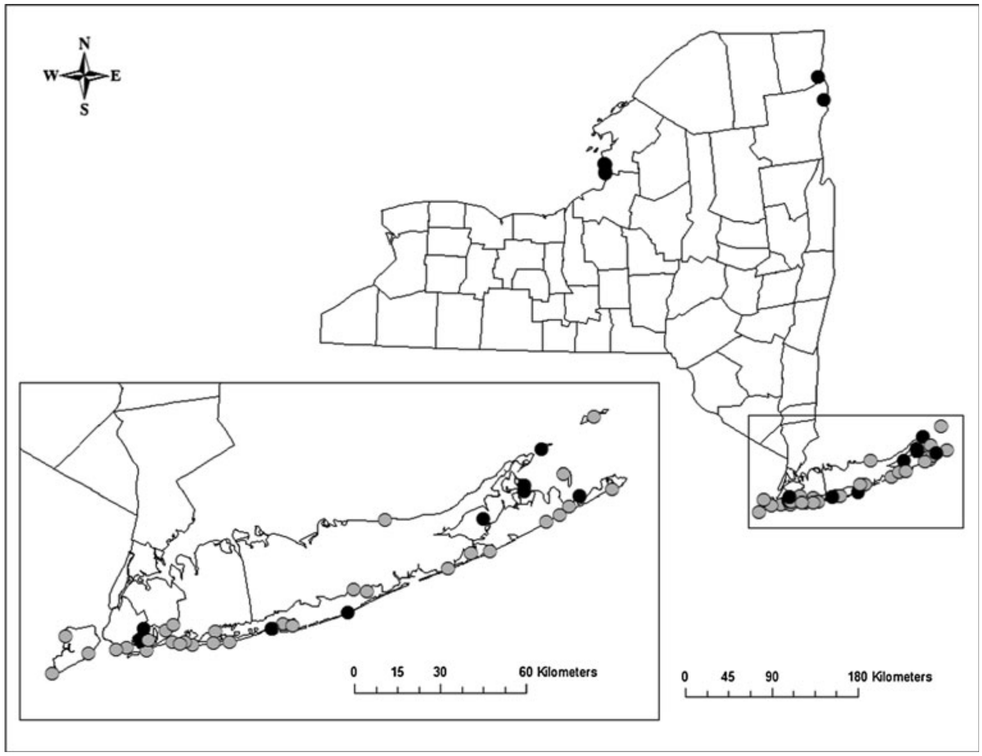

Fig. 3 Current (*black dots*) and approximate former (*gray dots*) distribution of *Cicindela hirticollis* in New York. Long Island is enlarged for greater detail. County boundaries are shown

manipulations of Great Lakes levels or climate-induced sea-level rise could decimate many populations of this species.

Two subspecies of *C. hirticollis, hirticollis* and *rhodensis*, occur in New York and intergrade on Long Island and northern New York (Pearson et al. 2006). In the implausible distribution depicted by Pearson et al. (2006), *C. h. rhodensis* occurs on Long Island, up to Lake Champlain, and along the Saint Lawrence to the north sides of Lake Ontario and Lake Erie, whereas *C. h. hirticollis* ranges similarly but south along the southern edges of Lake Ontario and Lake Erie. We and Mawdsley (2010) found individuals at Shelter Island, Plum Island, and Lake Champlain with characteristics of each subspecies. Museum specimens are not always identified to subspecies, so reconstructing the historical distributions of the subspecies would be challenging. It is clear, however, that with so few extant locations remaining, both subspecies are of a high level of concern. Future study of the genetics, distributions, and habitat preferences of these two subspecies in New York is sorely needed.

Lake Erie, whereas *C. h. hirticollis* ranges similarly but south along the southern edges of Lake Ontario and Lake Erie. The current phrasing sounds dismissive

Pine barrens tiger beetles

Pine barrens are open-canopy forests on sandy soils that are dominated by pitch pine (*Pinus rigida*), various oaks, and heath shrubs and herbs (Bernard and Seischab 1995). They occur throughout the northeastern United States (Forman 1979); in New York, they occur on the eastern portion of Long Island, in the Hudson Valley north of New York City, and in the Lake Champlain basin in the northeastern part of the state (Bernard and Seischab 1995). Several species of tiger beetles are endemic to pine barrens.

