CHAPTER 11

Interacting Populations in Biology

> Human society can be regarded as an ecological system, or "ecosystem," something like a great pond, filled not with fish and frogs, plants and bacteria, but with workers and employers, gas stations and power companies, counties, states, and nations, churches and lodges, automobiles and refrigerators, wheat and steel and uranium, and all the innumerable "species" of social life, organizations, households, businesses and commodities of all kinds.... These populations of social species act and interact on each other in a great variety of ways. Some are mutually competitiveãthe more television sets, the fewer movie houses, both competing for "nutrition" in the form of the consumers' dollar. Some are mutually cooperative or complementary, like automobiles and gas stations. Some have parasitic relationships—the more cops, the fewer robbers, but the more robbers, the more cops!
>
> Kenneth Boulding, *Principles of Economic Policy,*
> p.15

When I was still an undergraduate at San Francisco State I developed an interest in the structure of animal communities. Both Comte and Durkheim suggested that the study of such communities could be useful for the development of Sociology, and I took the suggestion seriously. After all, we and other social animals must share some organizing principles in common, whatever we believe may in addition distinguish us from them.

Back then I read Schaller's account[1] of the mountain gorilla and Wheeler's much earlier one on

ants[2] and on social insects in general.[3] I related Sociology's "human ecology", as developed by Park[4], Quinn[5] and Hawley[6], to Allee's [7] animal ecology and Odum's [8] general ecology. Among other things, I noted in all this a simple pattern in human behavior which paralleled one observed in many animal groups, a simple pattern I have come to call the "law of equidistant spacing".

The bus I rode from San Francisco State to my apartment in Haight- Ashbury arrived empty at the pick-up point, having discharged all its outbound passengers at the Stonestown Shopping Center a block away. If I boarded while the bus was still nearly empty, I could rush to the back seat and, from there, observe new arrivals as they chose their seats. These people appeared to be exercising "free will" — they looked around before sitting down, sometimes uncertainly, sometimes walking past a seat then returning to it. Even so, I could predict the seat they would "choose" while they were still up front paying their fare, before they even looked into the seating area. People (or pairs of them) tend to select seats equally distant from others already occupied. My "equidistant" predictions were correct perhaps 85-90% of the time. You can test this law with a counter example — try sitting immediately next to someone you don't know on a nearly empty bus!

I still use my **law of equidistant spacing**, which you can observe in birds sitting along a roof or telephone wire or among amoebas grazing on a bacterial field (see below), in introductory courses to suggest that "free will" need not be incompatible with sociological laws. All that is needed is an absence of conscious interaction (in the bus case people who don't know each other) or the presence of very large numbers so that local thought/will, behavior and interactions have minimal effect on the aggregate pattern.

I supplement it with more immediate examples.

When the sun comes out in Bellingham WA, students spread out on the lawn below my fifth floor office window like lizards sunning themselves on the rocks[9]. Should several of them leave for class, I can predict where their successors will "choose" to lie by invoking my law of equidistant spacing. I have noticed that seating in restaurants can be problematic because of the same law: asking to share a table in the smoking section of the University coffeeshop, when there may be empty tables immediately nearby in the non-smoking section, constitutes a form of "invasion", making both the asker and the sitter uncomfortable.

In trying to find out how far down(?) the evolutionary ladder I could find social life, I came across Bonner's work[10] on the "slime mold amoeba". I found these creatures fascinating, as do apparently many biologists: [11]

> The remarkable life cycle of the slime mold *Dictyostelium,* the best-known member of the Acrasiales, is of general interest to biologists because it provides a model system of a developing multicellular organism that can be experimentally manipulated with relative ease. For sociobiologists it has the more special attraction of displaying perhaps the most advanced social behavior of single-celled organisms — the aggregation of the myxamebas that initiates the multicellular half of the life cycle.

