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ABSTRACT

Tropical frugivorous birds are facing the effects of increased human land development. The conversion of forests to road and buildings interrupts the interaction forest trees and their frugivorous dispersers. This study uses the tree/frugivore mutualism to assess the effect proximity to human influences has upon a forest health. Measurements of the removal rates of *Citharexylum costaricensis* (Verbenaceae) fruits in a fragment near to the forest displayed significantly higher removal rates than in the urban fragment (Paired T-Test, T=0.996 df=15, p = 0.043, n =16). Separate trials with *Solanum rugosum* (Solanaceae) fruit displayed the same trend (Paired T-Tests, T = 0.695, df = 10, *P* = 0.404, n = 11). These results show that the human development influences near the urban fragment have a detrimental effect upon this important relationship, which in turn may lead to a loss of stability and biodiversity in urban forest fragments.

RESUMEN

Las aves frugívoras tropicales se enfrentan a los efectos del incremento en el desarrollo humano. La transformación de bosques a carreteras y edificios interrumpe las interacciones entre los árboles y sus dispersores. Este estudio usa el mutualismo árbol/frugívoro para evaluar el efecto de la proximidad a los asentamientos humanos para la salud del bosque. La tasa de remoción de frutos de *Citharexylum donnell-smithii* (Verbenaceae) en un fragmento cerca del bosque fue mayor que el fragmento urbano. *Solanum rugosum* (Solanaceae) mostró la misma tendencia. Estos resultados demuestran que el desarrollo humano tiene un efecto negativo en esta importante relación, que a la larga puede llevar a la perdida de estabilidad y biodiversidad en fragmentos urbanos de bosque.

INTRODUCTION

As forests are cleared and replaced by residential areas, the animal species that depend on the trees in these habitats for food are directly affected (Belisle and Fortin 2001, Cordeiro and Howe 2003, Crooks et al. 2004). This relationship between frugivores and trees is essential to the organism removing the seed, as well as, to the tree itself. While the animal obtains nutrients the tree is able to disperse its seeds. Fruit removal is witnessed in forests around the world. Urbanization is often the reason behind forest loss and disruption of important intraforest interactions. This may result in the worst of consequences; extinction (Marzluff 2001), not to mention many less publicized environmental changes. A loss of species or a readjustment of the environment around a species would directly affect the relationship between trees and frugivores by directly reducing the available frugivores or dispersers. And as anthropogenic changes disrupt this

mutualism, it may become more difficult for it to function effectively (Cordeiro and Howe 2003).

Previous studies have examined how different levels of deforestation have impacted fruit/frugivore mutualisms. The removal of fallen seeds by *Nasua narica* (Procyonidae) was studied in different sized forest fragments. It was determined that the seed removal rate was slower under more isolated trees. This suggests that dispersers visit solitary trees at lower frequencies than that of the non-solitary trees (Jurando 2006). Fragmentation and urbanization often lead to more solitary and exposed trees. This concept could be expected to apply to avian communities as well. Many forest avians have difficulties adjusting to differences in habitat quality (Githiru 2006). Furthermore, scientists determined that trees in disturbed forest areas in Tropical Africa showed a significant decrease in frugivore community species richness, as well as, overall visitor density. This decrease in frugivores in deforested areas resulted in a decrease in overall fruit removal, which was not compensated by disturbance adapted frugivores moving in from the already disturbed areas (Kirika et al. 2007). Another study compared the richness of birds in a developed forest with an orchard and found that the orchard only displayed 75% of the richness found in the forest, and also consisted of smaller birds (Round 2006). This may have an impact upon the dispersal levels and richness of fruiting trees in cleared or altered habitat.

Finally, it has been shown that birds homing abilities actually decreased in accordance to the amount of cleared land in their flight paths (Belisle 2001). This would decrease the likelihood of forest birds traveling through cleared lands to urban trees.

Contrary to this idea that the bird/tree relationship is strongest in continuous forest, Aldrich and Hamrick (1998) stated that trees in cleared areas were dominant over individuals in a continuous forest or in fragments. These trees received much more attention from their pollinators and dispersers, and therefore were more successful. There are many species of animals that are forage in cleared and developed areas very well (Mckinney 2002). These animals may serve to fill the trophic niche that is left by frugivore that cannot survive in cleared areas. Because of this, it is possible that trees that are in urban forests may still have an effective frugivore population to disperse their seeds.

The forests of the Monteverde/Santa Elena area in Costa Rica are a complex web of interactions that have already been effected by urban development. Much of this pre-montane wet forest was cleared roughly sixty years ago to make way for cattle pasture and eventually urban development (Nadkarni 2000). These forests are the primary habitat of a huge diversity of frugivores, which forage from many forest trees. Two examples being *Solanum rugosum* (Solanaceae) and *Citharexylum costaricensis* (Verbenaceae). These trees are found both in urban settings and at the forest edge. Their fruit could therefore be a useful tool in measuring the properties and tendencies of disperser flocks between developed and forested land.