Eastern pinebarrens tiger beetle (Cicindela abdominalis)

Blanchard (2006) surveyed the two historical locations in the late 1990s and 2000s (Fig. 4), and 17 locations overall. He never detected this species. In addition, J. Mawdsley (personal communication) has surveyed numerous locations in the Long Island pine barrens and has never detected this species.

New York is at the northern edge of this species' historical range (Pearson et al. 2006); Leonard and Bell (1999) do not even discuss this species in their account of New England's tiger beetles. As such, it might have been a rare visitor to Long Island's pine barrens when it was collected in the early part of the 19^{th} century, and with the increasing loss of pine barrens to development it might have vanished. Knisley and Hill (1992) suggest that vegetation succession in the face of fire suppression was a likely culprit in the extirpation of *C. abdominalis* from Virginia. It is likely extirpated from New York for similar reasons, compounded by the typical highly variable population dynamics at the edge of a species' range (Lawton 1993).

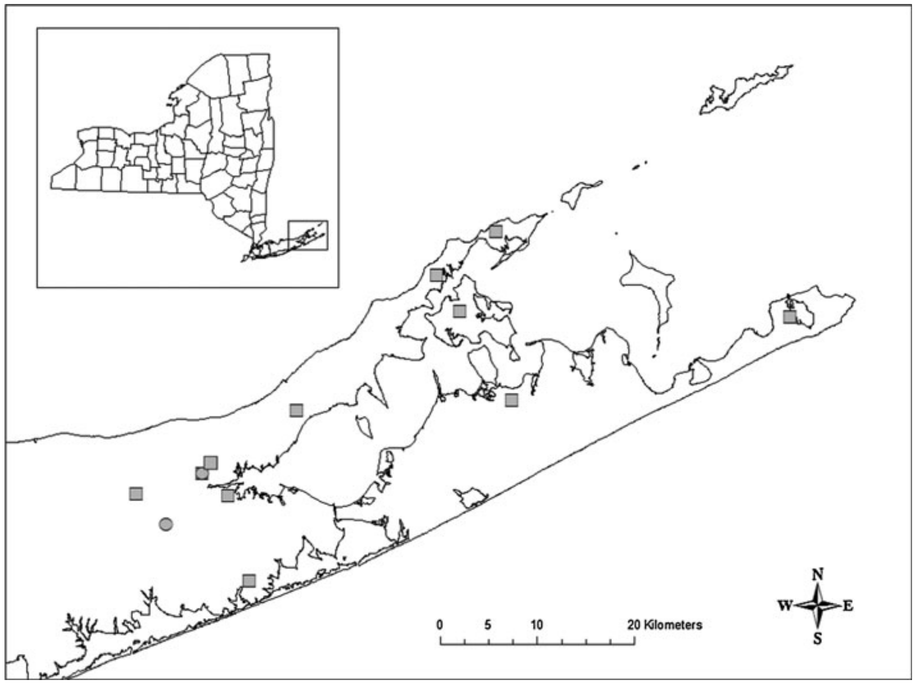

Fig. 4 Approximate historical locations for *Cicindela patruela consentanea* (*squares*) and *C. abdominalis* (*circles*) on Long Island, New York. County boundaries are shown

New Jersey pine barrens tiger beetle (Cicindela patruela consentanea)

Cicindela patruela consentanea was distributed historically throughout Long Island's pine barrens (Fig. 4), where it reached the northernmost extent of its distribution. Of the two subspecies in New York (the other being the nominate subspecies, *C. p. patruela*, discussed below), it is the more coastal, occurring from New Jersey south to Virginia (Mawdsley 2007b).

Blanchard (2006) reported searching for this species in 28 locations from 1998-2006 but never encountering it. J. Mawdsley (personal communication) has also searched extensively in Long Island's pine barrens, often specifically for this species, and has never encountered it there. Despite these survey results, both researchers feel that the species could still be rediscovered in New York, given its occurrence nearby in New Jersey.

As with *C. abdominalis*, New York is at the northern edge of *C. patruela consentanea*'s range, but the number of records of the latter species on Long Island (17 historical occurrences) suggests that it was more established there. Thus, its apparent extirpation from the state (Mawdsley 2007b) is a significant loss to New York's insect fauna. Mawdsley (2007b) cites urbanization and suppression of natural fire regimes as the chief causes of decline in this beetle, two threats that are clearly present on Long Island. Urbanization reduces the quantity of suitable forest, while fire suppression reduces the size and abundance of forest openings frequented by tiger beetles. Mawdsley (2005) documented the extirpation of the nominate subspecies, *C. p. patruela*, from the Washington, D.C. area, apparently resulting from urbanization. While urbanization on Long Island has not eliminated suitable pine barrens habitat there, a long history of alteration of the historical fire regime might have destined this species to extirpation.

