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Demographic Models and Island Colonisation in the Pacific

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ABSTRACT

The role of model building and testing in Pacific archaeology is discussed. As an illustrative example, a number of models are developed for the prehistory of the Galapagos Islands. The models focus on demographic variables and the social and biological problems associated with the colonisation of islands by small groups. These models make varying assumptions concerning the navigational prowess of prehistoric South Americans, and lead to different conclusions about the possible importance of South American voyaging in the settlement of Polynesia. That several models are plausible refutes Thor Heyerdahl's claim that the evidence for prehistoric South Americans on the Galapagos supports his theory of South American origins for Polynesian culture.

Keywords GALAPAGOS ISLANDS, ARCHAEOLOGY, DEMOGRAPHIC MODELS, ISLAND COLONISATION, EXTINCTION.

INTRODUCTION

The observation that all species of plants and animals are not everywhere equally abundant gives rise to many fundamental questions in ecology and population biology. MacArthur and Wilson (1963, 1967) have suggested, for example, that the distribution of species on islands reflects a balance between the colonisation of island habitats by new species and the extinction of resident species populations because of local competition among species, environmental perturbation, and other causes.

This equilibrium model of island colonisation emphasises that the species present on an island need not represent the result of a few episodic instances of migration. Rather, the MacArthur-Wilson model implies that the process by which an island biota changes is evolutionary, and founded on ordinary rather than extraordinary events.

Anthropologists have long been interested in the colonisation of Polynesia (Clark and Terrell 1978). In addition to some of the more imaginative and extraordinary migrations whereby Egyptians or Phoenicians are brought out to settle Polynesia (Fell 1974), recent work has concentrated on improving our knowledge of Polynesian voyaging (Levison, Ward and Webb 1973; Finney 1977; Gladwin 1970; Lewis 1972) and the viability of small founding populations (Black 1978; Law 1977; McArthur, Saunders and Tweedie 1976). These two variables are among those central to the theory of island biogeography developed by MacArthur and Wilson (1963, 1967). This common interest in individual variables foreshadows a more general sharing of theories and models between anthropologists and scholars working in fields such as population biology, ecology, and biogeography (Terrell 1975, Terrell and Fagen 1975). This paper will examine the application of models from biogeography to the study of the colonisation of Polynesia. A comparison will be made between biogeographical models and an established conceptual model in Pacific archaeology which "lets the facts speak for themselves". As a case in point, these models will be used to interpret archaeological evidence from the non-Polynesian Galapagos Islands. The contrasting assumptions underlying these different models and the differing interpretations placed on the "hard facts" of archaeology demonstrate the need for more careful attention to the development and testing of models in anthropological inquiry.

ARCHAEOLOGICAL EVIDENCE FROM THE GALAPAGOS ISLANDS

The voyage of the Beagle in 1835 is well remembered in the history of the biological sciences, for among its passengers was the young scientist Charles Darwin. At the close of his historic observations on the Galapagos Islands, Darwin commented upon the tameness of their many species of native birds. He suggested that the fear of man "is not acquired by individual birds in a short time, even when much persecuted; but that in the course of successive generations it becomes hereditary" (Darwin 1959:384).

Darwin's equation of tame fauna and absence of long term human settlement may, in part, account for the surprise which greeted the first archaeological evidence for prehistoric settlement on the Galapagos Islands. The 1953 Norwegian Archaeological Expedition to the Galapagos Islands (Heyerdahl and Skjolsvold 1956) located four small occupation sites on three of the islands. According to the excavators, the archaeological deposits in all of these sites were severely mixed, such that modern and pre-European artefacts were intermixed.

Pottery fragments made up the bulk of the deposits. On the basis of similarity in decoration and form, many of the pottery sherds are identified as belonging to pre-European ceramic traditions from coastal Peru and Ecuador (Heyerdahl and Skjolsvold 1956, Lanning 1970). Other artefacts identified as pre-European included several flint scrapers, a bit of obsidian, and two pieces of worked chalky stone. The excavators also mention that "small pieces of shell were usually found in most sections of the James Bay site"(Heyerdahl and Skjolsvold 1956:17), although they apparently neither saved nor analysed these midden components. The James Bay site was divided into 12 discrete concentrations. These concentrated deposits ranged in size from approximately 3 m × 3 m to 15 m × 7 m. Similar information is lacking on the other sites, which were examined in less detail.

Heyerdahl and Skjolsvold (1956:56) observe that the sites "did not have the characteristics of permanent or long-lasting habitation, but rather of temporary or possibly seasonal visits. The occupation sites encountered by our expedition did not contain material suggestive of organised settlements or communities." Although they clearly include the presence of burials and special funeral pottery as criteria for long term occupation, Heyerdahl and Skjolsvold do not identify other features which they feel are characteristic of permanent settlement.

FROM EVIDENCE TO INTERPRETATION

The careful development of models for interpreting archaeological data is rarely found in published reports from the Pacific (Clark and Terrell 1978). Instead, argument progresses from evidence to historical reconstruction without explicit mention of the interrelation between evidence and interpretation. Tattersall and Eldredge (1977) have called this sort of approach the writing of "scenarios". In their review of archaeology in Oceania, Clark and Terrell (1978) examine the Pacific tradition of "culture history scenarios" and their inherent pitfalls. Scenarios weave evidence and interpretation in a complex fashion. Only the most crudely constructed scenario would be in contradiction to the evidence upon which it is based. Thus scenarios are virtually *always* valid interpretations of the evidence. Yet they cleverly ignore the possibility that alternative models may equally well account for the data. Scenarios tend to break the cycle of discovery which John Platt (1966) has called "the method of strong inference".

