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"Geographical distribution of endangered species in the United States"

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These are preliminary lecture notes, intended only for distribution to participants.

Geographical distribution of endangered species in the United States

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Abstract

Geographical distribution data for endangered species in the United States were used to locate "hot-spots" of threatened biodiversity and to determine if correlations occur between the geographic distributions of different taxa. In general, the hot spots for different groups do not overlap, except in four regions of the country: the Hawaiian islands, Florida, southern Appalachia and southern California. A more detailed analysis that considers the taxonomic uniqueness of each region reveals that hotspots of vertebrate diversity do not generally correspond to hotspots of botanical or invertebrate diversity. The analysis also suggests that efforts that focus on conserving endangered plant species will maximize the incidental protection of all other species groups. However, this is partly an artifact of the fact that endangered plants are widely distributed across the nation. In contrast, within any region, the presence of endangered arthropods and birds provides the best indication of overall endangered biodiversity. The total area of land that needs to be managed to protect currently endangered and threatened species in the United States is a relatively small proportion of the land mass.

Introduction

Previous studies have shown that on a continental scale the distribution of well-studied taxa can act as surrogates or indicators for the distribution of poorly studied taxa (1-4). In contrast, studies of the distribution of 'hot spots' of diversity for various taxa within the British Isles suggest there is very little correlation between the distributions of different taxonomic groups (5,6). To date, however, no such analysis has been done on a continental or national scale for those species most likely to vanish in the foreseeable future (i.e., endangered species). If significant correlations occur in the geographic distributions of endangered species for different groups, it may be possible to use a few well-studied groups as surrogates or 'umbrella species' for the purposes of delineating protected areas for other poorly known taxa. The extent to which endangered species are concentrated into 'hot spots' of potential extinctions and the extent to which hot spots for different groups overlap, will also influence the strategies we adopt to avert species extinctions, as well as the impact of those strategies on other human activities (7). If endangered species are highly concentrated, then fewer areas are likely to experience conflicts between species protection and other activities.

In this study we have used a data-base for threatened and endangered species in the United States to examine patterns in the geographic distributions of imperiled species(8). The data-base lists the counties of occurrence of all plants and animals protected under the federal Endangered Species Act in the 50 states, plus all species, subspecies and populations proposed for protection under that statute as of August 1995 (a total of 933 species in 3139 counties). We grouped the species by state, county, and species group (amphibians, arachnids, birds, clams, crustacea, fish, insects, mammals, plants, reptiles, and snails), and then generated distribution maps using a GIS system (9). These maps were designed to identify areas with unusually high numbers of endangered species in each group.

A sorting algorith based on the principle of complementary subsets was used to evaluate the extent to which endangered species are clustered into hotspots (10,11). The algorithm selected first the county with the greatest number of listed species; all species found in that county were then excluded from further consideration while the algorithm searched for the county with the greatest number of species that were not represented in counties already selected. Ties for number of species were broken by assigning top rank to the county with the smallest area (or secondarily, the county with the smallest human population). This process was continued iteratively until all listed species were included. The algorithm maximizes the number of species sampled while minimizing the area required to do so. It is clearly erroneous to assume that because a particular species occurs in a county, a viable population can be maintained in that county. In this respect our analysis underestimates the amount of land necessary to preserve species with large area requirements (e.g. grizzly bears, *Ursus arctos horribilis*). On the other hand, it is equally inaccurate to assume that the entire land area of a county is occupied by its endangered species. Thus our analysis should not be taken as a measurement of how much land must be protected to conserve endangered species, but rather as an approximate indication of the extent to which endangered species are concentrated geographically. We then subdivided the data and repeated the analysis for each species group to determine whether any particlular group could be used as an overall indicator for others.

We also examined the associations between the density of endangered species in each state and the intensity of human economic and agricultural activities and the climate, topology and vegetative cover of the state. We collated data on a variety of economic and topographic indicators using the annual statistical survey of the United States (12). Stepwise multiple-linear regression was used to determine which variables were the best predictors of the density of endangered species.