Northern barrens tiger beetle (Cicindela patruela patruela)

Cicindela patruela patruela occurs at inland pine barrens in the Midwest, south to Georgia, and into southern New England (Pearson et al. 2006). There are only a handful of records from New England (Leonard and Bell 1999) and the subspecies had been known historically from only a few locations in New York (Fig. 5). It was presumed extirpated from New York until its rediscovery in 2004 by O. Blanchard in the Shawangunk Mountains (NYSDEC 2005). From 2006 to 2008, our surveys documented a considerably larger occupied area, including an expansion of known occupied microhabitat types within the barrens. Originally the beetles were known from anthropogenically cleared areas, such as a hiking trail and restoration zones. In 2008 we located *C. p. patruela* on exposed sandstone amid denser dwarf pitch pines, which is likely their original habitat at the site.

We surveyed several historical locations for *C. p. patruela* in addition to our visits to the occupied location (Table 2). Despite the presence of apparently suitable habitat at some locations, we did not find this species at any of these sites.

We conducted de novo surveys in several locations that seemed promising for *C. p. patruela* based on proximity to

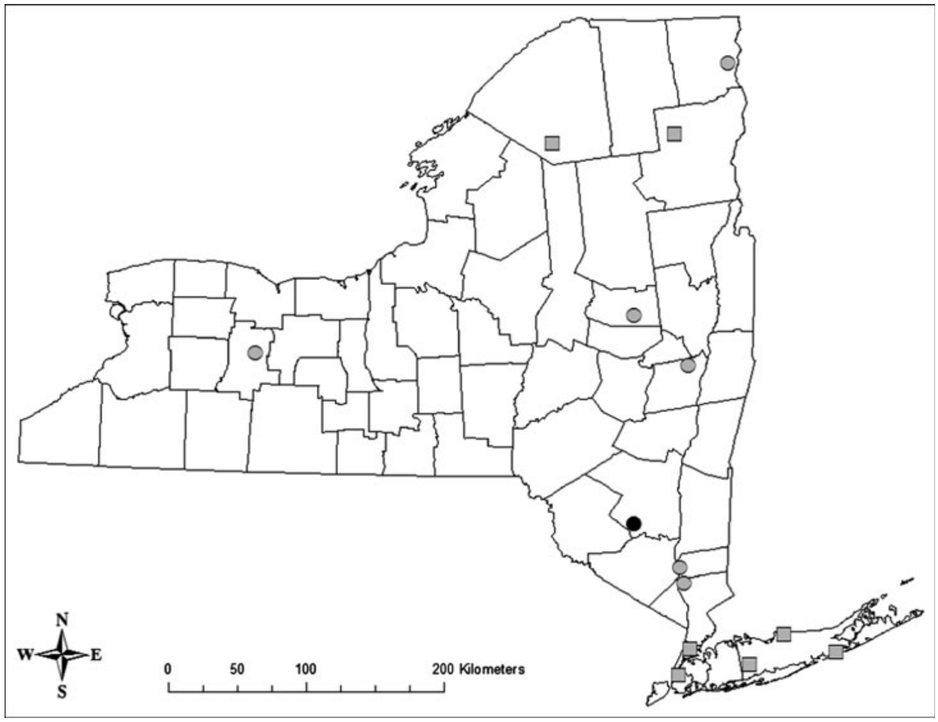

Fig. 5 New York locations for *Cicindela patruela patruela* (*gray circles* approximate historical locations; *black circle* extant location) and *C. unipunctata* (*gray squares* approximate historical locations). County boundaries are shown

the known location and/or otherwise suitable habitat. At the known location, the beetle occurs primarily in the Dwarf Pine Ridges natural community (Edinger et al. 2002), which is the only occurrence of this community type in the state. The beetle occurrence borders and in some places overlaps another community type, Pitch Pine-Oak Heath Rocky Summit. In our expanded searches, we focused on this latter community type. However, as was the case for historical follow-ups, we did not find the target species in any locations despite suitable-looking habitat.

