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Urban land cover decreases the occurrence of a wetland endemic mammal and its associated vegetation

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Abstract Urbanization and other land cover changes have been particularly detrimental to wetlands throughout the planet. One wetland specialist that may be sensitive to land cover changes surrounding wetlands is the round-tailed muskrat (*Neofiber alleni; hereafter* RTM). The RTM is a wetland obligate rodent that appears to have declined over the last half century and is a species of concern in Florida, where it is a near endemic. To determine if urbanization or other land cover influenced the distribution of RTMs we took a multiscaled approach to examine the occurrence of RTMs and their associated vegetation in North-Central Florida. We detected RTMs on 19 of 72 sample plots and used a Classification And Regression Tree (CART) to determine that dogfennel (*Eupatorium capillifolium)* was negatively associated with RTMs and maidencane (*Panicum hemitomon*) was positively associated with their occurrence on sampling plots. Examining the influence of landscape composition for 2 km surrounding our plots we found that RTM occurrence was negatively related to urban land cover. Further, we found that dogfennel increased and maidencane decreased as urbanization increased in the surrounding landscape. Our research suggests that conservation of RTMs and their associated vegetation should focus on limiting urban sprawl at least within 2 km of wetlands.

Keywords Round-tailed muskrat · Conservation · Hydrology · Wetland plant communities · Florida · Occupancy · Land cover

Introduction

Wetlands are highly productive systems that are critical to many plants and animals that can only be found within them (Gibbs 1993); however, half of the planet's wetlands have been lost and severely degraded (Zedler and Kercher 2005). This global pattern holds for the conterminous United States, which has also lost ≈ 50% of its' wetlands since the time of European colonization (Dahl 2011; Dahl 1990; Davidson 2014). Those wetlands that remain in the United States and throughout the planet are increasingly stressed by pollution, agriculture and urbanization (Dahl 2000). Urbanization has been particularly detrimental to wetlands (Dahl 2000), with increasing rates of pollution and drastically altered wetland hydrology. Wetlands adjacent to urban areas typically receive increased pulses of water from surface runoff and reductions in more typical slow moving groundwater flow (Booth 1991). These pulses of water often result in reduced hydro-periods, when wetlands do not have water, and more frequent and amplified flooding events (Booth 1991). This increased variability in water levels can stress wetlands (Booth et al. 2002) and is often reflected in plant and animal communities (David 1996; Richter and Azous 1995). Extremes of inundation and drying (Havens and Gawlik 2005) often reduce faunal and floral diversity (Reinelt et al. 1998; Richter and Azous 1995), favoring generalists that can survive in a temporally heterogeneous environment and reducing or eliminating

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specialists requiring longer and/or more stable hydro-periods (Richter and Azous 1995).

One wetland specialist that may be sensitive to environmental changes is the round-tailed muskrat (*Neofiber alleni; hereafter* RTM) a species of special concern in Florida (Lefebvre and Tilmant 1992). The RTM is a semi-aquatic, nocturnal rodent endemic to freshwater wetlands of Florida and a small area of southern Georgia (Brown 1997). They live in ball shaped lodges of grass above the water line and feed on aquatic vegetation (Birkenholz 1963). The RTM appears to select shallow marshes (< 50 cm) with soft substrates and is known to eat and occur in dense stands of maidencane (*Panicum hemitomon*) (Humphrey 1992). The RTM was ubiquitous in north-central Florida in the 1950s (Birkenholz 1963) but currently appears to have a patchy distribution that has declined over the last half century (Lefebvre and Tilmant 1992). This decline may have been a result of the loss and degradation of freshwater wetlands in Florida. The stresses on Florida's wetlands have been considerable. Since the mid-1980s the region has experienced considerable changes in land use, particularly in the growth of urbanized areas and in the loss of wetlands (Dahl 2005). To determine if urbanization or other land cover types influenced the distribution of RTMs we took a multi-faceted, multi-scaled approach to examine occurrence of RTMs and their associated vegetation in North-Central Florida. We predicted that RTMs and the vegetation that they utilized would decrease with increasing proximity to urbanization.