The report on the Galapagos Islands excavations (Heyerdahl and Skjolsvold 1956) appears to fall into the pattern of a scenario. As an interpretation it is reasonable, in that it does not contradict the meagre archaeological evidence. Yet the translation from evidence to interpretation requires a conceptual model which only rarely surfaces

in the report. It is necessary to make this conceptual model explicit in order to compare it with other models.

THE FISHING EXPEDITION MODEL

In defending their choice of where to look for sites, Heyerdahl and Skjolsvold (1956:11) state: "It was assumed that oversea (sic) visitors in prehistoric time would most likely be sailors or fishermen whose economy would be based on marine activity rather than inland occupation . . ." Having noted the arid climate of the Galapagos Islands, and having assumed a marine focus for the sites, they searched coastlines which combined a good landing area with a nearby water supply. As they interpret the evidence from the coastal sites which they examined, the assumption of a fishing economy is cycled back into the evidence:

> It is therefore our belief, on the basis of archaeological material available from the Galapagos Islands at the present time, that the exceptionally rich fishing grounds around the islands attracted fishermen from the mainland coast from the earliest days of deep-sea navigation off North Peru and Ecuador. These fishermen would seem to have made casual or perhaps even seasonal visits to the Galapagos group for centuries before the arrival of the first European visitors, and from different points on the mainland ranging from Coastal Ecuador to the Casma Valley area on the southern extremity of the North Peruvian Coast. (Heyerdahl and Skjolsvold 1956:57)

This scenario is further supported by a dubious piece of ethnographic analogy:

> An important indication of past events may be seen in the temporary visits by natives from the mainland during the fishing seasons. These native fishermen leave the coast of Ecuador in small, modern motor-craft to fish in the Galapagos waters. (Heyerdahl and Skjolsvold 1956:57)

A number of specific assumptions serve to tie together the archaeological evidence and what may be called the FISHING EXPEDITION MODEL. Although these assumptions are scattered throughout the report, taken together they form a cohesive set. Included in this set are the following:

Prehistoric groups from Coastal Peru and Ecuador:
(1)   landed on the islands at several different times,
(2)   contained both males and females (Heyerdahl and Skjolsvold 1956:60),
(3)   arrived deliberately,
(4)   were attracted by good fishing grounds,
(5)   stayed temporarily in small camps,
(6)   subsequently returned home.

Therefore
(7)   the archaeological survey of coastal areas located sites representing the full range of economic and cultural activities undertaken on the islands,
(8)   the art of navigation was sufficiently developed to allow two way voyaging across the 960 km water gap separating islands from mainland,
(9)   if these groups had remained the islands would have "received a considerable permanent population" (Heyerdahl and Skjolsvold 1956:59–60).

This set of propositions serves to limit the range of possible alternatives at various steps along the path from evidence to interpretation. If we accept each of them in turn, they point the way toward the scenario of Heyerdahl and Skjolsvold (1956). If we do not tacitly accept any given assumption, then alternative models may arise which also account for the archaeological data. These assumptions or propositions should, in fact, be treated as a set of hypotheses in need of testing.

The archaeological record may contain evidence which can be used to test some of these propositions. For example, if both males and females arrived (2) we might

expect to find archaeological evidence which could be related to specifically male or female activities. Similarly, if fishing was the main economic activity practised in the coastal camps (4 and 5) then artefacts associated with fishing, and certainly midden material, should be found in the sites. Under the FISHING EXPEDITION MODEL there should also be no sites which sacrifice access to the sea in favour of attractive locations for land based economies (7). As the FISHING EXPEDITION MODEL biased their survey strategy, Heyerdahl and Skjolsvold (1956) did not look in the areas where inland sites might be found.

The archaeological record is a poor source of data with which to test propositions about prehistoric navigation abilities (8), population dynamics (9), or the "deliberate" nature of a given voyage (3). The archaeological record simply does not contain the appropriate evidence. As the biologist C. H. Waddington (1977:122) observed, "there are many questions about history and evolution which can be very definitely stated, but which will probably always remain unanswerable". It may be wise, therefore, to develop a network of alternative models in which we replace certain of the assumptions of the FISHING EXPEDITION MODEL by other alternatives (Levins 1966, 1968). The theory of island biogeography (MacArthur and Wilson 1963, 1967) is a useful nexus for this set of alternative models, as it focuses attention on the effects of *differences* in population dynamics and dispersal ability on the viability of island populations.

THE COLONISATION MODEL

In order to study the process of island colonisation, MacArthur and Wilson (1967) have developed a mathematical model of colonisation. The first section of their model predicts the likelihood of establishing a successful colony and the expected time to extinction for an unsuccessful colony, given a knowledge of basic demographic parameters. Factors which contribute to the success or failure of a founding population include: (1) K, the carrying capacity of the environment for that species, (2) λ, the per capita birth rate, (3) μ, the per capita death rate, and (4) N, the size of the founding population. A second aspect of their model examines the factors which affect the rate of arrival of new colonists. The rate of immigration of new colonists is a function of the distance between island and source area for prospective colonists, mean overseas dispersal distance, the form of the survivorship probability distribution for that species, and the number of colonists leaving the source area. The two processes of immigration and local extinction form the central element in an equilibrium model of island colonisation (MacArthur and Wilson 1963, 1967). A local population will survive on an island if immigration rates are sufficient to balance local extinction. The predicted fate of a given population on an island changes under differing values for the variables in the model.