The objective of this study is to determine if the type of habitat affects the fruit removal process. If the clearing of land, truly does impacts the frugivore-tree relationship, and fruit in the forest is more effectively removed than fruit in developed areas there should be a difference in fruit removal rates between urban and forest fragments. Then I proposed that trees in urban settings will experience a lower level of fruit removal than similar trees in the forest. A higher removal rate for the forest trees

could give further evidence that trees near to cities do little to maintain this mutualism and emphasize the importance of forested corridors between forest fragments.

Materials and Methods

This study took take place between, 10 April 2008 and 8 May 2008 in the area surrounding the towns of Monteverde and Santa Elena, Costa Rica.

Study Species
S. rugosum is a small to medium sized tree found in forest edge, as well as, urban areas in this region, and fruits from May to September. Its fruits form bunches of small berries that provide a food source for many avian species in the area (Gargeullo 2008). *C. costaricensis* is another slightly larger species that is very common in this area and produces a large amount of fruit from January to June (Gargeullo 2008).

Study Sites
There were two main study sites. The first consisted of a small patch of trees near the center of Santa Elena. The second was located in a small cleared area in the protected forest of the Escuela Creativa. These two sites are less than half a kilometer apart and were at roughly the same elevation. They both consisted of a small portion of forest and a forest edge. The major difference between the site at the Escuela Creativa and at Santa Elena was the urban effects near to the Santa Elena site. The Santa Elena site was less than a hectare in area and was within 50 meters of paved roads. This area experiences moderate to light traffic and noise. The forest site at Escuela Creativa is far enough from the town to avoid most sounds, or influences of urban factors and is continuous with the Monteverde Cloud Forest Reserve and the Santa Elena Cloud Forest Reserve.

Procedure
Fruiting *C. costaricensis* and *S. rugosum* were located outside of each study area and bunches of ripe fruit were harvested from each tree. In each study site the same 16 tree/treelet species were identified. Each pair of trees was similar in height and in relatively open areas, which increased their visibility. All trees were not producing fruit at the time nor were they adjacent to any large fruiting trees. Using twine, five bunches of *C. costaricensis* or five bunches of *S. rugosum* fruit were attached to each species at roughly two meters above the ground. All the unripe fruits were then removed from each bunch and the number of ripe fruit was recorded. Finally, each tree was inspected every 24 hours for four days and the rate of removal of each species of fruit was noted.

Data Analysis

Percent removal of was calculated by dividing the number of berries removed after three days from the total initial number of berries attached to each tree. This was important to calculate because the number of berries attached to each tree was not constant. A paired T-test was run for each location to determine if there was a significant difference in the percent removal of *C. costaricensis* or *S. rugosum* fruits at each site. The total percent removal for each species of tree, in both study sites, was calculated by averaging the

percent removal (±Standard Deviation) of berry for Santa Elena and Escuela Creativa. A final T-test was used to determine if there was significant difference between the total amount of *C. costaricensis* and *S. rugosum* fruit removed.

RESULTS

It was determined that there was no difference in the percent removal of *S. rugosum* berries between the forest and town (Paired T-Tests, T = 0.695, df = 10, *P* = 0.404, n = 11). On average, each Escuela Creativa tree with *S. rugosum* fruit showed 42.46% (±34.41%) removal, while the trees in Santa Elena showed an average of 29.23% (±35.82%). The large standard deviations indicate that there was a large range of removal values in both sites.

There is a higher removal rate in the forest than in the town for *C. costaricensis* (Paired T-Test, T=0.996, df=15, p=0.043, n = 16; Fig. 1). The trees in the Escuela Creativa study site showed an average of 34.42% (±28.21%). removal, while those in the Santa Elena study site displayed a 20.12% (±17.00%) removal average (Figure 1).

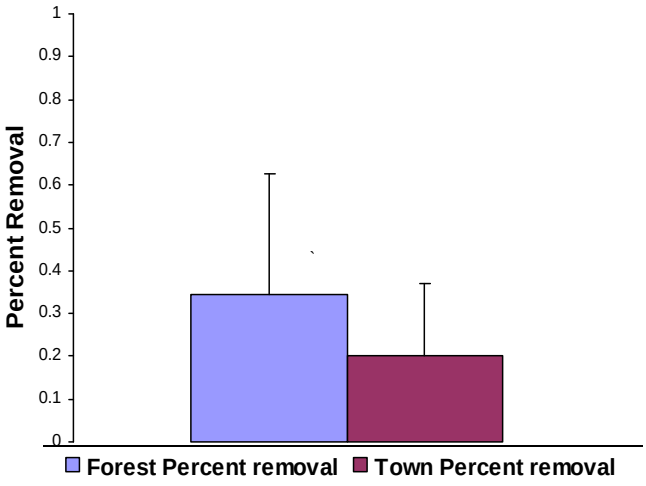

Figure 1: Percent removal for *Citharexylum costaricensis* fruit from various tree species found in forest and town study sites in Santa Elena, Costa Rica during a three day trial. The percent of *Citharexylum* . *costaricensis* fruit removed was greater in the forest study site (34.41% ±28.21%). than the town study site (20.12% ±17.00%). (Paired T-Test, T=0.996 df=15, p = 0.043, n =16).

