A KEY FOR ASSIGNING POLLINATOR SYNDROMES, WITH NOTES ON THE SYNDROME DIVERSITY OF FOUR FOREST SITES IN COSTA RICA

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Abstract: Understanding the mutualistic relationships between plants and pollinators is important, especially in tropical rainforests, where plant diversity is high. We recorded 16 attributes of flower morphology in four natural areas across Costa Rica. From this information, we constructed a dichotomous key to assign broad categories of pollinator syndromes to flowers, which allows us to analyze flower-pollinator syndromes among sites. We also analyzed the morphotype abundance across sites by assigning them to three classes (rare. 1 - 5; common, 5 - 50, abundant, 50 +). We found significantly more rare morphotypes than common or abundant at Monteverde Biological Reserve and La Selva Biological Reserve. At Palo Verde and Corcovado National Parks, we found morphotypes to be distributed more evenly between abundance classes. To analyze the effectiveness of our dichotomous key, we compared the key's results to a cluster analysis of 12 variables using Ward's hierarchical branch-joining process. The key and cluster analysis were 72% convergent, as measured by the mean heterogeneity of syndromes within clusters, indicating that our key separates most syndromes well. To make this key a useful tool for community analysis, future studies should focus on subdividing its broad categories.

Key Words: cluster analysis, flowers, rare species

INTRODUCTION

Many flowers have morphologies specialized to particular pollinators. In turn, many pollinators depend upon nectar or pollen rewards provided by the flowers. The presence of a particular flower morphology in a community is therefore a strong indicator of the presence of its pollinator. This reciprocal relationship has been the subject of many ecological and evolutionary studies.

In this study, we observed the flower morphologies in four natural areas across Costa Rica. We constructed an objective key to assign broad categories of pollinator types (known as syndromes) based on attributes of flower morphology. In this paper we present a brief analysis of the differences in sydrome diversity and abundance across sites, as well as our key and a qualitative analysis of its accuracy.

METHODS

We sampled flowers at four sites during the Costa Rican dry season. At Palo Verde National Park, a seasonal dry tropical forest near the Pacific coast, we sampled within marsh, primary forest, secondary forest, and edge/roadside habitats. At the Monteverde Cloud Forest Preserve, a cloud forest on the continental divide, we sampled along an elevational gradient in primary forest, riparian, and edge/roadside habitats. At Corcovado National Park, a seasonal humid lowland forest on the Pacific coast, we sampled in primary and secondary forest, riparian, and edge habitats. At La Selva Biological Reserve, a humid lowland rainforest, we sampled in primary forest, secondary forest, edge, marsh, and field habitats.

At each site, three pairs of observers walked different trails and recorded 16 categorical attributes including corolla widths and lengths (mm) (Table 1), for each morphotype of flower encountered. Teams collected representative specimens of each morphotype in order to compare and eliminate redundancies.

We assigned pollinator syndromes to morphotypes using a dichotomous key constructed from eight nested logical tests based upon observations of flowers with known pollinators (Table 2). We also performed a cluster analysis of 12 variables using Ward's hierarchical branch-joining process. We tested the value of our key qualitatively by comparison with the results of the cluster analysis grouped at varying degrees of resolution. A good key should assign the same pollinator syndrome to morphotypes that cluster together.

Table 1. Categories for recorded attributes of flower morphologies

Attitude	(**H**orizontal)Flowers point straight up with horizontal petals (**P**endant)Flowers hang straight down (**I**nclined)Flowers orientation is neither of the above
Accessibility	(**N**ormal)Flowers obstructed by leaves or other material (**H**igh)Flowers in the open, easily approachable from the air
Habitat	(**O**pen), (**R**iparian), (**A**quatic), (**C**anopy), (**S**ubcanopy), (**U**nderstory)
Odor	(**S**weet), (**F**ruity), (**D**ecay), (**M**usty), (**N**one)
Sex	(**H**ermaphroditic), (**M**onoecious), (**D**ioecious)
Pollen	(**H**igh)Can touch flower and see pollen on finger (**N**ormal)All other flowers
Piercing	(**M**ost)Tube shaped flowers, most with holes at the base (**S**ome)Tube shaped flowers, some with holes at the base (**N**one)Non-tube shaped flowers or tube shaped with no holes
#Plants	Estimated number of each plant morphotype with open flowers (1-5, 5-50, 50+)
#Flowers	Estimated average number of open flowers per plant (1-5, 5-50, 50+)
Clumping	(**H**igh), (**M**edium), (**N**one)
Symmetry	Symmetry of flower or inflorescence if flowers tiny (**R**adial), (**B**ilateral), (**Z**ygomorphic)
Brush	Stigmas form a brush (**Y**es), (**N**o)
Tube	(**N**one) Flowers not tube-shaped, If tube then(**H**ard), (**S**oft)
Corolla Size	(**L**arge), (**M**edium), (**S**mall), (**N**one)
Platform	(**N**one) Flowers not horizontal (**F**lat) Horizontal flower with landing pad even with petals (**B**owl) Horizontal flower with landing pad in depression
Color	Flower color

Table 2. The eight logical tests constituting our dichotomous key to pollinator syndromes. Tests were derived from observation of morphotypes with known pollinators.