Starting with this simple framework, differing models for the fate of human populations on the Galapagos Islands may be produced, for example:

Set 1. Prehistoric groups:
(1)   landed on the islands at several different times,
(2)   contained only males,
(3)   drifted accidentally to the islands,
(4)   became locally extinct.

Set 2. Prehistoric groups:
(1)   landed on the islands at several different times,
(2)   contained both males and females,
(3)   deliberately set off from the coast with their destination unknown,
(4)   became locally extinct.

Set 3. Prehistoric groups:
(1)   landed on the islands at several different times,
(2)   contained both males and females,
(3)   drifted accidentally to the islands,
(4)   subsequently left to return home.

The number of possible combinations is obviously large, and an attempt to list all possible permutations would prove useless. The three sets given here are intended only to give an idea of the range of possibilities. In these sets, many of the assumptions of the FISHING EXPEDITION MODEL are simply unnecessary. This is an important observation which will be discussed when the implications of the models are compared. At this point, however, we will concentrate on one set of alternative hypotheses:

   1a. the groups became locally extinct,
   1b. the groups subsequently returned home.

These alternatives are among those which are unlikely to be decided solely upon the basis of the archaeological record. We will examine the possibility of local extinction, making use of the mathematical model of MacArthur and Wilson (1967; see also Richter-Dyn and Goel 1972). Results from this mathematical model will be compared with those obtained independently from several computer simulation studies.

MacArthur and Wilson (1967:68-77) derive an expression for the probability that a founding population will fail to colonise. For a two-sex model with strict monogamy this probability of failure may be calculated as $Pf = (\mu/\lambda)^N$, where N is the number of male and female pairs, and μ and λ are the per capita death and birth rates, respectively. Results for a number of different values are plotted as the curves in Figure 1. These birth and death rates are taken from values used in published computer simulation studies (Law 1977; McArthur, Saunders and Tweedie 1976). The investigators who used these values have presented their own justification for the use of these birth and death rates as an approximation to prehistoric population dynamics in the Pacific. The values are used here to allow a direct comparison between the results of the mathematical model and the computer simulations.

The graphs demonstrate that if a founding population is small, then extinction of the local population is an alternative which must be considered. Given the lack of precision inherent in even educated guesses about prehistoric demography, it would not be wise to pick single values for λ, μ, and founding population size, suggesting that one might then calculate a realistic probability for local extinction. The results of the MacArthur-Wilson model may be more productively used to examine how well a simple biological model, devised to study mice and bugs, might be applied to man. As Lewontin (Introduction to Friedlander 1975:vii) has emphasised, we know much more about patterns of mortality, fertility, behaviour, and mating in man than in other animals. This knowledge leaves us unsatisfied with a simple model which uses only crude birth and death rates, and assumes strict monogamy. How do the results from more sophisticated models compare with the MacArthur and Wilson model?

