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Cover Photograph: Awakening *Terrapene carolina* (Box Turtle). Photograph © Omar Attum.

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The Distribution of Amur Honeysuckle and Box Turtle Habitat Use in an Urban Forest

Omar Attum[1,*], James Lowry[1], Bruce Kingsbury[2], and Evin Carter[2]

Abstract - Urban forests face major challenges to their ecological integrity because they are often small in size, surrounded by harsh edge-habitat, and can be vulnerable to colonization by invasive species. *Lonicera maackii* (Amur Honeysuckle) is considered one of the most problematic invasive species in the eastern US. In this study, we examined the distribution patterns of Amur Honeysuckle in an urban forest in Louisville, KY, USA, and the correlation between Amur Honeysuckle density and habitat use of *Terrapene carolina* (Box Turtle). We found no significant correlation between the density of young (<1 m tall) Amur Honeysuckle and distance to forest edge or hiking trails or density of mature (>1 m tall) Amur Honeysuckle and distance to forest edge. However, mature Amur Honeysuckle density increased as the distance from hiking trails increased. We also found no correlation between the density of young Amur Honeysuckle and Box Turtle habitat use, but at the landscape level, the likelihood of finding Box Turtles in an area decreases as the density of mature Amur Honeysuckle increases. Box Turtles were also more likely to be found in the vicinity of hiking trails than randomly selected points. Our results suggest that there is a negative correlation between mature Amur Honeysuckle density and Box Turtle habitat use, and that high densities of mature Amur Honeysuckle reduce available Box Turtle habitat.

Introduction

Urban forests face many challenges to their ecological integrity. They are often small in size and are characterized by increased edge habitat that can be harsh and vulnerable to colonization by nonnative invasive species (Ferreira and Laurance 1997, Hutchison and Vankat 1997, Murcia 1995, Pellissier et al. 2013). Furthermore, sources of nonnative species including residential areas and other heavily modified anthropogenic landscapes often surround urban forests.

Lonicera maackii (Rupr.) Maxim. (Amur Honeysuckle) is considered one of the most problematic nonnative invasive species in forests of the eastern US (Luken and Thieret 1996, Trisel and Gorchov 1994). Amur Honeysuckle was found to be the most important plant species in terms of explaining variation in the composition of woody plant communities within urban forests in Louisville, KY (Trammel and Carreiro 2011). Amur Honeysuckle often outcompetes native shrubs, and its establishment can lead to rapid modifications of ecosystems because it often attains heights up to 6 m, creates high-density understory thickets, and has an extended fruiting and leaf phenology that may modify environmental cues for native wildlife (Carter et al. 2015, Mack et al. 2000, Smith 2013).

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We would expect ectotherms to be negatively impacted by Amur Honeysuckle because of the propensity of the species to invade early-successional habitat and forest gaps. Forest edges and canopy gaps provide important thermoregulatory opportunities and a diversity of food resources for ectotherms (Blouin-Demers and Weatherhead 2002, Carter et al. 2015). Ectotherms often utilize canopy gaps to raise or maintain internal body temperature in temperate forests (Row and Blouin-Demers 2006). The association between thermoregulation opportunities and habitat use and the resulting effect on body temperature is recognized as a fundamental mechanism that determines immediate physiological performance as well as long-term reproductive success (Angilletta 2001; Bennett 1980; Huey and Kingsolver 1989, 2008; Huey and Stevenson 1979; Kingsolver and Huey 2008; Scheers and Damme 2002). Therefore, one expects that increased shade in the understory following invasion by invasive species could affect habitat use and result in direct fitness impacts for ectotherms (Carter et al. 2015, Hacking et al. 2014, Stellatelli et al. 2013).

In this study, we examined the relationship between Amur Honeysuckle distribution and density and *Terrapene carolina carolina* L. (Eastern Box Turtle, hereafter Box Turtle) habitat use in an urban forest.