Observed geographical patterns

The highest numbers of endangered species occur in Hawaii, southern California, the south eastern coastal states and southern Appalachia (Figure 1). When counties are selected on the basis of complementarity, the algorithm first selects counties in these regions (Figure 2). The complementary ordering of counties generates accumulation curves that can be used to examine the extent to which endangered species are clustered into hotspots. The accumulation curves represent the total area required to sample all the endangered species in each taxonomic group when the counties are ranked from those with the most endangered species to those with the least (Figure 3). For each group, greater than 50% of endangered species are represented within 0.81 to 3.33% of the land area (13). For endangered bird, reptile and mammal species, the sequential selection of counties on the basis of the unique species they contain leads to a steady increase in the number of populations of each endangered species already included in the counties sampled (Figure 3). The number of populations of most endangered plant and invertebrate species does not increase, because many endangered plant and invertebrate species are restricted to a single county. The data show that 48% of plants and 47% of arthropods are restricted to single counties. The average number of counties in which a listed plant or arthropod species is found is 3.4 and 3.9 counties, respectively. In contrast, only 36% of listed bird species are confined to single counties, while the average number of counties in which a listed bird is found is 62.3. Comparable figures on the percentage of single-county species within other groups and the average number of counties in which a listed species is found are as follows: mammals 26%, 32.6 counties/species; fish 32%; 7.7 counties/species; herptiles 14%, 18.7 counties/species; snails 57%, 1.5 counties/species; clams 3%, 12.1 counties/species.

The utility of using any one group of species as an indicator for other groups of endangered species can be quantified by calculating the proportion of each other group that occurs in the subsets of counties that contain all the species in any individual group (Table 1). An initial examination of this table suggests that the counties that contain a complete set of endangered plant species will contain the highest numbers of other endangered species. However, more counties are required to adequately sample endangered plants than for any other taxa, so we would expect this larger area to contain more species from other taxa. An area (and sampling effort) independent index of predictive power may be obtained by comparing the number of species contained in the complementary counties for each group with the number of species that would occur if a similar number of counties of approximately the same total area were selected at random. The ratio of these two values provides an indication of how accurately the presence of endangered species in one group indicates the presence of endangered species in other groups. This index suggests that arthropods and then birds, provide the best indicators for any particular area. In contrast, the presence of endangered plant species provides only a weak indication that other endangered species are present in a given county.

Underlying factors predicting distribution of endangered species?

The stepwise multiple-linear regression analysis reveals that the overall density of endangered species is strongly correlated with two anthropogenic variables (Table 2): the value of agricultural output and the year in which the state was incorporated (a rough index of the length of time for which each state has been undergoing industrial and agricultural development). When the analysis was repeated for each major taxonomic group, slightly different results were obtained. In particular, time since statehood dominates the analysis for endangered plants; agricultural activity is the key variable for mammals, birds and reptiles, but is less significant for fish and clams. Manufacturing activity seems to have had a significant impact on fish. In contrast to previous studies of patterns of overall species richness (14-16), in this analysis of endangered species geographical variables significantly influence the distribution of only a few taxa (for example, birds and herptiles correlate negatively with the maximum altitude of the state). Climatic variables, such as mean temperature and rainfall, are successful predictors of the numbers of endangered birds, fish, and clams.