1. Attitude horizontal? (2) Pendant? (**Bats**) Inclined? (3)
2. Is there a platform? Yes. (**Bees**) No. (3)
3. Is there a tube? Yes. (4) No. (6)
4. Is the tube red or orange and odorless? Yes. (**Hummingbirds**) No. (5)
5. Is the tube less than 10mm in depth? Yes. (**Bees**) No. (**Lepidopteran**)
6. Are flowers green or white and less than 2mm in width? Yes. (**Dipteran/Wind**) No. (7)
7. Do flowers smell musty or like decay? Yes. (**Dipteran**) No. (8)
8. Are flowers highly availible? Yes. (**Large insect**) No. (**Small insect**)

RESULTS

The number of morphotypes in each pollinator syndrome differed among sites (Fig. 1). La Selva and Monteverde had a higher proportion of rare morphotypes (76 % and 80 %, respectively) and a lower proportion of abundant morphotypes (4 % and 2 %, respectively) than Corcovado and Palo Verde (Fig. 2, $\chi^2 = 50.38$, df = 6, $P < 0.0001$).

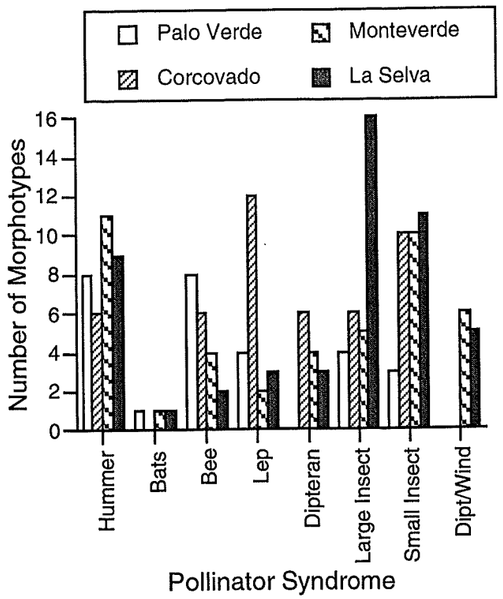

Fig. 1. Number of morphotype in each pollinator syndome. Bars of different pattern represent different site, as indicated in the key. Note that bats, dipterans, and dipteran/wind syndromes did not occur at all sites.

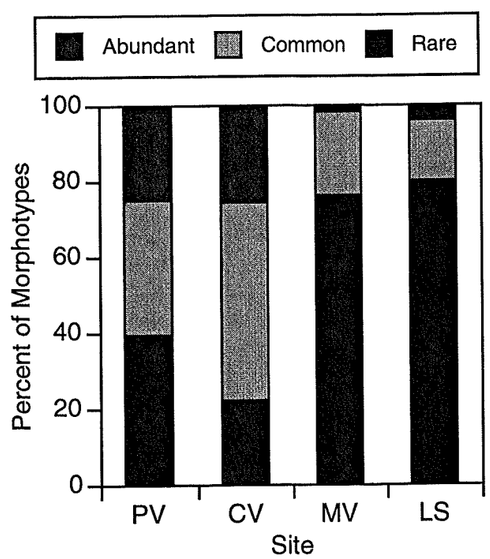

Fig. 2. Percent of morphotypes found in three categories, rare (1-5), common (5-50), and abundant (50+) morphotypes found for four sites in Costa Rica. Abbreviations on x-axis are: PV = Palo Verde, CV = Corcovado, MV = Monteverde, LS = La Selva.

The cluster analysis of flower morphology variables yielded 30 clusters of morphotypes with similar variable states. Our key only allowed for eight pollinator syndromes. While most syndromes formed several small homogeneous clusters, bee-pollinated flower morphotypes were scattered throughout the clusters and seldom grouped together. With all pollinator syndromes included, clusters had a mean syndrome homogeneity of 72% (SE = 0.05). With bees removed from the analysis, mean homogeneity rose to 80% (SE = 0.05). The dichotomous key and cluster analysis begin to converge at intermediate branch depths (Fig. 3).

Discussion

The high proportion of rare morphotypes at Monteverde and La Selva suggests a higher diversity of species at these sites than at the more seasonal lowland Pacific sites. These two sites, by nature of their

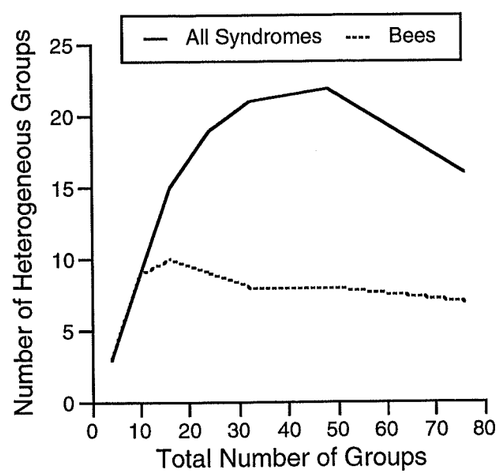

Fig. 3. A comparison of our 8-step dichotomous key with a cluster analysis of 12 variables. Values on the x-axis increase with the resolution of the clustering, from "lumping" to "splitting." The humped shape of the solid curve indicates that the cluster analysis begins to converge with the key at intermediate levels of resolution, suggesting that differences between most keyed syndromes are distinct. Bees do not group together, even with increasing resolution.

abiotic factors alone, may have high niche diversity. On the other hand, Palo Verde and Corcovado may host small niche diversity due to different landscapes. For example, Palo Verde is the most seasonal site and may have greater species turnover through the year. The evenness of flower morphotype distribution at Corcovado may be explained by the homogenous nature of habitat sampled at the site.

Our dichotomous key appears to function well for most syndromes. The key, with only eight variables, converges upon the cluster analysis of 12 variables at intermediate branch lengths, which means that syndromes tend to have clear differences and that the key performs at par with a model of greater complexity. The failure of the bee syndrome to group within clusters suggests that the key does not adequately assign the factors that determine bee pollination, or that we did not measure the correct attributes of bee-pollinated flowers. The key does not separate generalist pollinators. Rather, it classifies them as either large or small insects. Future improvement upon our pollinator syndrome classification should focus on these less stereotyped syndromes that we have not adequately addressed.