The lack of any detections of *C. p. patruela* in historical locations (or at least in areas of potentially suitable habitat within broadly defined historical locations) and seemingly suitable locations elsewhere confirms that this is a very rare insect in New York. Its single currently known occurrence, on a New York State Park and a preserve, is protected for the most part from off-road vehicles and other recreational activities that might compact larval burrows. However, the key to the persistence of this species in the Shawangunk Mountains, and therefore in the State, is fire management that promotes natural openings and pitch-pine forest regeneration. Such efforts to reverse the effects of decades of wildfire suppression are ongoing (The Shawangunk Ridge Biodiversity Partnership 2003) and should restore, maintain, and expand suitable habitat for this fire-dependent beetle. Whether potential colonists could find this outpost from the nearest source 100 km away, or whether the extant population is large enough to be self-sustaining without an influx of genetic material, are other questions entirely.

One-spotted tiger beetle (Cicindela unipunctata)

C. unipunctata has one of the oddest historical distributions of any of New York's rare tiger beetles. Based on historical records, it was distributed like a generalist, with records in such diverse locations as Long Island's pine barrens, the heart of the Adirondacks, New York City, and the Lower Hudson Valley (Fig. 5). There are no recent records of this species in New York. Like *C. abdominalis*, *C. unipunctata* is primarily a southern species. Knisley and Schultz (1997) note its distribution as New Jersey and south and also point out that it is rarely collected and probably undersampled.

Both Blanchard (2006) and Mawdsley (2010) conducted surveys in suitable habitat (loosely defined by Pearson et al. (2006) as "shaded forests") on Long Island during the course of this project, but did not encounter this species. J. Mawdsley (personal communication) has surveyed sandy roads and trails in Brookhaven National Laboratory (just southeast of one historical location) and sampled an array of pitfall traps there for 2 years but has never detected this species.

C. unipunctata is one of the more challenging tiger beetles to survey for, for two reasons. First, it is primarily crepuscular (Gordon 1939; Pearson et al. 2006; but see Knisley and Schultz 1997), so it is not easily found when surveyors are normally afield looking for beetles. Second, it typically forages under leaf litter on the forest floor (Knisley and Schultz 1997); as such, it is more likely to occur in very small forest openings, like game trails, than on the wider sandy roads and large sand patches where other tiger beetle species congregate (J. Mawdsley, personal communication). Thus, this species requires specially targeted and time-intensive survey efforts. Pitfall traps are probably a more effective technique than the typical visual encounter method for surveying most tiger beetles. Establishing a pitfall array requires the observer to return daily or weekly to the same sites to collect specimens from pitfall cups. Because this beetle is likely more elusive than declining, we believe it will be eventually located again in New York.

Riparian tiger beetles

Appalachian tiger beetle (Cicindela ancocisconensis)

This species was known historically in New York from a few rivers in the Catskills, Adirondacks, and Buffalo area. One of us (PGN) found this species on Cattaraugus Creek in 1999, and we subsequently located populations in several historical and new locations in the Catskills, Adirondacks, and Buffalo area. As its name strongly implies, it is an Appalachian species, occurring from northern Georgia generally along the Appalachians into Ontario and New Brunswick (Pearson et al. 2006). From 2007 to 2009, NY Natural Heritage biologists visited 16 historical and other prior known locations in New York and surveyed de novo for *C. ancocisconensis* at 28 sites in 16 counties. Overall, we re-located *C. ancocisconensis* at 5 (31%) of the 16 sites visited (Fig. 6). Most of the sites where we did not find the species still appeared suitable, despite the dynamism of riparian habitat.

De novo searches for *C. ancocisconensis* turned up nearly empty. The species was detected in only 3 (11%) of the 28 new locations surveyed (Fig. 6), despite an apparent abundance of suitable habitat.

This species persists in the three main regions from which it was known historically: the Catskills, Adirondacks, and western New York. However, it was not detected in most of the historical locations visited or in the great majority of new sites within and outside of these regions. Whether these results stem from the beetle's extreme rarity or low detectability, or our lack of understanding of suitable habitat or the appropriate survey window, remains to be determined. We would certainly have expected some changes in habitat from historical conditions; cobble bar habitats are dynamic and subject to extreme flooding and scour. Typically, however, habitat conditions appeared suitable but the beetles were not detected. In some locations, low abundance, one form of rarity (Rabinowitz 1981), is a likely culprit. This species was often recorded in small numbers (five or fewer individuals) while other species, even other rare species, were frequently recorded in much higher numbers. We share the view of Mawdsley (2007a) that this species is likely more common than is obvious from field surveys. One possible explanation he puts forth is that *C. ancocisconensis* commonly occupies the vegetated zone at the edge of cobble bars rather than the open, sandy spots frequented by other riparian specialists; we found this to be the case as well. Although we targeted