Discussion

Virtually all species groups have hot-spots with large numbers of endangered species. They are probably the product of two interacting factors: centers of endemism (e.g. clams in southwest Appalachia, plants in Florida) and anthropogenic activities (e.g. urbanization, agricultural development). In a small number of areas of the United States, the centers of endangered richness for different groups overlap. Two counties are hot spots for three groups: San Diego, CA (fish, mammals and plants) and Santa Cruz, CA (arthropods, herptiles and plants). Eight counties are hot spots for two groups: Hawaii, Honolulu, Kauai and Maui, HI (all birds and plants); Los Angeles, CA (arthropods and birds); San Francisco, CA (arthropods and plants); Bay, FL (herptiles and plants); Monroe, FL (birds and mammals); and Whitfield, GA (fish and molluscs). Aside from these locations, the key areas for most groups overlap only weakly, suggesting that the endangered species 'hot spots' for one group do not necessarily correspond with those for other groups. Nevertheless the analysis confirms previous studies that suggest that arthropods (1) and birds (2) act as important indicators for the presence of other endangered species. Unfortunately, the data available for endangered plants and arthropods are considerably less complete than those for other taxa (17,18). Increasing efforts to obtain information on these taxa is crucial in determining a more complete picture of the geographic distribution of endangered species in the United States.

Although there are no consistent correlations in the distributions of endangered species from different taxa, the existence of hot spots for most groups indicates that a large proportion of endangered species can be protected on a small proportion of land. If conservation efforts and funds can be focused in a few key areas it should be possible to conserve endangered species with great efficency.

References and footnotes

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13. All the currently listed US plant species can be found in 134 counties, 50% of them are present in counties whose net area is 6.73% of the total US land mass. The equivalent figures for the other groups are: molluscs, 38 counties (0.81%); arthropods, 37 counties (1.67%); herptiles, 28 counties (0.68%); fish, 57 counties (3.33%); birds, 18 counties (1.12%); mammals, 29 counties (1.46%).

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19. We would like to gratefully acknowledge Mary Hood at the Environmental Protection Agency for providing us with the raw data for this analysis, and User Support Services at Golden Software, Colorado, for providing help in producing the maps in Figure 1. We thank colleagues at Princeton and to the Environmental Defense Fund (EDF) for comments on a previous draft of this manuscript. The work was made possible by a grant to EDF from the Charles Stewart Mott Foundation.

Table 1. Proportion of endangered species in other groups that are included in the complementary set of counties that contains all the species in any one group. The next to last row gives the minimum number of counties that contain all the endangered species in any group, the next row gives the total area of these counties as a percentage of the US land mass. The final column gives the total proportion of all other endangered species that are contained in the sets of counties that contain all the species in one group. The final row provides an index of each species group as an indicator of biodiversity in other groups; it is calculated by comparing the numbers of other endangered species contained in the complementary set of counties for this species, divided by the number of species that would be present if approximately the equivalent number of counties of this same net area were selected at random.

	Plants	Molluscs	Arthropod	Herptiles	Fish	Birds	Mammals
Counties	134	38	37	28	57	18	29
Area (%)	9.61	1.15	2.38	0.97	4.76	1.59	2.08
# Species	503	84	57	43	107	72	58
Plants	1.00	0.16	0.22	0.14	0.15	0.38	0.27
Molluscs	0.39	1	0.29	0.01	0.44	0.02	0.06
Arthropod	0.54	0.14	1	0.44	0.16	0.12	0.19
Herptiles	0.74	0.21	0.44	1	0.35	0.35	0.42
Fish	0.55	0.15	0.49	0.09	1	0.13	0.21
Birds	0.94	0.43	0.21	0.42	0.38	1	0.53
Mammals	0.76	0.38	0.47	0.33	0.40	0.38	1
All others	0.73	0.21	0.31	0.25	0.18	0.31	0.28
Power	1.63	2.92	2.44	3.26	1.24	4.00	2.61

Table 2 (please see legend below)