Methods

To understand the relationship between RTM distribution and urbanization, and other land cover types, we first needed to understand the RTM's selection of wetland vegetation. Our knowledge of RTM's vegetation use has been limited. In south Florida RTMs utilized areas dominated by maidencane (Birkenholz 1963; Schooley and Branch 2011). However, in Georgia, RTMs have been found in areas with a more diverse array of plants (Bergstrom et al. 2000). Our lack of knowledge about what vegetation characteristics RTMs utilize constrains our ability to understand where they might occur. After establishing the relationships between RTMs and wetland vegetation on a fine scale we examined the influence of land cover on occurrence of RTMs and their associated vegetation communities on a broader scale.

Study area

Our study area was located in North Central Florida and centered on the Orange Creek Basin, which encompasses approximately 965 km^2 of Alachua, Marion, and Putnam counties in north-central Florida (St Johns River Water Management District 2015) and is the northern-most part of the Ocklawaha River Basin (Orange Creek Basin Management Action Plan 2007). Specifically, our study area included all freshwater wetlands within 20 km of the Orange Creek Basin's boundaries. This is a region with extensive freshwater wetlands and patchy urban development (Fig. 1). The region averages 123 cm of rainfall per year, with average monthly temperatures ranging from 5.5 °C to 32.7 °C (Southeast Regional Climate Center 2013). Over 50 years ago RTM was ubiquitous across our study site (Birkenholz 1963) but more recently it appears to be rare and sparsely distributed. During the same time period the study area has seen an increase in agricultural and urban land uses (Dahl 2005) providing us with the opportunity to link RTM distributions to land cover across a heterogeneous landscape.

Site selection

We used a stratified random design to place sampling 120 potential points within different sizes and types of wetlands known to historically or currently support RTMs. We classified wetlands with records of RTM occurrence into 4 types; freshwater marsh, basin marsh, depression marsh, and wet prairie, as identified by the Florida Natural Areas Inventory Land cover Classifications System (Florida Natural Areas Inventory [FNAI] 2012). These broad categories of frequently or continuously inundated, treeless wetlands are found across most of the state of Florida. All wetlands had a sand or peat substrate, and were dominated by grasses, sedges, and herbaceous vegetation communities with few or no shrubs (FNAI

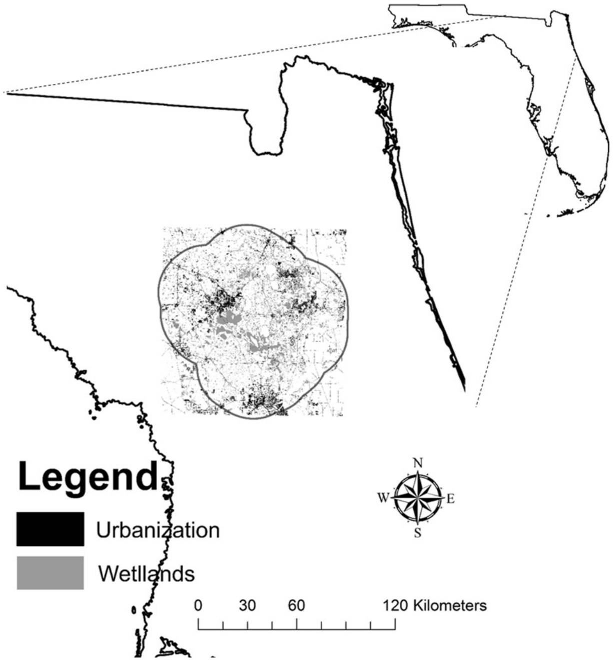

Fig. 1 Urbanization and wetlands within the study site in the orange creek basin of North-Central Florida USA

2012). We stratified the placement of points by wetland type and 3 sizes (small <3 ha, medium 3–10 ha, and large >10 ha), resulting in a total of 12 different strata. For spatial independence and so we were not sampling that same RTMs we placed a 500 m buffer around each point. This distance placed adjacent points outside the radius of the home ranges recorded for RTMs (Bergstrom et al. 2000; Schooley and Branch 2006). We placed random points in each stratum and sampled them based on accessibility (landowner permission).