The circled points plotted in Figure 1 a-d represent the percentage of failures reported by Law (1977) in his computer simulation of small populations. His simulation model used age specific birth and death rates from model life tables. Moving from 1a to 1d the levels of mortality become more severe, beginning with a modern African population (1a) and ending with an estimate for prehistoric populations (1d) taken from Weiss (1973). The rules governing mating in this program are in fact less restrictive than the monogamy assumed by the MacArthur and Wilson model. In the simulation, any fertile female (aged 17.5 – 47.5 years) is at risk of pregnancy if there is at least one mature male (aged 17.5 – 57.5 years). In addition a limit of three children per female per five years is placed on reproduction. This mating system has a minimal impact on biological reproductive capacity.
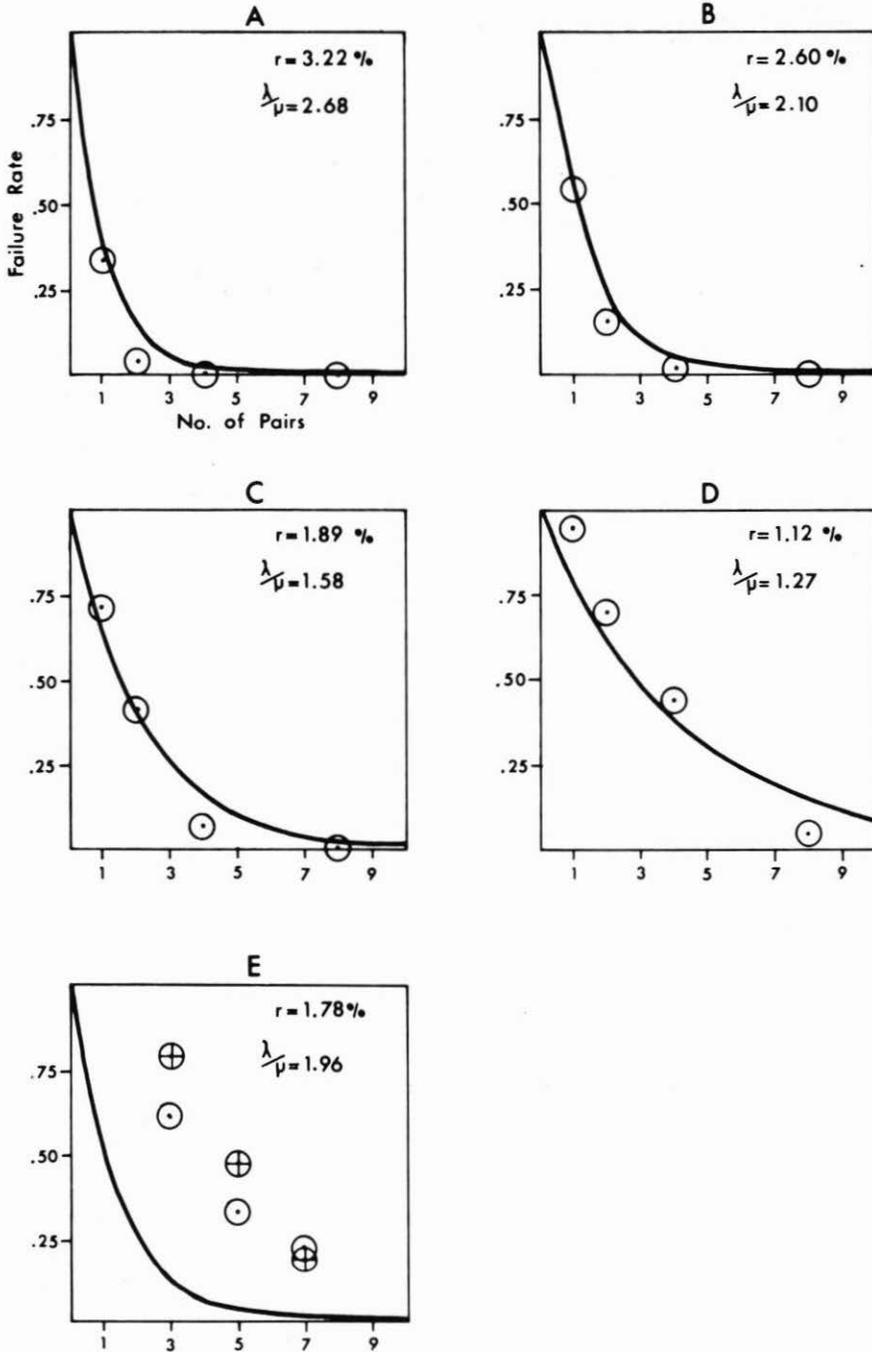
Figure 1: Failure rates for small founding populations under various conditions of fertility and mortality. In E the points with circle and cross represent values for populations with incest prohibitions.

McArthur, Saunders and Tweedie (1976) have used a more complex simulation model in examining the likelihood of success for small founding populations. Their simulated populations were all monogamous, and were subject to either no incest rules, or prohibition against marriage between siblings and between parents and offspring. The model life table used in their study is based on mortality and fertility patterns which have been established from direct experience with the demography of Pacific populations (McArthur, Saunders and Tweedie 1976). The results from their study are plotted in Figure 1e, along with the curve predicted by the MacArthur-Wilson model. The failure rates for populations with incest prohibitions are shown as circles with a cross.

The close relationship between the simple equation of MacArthur and Wilson and more realistic computer models incorporating age specific fertility and mortality patterns is apparent in Figure 1 a-d. Terrell (1977) has noted a similar correspondence between a simple biogeographical model relating island area to species diversity (MacArthur and Wilson 1967) and the observed pattern of linguistic diversity in the Solomon Islands. These correspondences are far from trivial, for they suggest that biogeographical models may be useful in the study of man, at least as a first approximation (Terrell 1977). As MacArthur and Wilson have observed:

> A good theory points to possible factors and relationships in the real world that would otherwise remain hidden, and thus stimulates new forms of empirical research. Even a first, crude theory can have these virtues. If it can also account for, say, 85% of the variation in some phenomenon of interest, it will have served its purpose well. (MacArthur and Wilson 1967:5)

The areas of departure between the simple mathematical model of MacArthur and Wilson (1967) and the more realistic computer simulation models (1e), direct us to ask the sorts of questions which John Terrell has emphasised in his discussion of the objectives of Human Biogeography:

> What factors, if any, must be introduced to model human populations that are not considered relevant to other species populations? Under what circumstances are they required? Are they universally needed whenever human populations are being studied? Or do they apply only in certain situations? (Terrell 1977:22-23)

The close correspondence between the simulation model developed by Law (1977) and the MacArthur-Wilson model occurs because both ignore random variation in the sex ratio of the small population. Random variation in the sex ratio of small strictly monogamous populations is one of the major factors in depressing biological reproductive capacity. The adaptation of the MacArthur-Wilson model to two-sex populations is based on *pairs* of males and females. This formulation does not take into account the possibility that offspring will not always enter the population in matched pairs. The lack of monogamous marriage rules in Law's computer program (1977) renders his populations unaffected by variation in the sex ratio unless one sex becomes extinct. The MacArthur-Wilson model appears to be a good approximation in cases where a monogamous marriage system is not operating in a founding population.

