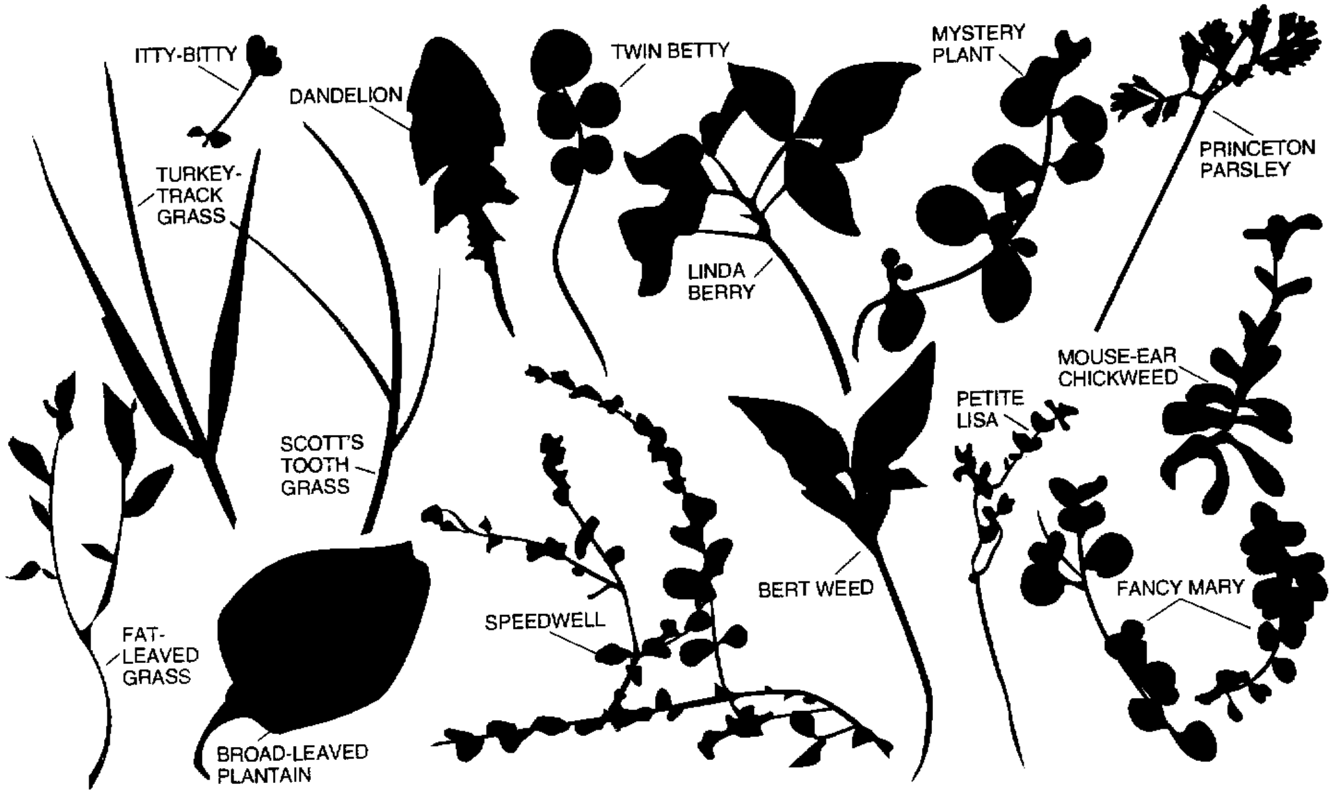
Biodiversity in the Backyard

Systematic inventories of plots of woodlands and fields can be of practical use in planning how best to conserve wildlife in a given patch of land. These surveys show vividly how the number of species encountered in a plot varies with the amount of land inspected. They also help to provide a quantitative way to see how human activity affects local biological diversity. With such observations, conservationists, ecological planners and policymakers can estimate the smallest amount of land needed to preserve a percentage of the natural flora and fauna. Particularly useful in this regard is the relation between the diversity of woodland creatures and plants and the size of forest "islands" in an urban or surburban "sea." Such relations are technically referred to as species-area curves.

HENRY S. HORN constructs satirical artwork and sings blues, madrigals and choral music. He is also professor of ecology and evolutionary biology and director of the program in environmental studies at Princeton University. He thanks Bristol-Myers Squibb for sponsorship, Elizabeth Horn for help in designing and directing this project, the elementary school teachers for their participation and, last but not least, Robert May, William Bonini, Sheldon Judson, Patricia Matuszewski and Amy Wolman for constructive commentary and moral support.

