SOME ENVIRONMENTAL AND CULTURAL FACTORS INFLUENCING THE STRUCTURING OF AUSTRALIAN ABORIGINAL POPULATIONS

JOSEPH B. BIRDSELL*

Department of Anthropology and Sociology,
The University of California at Los Angeles

Theory in population genetics has been so vigorously developed in recent decades that its mathematical elaboration has run far ahead of its concrete applications to natural populations. Much of the theory requires empirical checking, yet this is difficult since the parameters which determine the characteristics of populations are generally ill-defined. There is great need to isolate and quantitatively evaluate the variables influencing the structuring of natural populations.

Man is sometimes considered an intractable subject for studies in population genetics. He is warm-blooded, produces few offspring, is long lived, and most important, his culture partially shields him from the forces in the natural environment. Nevertheless, properly chosen human populations may offer unusual research advantages. The aboriginal Australians are such an example. They are unique in that only in Australia did there survive into modern times an entire continent of peoples whose economy was based exclusively upon hunting and collecting, and whose culture was broadly uniform in terms of extractive efficiency. In ecological terms the aborigines represent a latter day survival of man at an essentially paleolithic level of economy, despite the presence of pressure-chipping, microliths, and stone grinding in some regions. Hence they are important as capable of revealing some aspects of the evolutionary processes affecting man in the Pleistocene, a period in which he passed through the definitive stages of racial differentiation.

Determinants of Australian aboriginal population structure fall into two broad categories: (1) cultural; and (2) environmental. Certain of the more obvious cultural determinants have been discussed in a previous paper (Birdsell, 1950). Aboriginal populations in Australia do not represent an amorphous pattern of biological family units, but are structured in terms of two larger social units, the horde and the tribe. The horde, or local group, is equivalent to an extended family, usually numbers about 40 persons, and is the primary land-owning unit. Throughout Australia the horde is exogamous, patrilineal and patrilocal; that is, a man takes his wife from outside his local unit, she lives with his horde, and their children belong to it. Thus in each generation 50 per cent of the local group gene pool is introduced from other hordes outside its boundaries.

*Corresponding member, Institute for the Study of Human Variation, Columbia University, New York, N. Y.
The Australian tribe consists of a group of hordes which are united by a common dialect, by a common attributed line of descent, and by a similar culture. No form of authority exists to bind the hordes of a tribe into a single cohesive unit, but its existence as a discrete social entity is recognized both by the natives themselves and by anthropologists. The tribe owes its existence to subtle forces of internal cohesion which are operative even at the low level of social integration characteristic of Australia. Territoriality, limitations on intergroup communication and on personal mobility doubtless contribute to defining tribal limits through lower rates of social interaction between distant hordes. In terms of the concepts of genetic space and genetic distance (Birdsell, 1950) the nature of population structuring is such that tribal boundaries operate as the essential barriers to gene flow, and probably act in most regions as barriers to cultural diffusion. Tindale (1940) has listed 574 aboriginal tribes for Australia. Brown (1930) estimated that at the time of discovery the total aboriginal population numbered 251,000 as a minimum, but more probably exceeded 300,000. Using Tindale's total for the number of tribes, these estimates give 437 and 523 upwards respectively for the mean number of persons per tribe.

If a genetic isolate is defined (see Stern, 1949, among others) as a population which forms a more or less closed group, so that its members are less likely than is expected by chance to exchange genes with members of another group, then the Australian horde, with its rapid influx of genic materials in each generation, does not answer these requirements. The tribe, on the other hand, as a socially self-defining unit, fulfills the essential requirements of the isolate. Since population pyramids will be generally uniform from tribe to tribe, and tend to remain nearly constant through time, isolate size will be highly correlated with, but larger than, the size of the effective breeding population. A crude and preliminary analysis suggests that for Australia the size of the effective breeding population would be less than 40 per cent of the tribal population. Thus, the former would approximate but 40 persons for a tribe of 100; 200 for a tribal population of 500; and 400 for tribes totalling 1,000 natives. Hence the size of the effective breeding population in aboriginal Australia is small, and random genetic drift might be expected to be operative.