In contrast, the model of McArthur, Saunders and Tweedie (1976) is affected by random variation in the sex ratio. The probabilities of extinction are thus elevated above the predictions of the MacArthur-Wilson model (Fig. 1e). The added restrictions imposed by an incest prohibition further elevate the probabilities of failure for the smaller founding populations. McArthur, Saunders and Tweedie (1976:314) observe that "the imposition of incest taboos has no significant effect in general on the probability of extinction, but there is a suggestion that the smaller the founding group the greater the effect such restrictions would have in diminishing the likelihood of success". In fact, marriage restrictions do appear to have an effect on probability of failure, but there is often a significant interaction between population size and the effect of marriage restrictions which complicates analysis.

Further explorations of the effect of marriage systems on the demography of small closed populations have been undertaken (Black 1977, 1978; Hammel and Hutchinson

1974; MacCluer 1974; MacCluer and Dyke 1976; Morgan 1974; Weiss 1975). These studies have so far produced inconsistent results (Weiss 1975). The effects of incest prohibitions on population growth have ranged from a negative effect, through no effect, to an increase in growth in three different simulation models! Using a variety of multivariate approaches, Black (1977, 1978) has demonstrated that population structure, history, and marriage systems interact in a complex fashion. The experimental designs and methods of analysis used to date in simulation studies have produced apparently inconsistent results because each one has presented only a restricted local view of the global system. The current practice of using realistic simulation models to produce precise answers (Black 1977, 1978; Clark and Terrell 1978; Levins 1966, 1968) is producing unmanageable results. An example, taken from results produced by the demographic microsimulation model ISLAND (Black 1977, 1978) will illustrate the need for new approaches.

The ISLAND model is a Monte Carlo simulation model for the study of small populations. It is written in FORTRAN and consists of a set of 15 utility subprograms. Rather than forming one large all-purpose program, the utility subprograms are designed to allow independence and easy replacement so that the program can evolve. The operation of the program is described in detail elsewhere (Black 1977, 1978) and is similar in operation to several existing programs (Dyke and MacCluer 1974). ISLAND includes a flexible arrangement for specifying a variety of marriage rules to be followed by the simulated populations.

An experiment was conducted on ISLAND to determine the effects of different marriage systems on the survival of founding populations of 40 and 80 individuals, containing equal numbers of unrelated males and females. Mortality levels were taken from Coale and Demeny (1966) model life table West Level 10 Female. This moderate mortality schedule was paired with a moderate fertility schedule (Black 1977, 1978). Marriage was monogamous. Every person in the simulated population married if a suitable spouse was available. Remarriage was possible following the death of a spouse.

The marriage rules examined included two levels of clan system (C0: no clans, C2: two exogamous patrilineal clans) crossed with three levels of incest prohibition (I0: no incest prohibitions, I1: marriages of siblings, parent-child, and grandparent-grandchild prohibited, I2: marriages between first cousins and closer relatives prohibited). Ten replicate populations were examined for each founding population size (Nf=40, Nf=80) in a factorial analysis of variance design, requiring 120 runs of the program ISLAND.

The results from the ISLAND experiment suggest that founding population size and clan exogamy significantly alter achieved parity, age at marriage, number of unmarried persons, growth rate, and population size. There are also significant interaction effects between founding population size and clan structures. Incest prohibitions did not have any significant effects. The changes in dependent variables under different treatment levels are reported elsewhere in detail (Black 1977, 1978). The magnitudes of these changes are not directly generalisable to other combinations of founding population, mortality, and fertility. Therefore, our interest lies primarily in the qualitative behaviour of the populations under different treatment levels.

The general effect of marriage rules which restrict the pool of potential mates is expected to be detrimental to population growth, as predicted by a common sense approach (MacCluer and Dyke 1976:11). If the pool of potential mates is severely restricted such that some people are unable to find mates, the numbers of unmarried persons would be expected to rise along with the average age at marriage for males and females. Thus restrictive marriage rules should, in general, lead to lower population size, growth rate, and numbers of children. However, the interaction between several demographic variables may create a complex system in which the effects of certain restrictions on the pool of potential mates are not predicted by the simple
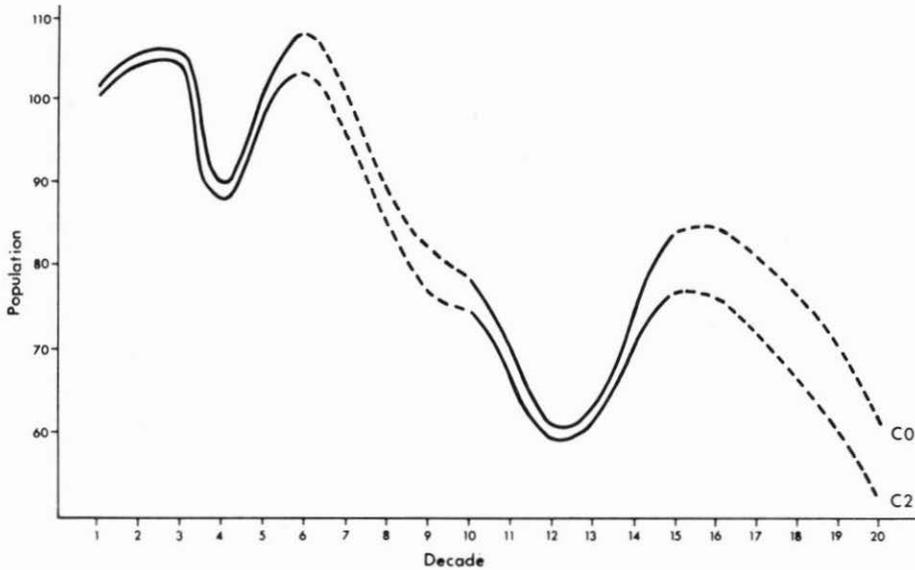
Figure 2: Population size over time stratified by clan structure (CO: no clans, C2: two exogamous clans). During the time periods shown by dotted lines, population size is significantly different ($p<0.1$) for the two treatment levels.

approach. Common sense suggests one reason for significant interactions between variables: restrictive marriage rules should have a greater effect in smaller populations, as the pool of potential mates is already smaller and random variation has a greater effect. The results from ISLAND demonstrate that additional interactions are occurring between variables which further complicate matters.