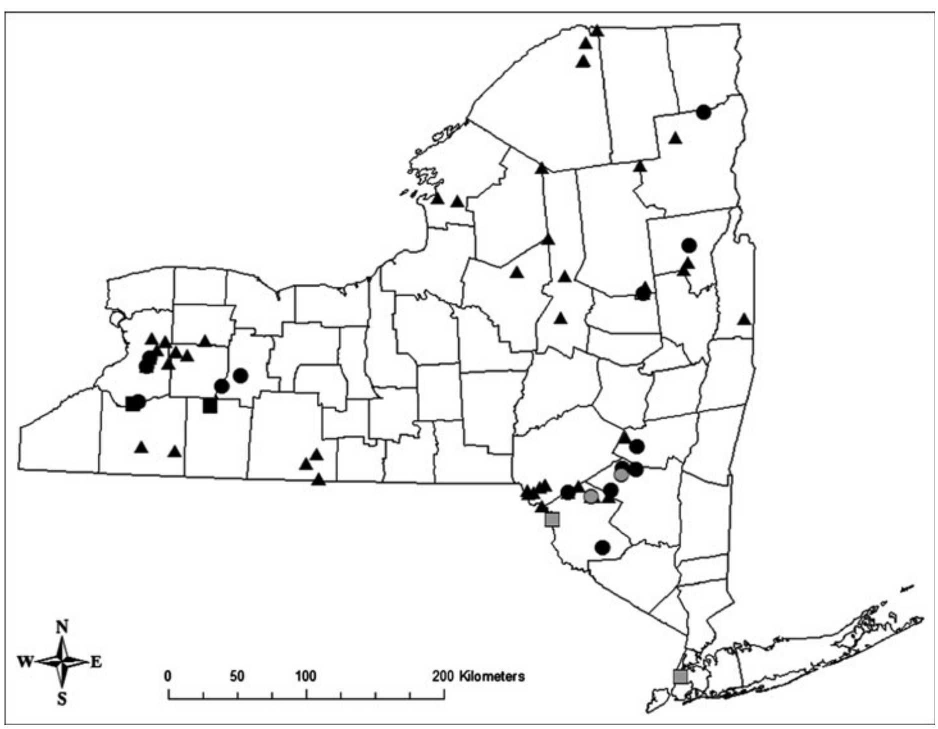

Fig. 6 New York locations for *Cicindela ancocisconensis* (*gray circles* approximate historical locations; *black circles* extant locations) and *C. marginipennis* (*gray squares* approximate historical locations; *black squares* extant locations). *Black triangles* are locations surveyed where neither species was detected. County boundaries are shown

this microhabitat, it is less frequently surveyed and a place where it is more difficult to detect and capture beetles. Finally, as a “spring-fall” species, *C. ancocisconensis* may be searched for in two distinct periods of the year. It is possible that one brood is generally smaller than the other, although we do not have data to address this question.

Cobblestone tiger beetle (Cicindela marginipennis)

Cicindela marginipennis was known historically from three locations in New York: Cattaraugus Creek in Cattaraugus County, the Delaware River at Callicoon in Delaware County (Leng in Leonard 1928), and New York City (Gordon 1939). Its broader distribution is disjunct, with one segment in Mississippi and Alabama and another ranging from Indiana east to Vermont and New Hampshire. It was recently discovered in Maine (Ward and Mays 2010) and Nova Scotia (see Neil and Majka 2008). In 2000, one of us (PGN) found a considerable population on the Genesee River in western New York. During this project, NY Natural Heritage biologists conducted follow-up surveys at three locations (Table 2). We reconfirmed the populations on the Cattaraugus Creek and Genesee River (Fig. 6), but failed to find any beetles on the Delaware. We now consider that occurrence to be extirpated, given the overgrowth of invasive vegetation on the cobble bars there.

We also surveyed new drainages for *C. marginipennis*, including the Upper Hudson, St. Lawrence, Allegheny, and Susquehanna. Because *C. marginipennis* overlaps with *C. ancocisconensis* at the two extant locations for *C. marginipennis*, all surveys for *C. ancocisconensis* (Table 2) were also surveys for *C. marginipennis* or at least served as reconnaissance for *C. marginipennis* habitat. Several of these surveys were in fact timed for *C. marginipennis.* None of the surveys yielded *C. marginipennis* detections.

