Annals of the Entomological Society of America

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Estimating the Foraging Range of *Cerceris fumipennis* (Hymenoptera: Crabronidae) using Land Cover Data

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Abstract

The invasive pest emerald ash borer (*Agrilus planipennis*, Coleoptera: Buprestidae) can be surveyed using biosurveillance. In this technique, the prey of the solitary buprestid hunting wasp, *Cerceris fumipennis* (Hymenoptera: Crabronidae), is monitored for the presence of EAB and other non-native buprestids. One outstanding question for this technique has been the foraging range, and thus the surveillance range, of *C. fumipennis*. Foraging occurs in forest canopies and wasps are difficult to track. In this study, we used 7 years of foraging data, and GIS landcover information to estimate the foraging range of *C. fumipennis*. Prey species for each collected colony site were divided between those with coniferous and deciduous hosts. The proportion of coniferous prey for each site was then correlated with the proportion of coniferous land cover from the National Land Cover Dataset 2016 map. Correlations were established for increasing radii circles that surrounded the colony. We assumed that *C. fumipennis* is an optimal forager and that the radius that shows the best correlation between the proportion of coniferous prey, and the proportion of coniferous land cover best represents the foraging range for each colony. Overall, we found that the highest such correlation was found between 1,000 and 1,500 m from the nest sites. We thus conclude that surveillance of a colony of *C. fumipennis* will yield information about the presence of non-native buprestids within a one 1.5 km radius.

Key Words: biosurveillance, foraging range, spatial analysis

Introduction

Emerald ash borer, *Agrilus planipennis* Fairmare (Coleoptera: Buprestidea) is the most destructive and costly invasive wood boring beetle in North America (Herms & McCullough, 2014). It was first detected in the Detroit, MI, in 2002, but dendrochronology has established that it likely arrived as early as 1990 (Siegert, et al., 2014). The beetle has since spread across the eastern half of North America. Its rapid and cryptic spread necessitated the development of improved detection techniques. There was little practical knowledge of effective trapping techniques for Buprestidae in general, and none for emerald ash borer (EAB) in particular. Focused resources and innovation quickly led to identification of optimal trap colors (Francese, et al., 2010), kairomones and short-range sex pheromones (Crook, et al., 2008; Wittman, et al., 2020) and the production of several effective trap types (Robinett, et al., 2021),

The predominate surveillance tool developed and used for detection of EAB has been purple and green prism traps (USDA APHIS). Lindgren funnel traps created with plastic in green have also been deployed. Research into the area that is surveilled by these trap types has been conducted by 'catch and release' methods. A recent study by Wittman et al. (2020) showed that traps baited with emerald ash borer pheromones *increased* the attraction of traps to EAB up to 70 m with an average range of 30 m.

Another approach to EAB detection was pioneered by Careless et al. (2014). Knowing that the native solitary wasp *Cerceris fumipennis* Say (Hymenoptera: Crabonidae) uses adult buprestid beetles to provision their subterranean nests, the authors hypothesized that the wasps would prey on EAB. This hypothesis proved to be correct, and? *C. fumpennis* was found to readily utilize EAB in areas where it was present.

Several features of *C. fumipennis* make it suitable for use in survey work. They are densely distributed throughout eastern North America (Muesebeck, et al., 1951) allowing for widespread survey. The female wasps are active from mid-June to early August, depending on annual temperatures (Rutledge, et al., 2015), which overlaps broadly with the period when adult EAB are present in ash tree canopies. Additionally, these wasps are commonly found and pose no threat to a surveyor as they do not sting people. Aggregations (or colonies) of a few to several hundred individual nests can be found in packed sandy soil, such as dirt roads and baseball fields (Nalepa, et al., 2012) which are easily accessed by surveyors.

Citizen-science groups, known as the Wasp Watchers, have been established in various states. These watchers 'adopt' a colony and after a hands-on training session, commit to monitoring for at least 3 days during the flight season. Watchers aim for 50 beetles per colony per season, but any collected beetles are frozen and submitted. Notably, the first detection of EAB in Connecticut was observed by a 'Watcher' monitoring a colony in 2012 (Rutledge, et al., 2013). Using this surveillance tool, the distribution, growth, and decline of EAB populations across a state is possible (Rutledge et. al. in prep).