Survey methods

We conducted surveys for RTMs by walking parallel transects through a 40 m × 40 m area of wetland and noting signs of RTMs (i.e. lodges, scat and feeding platforms) (Schooley and Branch 2005). We spaced transects (8–20 transects per plot) dependent upon how dense the vegetation was. We always placed transects close enough that water could be seen between adjacent transects, (generally ~3 m). Seeing water between transects helped insure that we did not miss smaller feeding platforms. In locations where water depths prohibited walking transects, we used canoes or airboats to traverse transects. We considered RTMs to be present on the sites if we detected lodges or scat, but disregarded sites with feeding platforms only. Feeding platforms alone can be unreliable because other animals, such as marsh rabbits (*Sylvilagus palustris*), make similar structures. We first visited 61 sampling sites and surveyed them twice between May and September 2013. We also surveyed an additional 11 sites once during March and April 2014 as part of an additional survey effort.

To understand the how composition of vegetation communities and water influenced the occurrence of RTM's on sampling plots we conducted surveys of vegetation and water depth and water cover. At each 40 m × 40 m plot we surveyed vegetation cover by placing a 0.5 m^2 pvc frame on the ground/water every 10 m for a total of 25 vegetation surveys per plot (Daubenmire 1959). Within each frame we estimated the percentage of area covered by each plant species and surface water (water cover), and took a water depth measurement. We averaged water depth and cover measurements and calculated % coverage for each plant species as the average coverage for the 25 plots. We conducted vegetation surveys on the 61 areas sampled between May and September 2013.

Fine scale environmental associations

We examined features we believed would influence the occurrence of RTMs on a sampling plot scale using stochastic gradient boosting with a machine learning classification and regression tree (CART). We used the CART approach due to our limited knowledge of relationship between vegetation and RTMs in the northern part of their range. Additionally, CART models are well suited for the elucidating thresholds and complex, often nonlinear relationships from spare data (De'ath and Fabricius 2000). These models use a machine-learning approach to partition data into classes (RTM present or absent) by our environmental characteristics to create a branching decision tree (McCune et al. 2002). We created a binary (RTMs present or not) CART model using the program TreeNet (Brown 2007) (Salford Predictive Modeler, Salford Systems, San Diego, CA) and populated it with the following variables: average water depth and % surface cover of: dogfennel (*Eupatorium capillifolium)*, maidencane, lilypad (*Nymphaea spp)*, cowlily (*Nuphar spp)*, and water cover. We selected these species because they were dominant plants on our survey sites and they are excellent indicators of habitat conditions (Van Deelen 1991; Jakubauskas et al. 2000; Johnson et al. 2007). We developed a CART model of RTMs fine scale environmental association based on data from 61 sample plots. Given our relatively small sample size we used v-fold cross validation to evaluate our model (Breiman et al. 1984; Burman 1989). This approach allowed us to partition our data so that it could be used to both build and test the model. We presented a classification and regression tree and the relative importance scores for each variable and evaluated the predictive fit of the final model using an Area Under the Receiver Operating Characteristic (AUROC).

Land cover analysis

We used data from the land cover Florida Natural Areas Inventory (FNAI 2012) to quantify the land cover within 2 km of sampling plots. Scales ≤2 km have been effective at discovering associations between wetland-obligate wildlife and broad land cover types (Houlahan et al. 2003; Simon et al. 2009; Pearse et al. 2012). We merged narrowly defined land cover types into broad land cover categories (Marsh, Forest and Shrubs, Forested Wetlands, Soil, Urban, Grassland, and Agriculture; Online Resource 1), and used the Calculate Geometry tool in ARCGIS (Environmental Systems Research Institute Release 10.1. Redlands, CA) to calculate the % of each land cover for a 2 km area surrounding the center of each sampling plot.

