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The Biogeography of the Butterflies of the Mediterranean Islands

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Summary

The number of species of butterflies of the Mediterranean islands is discussed with respect to MacArthur & Wilson's theory of island biogeography (MacArthur & Wilson, 1963 ; 1967). Seventy five per cent of the variation in fauna can be accounted for by the area of the island alone. If the minimum distance from the closest point of mainland is included in the analysis, ninety three per cent of the variation in fauna can be explained. A predictive model is proposed for islands with an unknown fauna within the Mediterranean :

$$y = 1.4094 + 1.7453x_1 - 1.9801x_2,$$

where 'y' represents the logarithm to base ten of the number of species comprising an island's fauna, 'x_1' represents the logarithm to base ten of the island's area in square miles, and 'x_2' represents the logarithm to base ten of the minimum distance from the island to the closest point of the mainland in miles.

Introduction

Biogeography is concerned with the study of patterns of distribution of organisms in both space and time (Cox *et al.*, 1973). As such, biogeographers usually want to determine which of the environmental factors are those which determine or limit the single or several species under consideration. Classical biogeography dates to Wallace (1880) who proposed six biogeographical regions to explain the discontinuous distribution of species. These were the Palaearctic, Nearctic, Oriental, Australasian and Neotropical regions, although the Palaearctic and Nearctic regions are often treated as sub-units of the Holarctic region (Gressitt, 1958). Whilst the

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extremes of geographical range are easily outlined upon a map, the actual occurrence involves not only the discontinuous macro-geographical distribution, but also limitation to a specialised niche within the region. The term "niche" was coined by Grinnell (1917) to describe the place of a species in the environment. Later, Elton (1927) placed emphasis on the function of the species in relation to those other species present. The more modern concept of the niche, developed independently by Pitelka (1941), Macfadyen (1957) and Hutchinson (1957), conceptualises the niche as a quality of the environment, rather than of the species. This aids in the realisation that species must constantly adapt more efficient means of exploiting a niche, thus modifying the species' niche exploitation pattern (Root, 1967). Thus ecological considerations have become increasingly important in biogeographical studies.

Islands have long been associated with such biogeographical studies. Whilst oceanic islands constitute five per cent of the land surface of the world, their intrinsic importance has not lead to the intense research. Rather this is due to the realisation that islands are paradigms of both geographic entities, ranging in size from the smallest of habitat patches to continents, and biological entities, ranging from trees to single-celled organisms : individual organisms can be considered as insular, being colonised by herbivores, pathogens etc. For a review, see Simberloff (1973).

According to current biogeographical theory, the number of species comprising an island's biota is the result of a series of dynamic interactions between the rates of immigration and extinction. These rates, in turn, are purported to depend primarily on the distance from the source of colonists, and the area of the island, respectively. Figure 1 shows this graphically. The general relationship describing the species-area curve is given by equation (1) :

$$S = CA^z, \tag{1}$$

where 'S' represents the number of species of a given taxon found upon an island, 'A' represents the area of that island, and 'C' and 'z' represent two constants. 'C' represents a parameter that depends on the effects of biogeographic region and the taxon itself acting on the population density. 'z' represents the faunal coefficient ; it is the slope of a double logarithmic plot of species and area. Actual values are clustered between the values of 0.20 and 0.35.

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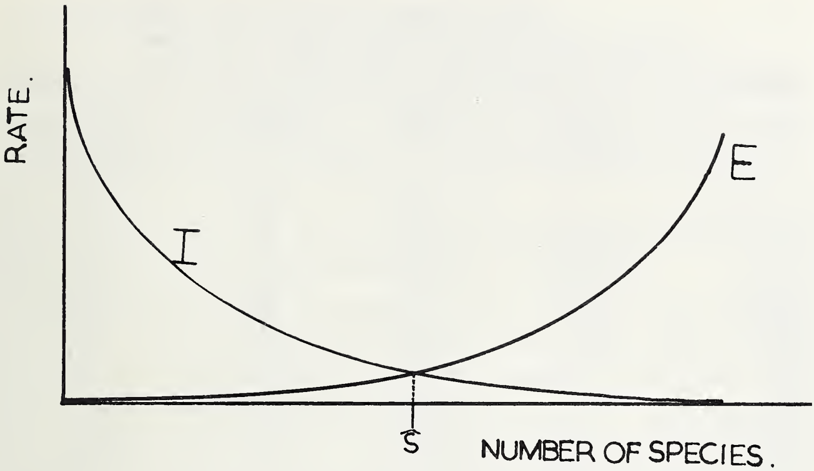

Fig. 1 Graphical equilibrium model of island biogeography. After MacArthur & Wilson (1963, 1967).
'Ŝ' represents the equilibrium number of species.
'I' represents the immigration curve.
'E' represents the extinction curve.

Area is an important determinant of the insular fauna for two reasons. First, as the size of the island decreases, so does the size of populations. Thus the probability of extinction increases as the island area decreases. Second, as the size of an island increases, so does the probability of encompassing a wider range of habitats, a larger number of niches.

Distance dictates the degree of isolation of an island, and is thus a very important consideration. Many authors have noted that insular faunas tend to become progressively impoverished with increasing isolation, e.g. Mayr (1940). As the size of the species pool of potential colonists at the faunal source sets a maximum value for the number of immigrant species, this is a further important consideration.

These theoretical considerations are to be discussed with respect to the butterfly fauna of some of the islands of the Mediterranean. The knowledge of the fauna of different islands varies, some faunas are known incompletely, e.g. Karpathos. However, this fact does not detract from the value of this study, it allows the size of the island's fauna to be predicted, and the model proposed can be tested.