Counting plant species within a lawn is an instructive analogue of such quantitative methods. (Tabulating things that crawl or fly is difficult and tends to lie beyond the amateur level.) I initially designed this project as an exercise for a summer course in mathematical geology and field biology for grade school teachers. The teachers have adapted it to be an exercise in exploration and classification for children in the lower grades. But even our preliminary analyses have been so informative that I plan to use the exercise in introductory data analysis and extrapolation for graduate students. The project can be done at any level of complexity, from childlike exploration to professional analysis. Although each level poses its own important questions about conservation, the basic issue that remains is how much land is needed to sustain species diversity.

The teachers and I selected a lawn behind a parking lot on the Princeton University campus. We worked in three teams of four people. One team started by staking string boundaries on the lawn in nested blocks. The blocks ranged in size from a meter square up to 16 by 16 meters. We set the boundaries for the largest area first. Because the ground bulged slightly (it made the sum of the four angles greater than 360 degrees), we fudged the plot into a square by making the diagonals equal in length. We divided this large square into four equal areas and then further subdivided one corner until the last blocks were one meter square [*see top illustration on opposite page*]. A tape measure and 3-4-5 right triangles came in handy.



LEAF SHAPES provided the basis for distinguishing plant species. The "discoverer" named the plant, an honor that led to several idiosyncratic appellations. Only a few of the 34 species found are shown.

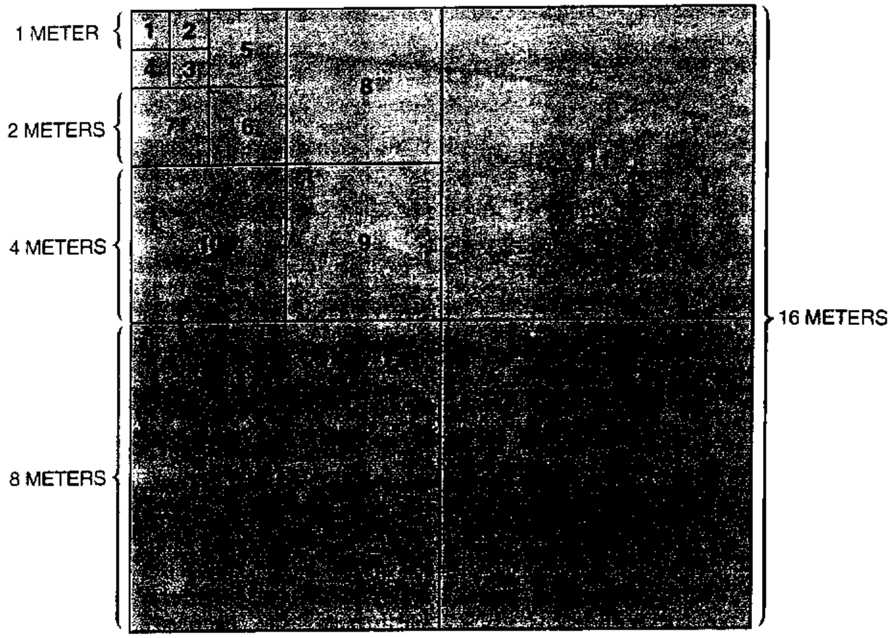
Of course, the area may be increased, or the smallest squares subdivided, depending on the number of species that appear during the investigation. A rough criterion for the right-size area is that a middle-aged and mildly myopic biologist can walk across it and count about 12 obviously different species. Such an area will yield about 30 to 40 species on closer examination.

For familiar plant species, we used the common name. A professional version of the activity would use a technical key to the flora. For our quantitative pattern and just for fun, we defined our own "species" by differences in the leaves. In effect, we were imitating the process by which the true species' names came about [see "How Many Species Inhabit the Earth?" by Robert M. May; SCIENTIFIC AMERICAN, October 1992].

We set up a "museum" of paper on which a "curator" wrote the name of each species found and taped a specimen next to it. While one crew set up the sampling boundaries, the other two explored the region for new species. Any specimen that showed novel features was taken back to the museum. The investigators compared the specimen with named species and assessed its novelty in consultation with the curator. If the specimen was truly new, it was added to the collection. The discoverer had the honor of naming it. Without thinking about it, we named species just as professional taxonomists do—as often for oneself or for a friend as for defining characteristics of the specimen, the habitat or related plants. Being amateurs, we could afford to be whimsical—hence, names such as "Hairy Harry" and "Itty-Bitty."