To understand the relationship between RTM distribution and surrounding land cover categories we used an occupancy modeling approach to account for imperfect detection (Mackenzie et al. 2006). First, we held detection constant and fitted 13 a priori models that included single variable models with all 7 land cover types (Marsh, Forest and Shrubs, Forested Wetlands, Soil/Sandhill, Urban, Grassland, and Agriculture), additive models, a null model and a global model (Table 1). We selected the best models based on their Akaike's Information Criterion corrected for small sample size value (AICc). We considered all models ≤4 AICc to be best competing models (Burnham and Anderson 2002). We then modified and compared the best models by adding

Table 1 Comparison of models of round-tailed muskrat in wetlands in the Orange Creek Basin, FL. Occupancy only models evaluate occupancy (psi) based on landcover measure within 2 km of sampling site while holding detection (p) constant. The best models with detection were parameterized with covariates from the sampling site that could influence detection. Models ranked based Akaike's Information Criterion corrected for small sample size (AICc), change in AIC (ΔAICc), AICc weight (AIC wgt) and the number of Parameters (# Par)

Model	# of Par.	AICc	Δ AICc	AICc wgt
Occupancy only models				
psi(Urban),p(.)	3	91.89	0	0.412
psi(Urban + Ag),p(.)	4	93.18	1.29	0.2161
psi(Bare Ground),p(.)	3	94.59	2.7	0.1068
psi(.),p(.)	2	96.02	4.13	0.0522
psi(Forest Wetland),p(.)	3	96.09	4.2	0.0504
psi(Grassland),p(.)	3	96.21	4.32	0.0475
psi(Ag),p(.)	3	96.94	5.05	0.033
psi(Forest),p(.)	3	97.62	5.73	0.0235
psi(Water),p(.)	3	97.99	6.1	0.0195
psi(Marsh),p(.)	3	98.17	6.28	0.0178
psi(Marsh + Forested Wetland),p(.)	4	98.25	6.36	0.0171
psi(Global),p(.)	10	101.17	9.28	0.004
Best models with detection				
psi(Urban),p(Maidencane)	4	87.92	0	0.5191
psi(Bare Ground),p(Maidencane)	4	90.7	2.78	0.1293
psi(.),p(Maidencane)	3	91.99	4.07	0.0678
psi(Urban),p(Water Depth)	4	92.1	4.18	0.0642
psi(Urban),p(Lillypad)	4	92.48	4.56	0.0531
psi(Urban),p(Dogfennel)	4	93.47	5.55	0.0324
psi(Urban),p(Water Cover)	4	93.55	5.63	0.0311
psi(Bare Ground),p(Water Cover)	4	93.63	5.71	0.0299
psi(Urban),p(Method)	4	93.85	5.93	0.0268
psi(Bare Ground),p(Water Depth)	4	94.79	6.87	0.0167
psi(Bare Ground),p(Lillypad)	4	95.16	7.24	0.0139
psi(Bare Ground),p(Dogfennel)	4	96.05	8.13	0.0089
psi(Bare Ground),p(Method)	4	96.56	8.64	0.0069

At 2 km scale (Marsh = % freshwater wetlands, Urban = % urbanization, Ag = % Agriculture, Forest = % upland forest and shrublands, Forest Wetland = % forested wetland, Water = % open water. Bare Ground = % soil, clear cut, sand and beach) at the 40 X 40 m plot scale (Dogfennel = % dogfennel, Maidencane = % maidencane, Lillypad = % lillypad, Water Depth = average water depth, Water cover = average water cover)

variables that might influence the detection of RTMs. To each of the best models we fitted an additional 8 models that varied detection. These detection models considered 6 variables derived from vegetation and water survey (see above: average depth, open water, maidencane, dogfennel, lilypad, and method [walking or boat]), as well as a null model. Again, we selected the top models based on AICc values and considered variables modifying detection and occupancy parameters to be a relevant predictor if their 95% CI did not include 0. We conducted our analysis using Program PRESENCE Version 6.1 (Hines 2006) and we evaluated the fit of the best model using the parametric bootstrap test (Mackenzie and Bailey 2004)

To further understand how different land covers might shape the distribution of RTMs throughout the Orange Creek Basin we examined the relationship between land cover and the vegetation that was most influential to RTM occurrence. Specifically, we looked at the relationship between the percent of urbanized land cover within 2 km of our sampling plots and the distribution of the three most important plant species for RTMs based on our CART model (lilypads, maidencane, and dogfennel). We examined these relationships using a generalized liner model (GLM) using SPSS Statistics V. 22(IBM, Armonk, New York). Due to the number of unoccupied sites we fit models with the presence of dogfennel and lilypads to a binary distribution. We used a Gaussian distribution to examine the relationship between urbanization and average cover of maidencane that was on a site. Maidencane was present on >90% of our sites.