One question that has been difficult to answer has been the foraging range, and thus the effective surveillance range of *C. fumipennis* from the colony. Direct observation of the wasps is near impossible. The wasps emerge from their burrows, perform a short orientation flight, and then rapidly ascend and fly to their foraging sites in tree canopies. Additionally, tracking technologies, such as RADAR used with honeybees (Alzaabi, et al., 2021) or VHF radio telemetry to track butterflies (Fisher, et al., 2021), would be impeded by the forest canopy (Zhu, et al., 2011). One approach to approximate dispersal ability was releasing female wasps varying distances from their nests. Those that successfully returned were released within their potential foraging range (Careless, et al., 2014; McCabe & Chandler, 2020; Fabré, 1915). With this method, a maximum and average flight speed were established, and an estimate, bounded on the upper end of the distance from which wasps returned, was calculated based on the average time it took wasps to preform round-trip foraging events. Results suggested the colony surveilled up to an area two to three km around the colony. Alternatively, as many of the buprestid beetles collected by *C. fumipennis* are host specific, Nalepa et al. (2013) reasoned that the wasps had to fly at least as far as the nearest infested trees of those host species to collect those species, and established that the wasps forage at a minimum of 200 m from their colony.

In this study, we approach the question from yet another angle. Like most generalist hunters, *C. fumipennis* prey selection is driven by prey density (Nalepa et al. 2013). Overall, the beetles returned to the colony will represent the levels of prey available in the area surrounding the colony. In turn, this prey availability will be determined by the host trees present. While several buprestids feed on only a single genus of tree (e.g. EAB and *Fraxinus* or *A. anxius* and *Betula*), few species feed on both conifers and deciduous trees. Thus, we would expect the proportion of conifer-feeding beetles collected at a colony would be related to the proportion of conifers in the surrounding area. If this is the case, the radius of the area around a colony which best correlates the proportion of conifers with the proportion of conifer feeding prey should reflect the foraging range of the colony. We use prey data from 37 colonies over 7 years to correlate the proportion of prey using coniferous hosts with reported landcover at different radii from the colony to identify the foraging distance of *C. fumipennis*.

Methods

Prey data

Beetles were collected over a 7-year period from *C. fumipennis* colonies across the state of Connecticut in collaboration with a group of citizen-scientists, the Connecticut Wasp Watchers. Briefly, beetles are collected from each colony using one of two methods. First, a wasp returning to her burrow carrying a paralyzed beetle was captured in a net. The wasp was allowed to fly away while the paralyzed beetle remained in the net for collection. Second, the ground around the burrows was scanned for abandoned beetles. All collected beetles were pinned, labeled, and identified by the author, or sent to identifiers in cases of difficulty. For a complete description of methods see Rutledge et al. (2013) and Careless et al. (2014).

Data from 37 colonies were selected (Figure 1). Each of these colonies yielded a minimum of 100 beetles, although this collection could take place over several years, and for each of these colonies EAB constituted less than 1% of prey captured during a year. The second criterion was established due to the distorting effect of EAB infestations, where the great abundance of EAB during peak outbreaks overwhelms the conifer/ deciduous dynamic. Similarly, data from colonies in eastern Connecticut from 2016, 2017, and 2018 reflected a steep population increase in *Agrilus bilineatus* (Weber) due to the presence of many stressed oaks in the wake of drought and a *Lymantria dispar dispar* (Linnaeus) outbreak (Pasquarella, 2018). Thus, data from colonies in those years was not used. In total, 7,469 beetles comprising 3 families, 16 genera and 60 species were used in this analysis.

Landcover Data

To calculate proportion of forested land surrounding our focal *C. fumipennis* colonies, we used the National Land Cover Dataset 2016 (USGS 2016). This product provides a 16-class land cover classification on a modified Anderson Level II classification level including 3 forestry cover types, deciduous, evergreen, and mixed canopy The resolution of the classified pixels is 30 m^2.