The first unexpected interaction effect might be called a "reversal effect". The dependent variable male age at marriage illustrates a reversal effect in the ISLAND results. Under conditions conducive to growth (larger founding population, no clan structure) female age at marriage decreases, and parity increases, earlier marriage producing a longer reproductive span for females. Contrary to expectations, however, male age at marriage *increases* under conditions conducive to growth. It appears that this result, which is contrary to expectations, is a result of the marriage rules used in the simulation model.

In the present study, females attempt to marry males who are, on average, four years their senior. This preference for older males is common to many human populations, though not universal. It was included in this study for comparability with other simulation studies. This criterion for optimal marriage is only met when the pool of mates is sufficiently large. Under adverse conditions the females must marry younger males if they are to find mates at all in a given year. When conditions improve females may again marry older males. Thus the apparent "reversed effect" for male age at marriage is in fact consistent with the results for parity and female age at marriage, and arises from the structural relationships in the model.

A "reversal effect" may similarly account for the apparently anomalous results presented by Morgan (1974) which show that incest prohibitions cause a small increase in population growth. The marriage system used by Morgan (1974) has males searching for females, rather than the reverse as used in ISLAND. If marriage restrictions in ISLAND can lower the achieved age at marriage for males, then the opposite effect may well occur in Morgan's model. An earlier age at marriage for females, resulting in a longer reproductive span, may account for the greater growth rate of populations with incest taboos (Morgan 1974). The reduction of male age at marriage in the
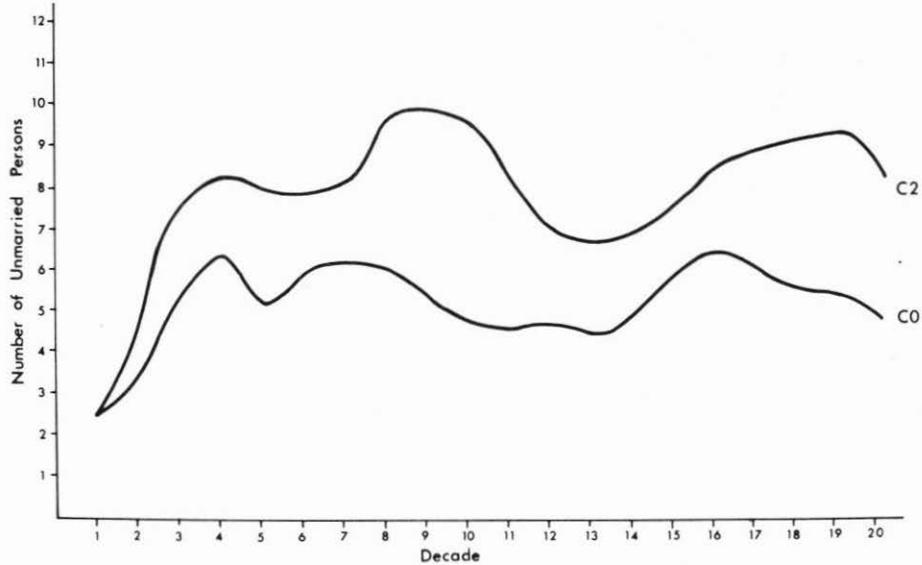
Figure 3:   Numbers of unmarried persons over time, stratified by clan structures (CO: no clans, C2: two exogamous clans).

ISLAND model does not significantly increase female reproductive span, and thus does not contribute to a greater growth rate for populations with incest prohibitions. At present we have no empirical justification for preferring the results from a marriage system such as Morgan's (1974) or that used in ISLAND. In fact, both are unsatisfactory. The problems in interpretation raised by these differences illustrate the need for more ethnographic and historical studies on populations.

A second type of interaction effect might be called a "time effect". Figure 2 shows the means for the two treatment levels of clan structure plotted across time. The differences between the sample means for the two levels of clan structure are not consistent over time. This "time effect" implies that the effects of clan structure may or may not be significant depending on when the population is measured. When the numbers of unmarried persons are stratified by clan level (Figure 3) the additional increase due to clan exogamy is clearly visible, and also variable over time. If only one measure of the population is made at an arbitrary point in time, different results may be produced. Neither final values nor one average for a long time interval are adequate for the study of the dynamic aspects of populations.

Given the existence of interaction effects between population size and clan exogamy in the ISLAND model, the varying results produced by other published studies (Hammel and Hutchinson 1974; MacCluer 1974; MacCluer and Dyke 1976; Morgan 1974; Weiss 1975) do not appear inconsistent. For example, incest prohibitions in populations of moderate size (>50) may not produce a significant reduction in the pool of potential mates. Yet these same restrictions in smaller populations (under the same conditions of mortality and fertility) may produce a significant effect. The complex interactions between variables may also produce unusual "reversal effects". Finally, the significance of marriage restrictions varies over time, and may be dependent on the recent history of the population.