After completing the survey, we added the totals in each block. We also accumulated a running count of the numbers, starting with those in the smallest square and then adding those in subsequent blocks until we had included the entire plot. (A sample tally sheet appears at the right.) Even without technical analysis, the results provoke many interesting observations. Some species are common to nearly every block; others are rare. Some appear as lone or scattered individuals. Others are found in clumps of several individuals, although the clumps themselves are unique or scattered. Is there any pattern to which species are common and widespread, which are clumped, and which are rare and scattered?

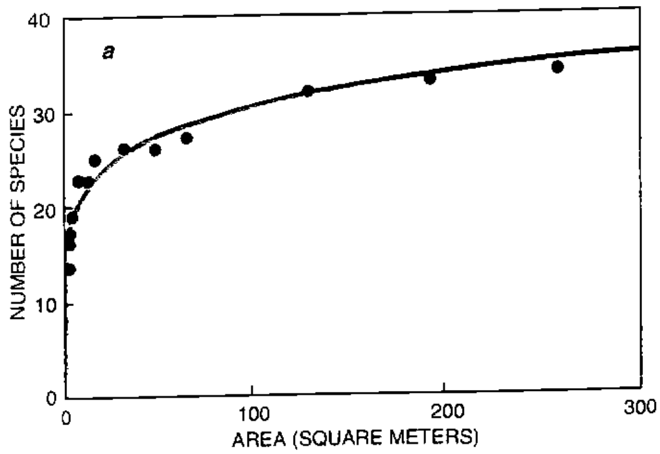
To explore for patterns, we plotted the number of species against the area surveyed in several ways. First, we graphed the cumulative numbers of species for each surveyed square, start-

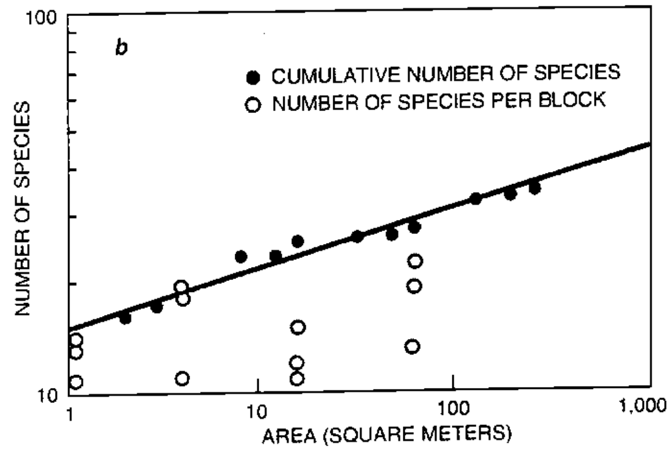


SAMPLING PLOTS consisted of 13 subdivisions of a 256-square-meter area. The plots were numbered in a clockwise spiral pattern.

	BLOCK NUMBER												
SPECIES	1	2	3	4	5	6	7	8	9	10	11	12	13
TURKEYTRACK GRASS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SCOTT'S TOOTH GRASS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
LITTLE BROAD-LEAVED GRASS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
FAT-LEAVED GRASS	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
WHITE CLOVER	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
ALSIKE CLOVER	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓
HOP CLOVER				✓			✓			✓			✓
YELLOW WOOD SORREL	✓		✓	✓		✓	✓	✓			✓		✓
MOUSE-EAR CHICKWEED	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
JAMES'S 3-LEAF							✓			✓			✓
SMOOTH-LEAVED BARBARA		✓		✓	✓		✓		✓	✓			✓
HAIRY HARRY				✓	✓		✓						✓
BROAD-LEAVED PLANTAIN	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
FANCY MARY	✓	✓			✓				✓		✓	✓	✓
DANDELION	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
ITTY-BITTY					✓		✓						✓
WHITE ASH TREE								✓		✓			
SPEEDWELL		✓	✓		✓	✓	✓	✓	✓		✓	✓	✓
BERT WEED							✓						✓
INDIAN STRAWBERRY			✓			✓		✓			✓	✓	✓
BROWN-TOP MUSHROOM					✓								
PETITE LISA	✓				✓							✓	
BOSS MOSS	✓	✓		✓	✓		✓			✓			
FIELD SPEEDWELL	✓											✓	
FUZZY CHICKWEED											✓	✓	
SCARLET PIMPERNEL										✓			✓
TWIN BETTY												✓	
NARROW-LEAVED PLANTAIN					✓								
MYSTERY PLANT					✓						✓		✓
NOVA TERRA SHARON											✓		
PRINCETON PARSLEY											✓		
POISON IVY											✓		
LINDA BERRY													✓
ERNIE WEED											✓		
TOTAL PER BLOCK	14	13	11	13	19	11	18	11	12	15	19	13	22
CUMULATIVE TOTAL	14	16	17	19	23	23	25	26	26	27	32	33	34
AREA OF BLOCK	1	1	1	1	4	4	4	16	16	16	64	64	64
CUMULATIVE AREA	1	2	3	4	8	12	16	32	48	64	128	192	256

TALLY SHEET kept track of the species found. The red check marks denote the smallest block number in which the species was encountered. The cumulative total is the running count of the red checks. The areas are in square meters.