Analysis

For each site beetles were separated by host plant into conifer feeders and deciduous tree feeders using host information for the beetles from Bright (1987) and (Paiero, et al., 2012). Species that feed on both deciduous trees and conifers were not included (e.g., *Chrysobothris sexsignata* (Say)). The proportion of coniferous-feeding prey species to deciduous-feeding prey species was calculated for each site (Figure 1).

For each of our 37 colonies, we calculated the proportion of pixels classified as evergreen to the proportion of the other forest types within a range from 500 m in radius to 3,500 m in radius in increments of 500 m (Figure 2). We also looked at the difference between the proportion of evergreen pixels as the radii increased, by taking the absolute difference between the proportion at 500 m and 1,000 m, 1,500 m, and 2,000 m etc. for each site and then averaging it.

Linear regressions were performed with the proportion of evergreen landcover as the independent variable and the proportion of conifer-feeding prey as the dependent variable for each radius from 500 m to 3,000 m and significance (α = 0.05) and the coefficient of determination, R^2, was determined for each correlation. Plotting the R^2 against distance allowed for easy visualization of the strongest correlations.

Results

Proportion of conifers surrounding the colonies ranged from 0 - 0.37 at all distances with an average of 0.102. Looking at the difference of conifer proportions at different distances from the colony, the greatest difference was between the area with a 500 m radius and the area within a 1,000 m radius. Between them there was an average absolute change in the proportion of conifers of 0.054 (SE ± 0.008) (Figure 3). As the circles got larger, the differences among them got smaller. The proportion of conifer feeding prey likewise varied among colonies and ranged from 0 – 0.4012 with an average of 0.0760 (SE ± 0.0161).

Of the linear regressions performed, the coefficient of determination, R^2 ranged from 0.0631 – 0.4209, and were significant at the 0.05 level for all distances (Figure 4). The regressions with the highest R^2 were those with the proportion of conifers in the circle with the 1,000 m radius (R^2 = 0.4462) and the 1,500 m radius (R2 = 0.4433). After that distance, the proportions were still significantly related, but the R^2 dropped almost in half (Table 1, Figure 5).

Discussion

Using *C. fumipennis* to surveil for invasive buprestid species, including emerald ash borer, is an innovative approach to a difficult problem. However, since its inception, the question of how much area was actively surveilled by a colony has been a vexing one ((Nalepa, et al., 2013; Careless, et al., 2014; McCabe & Chandler, 2020). Using land cover data in a GIS framework allowed us to approach this question from a different perspective. We found that the strongest correlation between prey type and forest type was for areas in a 1.0 – 1.5 km radius of the colony. Previous research approaches yielded a range of 200 m to 2.5 km (Nalepa, et al., 2013; Careless, et al., 2014; McCabe & Chandler, 2020). Our results are well within that range but serve to tighten the proposed window.

Our results show variation in how well the proportion of conifer-feeding prey reflects the proportion of conifers in the surrounding area for each colony. We would expect this, as optimal foraging theory suggests that each wasp should maximize the amount of prey captured, and thus the number of potential offspring for effort put forth (Pyke, 2019). This effort could refer to distance travelled to get prey, time spent searching for and subduing prey (Holling, 1966), weight of prey carried (Coelho, et al., 2012) (Gayubo, 2011), and the number of trips required to provision a single brood cell. Locations that have a large population of beetles situated near the field could require less area to be searched to find sufficient beetles than locations with sparse populations of beetles near the colony. However, the strong significance of the regressions, coupled with the large database upon which these calculations are made, suggest that overall, the estimate of foraging distance is valid.

Individual traps have an attraction range that is two orders of magnitude lower than the hunting range of a *C. fumipennis* colony (Wittman, et al., 2020). The advantage of traps is in their flexibility, you can hang a trap anywhere you would like. Biosurveillance is limited to location in which a colony is present and active. However, a *single C. fumipennis* colony can quickly surveil a much larger area than a trap, and thus potentially result in an earlier detection of non-native species.

Understanding the likely foraging range of *C. fumipennis* allows us to interpret results of surveys more confidently for target species such as EAB, or other potentially invasive buprestid such as *Agrilus* *biguttatus* (Fabricius), a European oak borer. A negative result can be understood to pertain to a 1.0 to 1.5 km radius surrounding the colony, not just the edge of forest closest to the colony. Further analysis of this database will likely lead to more insights into the foraging behavior of solitary wasps.