	ALL	Plants	Mammal	Birds	Reptiles	Fish	Mo;;usc
r^2	.736	.737	.712	.705	.544	.503	.211
F	27.17 (42,5)	17.48 (39,8)	39.67 (44,3)	38.5 (44,3)	12.22 (42,5)	10.53 (42,5)	7.294 (45,2)
Farm$	**0.803**	**0.702**	**0.744**	**0.803**	0.380		
YearInc	**-0.303**	**-0.314**					
Def$	**-0.452**	**-0.618**			**-0.657**		
H_2O	**0.394**	0.193			**1.464**		
Temp		0.130		**-0.195**		**0.691**	
MaxAlt		0.217	-0.153	**-0.235**	**-0.331**	-0.287	
Export$	-0.099	-0.104				**0.447**	
Forest%			0.108				
Urban%		0.426			**-0.815**		
Rainfall						**-1.018**	**0.454**
Elev						0.335	
Wetld%							**-0.409**

Table 2. Results of forward stepwise multiple regression to examine relationship between the density of endangered species and other environmental and anthropogenic variables. The analysis was performed on the entire data-set and then upon each major taxonomic division. The analysis was performed at the state level with density of endangered species expressed as total number of endangered species recorded in the state, divided by total area of the state for all terrestrial species. In the case of predominantly aquatic species (fish and clams), only the area of each state classified as water or wetland was used to calculate density. The geographical, demographic and economic data were taken from the 111th Edition of the Statistical Abstract of the United States. In each case we have quoted the multiple r^2 and the F-statistic for the final regression. The table gives significant values of (**bold if significant at p<0.01**, normal type if p<0.05). The variables included in the analysis are: Farm$ - the annual value of farm products produced in the state ($/km^2); YearInc - the year in which the State was incorporated into the Union of the United States; H_2O - water use in the state (gallons/km^2/year); DEF$ - defense spending ($/km^2/yr); Exp$ - manufacturing exports

($/km2/yr); Forest% - percent of the net state area that is forested; Urban% - percent of the state that is urban; Federal% - percent of the state under federal management; Wetlands - percent of the state classified as wetlands; Crop% - percent of the state classified as wetlands; HUMPOP - human population density in the state (#/km^2); METRO% - percent of the human population living in urban areas; ELEV - mean elevation in the state; MAXALT - highest point in the state; TEMP - average annual temperature in the state; RAIN - average annual rainfall in the state.