In an earlier paper (Birdsell, 1950) concerned with the construction of simple gene flow models for Australia, one of the primary simplifying assumptions used was that the average aboriginal tribal population was constant and approximated 500 individuals. Clearly not true when applied to

1 The real determinant of rates of gene flow between groups is sanctioned sexual relations, which occur commonly between hordes and occasionally between tribes. Since it would be difficult if not impossible to measure directly, it may require indirect evaluation through differences in intergroup marriage rates. There are little published data at the level of inter-horde marriage rates. N. B. Tindale has prepared a manuscript providing the first comprehensive data on the frequency of intertribal marriages. This paper should assist in defining the rates of interisolate gene flow in Australia. There are some suggestions in the literature that the rate is higher between small tribes than between large tribes.
a small series of tribes, it was presumed to hold as a central statistical
tendency when applied to large numbers of tribes. The present study is a
result of the further investigation of this primary assumption.

MATERIALS AND METHODOLOGY

The basic materials for this analysis are derived from the excellent an-
notated Australian tribal map published by Norman B. Tindale (1940), my
collaborator in the original field work of the Harvard-Adelaide Universities
Anthropological Expedition of 1938-1939. In this paper Tindale briefly dis-
cusses the physiographic and ecological controls apparent in tribal distrib-
utions. He notes a high degree of correlation between tribal boundaries
and ecological and geographical limits. Thus mountain ranges, divides,
rivers, general ecological and plant associational boundaries, microclimatic
zone limits, straits and peninsulas often furnish clear-cut and stable bound-
aries. In deserts the cluster distributions of hordes around the few per-
manent waters are equally clear, and waterless stretches delimit many
tribal boundaries. Tindale (1940, p. 150) further stresses that "The general
reverse relationship between size of tribal area and rainfall is marked."
In qualitative form this important but not unexpected relationship is not an
efficient predictive device.

The present investigation was begun in order to quantify the relationship
between rainfall and the size of the Australian tribal area as a step in de-
vising a method for evaluating the size of tribal populations. First, the
area was determined from Tindale's map for the 409 mainland tribes whose
boundaries could be considered as reasonably established. The tribal
boundaries are given as they existed just prior to the advent of white inter-
ference. This total series is shown by the combined hachured areas in fig-
ure 1. Tindale differentiated between well established and probable bound-
aries, but both classes have necessarily been used in this study. For 14
tribes portions of boundaries had to be arbitrarily assumed, and where pos-
sible these were based on natural ecological limits. Thus a slight, but un-
known, degree of inaccuracy has been introduced in the identification of
tribal limits. Since a closed spatial system is involved, this error may be
presumed to be non-systematic, but it contributes to the unexplained vari-
ance in the correlation between the primary variables.

The determination of all areas was made with a Keufel and Esser plan-
imeter, model No. 4236. The projection used for Tindale's map could not
be determined accurately, but it seemed to be a compromise between equal
area and equal distance systems. Empirical planimeter tests against areas

2After the completion of the present analysis it was discovered that N. B. Tin-
dale had commenced a similar type of investigation using the same basic materials.
After discussing this instance of parallel invention, we have decided to exchange
materials at the data level, but to work totally independently at the conceptual
level. Thus, when time becomes available, Tindale will publish his independent
analysis, and Birdsell will publish his investigation in a more comprehensive and
refined form than presented here. Opportunities for replicative research of this
type are rare in the natural sciences, and the implications of these data are of suf-
cient importance to provide justification in this instance.
of known size (based upon 16 trials each, involving four replications of four different combinations of planimeter arm position, placement of the pole weight, and direction of tracing) gave one planimeter unit equal to 100.0 square miles ± 1.0. The centers of the areas so tested ranged from 320 to 1,040 miles distant from the center of the map, and the three tests revealed no consistent system of distortion of area values proceeding toward the margins of the continent. It was therefore assumed that no error of importance would be introduced by using the above conversion value throughout Tindale's map.