Acknowledgements

This data set is the result of the hard work and support of many people and agencies. First and foremost I'd like to thank the Wasp Watchers of Connecticut who have collected half of the beetles included in this analysis. Seasonal workers, J. Fitzgerald, J. Tate, E. Kim, D. Hill, S., A. Kahn, all added to the data base and helped to curate the collection. M. Scott deserves special recognition as the primary collector, identifier and curator of the buprestid collection. Many thanks to K. Fisher, G. Molaei and XX for helpful comments on this manuscript. Finally, S. Stebbins has lent much GIS support to the project. Financial support was provided by USFS, USDA Plant Protection Act 7771, and CAPS funding.

Tables

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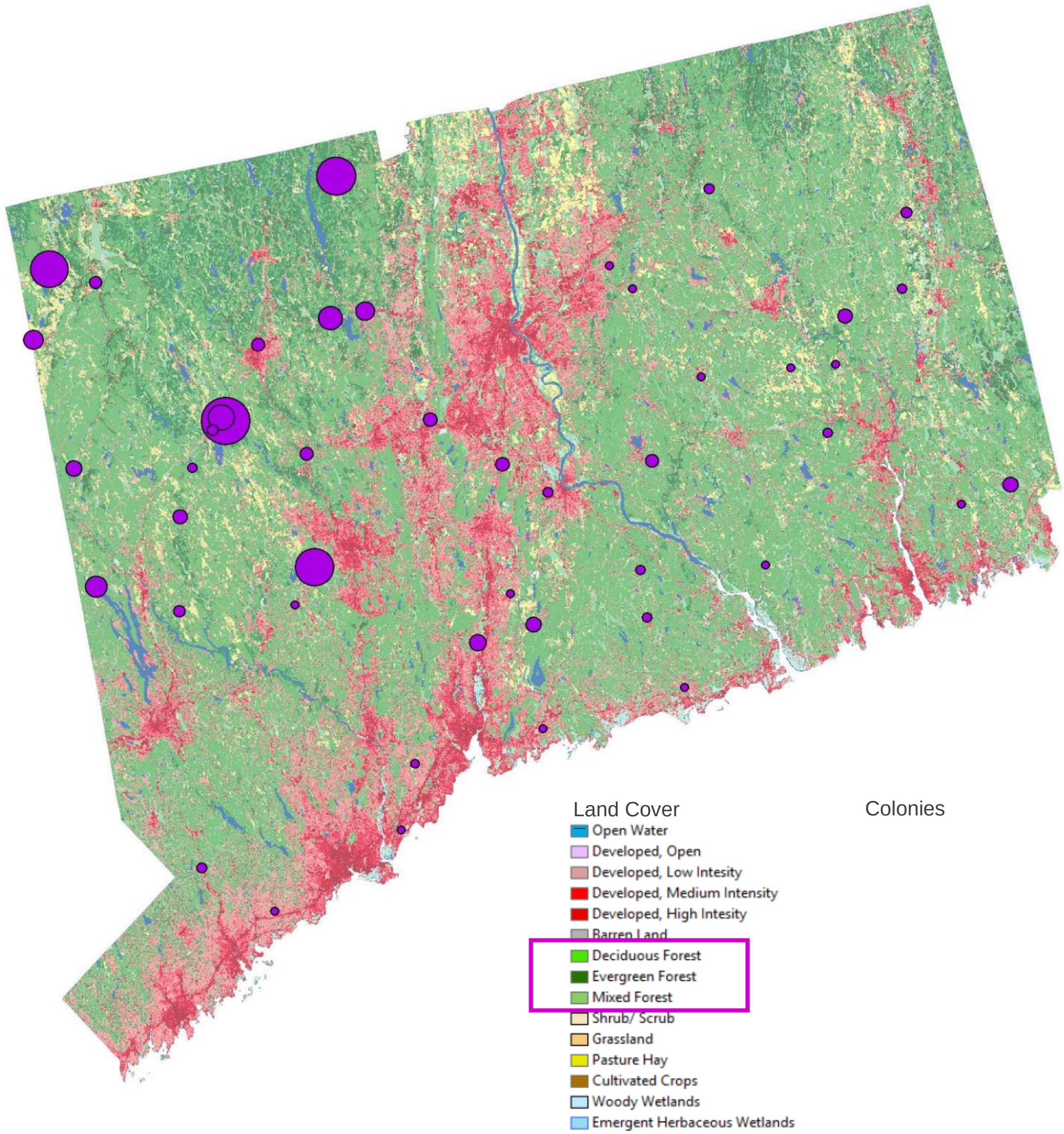
Table 1. Statistical data for linear correlations between the proportion of conifers in the landcover surrounding each colony, and the proportion of conifer feeding prey collected by females in that colony. Correlations were performed for areas surrounding the colony with radii of 500 m through 3,500 m at 500 m intervals.