General discussion

Fifteen (60%) of the 25 tiger beetle taxa in New York are considered to be at risk (S1-S3; equivalent to IUCN status of Critically Endangered, Endangered, Vulnerable, or Near Threatened; Appendix), extirpated, or reported but with uncertain status; this is a huge percentage, and probably one of the highest for any taxon, but within the range of beetles in other states and provinces in northeastern North America (NatureServe 2010). What makes tiger beetles of such high conservation concern? The species accounts above make clear that the combination of specialization on rare ecosystems and human disturbance of those ecosystems has proven highly detrimental to New York’s tiger beetle fauna.

Rarity and conservation of tiger beetles

Strategies for conserving imperiled tiger beetles depend in part on the reasons for rarity. To that end, we have attempted to classify some of New York’s extant tiger beetles according to the schema of Rabinowitz et al. (1986). In this schema, rarity is defined by placement along three axes: geographic range, habitat specificity, and local abundance. Only those species that have wide geographic range, low habitat specificity, and high local abundance (the upper left box) are considered common. From our classification (Table 3), which is based on observations throughout the state, but not systematic inventory, New York’s extant rare tiger beetles are rare for a variety of reasons. We considered all four extant rare species to be habitat specialists. Three of these seem to be abundant throughout their range in New York—the exception being *C. ancocisconensis*, which appears abundant along two rivers in western New York but sparse elsewhere. The frequent occurrence of small populations of *C. ancocisconensis*—although data from

Table 3 Seven forms of rarity in New York’s tiger beetles

	Wide geographic range		Narrow geographic range	
	Broad habitat use	Restricted habitat use	Broad habitat use	Restricted habitat use
Populations somewhere large	Common	Locally abundant over a large range in a specific habitat type	Locally abundant in several habitats, but restricted geographically	Locally abundant in a specific habitat, but restricted geographically
	e.g., *C. repanda*	*C. hirticollis*	No New York species identified	*C. marginipennis* *C. patruela*
Populations everywhere small	Constantly sparse over a large range and in several habitats	Constantly sparse in a specific habitat, but over a large range	Constantly sparse and geographically restricted in several habitats	Constantly sparse and geographically restricted in a specific habitat
	e.g., *C. sexguttata*	*C. ancocisconensis*	No New York species identified	No New York species identified

Adapted from Rabinowitz et al. (1986)

systematic inventory are lacking to determine this with more certainty—suggest that rarity might be less a consequence of human activity than of the species' biology, or that detectability of this species is especially low (more on this below). *C. marginipennis* and *C. patruela* are narrowly distributed within the state, while *C. hirticollis* is broadly distributed. Thus, site-specific conservation is likely to have a greater influence on the two former species, while broad changes in management of the beetle's habitat type is likely to have a greater influence on the latter. Only one species, *C. repanda*, could reliably be determined to meet all three of Rabinowitz et al.'s (1986) criteria of commonness: wide geographic range, broad habitat use, and high abundance everywhere. Sufficient data for classification into this schema are lacking for many species.

Additional species of unknown status

Additional tiger beetle species could use clarification of their status. *Cicindela puritana* is a federally Threatened river species that Gordon (1939) noted was found at Windsor, Broome County, on the Susquehanna River; at Oakwood, Staten Island; and vaguely in "N.Y." Most other authors (e.g., Hill and Knisley 1993b; Pearson et al. 2006) omit New York from its historical (and current) distribution. One of us (PGN) examined specimens at the Staten Island Museum and found the Oakwood specimen, and an additional specimen from Gardiner's Island, to be incorrectly identified (they were actually *C. marginata*); he and a colleague surmised that the Windsor record was possibly from Windsor, Connecticut, which is on the Connecticut River, the closest known occurrence of *C. puritana* at this time (Hill and Knisley 1993b). While probably not worth targeted survey efforts, this species could yet turn up in New York and surveyors should keep an eye out in suitable habitat along large rivers.