FIGURE 1. Distribution of total and basic series of tribes.

The area of each tribe was determined from the average of four planimeter runs, each involving either a change in the position of the pole weight, planimeter arm, or the direction of tracing. The range of the four values was usually ±1.0 planimeter units over a range between 10 and 500 planimeter units, indicating that the relative error of estimate decreased as the size of the tribal area increased. For very small tribes, with areas less than 10 planimeter units, the procedure was modified by extending each tracing of the boundary to five continuing replications, then dividing the resultant reading by five, and so obtaining a lower error of estimate.
In addition to the generally non-systematic errors introduced by the above operations, and which contribute to some small extent to the unexplained variance, there remains another possible source of error. This involves the definition and identification of the tribe as an entity. Tindale accomplished the enormous task of surveying the distribution of Australian aboriginal tribes with great skill, but he noted a number of difficulties encountered in the process. Much of the literature on the subject is filled with synonyms and confusing variations of tribal names. In many instances the earlier workers confused horde-like units with tribes. Tindale carefully evaluated these errors in nomenclature, and brought the data into a single, consistent system. Of the approximately 600 tribes on the continent, he obtained fresh information in the field on 400 tribal units, thus providing a sound matrix for the entire survey. Even so, other complications rendered his work difficult. He notes that tribal fragmentation seems to have occurred in three areas: (1) among the Murningin people of northeast Arnhem Land; (2) among the tribes along the Daly River in Northern Territory; and (3) in the Boulia district in central Queensland. On the other hand, consolidation among tribal groups seems to have occurred in the central interior of New South Wales, among such tribes as the Kamilaroi and Wiradjuri. This trend appears to reflect the development of a more advanced type of political organization based upon matrilineal descent. In addition to these regionally systematic variations, it is to be noted that sporadic shifts in the fortunes of individual tribes may result in their gradual differentiation into new multiple tribal units, in the case of growth in numbers, or their absorption into neighboring tribes in instances of declining population. Both tendencies alter the size of the tribal population, and hence the nature of intra-tribal and inter-tribal interactions. As pointed out in later sections, systematic regional deviations in either direction can be corrected for, but those of erratic occurrence cannot be excluded. Such cases result in increasing the unexplained variance of the size of the tribal area. The same will be true of those occasional cases involving inadequate data in which horde-like units have been elevated to full tribal status. In total effect these errors may have introduced a small systematic bias toward elevating portions of tribes to full tribal status. The size of this error cannot be estimated, but the thorough nature of Tindale’s survey assures that it has been kept at a minimum.

Mean annual rainfall, the independent variable with which size of tribal areas is to be correlated, was obtained from a map modified after that published in the "Climatological Atlas of Australia" (1940 ?). The map is shown in figure 2. The method used in estimating the rainfall values for each tribal territory was crude but reasonably effective. It is analogous to estimating the center of gravity of an irregularly shaped and variably loaded plane surface. The “center of gravity” gives, through its position with respect to the isohyets traversing the area, the average mean annual rainfall for the tribal territory. In simple cases, as in arid regions, the estimate can be made rapidly by eye. In more involved instances, in which
several isohyets cross a single tribal area, the latter is broken down into a number of sub-areas, and the mean annual rainfall is estimated for each. The resultant average rainfall for the entire tribal area is then calculated by a method of weighted means.

To test the error of estimate, replicative estimates of rainfall were made along three transects which covered the full range of values from four inches to 150 inches annually. Each transect originated in the territory of the Wonkanguru in the Lake Eyre Basin, an area of minimal rainfall: the first extended north to the Njangga tribe on the Gulf of Carpentaria; the second stretched northeast to terminate in the rainforest with the Mamu tribe; and the third ran a little south of east to end in Dainggati tribal territory on the northern coast of New South Wales. Thus 33 tribes were subjected to re-estimation. In 23 cases the estimates of mean annual rainfall taken to the nearest inch were identical in the two trials. A brief analysis of the error of estimate gives approximately a mean error of ±1.0 per cent distributed over the total 33 cases. The value of the error was roughly constant over the total range of rainfall values.