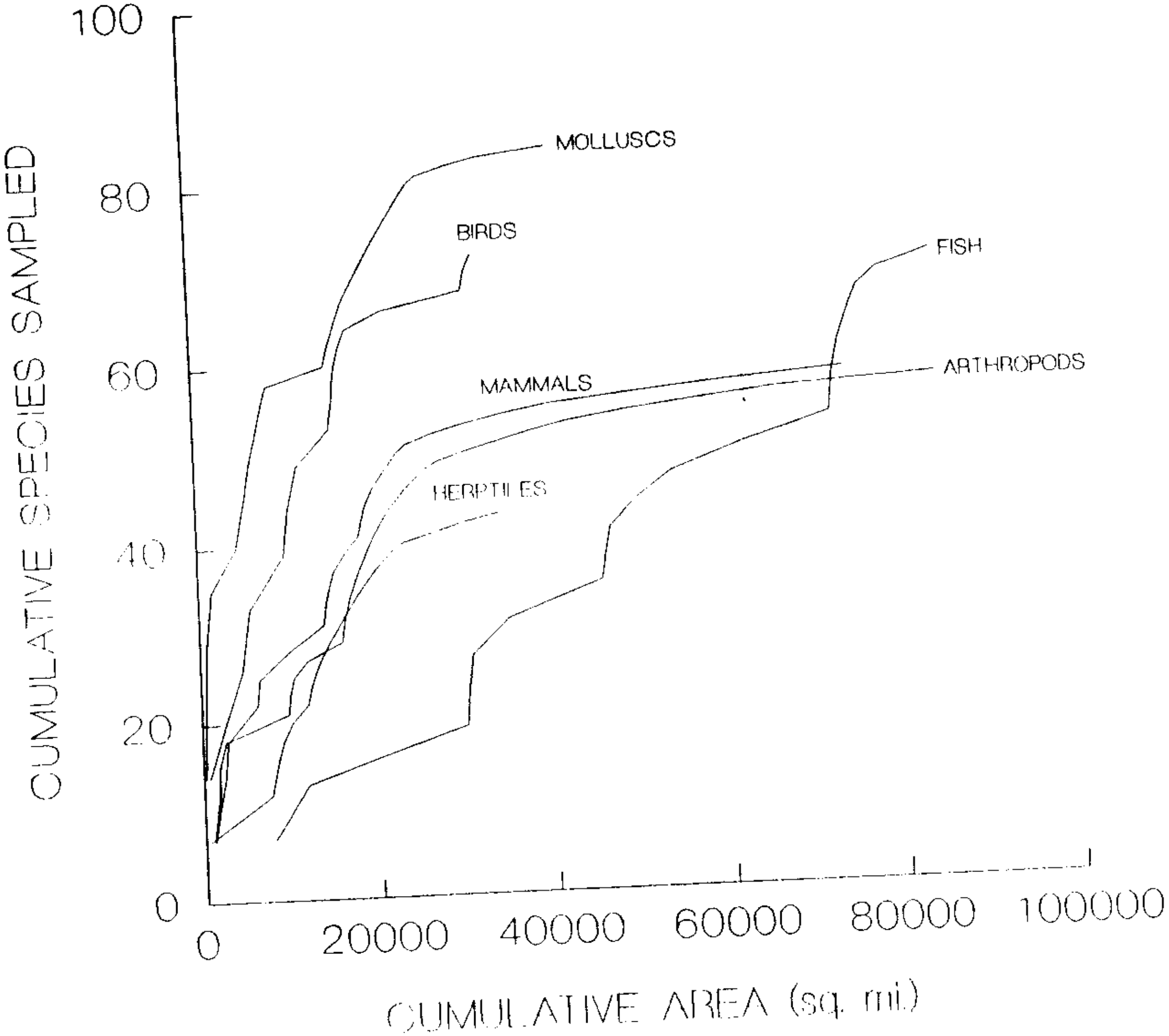
FIGURE LEGENDS

Figure 1. The geographical distribution of four groups of endangered species in the United States: (A) plants, (B) birds, (C) fish, (D) molluscs. The maps illustrate the number of listed species in each county. Alaska and Hawaii are shown (not in scale) in the bottom left-hand corner of the maps.