Methods

Study species

Box Turtles utilize a wide range of habitats including upland and lowland hardwood and pine forests, meadows, and the fringes of wetlands (Dodd 2001, Greenspan et al. 2015, Kapfer et al. 2013). The species is a good model to study the effects of Amur Honeysuckle at our study site because Box Turtles inhabit mesic forests with high tree-cover, but are dependent for thermoregulation upon the patches of open understory and forest edges that are vulnerable to Amur Honeysuckle invasion (Dodd 2001). In addition, Box Turtles are omnivores that feed on a diversity of plant and insect species often associated with forest-canopy gaps (Dodd 2001, Rossel et al. 2006). They are long-lived and typically have a home-range size of 1–10 ha (Dodd 2001, Greenspan et al. 2015, Kapfer al. 2013). Box turtles have experienced population declines throughout much of their range as a result of land-use changes such as habitat destruction and degradation, and are a species of conservation concern (Dodd 2001).

Study site

We conducted our study in Blackacre State Nature Reserve (BSNR) in Louisville, KY (38.19611°N, 85.53416°W). The study site (44 ha) consists of an ~70-year-old secondary-growth, urban forest dominated by *Quercus rubra* L. (Red Oak), *Q. velutina* Lam. (Black Oak), and *Acer saccharum* Marshall (Sugar Maple). Other species include *Carya ovata* (Mill.) K. Koch (Shagbark Hickory), *C. laciniosa* (Michx. f.) G. Don (Shellbark Hickory), *Gymnocladus dioicus* (L.) K. Koch (Kentucky Coffee Tree), *Asimina triloba* (L.) Dunal (Pawpaw), and *Juniperus virginiana* L. (Eastern Red Cedar). BSNR is surrounded by residential neighborhoods, a railroad, and an industrial park. Amur Honeysuckle is well established and appears to be the most prevalent and widespread invasive species at BSNR. Other nonnative invasive species include *Lonicera japonica* Thunb. (Japanese Honeysuckle), *Rosa multiflora* Thunb. (Multiflora Rose), *Eleagnus angustifolia* L. (Russian Olive), *Alliaria petiolata* (M. Bieb.) Cavara & Grande (Garlic Mustard), *Sorghum halepense* (L.) Pers. (Johnson Grass), and *Euonymus fortunei* (Turcz.) Hand.-Maz. (Winter Creeper).

Field survey

During June and August 2011, we assessed the distribution and density of young (<1 m tall) and mature (≥1 m tall) Amur Honeysuckle at 380 random points within BSNR as part of an existing monitoring program. We used a hand-held GPS (3-m accuracy) to navigate to each survey point and record the number of Amur Honeysuckle plants in each height class within a 3-m radius of the point. We calculated density as the number of individuals per 3-m-radius circle. We examined the relationship between density and distance from edge habitat as determined with GIS software. We defined 2 types of edge habitat: forest edge as the perimeter of any continuous gap > 4 m wide within areas of forest, and hiking trail.

We used radiotelemetry to monitor the movement patterns of 12 Box Turtles—3 females (mean mass = 426.6 ± SE 13.4 g, carapace length = 13.3 ± 0.04 cm) and 9 males (mean mass = 388.1 ± 7.9 g, carapace length = 12.75 ± 0.03 cm). We captured the Box Turtles between May and August 2010, and glued radio transmitters to the lateral-posterior end of the carapace with epoxy. The weight of the transmitters, ~10 g, was less than the maximum recommended 4–6% of body weight (Cochran 1980). We attached transmitters in the field, and released the Box Turtles at their capture site after the epoxy dried; all turtles were tracked the following year, ~2 times per week from May to November 2011.

Each time a radiotelemetered turtle was located, we recorded the UTM coordinates, date, time, and a suite of microhabitat characteristics within a 3-m radius at each turtle location, including the number of young and mature Amur Honeysuckle plants, percent upper-canopy cover (determined with a spherical densiometer), leaf-litter depth, distance to nearest tree (diameter ≥ 20 cm), distance to nearest fallen log (diameter ≥ 20 cm), and distance to nearest native shrub. In order to examine microhabitat use, we collected equivalent data 20 m away from each turtle location at a randomly selected direction (1–360°). We estimated activity-range size using a minimum convex polygon (MCP).