A further source of error in the independent variable results from the generalized nature of the map used to estimate rainfall. In the few tribes
where it has been possible to check against more detailed data, the error from this source was sometimes appreciable. It is hoped that in a future analysis it will be possible to obtain data giving more accurate microgeographical rainfall values than those here used from necessity. Yet another source of possible error lies in the factor of time. Current rainfall estimates are based primarily upon records of 50 years or less in duration. In the older settled area of the south and east the tribal boundaries are given as they existed a century or more ago. To the extent that slight climatic shifts may have occurred in this ill-defined time interval the estimate of current rainfall may be systematically in error.

Beyond Tindale’s comment that a general reverse relationship exists between the size of tribal area and rainfall, and the fact that his map shows it quite clearly, there are good theoretical reasons to expect such a correlation. In mammalian ecology it is generally recognized that the density of a given type of population will be some function of the critical environmental variables. While this relationship has not previously been demonstrated quantitatively for man, it seems likely that for hunting and gathering peoples similar forms of environmental determinism might obtain. In aboriginal Australia, with its moderate temperatures and small altitudinal variations as compared to other continents, it might be presumed that the biotically effective quantity of rainfall would prove one of the more important of the variables of the environment.

There remains the important problem of functionally relating the size of the tribal area to density. There is no reason for rainfall directly to determine the area occupied by the Australian social unit known as the tribe. Unfortunately there are too few estimates of the population size of aboriginal tribes to work directly with density as the dependent variable. The bridging device is found in the definition of population density as the number of individuals per unit of area. It follows that an exact inverse relationship is established between tribal area and tribal density if the population size of the tribes is held constant throughout this series. Thus it becomes crucial for the following analysis to make the intervening assumptions that: (1) population densities are causally and inversely related to the mean annual rainfall within the tribal territory; and (2) in a statistical sense the population size of the Australian tribe may be considered a constant, in this case approximately 500 persons. If the mean annual rainfall, which is the best simple measure available for biotically effective rainfall, does in fact show a reasonably high degree of correlation with the size of the tribal area, it will tend to validate both of the foregoing interlocked assumptions.

Since a certain rashness is apparent in the above statements, further explanations and qualifications are in order. The degree of correlation between two variables merely demonstrates the degree of association, and may or may not indicate a causal relationship. In the present instance as later evidence will show the ecology of the aborigines clearly argues that such a relationship is causal in nature. A further qualification must be
added with regard to the interpretation of such a correlation. If other critical parameters vary as some systematic function of rainfall, it would not be apparent from this form of analysis. Thus if the slight regional differences in aboriginal culture were to affect efficiency in extracting energy from the environment in some fashion associated with changes in rainfall, this complicating factor could not be identified in the primary correlation. Or if for any reason the average size of the tribal population varied as a function of rainfall, the distorting influence of this factor could not be detected. Thus, for example, tribes might have consistently small sized populations in desert areas, and larger ones in regions of high rainfall without this being apparent in the original correlation. But there is little evidence to suggest that this type of variation is important.

The scattergram showing the relationship between the size of the tribal area of the 409 tribes of the total series and their mean annual rainfall is given in figure 3. The distribution is by no means a random one, and shows a high degree of association. Several attempts at curve-fitting indicated that the data were satisfied by an exponential equation in the form:

\[ Y = aX^b \]

where \( Y \) is the tribal area and \( X \) is mean annual rainfall. The coefficient of curvilinear correlation, \( \rho \), is 0.59 and \( \sigma \log Y \) is 0.42854. Calculation of the constants gives the following equation:

\[ Y = 615.00 X^{-0.08980}. \]

The band of error calculated to give 95 per cent inclusion of the data is shown by the dotted lines in figure 3. It will be noted that rather fewer points fall outside than might have been expected. The logarithmic curve fits the central mass of the data fairly well, but in the asymptotic regions the data conform less closely to the curve.