Results

We detected RTMs on 19 of 72 sample plots throughout the Orange Creek Basin. Of the 61 plots that we surveyed twice we detected RTMs during both surveys all but once (12 of 13). Based on the null occupancy model the overall probability of detecting RTMs during one survey if they were present was >0.95.

Our optimal CART model achieved a moderately good predictive model with an AUROC of 0.862 (Fawcett 2005; Fan et al. 2006). This model included five nodes, water depth (relative importance score = 77), dogfennel (relative importance score = 100), lilypads (relative importance score = 53), open water (relative importance score = 38) and maidencane (relative importance score = 79). The most important variable in the model was dogfennel which was negatively related to RTM occurrence. Out of 34 locations that had dogfennel just 3 had RTMs. The model also predicted RTMs would be more likely to occur (47%) on plots with at least some coverage of lily pads (> 1%) when compared to those site with negligible (< 1%) lilypad coverage (10%, Fig. 2). On sites with >1% lilypad coverage RTMs were predicted to occur in areas with ≤31 cm of water. On sites with reduced lilypads (< 1%) RTMs were predicted (73%) to occur in areas with >43% open water on the plot. On these plots with open water (> 43%) the model predicted RTMs were more likely to occur (75%) in areas with >6.5% coverage of maidencane (Fig. 2).

At a scale of 2 km we found that the land cover model that best explained the occurrence of RTMs included one variable, urban land cover (Table 1). There were 3 competing models (< 4 Δ AICc). One competing model included the additional variable (agriculture) that did not improve the fit of the model and was accordingly disregarded (Burnham and Anderson 2002). The other competing model included the variable bare ground. Evaluating models that modified detection of the best occurrence models, we found the models that included the variable % maidencane influencing detection fit the data better than models without detection parameters. The best overall model showed urbanization was an important predictor of RTM occurrence ($\beta = -1.05.$, 95% CI -2.06 – -0.041; Fig. 3). The probability of RTM occurrence was as high as 0.40 when there was no urbanization and reduced to <0.05 once urbanization accounted for >15% of the surrounding land cover (Fig. 3). This model had a relatively good model fit, $c = 0.90$. Examining the competing model (psi [bare ground], p [maidencane]), with confidence intervals containing 0 ($\beta = -0.64.$, 95% CI -1.42 – 0.144); bare ground did not appear to a relevant predictor of RTM occurrence. Although maidencane improved the overall model fit of urban and bare ground models in both models its 95% CIs crossed 0 (urban, $\beta = -2.99.$, 95% CI -8.62 – 3.041, bare ground $\beta = -2.97.$, 95% CI -4.09 – 10.03) suggesting it was not a strong predictor of RTM detection.