meters	R^2	$F_{1.35}$	P
500	0.115668	4.597834	0.039036
1,000	0.446197	28.19939	6.27E-06
1,500	0.443326	27.87345	6.88E-06
2,000	0.358058	19.52204	9.16E-05
2,500	0.283067	13.81905	0.000701
3,000	0.238933	10.98809	0.002142
3,500	0.250296	11.6851	0.001614

Figures

1. Map of Connecticut showing landcover classification and location of focal *Cerceris fumipennis* colonies. The size of the colony symbol is proportional to the proportion of conifer-feeding prey captured at that colony.
2. Two focal colonies in the towns of Cornwall (A) and Ledyard (B) Connecticut. Rings show 500m interval distances from the colony. Landcover pixels are 30 m^2. Within1 km of the colony 21% of Cornwall's forested pixels are classified as conifers, while Ledyard has no conifer-classified pixels within 1 km of the colony.
3. Average absolute differences in proportion of conifers in rings surrounding the colonies.
4. Regressions of proportion of conifers in the area surrounding the colony, and the proportion of conifer feeding prey at each distance. All regressions were significant at an alpha level of 0.05.
5. Relationship between the coefficient of determination, R^2, for the linear model of the proportion of conifers in the areas surrounding the colony and the proportion of conifer feeding prey collected by *C. fumipennis* by distance.

275 Figure 1


Land Cover
Open Water
Developed, Open
Developed, Low Intesity
Developed, Medium Intensity
Developed, High Intesity
Barren Land
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/ Scrub
Grassland
Pasture Hay
Cultivated Crops
Woody Wetlands
Emergent Herbaceous Wetlands
Colonies