A curvilinear coefficient of 0.6 for the unselected total series is encouraging, but from an ecological point of view the series is a heterogeneous one. Before proceeding to interpretation it seems wise to obtain an ecologically more homogeneous series by making certain types of systematic correction. Since our method involves assumptions that: (1) the size of the tribal populations approximates a statistical constant, and (2) that the size of the tribal area is an inverse expression of the tribal density, it will be advisable to eliminate systematically from further consideration those groups of tribes which show marked deviations from either assumption. Thus the categories of tribes subject to such exclusion may be chosen by two types of criteria: (1) systematic deviations from expected densities due to variation in ecological factors; and (2) deviations in either direction from the assumed constant size of 500 persons per tribe owing to the action of cultural variables. A validation for these categorical exclusions will be presented in later sections.

Ecologically, any environmental factors which alter the relationship between the area occupied by a tribe and the density expected for its rainfall regime will be considered grounds for exclusion. To provide the broadest
and most stable basis for comparison, our ecological standard will consist of those tribes whose resources are primarily terrestrial in origin, and whose territories are essentially watered by rainfall which falls within their territories. Those tribes whose domain lay wholly or partially upon islands were excluded prior to the creation of the basic series of 409 tribes. All coastally situated tribes are now further eliminated, since marine food resources would be expected to increase the population density compared to purely terrestrial tribal standards. Just as marine food resources alter the usual density-area relationships, so will the foods provided by rivers. While much of the southern and western coasts, as well as nearly all of the interior of Australia, is characterized by intermittent or transient streams and rivers, there are coastal areas, particularly in the east and north, where permanent rivers are the rule. In such cases their waters are largely dep-
rived from small drainage areas, and the riverine food resources are con-
considered here to be a normal manifestation of a high rainfall regime. But in
the interior of the southeastern portion of the continent there exists a
great and largely permanent river system, the Murray-Darling, which repre-
sents a rather different set of ecological conditions. There, in near-desert
country, largely with less than 20 inches of rainfall annually, flow great
rivers whose waters are derived from the western slopes of the Dividing
Range. Insofar as the plains tribes of this drainage system are concerned,
such rivers represent unearned surface water resources, since they are pri-
marily nourished by rainfall from outside the plains country. Such riverine
resources, like marine foods, alter the assumed relationship between the
size of the tribal area and population density. For this reason, the tribes
along the Murray and Darling Rivers, and their major tributaries, have been
systematically excluded from the basic series.

From the cultural point of view, several factors operate so as to cause
systematic deviations from the assumption that the size of the tribal popu-
lation approximates a constant value of about 500 persons. Such deviations
will disturb the usual relationship between size of tribal area and popula-
tion density. As noted by Tindale (1940, p. 150) a group of tribes occur in
the eastern interior of New South Wales in which a more advanced type of
political organization, characterized by matrilineal descent, has allowed
the development of especially widespread communities; that is, tribal
entities in which the population size substantially exceeds 500 persons.
He specifies the Kamilaroi and Wiradjuri as examples. Kryzwicki (1934)
considered the Kamilaroi to have totalled between 6,000 and 7,000 persons
and the Wiradjuri to have numbered about 3,000. His opinion was based upon
rather unsatisfactory estimates by early settlers, but even though these
tribal populations may have been overestimated, they must be eliminated
from our basic series as essentially representing confederacies of tribes.
Data for the neighboring Wongaibon tribe are less exact, but it too can be
safely excluded owing to the systematic operation of cultural factors in
this region.