Statistical analysis

We employed linear regression to look for a correlation between young and mature Amur Honeysuckle density and distance to each edge category. We tested whether the microhabitat at Box Turtle locations and random points 20 m away was different through a backward stepwise logistic regression. We used separate logistic regressions to test if Box Turtles avoided areas with high densities of young and mature Amur Honeysuckle at the microhabitat and landscape level. At the microhabitat level—habitat immediately available to the individual—we compared Amur Honeysuckle density at the Box Turtle locations to the Amur Honeysuckle density at the random points 20 m away. At the landscape level—the availability of microhabitat for the population at the study site—we compared Amur Honeysuckle density at the Box Turtle location to the previously generated 380 random points within the study site. We used logistic regression to test whether Box Turtles were more likely to occur near hiking trails than other areas by comparing the distances of Box Turtle locations from hiking trails and an equivalent number of random points within a minimum convex polygon of all turtle locations. All data were normalized by square-root transformation (sqrt [y+1]) prior to analysis.

Results

There was no significant correlation between the density of young Amur Honeysuckle and distance to the edge habitats either when combined ($F_{2,376} = 2.343$, $t = -1.208$, $P = 0.097$), or when analyzed separately: distance to forest edge ($B = -0.001 \pm$ SE 0.001, $t = -0.850$, $P = 0.396$) and distance to hiking trail ($B = 0.001 \pm$ SE 0.001, $t = 1.794$, $P = 0.074$). There was no apparent correlation between mature Amur Honeysuckle density and distance to forest edge ($B = -0.001 \pm$ SE 0.001, $t = -0.563$, $P = 0.57$), but mature Amur Honeysuckle density increased with increasing distance from hiking trails ($B = 0.003 \pm$ SE 0.001, $t = 2.885$, $P = 0.004$). However, this model explained only 2.5% ($r^2 = 0.025$) of the variation.

Mean activity-range of Box Turtles was 1.09 ha ± SE 0.093. There was no significant difference between the measured microhabitats at turtle locations and random points ($\chi^2 = 2.89$, df = 1, $P = 0.48$). Box Turtles were found in areas with a mean upper-canopy cover of 82% ± SE 5.87, leaf litter depth of 7.79 cm ± SE 0.25, at a distance of 2.72 m ± SE 0.11 away from a tree, 5.21 m ± SE 0.23 away from a fallen log, and 0.183 m ± SE 0.032 away from a native shrub.

We detected no significant difference between young Amur Honeysuckle density at the turtle locations and the random points at the microhabitat ($\chi^2 = 0.014$, df = 1, $P = 0.91$) or landscape level ($\chi^2 = 0.487$, df = 1, $P = 0.49$; Fig. 1) or between mature Amur Honeysuckle density at the turtle location and at the random locations at the microhabitat level ($\chi^2 = 2.894$, df = 1, $P = 0.09$; Fig. 1). At the landscape level, however, Box Turtles generally avoided areas with a high density of mature Amur Honeysuckle ($\chi^2 = 7.67$ df= 1, $P = 0.006$; Fig. 1). Box Turtles were less likely to occur in a given area as density of mature Amur Honeysuckle increased (Wald = 7.59, $B = 1.042 \pm$ SE 0.38, df = 1, $P = 0.006$). Distance to hiking trails was a significant predictor of Box Turtle distribution ($\chi^2 = 72.346$, df = 1, $P < 0.001$); Box Turtles were significantly more likely to be observed near hiking trails (Wald = 59.719, $B = -0.016 \pm$ SE 0.002, df = 1, $P < 0.001$; 24.6 m ± SE 1.5 m) than the random points (46.7 m ± SE 2.6 m).