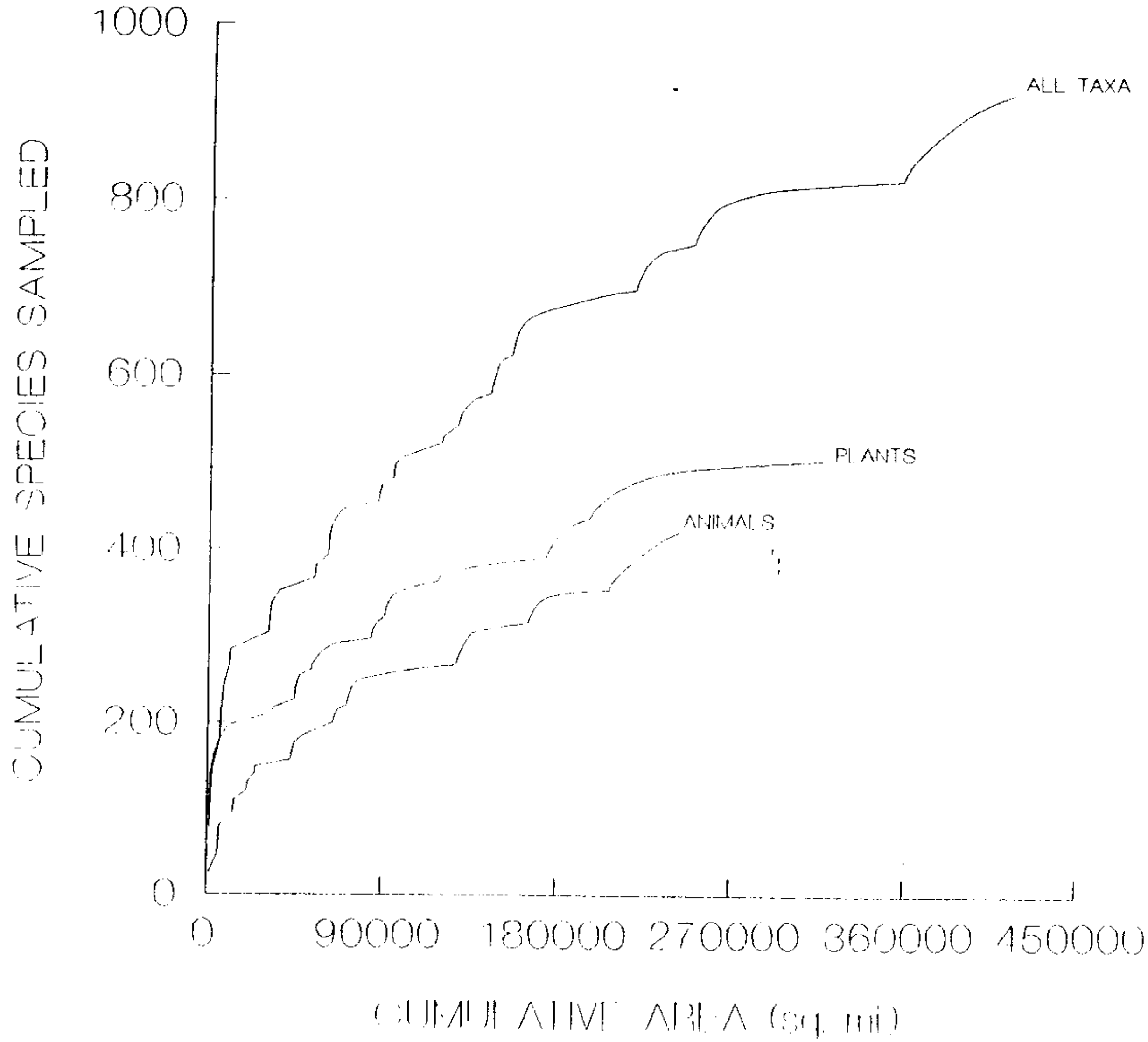
[We can also supply maps for each of the other groups, if publication space permits this]