FIG 11-1
LIFE CYCLE
OF THE
SLIME-MOLD
AMOEBA
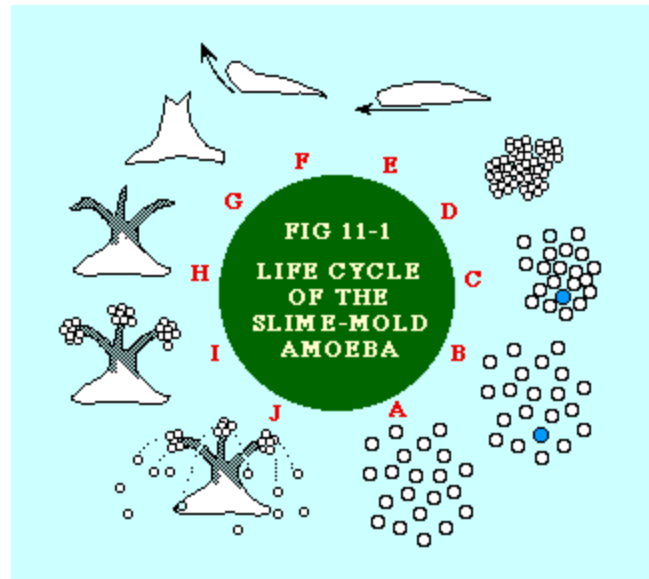
As single cells they behave like true amoebæ, grazing (equidistantly) on bacteria fields and dividing frequently (A). When food runs out for a given amoeba (say the blue spot in B), it becomes the focal point for mass migrations of others. The resulting cluster forms a sausage-like slug, as big as 2 millimeters in length (E). "It" behaves like a multicellular organism, with distinct head end, moving slowly toward heat and light.[12] One or two weeks later "it" turns upright (F) forming a fruiting body, with some of the former amoebæ forming a base and stalk (H), others forming spore-bearing spheres (I) at the top. The spores subsequently spray outward (J), emerging later as single cells, and the cycle repeats.

In graduate school I tried to submit a 50-60 page paper on animal communities as part of the assignment for a seminar entitled "Social Structure and Process". It was rejected outright: the topic could be of no interest to sociologists. I nevertheless remained intrigued by what faculty referred to as sub-human social structures, particularly in seminars on the history of social thought. So much early social philosophy and 19th century sociological theory was taken up with the analogy between society and the organism, but I found it extremely useful to suggest a slightly different one, between society and an

ecosystem. In another arena, teaching intro sociology courses, I enjoyed telling well-scrubbed fraternity and sorority types in my classes about the ecological system we carry around on and in our bodies.[13]

I continued my interest in animal societies after arriving at Western, publishing two articles which suggested that the ecological system might serve as a paradigm for the quantitative analysis of human society.[14] Central to each was the notion of a set of interacting populations, as illustrated with the nine species in Fig. 11-2. Here, species X_1 is dependent upon species X_7 which, in turn is dependent on species X_9, and so on. "Dependent on" usually means a predator-prey relation, but it could also refer to parasite- host, symbiotic or commensalistic relations.

FIG 11-2. INTERACTING POPULATIONS
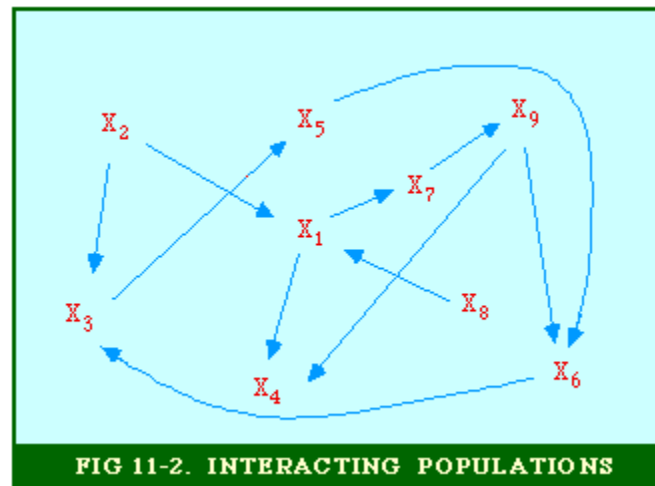
This general interdependence can be described by the set of simultaneous equations, the ecosystem:

$$(1)\quad \begin{aligned} \frac{dX_1}{dt} &= f_1\left(\frac{dX_1}{dt} + \frac{dX_2}{dt} + \ldots + \frac{dX_k}{dt}\right) \\ \frac{dX_2}{dt} &= f_2\left(\frac{dX_1}{dt} + \frac{dX_2}{dt} + \ldots + \frac{dX_k}{dt}\right) \\ & \quad\quad\quad \ldots \\ \frac{dX_k}{dt} &= f_k\left(\frac{dX_1}{dt} + \frac{dX_2}{dt} + \ldots + \frac{dX_k}{dt}\right) \end{aligned}$$

where the k equations with k unknowns presumably have a stable solution at $dX_i/dt = 0$ for $i = 1,2,\ldots,k$. Real ecosystems would show fluctuation around the

X_i equilibrium values, and there are also, of course, exogenous factors not represented here.