Allowances by exclusion must be made for a further set of cultural influ-
ences. Tindale (1940, p. 150) indicated certain areas of postulated cultural
clash, in which tribal fragmentation seems to have taken place, as excep-
tions to the generally inverse relationship between the size of tribal terri-
tory and rainfall. He specifies northeast Arnhem Land, the Daly River dis-
trict of the Northern Territory, and the region around Boulia, Queensland,
as examples of this tendency. These areas seem to reveal an intensified
form of tribal fragmentation, but in a less extreme form the phenomenon is
more widespread. The boundaries which separate the centrally situated
circumcising and subincising tribes from the marginal groups which prac-
tice neither initiatory rite are shown in figure 7. An examination of Tin-
dale's map reveals that the tribal areas lying just west of the eastern lim-
its of the circumcising and subincising boundaries are notably smaller than
those just to the east of the circumcising line. The Boulia district of
fragmentation is just to the west of the there combined boundary lines.
Similar evidence for fragmentation associated with the spread of the initiatory rites occurs along their northern boundaries in the Northern Territory. Between the line representing the advancing front of the rite of circumcision and the less extended boundary of the subincision rite lie the two other areas of fragmentation mentioned by Tindale, the Daly River district and the Mungin region of northeast Arnhem Land. While these are focal points for the phenomenon of fragmentation, the same process seems to a lesser degree to have affected the other tribes which have recently taken over either or both of these ceremonies. Since in the case of neither the eastern nor northern limiting boundaries of the rites are there any visible ecological factors to explain the changes in tribal densities implied by the reduced size of the tribal areas, it must be presumed that the size of the tribal populations there is smaller than the assumed constant of 500 persons. The ethnological evidence for fragmentation tends to confirm such a conclusion.

The western boundaries of the rites of circumcision and subincision coincide. The signs of fragmentation expected to the east of the line are not visible from the map. As will be seen later, there are a number of possible explanations for this apparent difference. Nonetheless, to remove the potentially disturbing factor of fragmentation and consequently small-sized tribal populations from our analysis, a band of tribes lying just inside the limits of both the circumcising and subincising boundaries on their eastern, northern and western limits have been excluded from the basic series. While the width of the excluded band varies to some degree with the intensity of the fragmentation, in general it ranged three tribes deep inside the subincising boundary. The Boulia area, because of the extreme form of the phenomenon there, was treated more drastically.

Of the total original series of 409 tribes, 286 have been systematically eliminated from further consideration on the grounds that either ecological factors distorted the basic relationship between the size of tribal area and population density, or cultural variables produced undue deviations in the size of the tribal population as compared to the assumed constant of 500 persons per tribe. There remain 123 tribes which seem to be ecologically and culturally relatively constant in their characteristics, in so far as they effect this analysis. These 123 tribes constitute our basic series. As shown in figure 1 in the cross-hachured area, the basic series consists of three blocks of tribes: a large series numbering about two thirds of the total centered in Queensland; and two smaller groups of about 20 tribes each, one spreading through the desert area of the interior, the other extending through the southern portion of the Dividing Range to terminate in the west in the mallee scrub just short of the mouth of the Murray River. Thus the basic series, while ranging through nearly the full variation in rainfall, from five to 151 inches, is predominantly representative of the regional ecological conditions obtaining in non-coastal Queensland. In so far as the ecological variables for this region may not be representative for the continent as a whole, a systematic error may have been introduced into the analysis.
FIGURE 4. Correlation between rainfall and size of tribal area for the basic series.