Other habitat specialists are worth a mention. *C. marginata* is a salt marsh and mud flat specialist that seems to have fewer records than would be expected for New York. Blanchard (2006) reported not finding the species in numerous locations, including some where he had previously detected it; at least a couple of these sites were overgrown with the invasive common reed (*Phragmites australis*). We know of two recent sightings, from Brooklyn and Shelter Island. With coastal wetlands threatened by development, recreation, and climate change, this species could be on the verge of decline or already experiencing decline. *C. scutellaris rugifrons* is a green form of the species (*C. scutellaris lecontei* is brown) that is known from coastal pine barrens. Its New York records (Gordon [1939] lists 22) are all from Long Island. Blanchard (2006) reports finding this species in the five locations he looked for it, and suspects it to be more tolerant of the habitat changes that appear to have negatively affected other pine barrens tiger beetles. All these taxa are ranked S3 (Vulnerable). *C. lepida* is another S3 species that might need reassessment; it was recently found to be "broadly distributed and locally abundant" in New York (Stanton and Kurczewski 1999). *C. longilabris* is an S3S4 high-elevation specialist that is also potentially vulnerable to effects of climate change. It has been detected in the Adirondacks during this project, but no specific survey efforts to our knowledge have been done to clarify its distribution in the state.

Finally, *Tetracha* (= *Megacephala*) *virginica* is a southern species and a member of the only other genus in the Cicindelidae known from eastern North America (Knisley and Schultz 1997; Pearson et al. 2006). To our knowledge, it was collected only once in New York, in Central Park (apparently on Long Island, not New York City) in 1911 (Leng in Leonard 1928, Gordon 1939) and not since. However, Knisley & Schultz (1997) note its range as extending into southern Connecticut. Like *C. unipunctata*, this is a crepuscular or even nocturnal species (Gordon 1939; Pearson et al. 2006) and thus less likely to turn up in typical tiger beetle surveys.

Monitoring, detectability, and tiger beetle occurrences

Long-term monitoring is vital to a current understanding of the status of these rare insects. Monitoring could consist of regular visits to update the status of known occurrences and also apparently unoccupied sites with suitable habitat; for most species, determining occupancy (*sensu* Mackenzie et al. 2006) would be sufficient, although for species with just a handful of occurrences, like *C. p. patruela* and *C. marginipennis*, an estimate of population size might be desirable. A chief concern from a monitoring perspective is how certain we are that we're detecting tiger beetles when they're present. Rare tiger beetles occur in naturally patchy habitats: pine barrens, beaches, riparian cobble bars. Within these habitats their distribution is similarly patchy because of low abundance (for some species) and microhabitat preferences. A consequence of this biology, compounded by the beetles' strong responses to weather conditions, not to mention observer differences, is that detection of tiger beetles is imperfect. Imperfect detection is the bane of the field biologist's existence, even beyond the frustration of not finding something one strongly suspects is there. Its implications for monitoring and determining occupancy have been the focus of much recent literature (e.g., Mackenzie et al. 2006).

Our own experiences surveying for tiger beetles have strongly suggested that our future surveys need to incorporate methods for addressing imperfect detection. For example, *C. ancocisconensis* was frequently detected in low abundance where it was present. On the Upper Hudson River, we spent 2 h searching two large cobble bars for the species before we detected a single individual (see below for a discussion of detections of single individuals). Had we stopped searching at 1 h 55 min, we would have declared *C. ancocisconensis* “not detected” and moved on. Because not all surveys can last as long, repeat visits during each species’ flight season are often necessary to more confidently determine presence or absence. Hudgins (2010) determined that two surveys were necessary to detect *C. marginipennis* on 80% of occupied cobble bars and three surveys were necessary to detect it on 90% of occupied cobble bars. This kind of detectability study would be highly valuable for additional rare species in other habitat types. Further definition of the portion of the flight period most suitable for surveying could also be important. Finally, with additional survey data an approach like that of Pearson et al. (2010) could be employed to analyze extinctions and their causes statistically.

Information collected over the course of this project has implications for how occupied locations of tiger beetles are defined, a relevant question for Natural Heritage Programs, Conservation Data Centers, and other groups that track rare species. Some, if not all, tiger beetles have evolved as long-distance (100 km) dispersers (Pearson and Vogler 2001) and they are known to move shorter distances (100 m) within seasons (Hudgins et al. 2011). For this reason, detections of single individuals in apparently unsuitable habitat likely represent dispersing beetles, and further, even detections in apparently suitable habitat do not necessarily indicate a breeding population (Mawdsley 2007b). Mawdsley (2007b) also points out that long-distance dispersal complicates the interpretation of museum records: did *C. unipunctata* really have established populations in the seemingly unsuitable Adirondacks, or were those individuals simply dispersers? Further, is there any value to considering tiger beetle dispersal habitat in conservation planning, and is such habitat even predictable? These are open questions.