I don't mean to suggest that Sociology should attempt to find the exact form of such functions as Eqs. 1, or that it should only concern itself with the relation between human and non-human species. What I am suggesting is that we might benefit from thinking of society itself as a set of interacting populations. Consider a university as a small society: so many students producing so many student credit hours which generate so many faculty positions; so many dorm rooms, class rooms, recreation facilities, parking places, etc. It seems a useful way to think of "social structure".

Almost from the beginning of my interest in non-human social structure, the most influential work I came across was Wynne-Edwards' *Animal Dispersion in Relation to Social Behavior*.[15] One of the primary thrusts of this work is to argue that much social behavior previously thought to be connected with mating (a Freudian influence?) was in fact connected with regulating demographic pressure on the food supply (a Marxian/Malthusian influence?).

Dawn-and-dusk bird song, for example, occurs even at times when mating is not taking place; its purpose, rather than broadcasting appeal to potential mates, appears rather to be to serve as a census of bird density, an indication to others whether to land or continue flying to other feeding sites. The hierarchy ("pecking order") has a similar demographic function: it identifies the surplus individuals who must leave should the food supply become too low to support the existing group. The "willing" exit of the surplus prevents a "war of each against all" which could wipe out the group. The traditionally claimed libidinal and power motives behind animal behavior prove far less important to group survival than does regulation of population-density vis-a-vis the food-density, says

Wynne-Edwards. [16]

FIG 11-3
NORTH ATLANTIC

average volume of macroplankton in cc in a standard haul
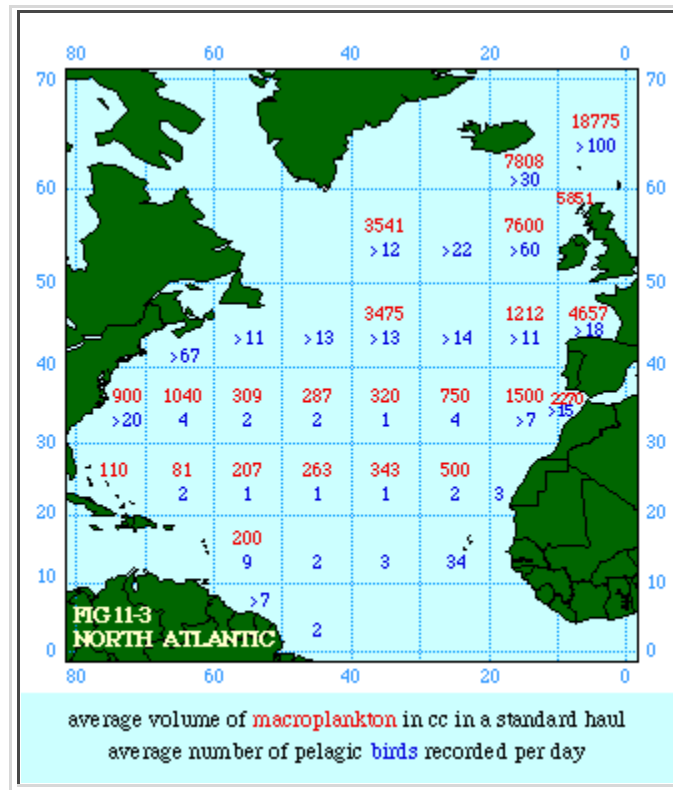average number of pelagic birds recorded per day

Fig. 11-3 is an adaptation of a map on the second page of Wynne-Edwards' book. It is based on Danish oceanographic expeditions made in search of the birthplace of freshwater eels, between 1913 and 1928. Standard hauls of macroplankton were taken all over the North Atlantic to be used as a broad index of the richness of surface waters, in terms of food for pelagic birds. The data are shown for 10deg. quadrants, upper figures showing the average volume of macroplankton in cc in a standard haul, and lower figures (bold face) the average number of birds recorded per day. He concludes:[17]

> In spite of the collective character of the data and the differences in season at which the different areas were sampled, the correlation that emerges between bird density and abundance of plankton is very strong: in numerical terms it can be expressed by a coefficient of +0.85. The probability that such a situation could have

> arisen by chance alone is negligible (P <<
> 0.001).... The population-density in fact
> appears to be graded so that in every area it
> bears about the same constant average
> relation to the amount of plankton present.

With N birds and P plankton, and computed[18]
quadrant areas A, the 21 cases with N and P given
produced Eq. 7 with r^2 = .77; p{β=2/3} = .113. The
finding "fails to reject" (supports) Eq. 10-11, the
density of one species being related to the other with
the 2/3 slope.