The scattergram showing the relationship between the size of the tribal area and mean annual rainfall for each of the 123 tribes of the basic series is given in figure 4. The distributional pattern is again that of a J-shaped curve, and these more cohesive data are likewise satisfactorily fitted by an exponential equation. Solving for the constants, the equation takes the form:

\[ Y = 7,112.8 X^{-1.58451} \]

Rho, the coefficient of curvilinear correlation, here reaches the very satisfactory value of 0.81. The band of error shown by the dotted lines, and calculated to give 95 per cent inclusion of the data, is derived from \( \sigma = 0.31495 \). But 2 of the 123 tribes fall outside the band of error. This exponential curve, unlike that fitted to the total series, shows a more satisfactory relationship with the central body of the data, and more importantly with the data along both asymptotes. This improved degree of fit suggests that the systematic exclusions practiced in defining the basic series have

*The first constant in the equation in figures 4 and 5 should read 7,112.8 as in the text.
in fact diminished the heterogeneity of the data arising from ecological and cultural variables. The degree of displacement between the curves for the total and basic series is shown in figure 5. It must be inferred that there exists a very high degree of association between the size of the tribal area in the basic series and the mean annual rainfall occurring within its territory.

FOOD RESOURCES

Now it is time to reconsider the question of whether the association between these two variables is to be interpreted as causal in nature. Ethnologically it is well established that the diet of the aborigines in Australia is characterized by its broadly omnivorous nature. They consume all the edible animal and plant food in their environment which can be economically obtained and prepared by the techniques available at their cultural level. Examples may be quoted to give emphasis to this statement. Grey (1841), one of the most accurate of the very early recorders of native life, noted the following items of diet for the groups of tribes along the southwestern coastal region of Western Australia:

A. Animal Foods
   (1) 6 sorts of kangaroos.
   (2) 5 marsupials somewhat smaller than rabbits.
   (3) 2 species of opossum.
   (4) 9 species of marsupial rats and mice.
   (5) Dingo.
   (6) 1 type of whale.
   (7) 2 species of seal.
   (8) Birds of every kind including emus and wild turkeys.
   (9) 3 types of turtle.
   (10) 11 kinds of frog.
   (11) 7 types of iguanas and lizards.
   (12) 8 sorts of snakes.
   (13) Eggs of every species of bird and lizard.
   (14) 29 kinds of fish.
   (15) All saltwater shellfish except oysters.
   (16) 4 kinds of freshwater shellfish.
   (17) 4 kinds of grubs.

B. Plant Foods.
   (1) 29 kinds of roots.
   (2) 4 kinds of fruit.
   (3) 2 species of cycad nut.
   (4) 2 other types of nut.
   (5) Seeds of several species of leguminous plants.
   (6) 2 kinds of mesembrandthemum.
   (7) 7 types of fungus.
   (8) 4 sorts of gum.
   (9) 2 kinds of manna.
   (10) Flowers of several species of Banksia.

This exhaustive inventory suggests that very few food resources in the environment remain unexploited. Two further dietaries may be quoted for reference. The first, from Sweeney (1947), lists the foods eaten by a single desert tribe, the Walpari. The second, from Roth (1901), details the wide variety of foods eaten by the coastal and interior tribes of Queensland. Such sample dietaries serve to substantiate the claim that the aborigines exploit all, or very nearly all, of the sources of energy culturally available to them in their environment, and cover the full range of food size which can be economically utilized. In a dry continent such as Australia, ranging from tropical to temperate climate, the variations in the flora will be de-
ependent to a large degree upon the rainfall received. It would be expected that the biomass of the flora would be correlated to a high degree and in a causal sense with the mean annual rainfall. The densities of aboriginal man, standing near the peak of the trophic pyramid and exploiting all lower levels, both animal and plant, must also respond sensitively to variations in rainfall. For these reasons it seems proper to assign a causal relationship to the high degree of correlation existing between the size of tribal territory in the basic series, and the independent variable, mean annual rainfall. The density of the aboriginal population in Australia was determined to a large measure by rainfall operating indirectly through the biota.