Discussion

Neither distance to forest edge nor to hiking trails was a strong predictor of Amur Honeysuckle density. Although the density of mature Amur Honeysuckle was partially explained by distance to hiking trails, it explained only 2.5% of the variation. Our findings suggest that either there may be other important predictors of Amur Honeysuckle density than those we tested or that Amur Honeysuckle has successfully colonized all habitats at our study site equally and therefore has a widespread distribution (Fig. 1). Colonization of forests by exotic invasive plants is influenced by a variety of factors such as patch size, wildlife vectors, forest age, light availability, and disturbance history (Hoffmeister et al. 2000, Masters and Sheley 2001, Pellissier et al. 2013, Vellend 2002, Wimberly and Spies 2001).

Our results suggest that high density of mature Amur Honeysuckle reduces Box Turtle habitat availability at the landscape level because Box Turtles were less likely to be found in those areas (Fig. 1). Although the species is widespread at our study site, we found lower densities of mature Amur Honeysuckle at both the turtle locations and the nearby random locations (microhabitat sites) compared to densities at random points scattered throughout the study site landscape; thus, Box Turtles seem to utilize areas with lower densities of mature Amur Honeysuckle (Fig. 1).

The negative correlation between mature Amur Honeysuckle density and Box Turtle locations at the landscape level may be the result of decreased