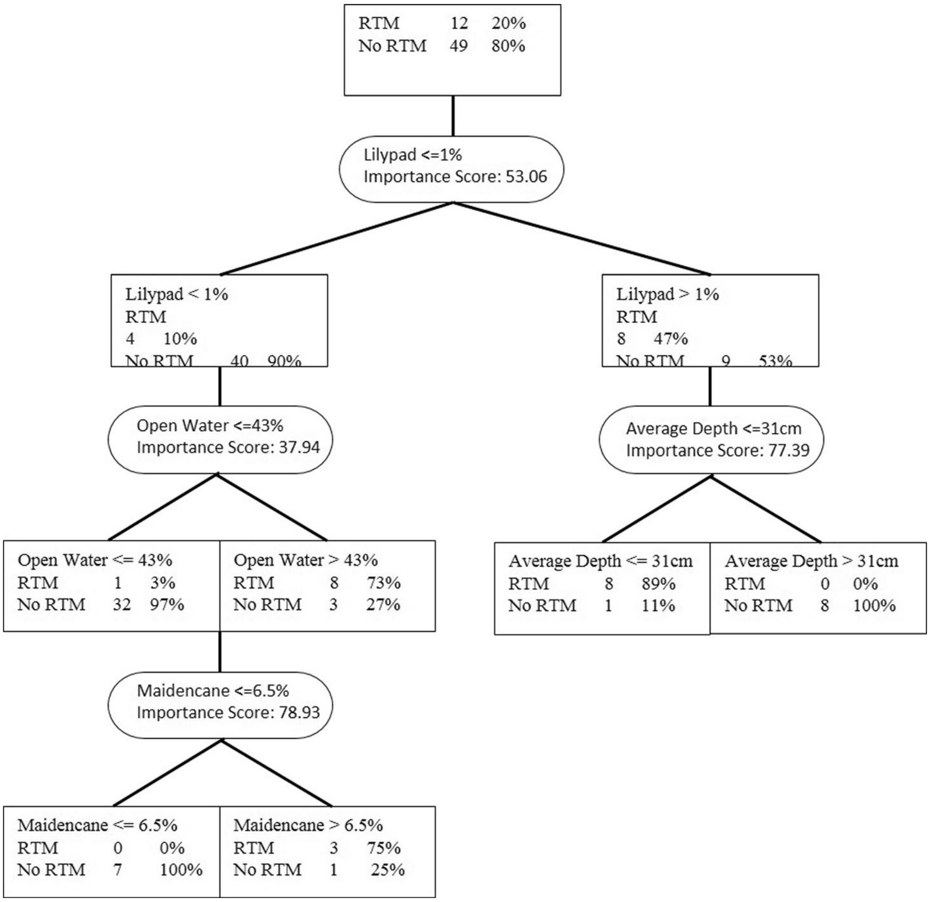

Fig. 2 Classification and regression depicting the relationship between measure of vegetation and water on and round-tailed muskrat occurrence on 40 × 40 m plots in the Orange Creek Basin of North-Central Florida USA. Each split represents the deciding level at which the variable is important. Dogfennel was not shown due to having a simple yes/no relationship with RTMs. Based on the analyiss locations with dogfennel did not have RTMs

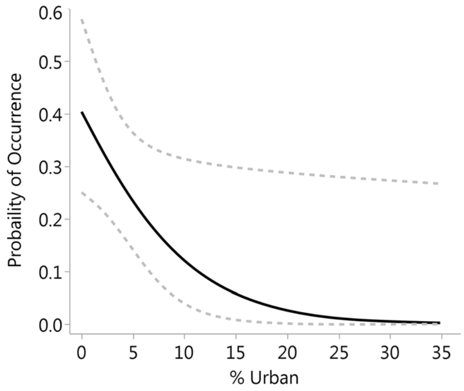

Fig. 3 Occupancy model derived probabilities of round-tailed muskrat occurrence as a function of the percentage of urban land cover within 2 km area of 40 × 40 m plots in the Orange Creek Basin of North-Central Florida USA

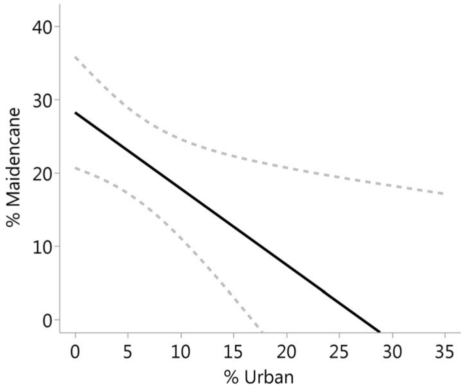

Fig. 5 The % of Maidencane on 40 × 40 m plots in the Orange Creek Basin of North-Central Florida USA as a function of urban land cover within 2 km area, as predicted by generalized linear modeling

The amount of urban land cover surrounding our sites was correlated with the amount of maidencane cover ($\chi^2 = 5.832$, $p = 0.016$, $\beta = -1.041$, 95% CI [−1.886 – -0.196]) and the occurrence of dogfennel ($\chi^2 = 6.940$, $p = 0.008$, $\beta = 0.177$, 95% CI [0.045–0.309]). As urbanization increased around the sites the amount of maidencane cover decreased and the occurrence of dogfennel increased (Figs. 4 and 5). The amount of urbanization with 2 km of each sampling site did not influence the occurrence of lilypads ($\chi^2 = 1.117$, $p = 0.291$, $\beta = -0.041$, 95% CI [−0.117 – 0.35])