If the demography of small populations is best thought of as a complex, dynamic system then one measure of population structure at a single point in time is unlikely to give a realistic picture of the total system. Likewise, the computer simulation approach using realistic programs but only a few selected life tables, founding populations, marriage systems, or other factors is unlikely to produce a global view of the

system. Rather than concentrate on estimating the magnitude of effects precisely under very specific conditions, future work should relax precision in favour of generality. Recent advances in methods for the study of the topography of complex epigenetic landscapes (Waddington 1977) offer one prospect for future work.

Having examined some effects of marriage systems on population dynamics, one may ask as Vayda (1959) has: would people follow their "official" marriage rules under the very unusual conditions of small founding populations? If under unusual circumstances marriage systems are temporarily abandoned in favour of maximum reproduction, then the MacArthur-Wilson model may be an excellent approximation. If the full set of cultural restrictions on marriage are to prevail then more complex models are required. An optimal breeding strategy for colonising groups might include incest prohibitions on mating, but no formal marriage system. This alternative might not be affected by most of the variation in sex ratio, while avoiding the social and genetic consequences of close inbreeding (Cavalli-Sforza and Bodmer 1971, Schull 1958, Rossman and Schull 1974, Reid 1973).

Before we can arrive at a reasonable set of alternative breeding strategies, it will be necessary to have much more detailed ethnographic accounts of the marriage systems and demography of small populations. We need to know what responses a population makes to a restricted pool of mates and the possibility of many adults remaining unmarried. Much of the appropriate data is likely to come from historical demography, and Dyke (1971) has developed a useful approach to the problem.

The MacArthur-Wilson model remains a useful tool, providing extinction probabilities for small founding populations which abandon all marriage restrictions in favour of maximum reproduction. In other words, the MacArthur-Wilson model defines the boundary conditions imposed by human biology. The interaction of biology and culture may raise extinction probabilities above the basic limits imposed by human reproductive capacity.

Despite its utility as a first approximation, the MacArthur-Wilson model leaves out many factors which influence the fate of a species. In particular, no information is included about the suitability of the island environment. An unsuitable environment would again raise extinction probabilities above those predicted by the MacArthur-Wilson model.

The Galapagos Islands lie inside a large region of low rainfall which Palmer and Pyle (1966:93-94) designate the "dry zone". Islands in this dry zone have an extremely arid environment, little ground water, and are subject to highly variable rainfall (Palmer and Pyle 1966, Heyerdahl and Skjolsvold 1956). Interestingly, the other islands of this dry zone were also uninhabited at contact, yet have archaeological remains (Palmer and Pyle 1966:93-94; Levison, Ward and Webb 1973). The unsuitable climate of the Galapagos Islands would raise the extinction probability for prehistoric colonists, but it is not possible to estimate the magnitude of this effect. Though the MacArthur-Wilson model gives "optimistic" results (Fig.1), extinction of local populations on the Galapagos Islands is an alternative which cannot be rejected out of hand.

LOCAL MODELS AND THEIR WIDER IMPLICATIONS

Setting aside the polemic question "which model is correct?" more constructive discussion may arise from a comparison of the FISHING EXPEDITION MODEL and versions of the COLONISATION MODEL in their assumptions and implications. As noted previously, a number of the assumptions inherent in the FISHING EXPEDITION MODEL are entirely absent from the COLONISATION MODEL. These assumptions are elements of special pleading in the scenario of Heyerdahl and Skjolsvold (1956), placed there not because they are required by the data, but because they produce later implications which are in accord with other theories favoured by the

investigators (Heyerdahl 1952, 1968). In particular, two untested assumptions of the
FISHING EXPEDITION MODEL about the attraction of good fishing grounds (4)
and the colonists' ability to carry out two-way voyaging (8), are later taken to be *evi-
dence* in favour of South Americans having colonised Polynesia (Heyerdahl 1968).

The alternatives presented by the COLONISATION MODEL demonstrate that
the interpretation of the archaeological evidence favoured by Heyerdahl and Skjols-
vold (1956) is not the only one which is in accord with the "hard facts" of archaeology.
Several models fit the present evidence. Further, these different models lead to widely
differing implications about the local prehistory of the Galapagos Islands and to
broader questions about the settlement of Polynesia.

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REFERENCES

Black, Stephen. 1977. The demography of small closed populations: a computer simu-
lation. Unpublished M.A. Thesis, University of Auckland.

Black, Stephen. 1978. Polynesian Outliers: a study in the survival of small populations.
In Hodder, I. (Ed.). *Simulation Studies in Archaeology.* Cambridge University Press,
Cambridge.

Cavalli-Sforza, L. L. and Bodmer, W. F. 1971. *The Genetics of Human Populations.*
W. H. Freeman and Company, San Francisco.

Clark, Jeffrey T. and Terrell, J. 1978. Archaeology in Oceania. *Annual Review of
Anthropology* 7:293-319.

Coale, A. J. and Demeny, Paul. 1966. *Regional Model Life Tables and Stable Popu-
lations.* Princeton University Press, Princeton.

Darwin, Charles. 1959. *The Voyage of the Beagle.* Everyman Paperback Edition re-
printed 1972. J. M. Dent and Sons, London.