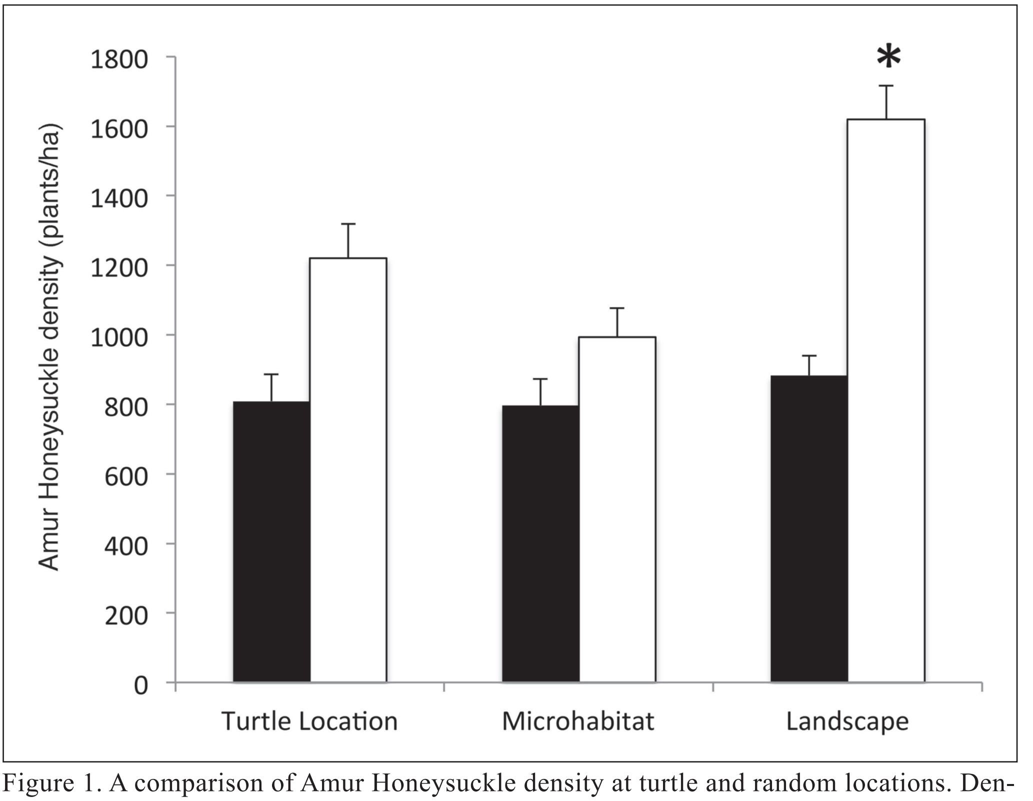

Figure 1. A comparison of Amur Honeysuckle density at turtle and random locations. Density of young Amur Honeysuckle (<1 m tall) is represented with a black bar. Density of mature Amur Honeysuckle (≥1 m tall) is represented with a white bar. Microhabitat represents Amur Honeysuckle density at the random points 20 m away from the turtle locations. Landscape represents Amur Honeysuckle density at random points generated at the landscape level. * indicates a significant difference between mature Amur Honeysuckle density at the landscape level and mature Amur Honeysuckle density at turtle locations.

thermoregulatory opportunities caused by increased shade and lower temperatures in the understory (Watling et al. 2011) or reduced food availability (Heleno et al. 2009). Box Turtle habitat use in temperate forests is largely believed to be shaped by thermoregulatory opportunities and food availability; there is often a limited availability of gaps in temperate forests (Dodd 2001, Rossel et al. 2006). Reptiles in temperate forests bask in natural canopy gaps to increase their internal body temperature through thermoregulation (Jaggi and Baur 1999, Pringle 2003). Amur Honeysuckle may reduce thermoregulatory opportunities by increasing understory shade in natural canopy gaps because invaded patches are significantly cooler than intact forest patches (Carter et al. 2015). Forest patches invaded by Amur Honeysuckle are characterized by a reduction and homogenization of environmental temperatures, and these habitat modifications reduce the quality of thermal habitats for ectotherms (Carter et al. 2015, Hacking et al. 2014, Stellatelli et al. 2013, Watling et al. 2011). Carter et al. (2015) proposed that reduced thermoregulatory opportunities and a reduction of thermoregulatory habitat quality was a main reason for the avoidance of exotic vegetation by a temperate forest snake that occurs in the same region in which we conducted our research. Other factors such as water and nesting-habitat availability may be important, but we did not examine these variables during the course of this study (Dodd 2001).

High density of mature Amur Honeysuckle may also reduce potential food availability by reducing plant and insect diversity. Native plant diversity has been found to be low in areas with high Amur Honeysuckle density because this species outcompetes native understory plants for space and nutrients, and decreases light availability (Collier et al. 2002). In addition, insect diversity and abundance are often higher in canopy gaps (Horn et al. 2005) and lower in areas with high Amur Honeysuckle density (Burghardt et. al. 2010). In contrast, we found no negative correlation between Box Turtle habitat use and young Amur Honeysuckle, likely because the young shrubs provide little understory shade. Carter et al. (2015) suggested that invasive species associated with non-structural habitat modifications, such as young plants or low-density areas may have relatively minor thermoregulatory consequences for ectotherms.

We believe that Box Turtles were more common in the vicinity of hiking trails because hiking trails and their margins are managed artificial canopy gaps in an environment with reduced availability of natural canopy gaps. Other temperate forest species are believed to use artificial canopy gaps created for recreational use (Horn et al. 2005). For example, *Agkistrodon contortix* L. (Copperhead Snake) were believed to regularly use maintained, understory artificial canopy gaps for thermoregulatory purposes in a forest with a high density of invasive species (Carter et al. 2014).

Urban forest management for temperate reptiles such as the Eastern Box Turtle should focus on eradication of Amur Honeysuckle to increase habitat availability. When complete eradication of Amur Honeysuckle is not feasible, we suggest continuous maintenance and removal of mature Amur Honeysuckle around artificial canopy gaps, creation of new artificial canopy gaps and Amur Honeysuckle-free zones, or reducing the foliage density (Carter et al. 2015, Inman et al. 2007). Community structure and processes should be maintained by planting native midstory plants in areas where Amur Honeysuckle has been removed (Hartman 2004). In this study, we did not investigate the specific reasons that Box Turtles avoided areas with high densities of mature Amur Honeysuckle, but our results suggest that Amur Honeysuckle reduces habitat availability for Box Turtles.

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