FIG 11-4. DENSITY-DENSITY (DATA FROM FIG. 11-3)
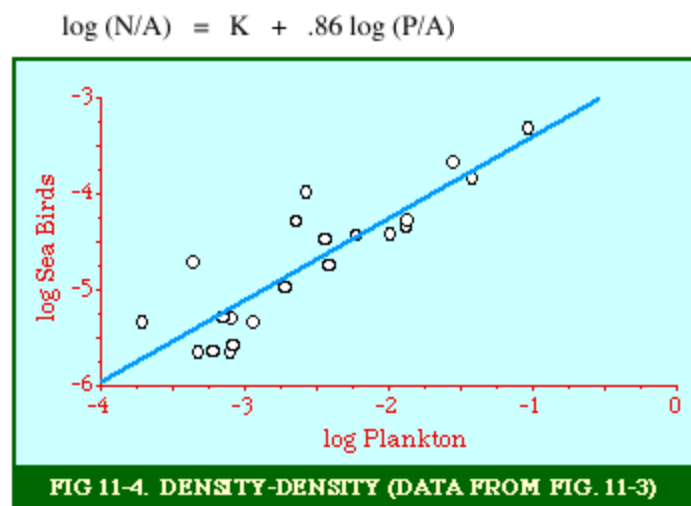
> I don't think this is mere coincidence. The
> components of the initial Eq. 10-6 need not
> be restricted to governments. The sea birds
> represented here have a "maintenance cost"
> and an "interaction cost", just as county
> seats do. Animals are subject to time
> minimization constraints: so many calories
> burned per day requires so much food per
> day. Anything which minimizes the time it
> takes a predator to find prey (better
> eyesight, faster flight), improves its survival
> probability. The prey may also increase the
> predator's search time (interaction time),
> through camouflage, burrowing, or other
> defenses.

> **Brain-Body Ratios**

I found another possible application of time-minimization to biological phenomena in an article[19] dealing with brain size and maternal basal metabolic rates. The equation which got my attention was

$$(2) \qquad E \; = \; k\,P^{2/3}$$

where E is brain weight and P is body weight. In connection with this, the author states

> However, previous analyses of brain size allometry in the major vertebrate groups have been limited by small sample sizes and/or inadequate testing of the value for the allometric exponent. Re-analysis of brain size allometry in placental mammals, taking a representative sample of 309 species from 13 orders, yields the following allometric formula
> $$\log E \; = \; 0.76 \log P \; + \; 1.77$$
> (r = 0.96; 95% confidence limits for [the slope] = 0.73-0.78). Hence, for placental mammals there is no empirical justification for the widely accepted value of 0.67 for the allometric exponent. The value of 0.76 [was] confirmed by at least two independent analyses of large samples of mammal species.

This means

$$(3) \qquad E \; = \; k\,P^{2/3}$$

The equations and derivations we have dealt with so far have all applied to a two-dimensional, flat, areal world. If we begin as before with

$$(*10\text{-}6) \quad T = hN + \frac{2S}{v}P$$

we must define distance as the **cube**-root rather than the square- root (organisms, being three dimensional, distances within them should be proportional to the cube-root of their **volume**, V). We have N brain cells interacting with P body cells under the constraint of time minimization:

$$(4) \quad T = hN + \frac{2w(V/N)^{1/3}}{v}P$$

The concluding equation, parallel with Eq. 10-15, becomes

$$(5) \quad C = kD^{3/4}$$

Again, this need not be thought of solely as coincidence or empty analogy. Brain cells must interact with other cells throughout the volume of the body. Presumably it is in the interest of the organism (or the population which produced it) to minimize the time it takes for such interaction.

Is this good biology? I'm not qualified to say. I present these studies because they fall within the framework of the sociological studies in earlier chapters and might perhaps suggest further avenues of work. As I mentioned above, there ought to be **some** connection between Biology and Sociology. Just what that connection is remains to be seen.

Next Chapter

NOTES:

[1] George B. Schaller, *The Mountain Gorilla: Ecology and Behavior*, Chicago:

University of Chicago Press, 1963

[2] W. M. Wheeler, *Ants: Their Structure, Development and Behavior*, New York: Columbia, 1910.

[3] W. M. Wheeler, *The Social Insects: Their Origin and Evolution*. New York: Harcourt, Brace, 1928.

[4] Robert E. Park, "Human Ecology", *American Journal of Sociology*, 42:1-15.

[5] James A. Quinn, *Human Ecology*, New York: Prentice-Hall, 1950.

[6] Amos H. Hawley, *Human Ecology*, New York: Ronald Press, 1950.

[7] W. C. Allee, *Animal Aggregations: a Study in General Sociology*, Chicago: University of Chicago Press, 1931. *The Social Life of Animals*, New York: W.W. Norton, 1938.