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Table 1
The area and the number of species regularly breeding upon certain islands is shown

Island	Area square miles	Log_{10} Area	Number of species	Log_{10} number of species
Formentera	37	1.5682	24	1.3802
Ibiza	221	2.3444	26	1.4151
Minorca	271	2.4330	27	1.4314
Majorca	1405	3.1477	29	1.4624
Corsica	3367	3.5272	49	1.6902
Sardinia	9196	3.9636	51	1.7076
Sicily	9831	3.9926	89	1.9494
Malta	95	1.9777	16	1.2041
Crete	3207	3.5061	34	1.6232
Karpathos	111	2.0453	25	1.3979
Rhodes	542	2.7340	46	1.6626
Cyprus	3572	3.5529	50	1.6990

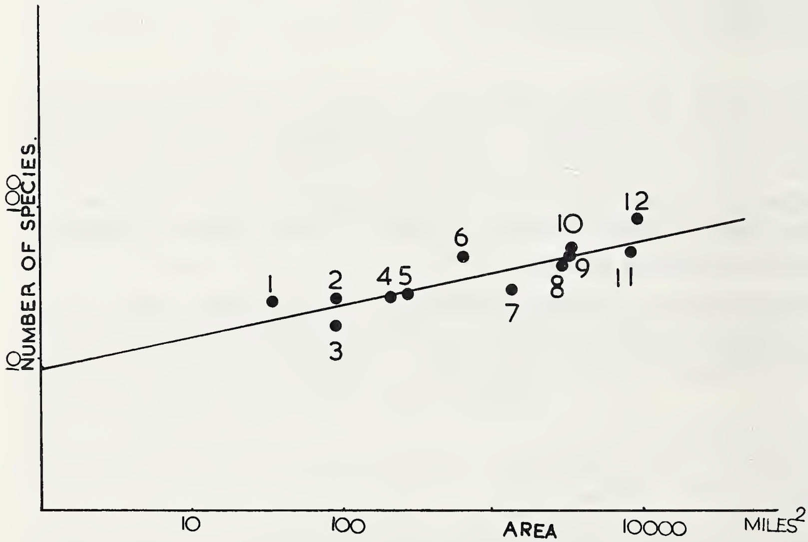

Fig. 2. Double logarithmic plot of area of island and number of species of butterfly shown for various Mediterranean islands : 1 Formentera ; 2 Karpathos ; 3 Malta ; 4 Ibiza ; 5 Minorca ; 6 Rhodes ; 7 Majorca ; 8 Crete ; 9 Corsica ; 10 Cyprus ; 11 Sardinia ; 12 Sicily.
The equation of the regression line is : $y = 0.9424 + 0.2137x$.

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The Butterflies of the Mediterranean Islands

The islands included in this study are Formentera, Ibiza, Minorca, Majorca, Corsica, Sardinia, Malta, Crete, Karpathos, Rhodes, Sicily and Cyprus. Data on the fauna of the islands were extracted from the extensive references contained in Bang-Haas (1930), Bretherton (1966) and Higgins & Riley (1970).

Table 1 shows the data used in the regression analysis of fauna and area, the data being presented graphically in Figure 2.

The single linear regression analysis results in a line with a gradient of 0.214, and as previously discussed this is the value of the parameter z. This lies inside the observed range. The fact that this is a low value indicates that the taxon studied are poor dispersers. As the majority of species under consideration are not considered to be migrants this adds to the growing realisation that butterflies are poor dispersers, adults flying within very small confines. A coefficient of determination of 0.749 is produced from the regression analysis : thus almost seventy five per cent of the variation of insular butterfly fauna is attributable to island area alone. This value is highly significant.

A multiple linear regression analysis was performed, including data presented in Table 2. The equation resulting from this is :

$$y = 1.4094 + 1.7453x_1 - 1.9801x_2, \qquad (2)$$

Table 2
The minimum distance from the mainland is shown for certain islands

Island	Distance to closest point of mainland in miles	Log_{10} Minimum distance
Formentera	70	1.8451
Ibiza	55	1.7404
Minorca	110	2.0414
Majorca	175	2.2430
Corsica	80	1.9031
Sardinia	180	2.2553
Sicily	5	0.6990
Malta	205	2.3117
Crete	60	1.7781
Karpathos	160	2.2040
Rhodes	20	1.3010
Cyprus	55	1.7404

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where 'x_1' represents $\log_{10}$ area of the island, 'x_2' represents $\log_{10}$ minimum distance to the mainland. 'y' represents the $\log_{10}$ number of species comprising the fauna. Associated with this regression line is a coefficient of determination of 0.931. This indicates that just over ninety three per cent of the variation in fauna is accountable using the two variables chosen : area and distance from the mainland.

There only remains a small percentage of unexplained variation. As previously discussed, the size of the species pool of potential colonists at the faunal source is important. Further influencing factors are concerned with the geography of the islands : islands that are clumped together raise each others immigration rate. Such an effect would be most noticeable on small islands, where the deviation, expressed as a percentage, would be greatest. Thus the high value of Formentera may be explained using this agency. Islands connected to the mainland by a series of stepping stone islands will also deviate from the proposed model. In the outer islands there will be a reduced area effect : there will effectively be a reduced species pool available to emigrate to the more isolated islands.

Thus with these limitations in mind, it is possible to use the multiple linear regression equation as a predictive model. As the constant 'C' is only a constant for a biogeographic region, or part thereof, this model can only be used on the islands in the Mediterranean.

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