Discussion

As we predicted the occurrence of the wetland-obligate RTM was negatively correlated with urban land cover. Both RTMs and their associated vegetation changed with increasing levels of urbanization in the Orange Creek Basin of North-Central Florida. The probability of RTMs occurring in a wetland decreased considerably as urbanization in the surround landscape increased (Fig. 3). The probability of finding an RTM in wetlands surround by >15% urban land cover was considerably reduced (< 0.05). Moreover, wetlands surrounded by urban land cover were more likely to have dogfennel which was negatively associated with localized RTMs occurrence, and were less likely to have maidencane that was positively correlated with RTM occurrence.

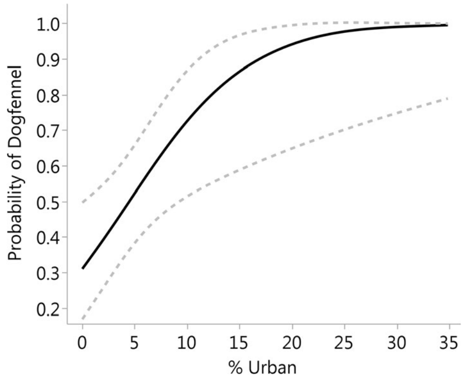

Fig. 4 The probability of dogfennel occurrence on 40 × 40 m plots in the Orange Creek Basin of North-Central Florida USA as a function of urban land cover within 2 km area, as predicted by generalized linear modeling

There is a clear mechanistic link between urbanization and increased prevalence of dogfennel. The more frequent drying of wetlands around urban areas (Reinelt et al. 1998) is likely to favor dogfennel that grows on disturbed and dry wetlands (Wunderlin and Hansen 2003). There are also a number of potential explanations for the negative relationship between RTMs and dogfennel. First, dogfennel does not grow in the wet environments RTMs utilize for their lodges and foraging. Locations with dogfennel were undoubtedly dry at some point in the recent past. Possibly there is a lag time between when the wetland becomes inundated and RTMs build lodges in an area. Secondly, RTMs may not be able to utilize areas with dogfennel because the plants they use to build structures (lodges, feeding platforms) have been displaced by dogfennel. Third, RTMs may not utilize areas with dogfennel because it is likely inedible to them (Van Deelen 1991).

In contrast to dogfennel, maidencane is less productive in dry wetlands and needs moist soil to grow (Willis and Hester 2004; United States Department of Agriculture 2016). Thus, it is not surprising that maidencane prevalence decreased with increasing urbanization. Maidencane has been considered a species of great importance to RTMs (Birkenholz 1963; Schooley and Branch 2011), with previous research suggesting that maidencane was the dominant food source for RTMs in north-central Florida (Birkenholz 1963). Maidencane had the second highest relative importance score in our CART analysis but it was only positively linked to RTMs in areas with open water. RTMs will eat underwater stems of maidencane in the winter (Birkenholz 1963) but our surveys only recorded maidencane at or above the water's surface so it is possible that we underestimated the amount of maidencane available at the plots. Additionally, our occupancy models suggested a weak (95% CI cross 0) negative trend between maidenane and RTM detection, thus it is possible that our CART analysis, that did not account for imperfect detection, may have underrepresented the importance of maidencane. Finally, we cannot rule out the possibility that RTMs use but do not nest in areas of maidencane that do not have opened water.

The relationship between urban land cover and wetland plant communities and the clear linkage between wetland vegetation and RTM occurrence demonstrates the influence of urbanization on multiple interacting trophic levels. Our research suggests that on a landscape scale management and conservation of wetlands and RTMs should focus on limiting urban sprawl within at least 2 km of wetlands, not just directly adjacent to them. This is clearly a daunting task as projections of Florida's population suggest continued population growth in the coming decades (Smith and Rayer 2012). This population growth is expected to increase demand for natural resources and land. It is projected that Florida will develop over 2,800,000 ha of conservation and agricultural lands in the next 50 years (Zwick and Carr 2006). This increased development is almost certain to stress the states wetlands and their diverse plant and animal communities, especially those that already are listed as species of concern, like the RTM.

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