[8] E. P. Odum, *Fundamentals of Ecology*, 2nd ed., Philadelphia: W. B. Saunders Co, 1959.

[9] This used to be true. Since I wrote this the powers-that-be have constructed a "people space" out there which tore up the lawn completely.

[10] see J. T. Bonner, *Cells and Societies*, Princeton, NJ: Princeton, 1955. *The Cellular Slime Molds*, 2nd ed, Princeton NJ: Princeton University Press, 1967.

[11] This quote and the brief description of the life cycle of the slime-mold is from Edward O. Wilson, *Sociobiology: the New Synthesis*, 387-92, Cambridge MA: Harvard University Press, 1975. Fig. 11-1 is my simplified rendition of Wilson's description.

[12] Now there, I submit, is a "structural functionalism" beyond the dreams of Talcott Parsons.

[13] Mary J. Marples, "Life on the Human Skin", *Scientific American*, 220:108-15, 1969.

[14] G. Edward Stephan, "Interacting Populations in Space and Time: a Paradigm for the Quantitative Analysis of Social Structure", *Pacific Sociological Review*, 15:309-26, 1972. It was a generalization to the field of Sociology from an earlier paper directed toward a subfield: G. Edward Stephan, "The Concept of Community in Human Ecology", *Pacific Sociological Review*, 13:218-28, 1971. The immediate stimulus for the idea derived from Kenneth E. Boulding, *A Reconstruction of Economics*, New York: Science Editions, 1962. A similar argument, directed toward Geography, can be found in D. R. Stoddart, "Organism and Ecosystem as Geographical Models", Pp. 511-48 in R. J. Chorley and Peter Haggett (editors), *Models in Geography*, London: Methuen, 1967. The classic presentations were Alfred J. Lotka, *Elements of Mathematical Biology* (originally *Elements of Physical Biology*), New York: Dover [1924] 1956 and Vito Volterra, "*Variazione e fluttuazioni del numero d'individui in specie animal conviventi*", abridged translation in R. N. Chapman, *Animal Ecology*, New York: McGraw-Hill, [1926] 1931. Lotka, incidentally, attributed the invention of the notion to Herbert Spencer.

[15] V. C. Wynne-Edwards, *Animal Dispersion in Relation to Social Behavior*, New York: Hafner, 1962. Also, "Self-regulating Systems in Populations of

Animals", *Science*, 147:1543- 8, 1965.

[16] This, incidentally, reinforces the view propounded by Wheeler, *Op. Cit.*, regarding the "nutrient basis" of ant social structure. The ant nursemaid is driven to carrying for her pupæic charges, he argued, not by an altruistic concern for the young but by the possibility that she might find a dead one to eat. Ant society is possible, he says, because permanently half-starved ants receive their sustenance only through contributing to the maintenance of the group.

[17] V. C. Wynne-Edwards, *Op. Cit.*, p 3.

[18] *Area of a Geographic Quadrant*:

AREA OF A GEOGRAPHIC QUADRANT
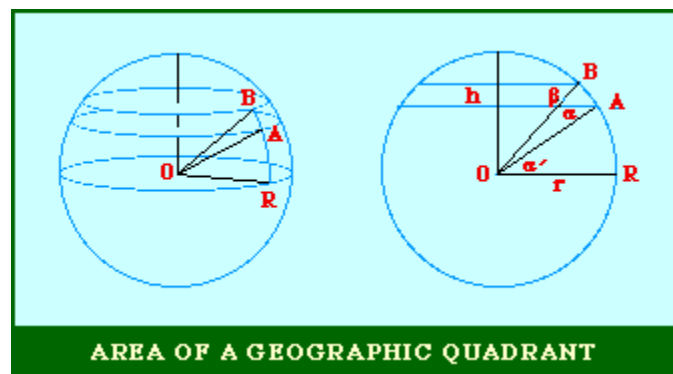
The surface of a sphere, between disks B and A, is called a "spherical cap". Its height h is obtained from

$$h = r(\sin\beta - \sin\alpha)$$

where, for our purposes, $\alpha = \alpha' = AOR$ and $\beta = BOR$ are the upper and lower latitudes of a geographic quadrant located in the cap, and r is the earth's radius (= OR), 3,960 miles. The area of the cap is

$$A = 2\pi rh$$

so the area of a geographic quadrant will be this area multiplied by quadrant-

degrees/360. Here quadrants are
10-degrees, and

$$A = 2,736,955 (\sin \beta - \sin \alpha) \text{ sq. mi.}$$

[19] R. D. Martin, "Relative Brain Size and
Basal Metabolic Rate in Terrestrial
Vertebrates", *Nature*, 293:57-60, 1981.