SPECIES-AREA CURVE shows that the cumulative number of plant species encountered increases with the area surveyed (a). *A logarithmic graph of the data reveals a straight line* (b), *which provides the constants* c *and* z [see box below]. *The plots of the number of species per block, however, were inconsistent. Experimenter fatigue is a possible reason for the inaccuracy.*

ing with the most subdivided corner. This cumulative curve shows that 75 percent of our species are found in areas as small as 20 square meters [*see illustration above*].

To test the quantitative pattern we found against the traditional species-area equation [*see box below*], we plotted the same data on logarithmic axes. Some of our grade school teachers were wary of logarithms, but the sampling squares are already scaled multiplicatively by a factor of two in length, or a factor of four in area. A logarithmic scale is easy to construct for the number of species by marking fixed intervals on linear graph paper with 1, 2, 4, 8, 16 and so on. The bilogarithmic plot of our data is a straight line, which conforms to the theoretical generalization given by the species-area equation.

On the same graph, we plotted the surveys for each individual block. We expected the plots to show the same pattern as the cumulative data did, perhaps with a bit of variation and a slightly lower slope and species-intercept point. That is because the cumulative curve must rise continuously with increasing area. We discovered to our dismay that the pattern of the individual blocks was somewhat inconsistent.

Discussion suggested possible causes. One group admitted to being less than thorough in their surveys. They were more interested in the morphology of what they found than in the numbers. Several admitted to accumulating fatigue during the second hour of crawling around the larger plots. It is possible that lapses by one group or by a few individuals were compensated by others in the cumulative data, hence explaining the consistency of those data. It is also possible, however, that we underestimated the slope of the species-area curve for our lawn. In any case, the teachers were so impressed with the regularity of the cumulative data that they started an animated conversation about how to conduct more careful surveys the next time.

The discussion led to further questions. Can our results be safely extrapolated to areas larger than those sampled? How much area would be needed to preserve 50 percent, or even 90 percent, of the regional lawn species? How would the diversity of plants in real "islands" of lawn in a paved parking lot differ from marked-off samples of the same size in a continuous lawn? What insights does this analysis give into the planning of urban parks?

This exercise is just a conceptual metaphor for some far more practical uses of species-area curves. It is, however, a large empirical step toward making your own surveys of trees, shrubs, vines, wildflowers, ferns, mushrooms or vegetables in patches of various sizes. Then plot the number of species against area, think about the results and take your data to the next meeting of your local planning board.

Deriving the Species-Area Curve

For many groups of organisms, the number of species encountered increases as the area increases. A suitable relation can be expressed as

$$S = c A^z$$

where S is the total number of species observed in a surveyed area, A is the area surveyed and c and z are constants fitted to the data.

Taking the logarithm of both sides gives

$$\log S = \log c + z \log A.$$

This equation is an empirical generalization. Many researchers are currently trying to pose theories that "predict" it. The reality of this equation can be tested, for a given region and group of organisms, by plotting surveys on logarithmic scales of both species and area to see if they conform to the generalization of a straight line. If they do, then the relation can be characterized by only two fitted parameters, c and z.

As appropriate as this equation may be, the species-area curve is often more rhetorically convincing as an argument for conservation if the number of species and area are plotted linearly. Then it is clear that efforts to find as many species as possible have diminishing returns.

FURTHER READING

THE FRAGMENTED FOREST: ISLAND BIOGEOGRAPHY THEORY AND THE PRESERVATION OF BIOTIC DIVERSITY. Larry D. Harris. University of Chicago Press, 1984.

WEEDS. Alexander C. Martin. Western Publishing Company, 1987.

ECOLOGICAL DIVERSITY AND ITS MEASUREMENT. Anne E. Magurran. Princeton University Press, 1988.

NATURE RESERVES: ISLAND THEORY AND CONSERVATION PRACTICE. Craig L. Shafer. Smithsonian Institution Press, 1990.

THE DIVERSITY OF LIFE. Edward O. Wilson. Belknap Press/Harvard University Press, 1992.