There is no question, however, that the best indication of a breeding population, the primary element of conservation concern, is the presence of larvae. Observations of mating or oviposition can also strongly suggest a breeding population. While identifying the presence of larval burrows is fairly straightforward, identifying the larvae themselves can be challenging. Larvae of some species (e.g., *C. marginipennis*) have not yet been described, so the only way to document those species is noting the presence of adults. Presence of multiple individual adults in suitable habitat, especially when documented over multiple years, does provide strong evidence of a breeding population. Most survey efforts will continue to consist of adult counts for this reason.

Dispersal and changes in patch occupancy (like that documented for *C. marginipennis* by Hudgins et al. 2011) strongly suggest that tiger beetle occurrences should be mapped as metapopulations; for Natural Heritage programs this means using NatureServe’s (2002) methodology of defining a principal occurrence and sub-occurrences. With this methodology, occupancy in any particular year of any particular patch is secondary in importance to occupancy of the principal occurrence as a whole. Cobble bars, dunes, and openings in pine barrens are temporary features, and the beetles’ occupancy of a given patch of ground is similarly temporary. Most important in defining and mapping an occurrence is representing the area of conservation concern, which for many species is a larger area within which patch dynamics operate. We are in the infancy of understanding these patterns for most species.

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Appendix: Definitions of natural heritage global and state ranks (adapted from NatureServe 2010)

Global and state status ranks

The New York Natural Heritage Program’s statewide inventory efforts revolve around lists of rare species and all types of natural communities known to occur, or to have historically occurred, in the state. These lists are based on a variety of sources including museum collections, scientific literature, information from state and local government agencies, regional and local experts, and data from neighboring states.

Each rare species is assigned a rank based on its rarity and vulnerability. Like that in all state Natural Heritage Programs, NY Natural Heritage’s ranking system assesses rarity at two geographic scales: global and state. The global rarity rank reflects the status of a species or community throughout its range, whereas the state rarity rank indicates its status within New York. Global ranks are maintained and updated by NatureServe, which coordinates the network of Natural Heritage programs. Both global and state ranks are usually based on the range of the species or community, the number of occurrences, the viability of the occurrences, and the vulnerability of the species or community around the globe or across the state. As new data become available, the ranks may be revised to reflect the most current information. Subspecific taxa are also assigned a taxon rank which indicates the subspecies' rarity rank throughout its range.

For the most part, global and state ranks follow a straightforward scale of 1 (rarest/most imperiled) to 5 (common/secure), as follows. Translation to IUCN categories (Master et al. 2009) is noted.

GX, SX—Presumed Extinct or Extirpated Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered (IUCN: Extinct, Extinct in the Wild, Regionally Extinct).

GH, SH—Possibly Extinct Known from only historical occurrences but still some hope of rediscovery. There is evidence that the species may be extinct throughout its range or extirpated from the state, but not enough to state this with certainty (IUCN: Critically Endangered).

G1, S1—Critically Imperiled At very high risk of extinction or extirpation due to extreme rarity (often 5 or fewer populations), very steep declines, or other factors (IUCN: Critically Endangered, Endangered).

G2, S2—Imperiled At high risk of extinction or extirpation due to very restricted range, very few populations, steep declines, or other factors (IUCN: Vulnerable).

G3, S3—Vulnerable At moderate risk of extinction or extirpation due to a restricted range, relatively few populations, recent and widespread declines, or other factors (IUCN: Near Threatened).

G4, S4—Apparently Secure Uncommon but not rare; some cause for long-term concern due to declines or other factors (IUCN: Least Concern).

G5, S5—Secure Common; widespread and abundant (IUCN: Least Concern).

GU, SU—Unrankable Currently unrankable due to lack of information or due to substantially conflicting information about status or trends (IUCN: Data Deficient).

SNA—Not Applicable A conservation status rank is not applicable because the species or ecosystem is not a suitable target for conservation activities. Examples include a visitor to the state but not a regular occupant (such as a bird or insect migrating through the state), or a species that is predicted to occur in the state but that has not been found.

Note that combination (or "range") ranks are possible (e.g., S1S2, S2S3). These ranks reflect uncertainty in the information available such that it could not be determined whether one or the other rank was appropriate. They do not indicate a value in between the two numbers.

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