When the data from the two berry trials were combined and averaged, a trend was shown that there was a higher total percent removal in the Escuela Creativa fragment trees than in the Santa Elena fragment trees (Paired T-Test, T=0.928, df=11, p=0.093). The tree species in each fragment used to test the removal rates of the berries showed varying amounts of removal.

DISCUSSION

The removal rates of *C. costaricensis* and *S. rugosum* berries displayed trends that frugivores in forested areas have a higher rate of removing fruit than do frugivores in more developed areas. The results indicate that frugivores remove a higher percentage of berries in the forested regions, than in urban development. This implies a disruption of the tree/disperser relationship, and therefore a need for conservation of the tree/frugivore relationship. this will require environmentally minded urban planning and conservation of multiple ecological functions in forest fragments near developments.

The *S. rugosum* data showed the trend resulted in data that failed to provide statistical significance, yet still displayed a trend of higher fruit removal in the forest than in Santa Elena. The number of tree species studied for this portion of the experiment was small (n = 11) this was because as the project progressed, the fruiting season ended for this berry and the berry supply began to dry out. This resulted in a decreased amount of berries available for testing and may have led to a decreasing removal rate. Nevertheless, the average percent removal values of 42.46% (±34.41%) for the Escuela Creativa study site and 29.23% (±35.82%) for the Santa Elena site still show the trend that frugivore species guilds in the forest are more effective in removing fruits than they were in the more developed area. This low sample size could be overcome by selecting a species, which was in prime fruiting season.

The results from the *C. costaricensis* trial show that trees near continuous forest tend to be more successful in dispersing their fruit than trees that have to deal with the near developed areas. There are several possibilities for this: the study area is small, and it is very near an urbanized area. Fragmentation causes problems because it not only isolates the species from more intact forest, but it also means that there is a reduced diversity and abundance of species available for dispersal (Crooks et al., 2004).

It is important to relate the results from this study to the health of the Monteverde/Santa Elena area. Trophic interactions play an important role in forest stability (Worm and Duffy 2003). In order for both trees and their dispersers to survive the tree/frugivore relationship must be upheld.

These results also influence the way developed areas are viewed near Santa Elena. Proponents of the Intermediate Disturbance Hypothesis may state that areas near disturbance can be an important center of biodiversity when near to a forest (Molino and Sabatier 2001). Also species that can successfully survive alongside humans can fill some of the tropic roles left by forest specialists (McKinney 2002). It has been determined that in the Canary Islands, bird species acclimated to urban surroundings (Palomino and Carrascal 2005). The results of my study suggest that this is not the case in Santa Elena. The higher level of biodiversity, connectedness, and complexity in the tropics (Mittelbach et al. 2007), may prevent the frugivore/tree relationship in developments rival that of the forest.

The reduction in fruit removal will lead to both a decrease in trees and frugivore success. This will therefore cause a reduction in diversity (Crooks et al. 2004), and a decrease in stability (Wang and Smith 2002), as well. Therefore, without a change of policy in the Monteverde/Santa Elena area, these small urban forest fragments may have a very limited and unstable future.

The solutions to the disruption of this tree/frugivore relationship are the same as the solutions to the problem of forest fragmentation worldwide. This truly complicates the situation. With a large portion of tropical habitats being developed and fragmented (Peres et al. 2006), it is essential for measures to be taken to retain the diversity held in these small patches of forest.

Furthermore, the Monteverde/Santa Elena has an advantage over many other areas with fragmented forest because much of its surrounding forest is protected. A solution to this problem would be to build forested corridors from forests to fragments. This “greenway” technique has been applied in many temperate zones and has seen

measurable success (Linehan et al. 1995). This would increase the biodiversity of these urban forest patches and would increase the stability and health of these patches forest.

Further studies should increase the size and breadth of the sample size. . A wider of variety of fruits should be used increase the accuracy of the study, representing more diverse species interactions. Also, specific tree species and their frugivores should be monitored in an attempt to determine the best way to protect biodiversity near developments. Cooperation is needed between the different specializations inside the biological studies in an attempt to clean up the urban fragments of the forest around Santa Elena. For example, the fragment size cannot just be increased, because it will still be disrupted by the illegal pollution from the nearby developments. Instead fragments must be cared for by local governments on all levels. If this is successful, it could be possible to see the biodiversity and stability of urban fragments in Santa Elena be a better representation of the amazing forests that surround the area.

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