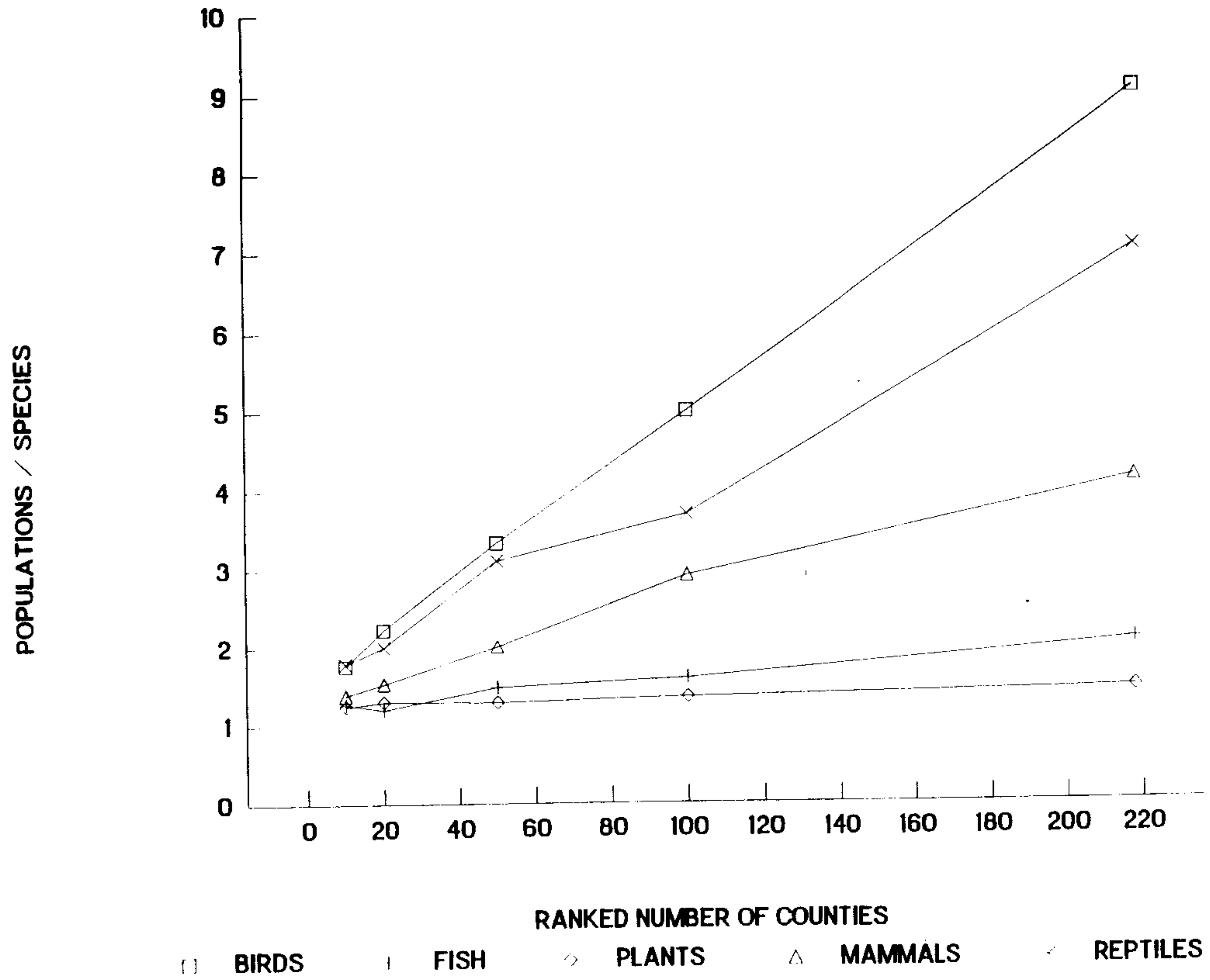
Figure 2. Complementary sets of counties that contain 50% of the endangered species for each taxonomic group. The analysis identified 2 counties that contain high numbers of endangered species from 3 groups and 9 counties that contain high numbers of species from 2 groups. Hawaii is shown (not in scale) in the box in the lower left-hand corner.

Figure 3. (A) The relationship between the cumulative area of land sampled and the cumulative number of endangered species that are included. The sudden increases in the slope of the curves occur when the algorithm switches to adding the next lowest integer number of species to the pool of endangered species sampled - counties are added by picking the smallest counties that add this number of new species to the pool. (B) The average number of populations of each species in the sequentially selected counties.



CUMULATIVE SPECIES SAMPLED
100
80
60
40
20
0
0
20000
40000
60000
80000
100000
CUMULATIVE AREA (sq. mi.)
MOLLUSCS
BIRDS
FISH
MAMMALS
ARTHROPODS
HERPTILES


CUMULATIVE SPECIES SAMPLED
1000
800
600
400
200
0
ALL TAXA
PLANTS
ANIMALS
0
90000
180000
270000
360000
450000
CUMULATIVE AREA (sq. mi)


POPULATIONS / SPECIES
10
9
8
7
6
5
4
3
2
1
0
0
20
40
60
80
100
120
140
160
180
200
220
RANKED NUMBER OF COUNTIES
BIRDS
FISH
PLANTS
MAMMALS
REPTILES