276

Figure 2

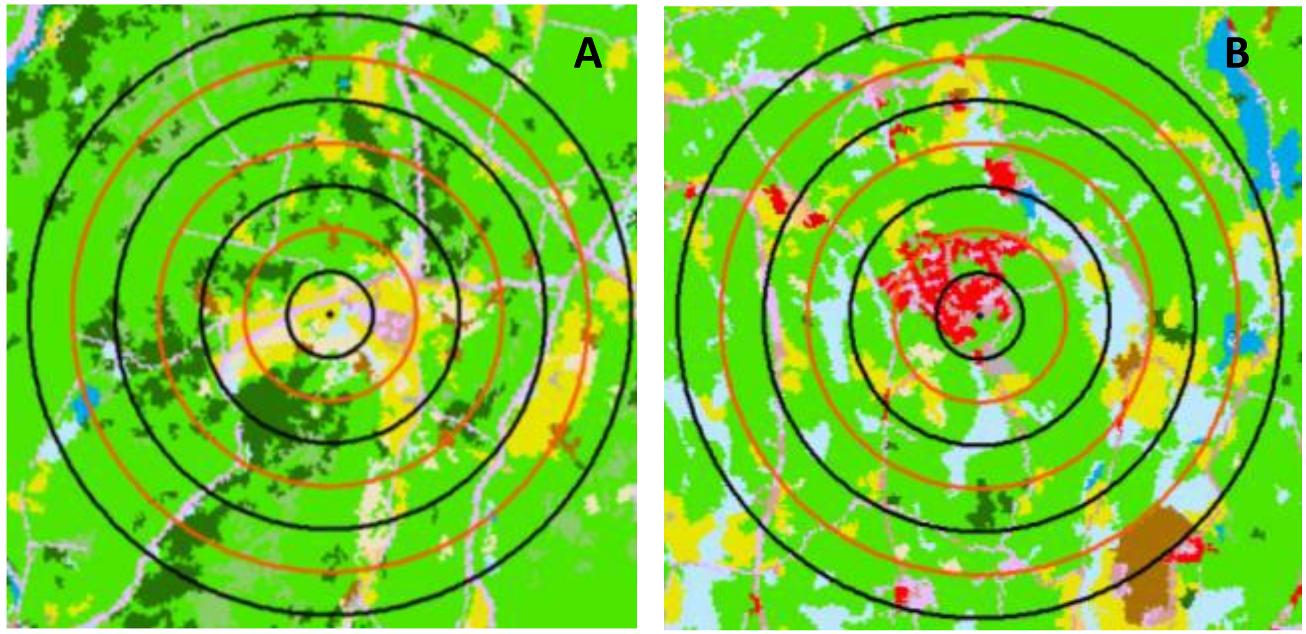
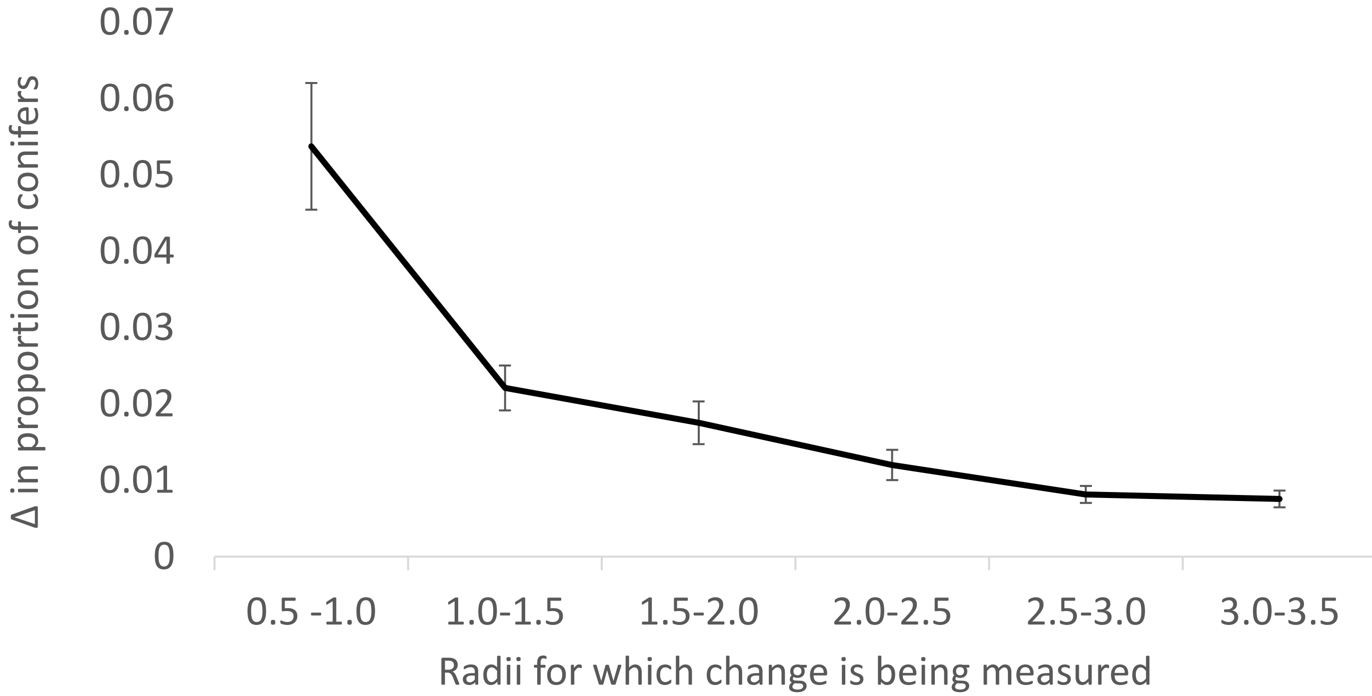


Figure 3


0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Δ in proportion of conifers
0.5 -1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
3.0-3.5
Radii for which change is being measured