Dyke, Bennett. 1971. Potential mates in a small human population. *Social Biology*
18:28-39.

Dyke, Bennett and MacCluer, J. W. (Eds.) 1974. *Computer Simulation in Human Popu-
lation Studies.* Academic Press, New York.

Fell, Barry. 1974. An Egyptian shipwreck at Pitcairn Island. *The Epigraphic Society,
Occasional Publications* No. 1.

Finney, Ben R. 1977. Voyaging canoes and the settlement of Polynesia. *Science*
196:1277-1285.

Friedlaender, Jonathan Scott. 1975. *Patterns of Human Variation.* Harvard University
Press, Cambridge, Mass.

Gladwin, Thomas. 1970. *East is a Big Bird.* Harvard University Press, Cambridge,
Mass.

Hammel, E. A. and Hutchinson, David. 1974. Two tests of computer microsimulation: the effect of an incest tabu on population viability and the effect of age differences between spouses on the skewing of consanguineal relationships between them. *In* Dyke, B. and MacCluer, J. W. (Eds.), 1974:1-14.

Heyerdahl, Thor. 1952. *American Indians in the Pacific: the theory behind the Kon-Tiki Expedition.* Allen and Unwin, London.

Heyerdahl, Thor. 1968. *Sea Routes to Polynesia.* Allen and Unwin, London.

Heyerdahl, Thor and Skjolsvold, Arne. 1956. Archaeological evidence of Pre-Spanish visits to the Galapagos Islands. Memoirs of the Society for American Archaeology No. 12. *American Antiquity* 22(2) Part 3.

Lanning, Edward P. 1970. South America as a source of aspects of Polynesian Cultures. *In* Green, R. C. and Kelly, M. (Eds.), Studies in Oceanic Culture History Vol. 1. *Pacific Anthropological Records* No. 11. B. P. Bishop Museum, Honolulu.

Law, Garry. 1977. Genesis in Oceania. *New Zealand Archaeological Association Newsletter* 20:86-106.

Levins, Richard. 1966. The strategy of model building in ecology. *American Scientist* 54:421-431.

Levins, Richard. 1968. Evolution in changing environments. *Monographs in Population Biology* No. 2. Princeton University Press, Princeton.

Levison, M., Ward, R. G. and Webb, J. W. 1973. *The Settlement of Polynesia: a computer simulation.* Australian National University Press.

Lewis, David Henry. 1972. *We, The Navigators.* Reed, Wellington.

MacArthur, R. H. and Wilson, E. O. 1963. An equilibrium theory of insular zoogeography. *Evolution* 17:373-387.

MacArthur, R. H. and Wilson, E. O. 1067. The Theory of Island Biogeography. *Monographs in Population Biology* No. 1. Princeton University Press, Princeton.

McArthur, Norma, Saunders, I. W., and Tweedie, R. L. 1976. Small population isolates: a micro-simulation study. *Journal of the Polynesian Society* 85:307-326.

MacCluer, Jean W. 1974. Avoidance of incest: genetic and demographic consequences. *In* Dyke, B. and MacCluer, J. W. (Eds.), 1974: 197-220.

Morgan, Kenneth. 1974. Computer simulation of incest prohibition and clan proscription rules in closed, finite populations. *In* Dyke, B. and MacCluer, J.W. (Eds.), 1974.

Palmer, C. E. and Pyle, R. L. 1966. The climatological setting of the Galapagos. *In* Bowman, R. (Ed.), *The Galapagos.* University of California Press, Berkeley.

Platt, John R. 1966. *The Step to Man.* John Wiley and Sons, New York.

Reid, Russell M. 1973. Inbreeding in human populations. *In* Crawford, M. L. and workman, P.L. (Eds.), *Methods and Theories of Anthropological Genetics.* University of New Mexico Press, Albuquerque.

Richter-Dyn, Nira, and Goel, Narendra S. 1972. On the extinction of a colonising species. *Theoretical Population Biology* 3: 406-433.

Rossman, David L. and Schull, W. J. 1974. Recessive lethals and the birth interval. *In* Dyke, B. and MacCluer, J. W. (Eds.), 1974:143-160.

Schull, W. J. 1958. Empirical risks in consanguineous marriages: sex ratio, malformation and viability. *American Journal of Human Genetics* 10:294-343.

Tattersall, I. and Eldredge, N. 1977. Fact, theory, and fantasy in human paleontology. *American Scientist* 65:204-211.

Terrell, John E. 1975. Island Biogeography and Man in Melanesia. *Archaeology and Physical Anthropology in Oceania* 11:1-17.

Terrell, John E. 1977. Human biogeography in the Solomon Islands. *Fieldiana Anthropology* 68:1-47.

Terrell, John E. and Fagen, J. 1975. The Savage and the Innocent: sophisticated techniques and naive theory in the study of human population genetics in Melanesia. *Yearbook of Physical Anthropology* 19:2-18.

Vayda, Andrew P. 1959. Polynesian cultural distribution in new perspective. *American Anthropologist* 61:817-828.

Waddington, C. H. 1977. *Tools for Thought.* Paladin, St. Albans.

Weiss, Kenneth M. 1973. Demographic models for Anthropology. Memoirs of the Society for American Anthropology No. 27. *Amercian Antiquity* 38(2),Part 2.

Weiss, Kenneth M. 1975. The mysterious adventures of Electro sapiens. *Reviews in Anthropology* 2:183-191.