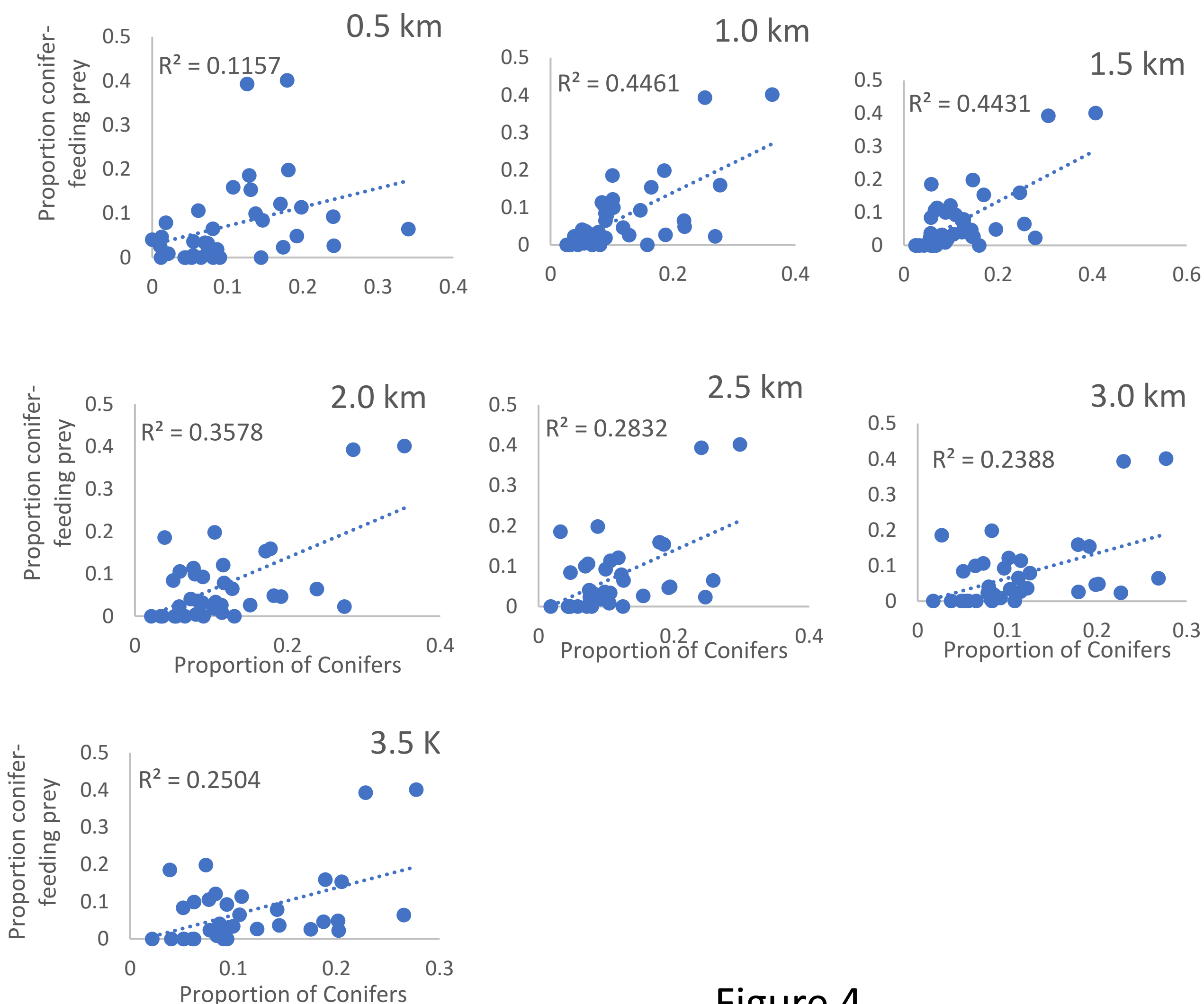
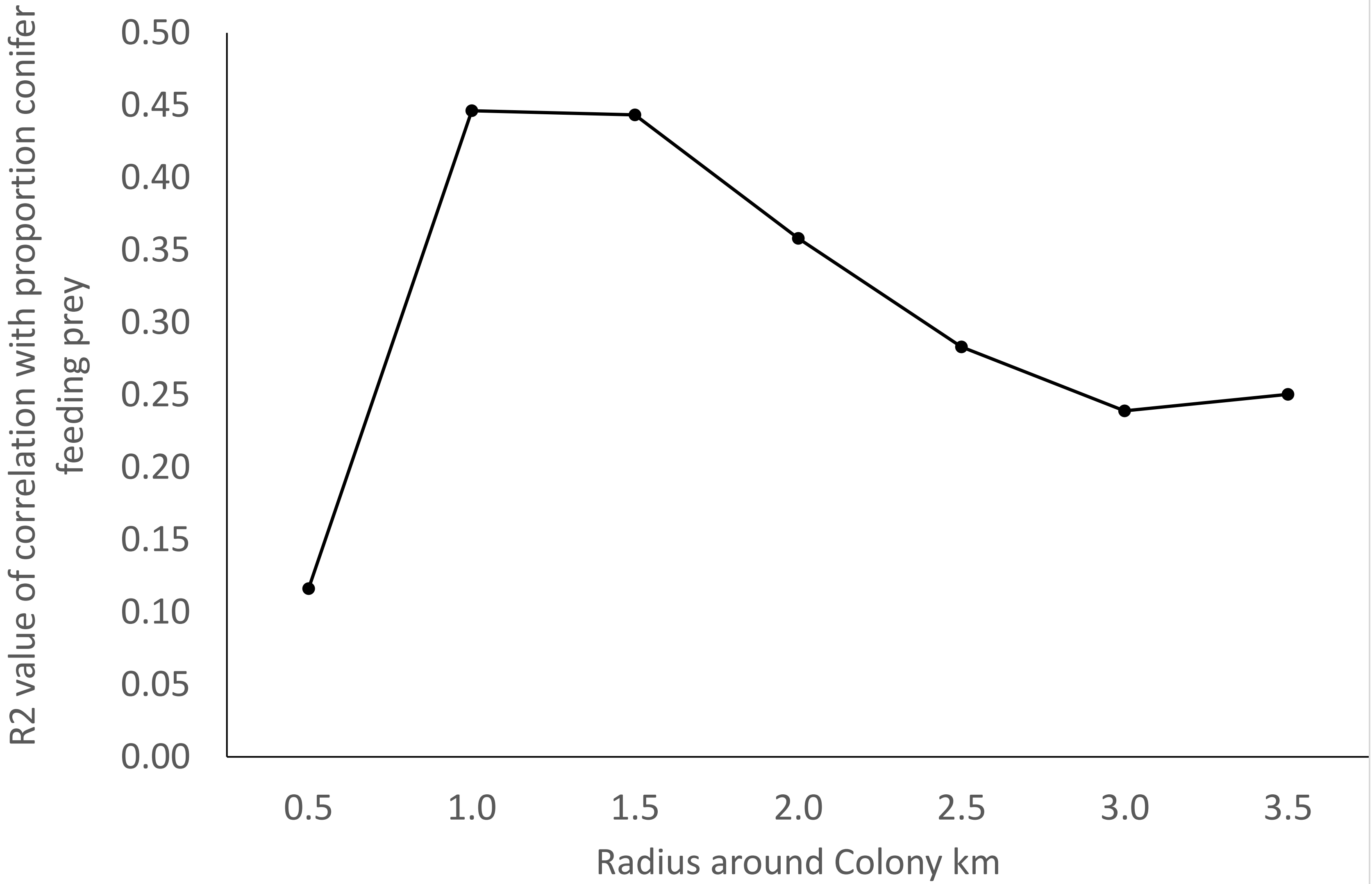

0.5 km
R² = 0.1157
1.0 km
R² = 0.4461
1.5 km
R² = 0.4431
2.0 km
R² = 0.3578
2.5 km
R² = 0.2832
3.0 km
R² = 0.2388
3.5 K
R² = 0.2504
Proportion conifer-feeding prey
Proportion of Conifers

Figure 4

Figure 5


R2 value of correlation with proportion conifer feeding prey
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Radius around Colony km

285