THE EXCLUDED MATERIAL

Since the basic series was created by systematic exclusion of certain groups of tribes which were considered ecologically or culturally to increase the heterogeneity of the data, it will now be profitable to reexamine the relationship of these categories to the basic series. Table 1 lists the excluded categories, and gives the mean area ratio and mean density ratio for each. The area ratio represents the measured area of the tribal territory divided by the area predicted by the basic equation for its value of rainfall. The density ratio is the reciprocal of the area ratio. In most instances it may be considered to indicate the ratio of the actual tribal density compared to the density predicted from the basic equation, based upon the assumed tribal population size of 500 persons. In a few instances, where the ecological factors remain essentially constant and the cultural factors vary, the density ratio must be interpreted as reflecting variations in the size of the tribal population rather than deviations in density. Thus an area ratio of 0.500 indicates that the tribe occupies half the area predicted from its rainfall regime. This reduced area may either be due to ecological advantages in its territory, or to a population half the size of the expected 500 persons. The density ratio in this case would be 2.00, and might either mean the tribal density was twice that predicted, or that the size of the population was half that expected, depending upon whether the deviation is interpreted as resulting from ecological or cultural factors. In more complex instances both types of factors may be operative, but this possibility is necessarily ignored in the present analysis. While interpretations of this type cannot safely be applied to single tribes, it is considered that they may hold with some validity for systematic categories of tribes.

One of the most revealing categories of exclusion involves the ecological effect of unearned surface water upon population density. Unearned surface water in this sense refers to rivers, or freshwater lakes, which depend for their existence upon rainfall from distant regions. The Murray and Darling Rivers are the best Australian examples. Both originate on the relatively well-watered western slopes of the Dividing Range and flow through increasingly arid country. Much of their way lies through regions with but 10 to 15 inches of rainfall, and hence in their lower reaches the
TABLE I
EFFECTS OF ECOLOGICAL AND CULTURAL FACTORS UPON DENSITY RATIOS.

<table>
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<tr>
<th>Area ratios</th>
<th>Density ratios</th>
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1. Ecological Factors Changing Densities of Tribal Populations.

A. Uneared Surface Water:
(1) 9 lowest tribes on Murray River: 0.058 17.33
(2) 5 lowest tribes on Murray River: 0.026 38.46

B. Marine Resources of Islands:
(1) 27 tribes partially or completely insular: 0.402 2.49
(2) 26 tribes (omitting Tiwi) partially or completely insular: 0.326 3.07
(3) 13 tribes completely insular: 0.349 2.86
(4) 12 tribes (omitting Tiwi) completely insular: 0.179 5.58
(5) 5 tribes with 20 to 65 per cent insular domains: 0.220 4.56
(6) 8 tribes with 0.005 to 10 per cent insular domains: 0.653 1.53

C. Marine Resources of Mainland Coastal Tribes:
(1) Total available sample of 119 tribes: 0.751 1.33
(2) Southern coast: 8 tribes (Wirangu through Wardandi): 1.425 0.70
(3) Western coast: 17 tribes (Pindjarup through Nguluma): 0.453 2.21
(4) Eighty mile Beach coast: 2 tribes (Njangamada and Karadjer): 0.620 1.61
(5) Dampier Land coast: 7 tribes (Jauor through Ninanboro): 0.184 5.44
(6) Arnhem Land coast: 6 tribes (Wogait with 3 breaks through Gunavidji): 0.408 2.45
(7) Gulf of Carpentaria: 10 tribes (Nungubuju with 1 break through Karundi): 0.895 1.12
(8) Eastern coast Cape York Peninsula: 15 tribes (Ankamuti with 1 break through Koko-imudji): 0.586 1.71
(9) Rainforest coast of Queensland: 8 tribes (Jungkurara through Warkamai): 0.961 1.04
(10) Central coastal Queensland: 9 tribes (Bindal through Kabikabi): 1.267 0.79
(11) Southern coastal Queensland and northern New South Wales: 13 tribes (Jagara through Awabakal): 1.050 0.95
(12) Southern New South Wales and eastern Victorian coasts: 10 tribes (Kameraigal through Bratauolung): 0.671 1.49
(13) Western Victorian and eastern South Australian coasts: 14 tribes (Kurung through Nauo): 0.606 1.65

2. Cultural Factors Changing Size of Tribal Populations.

A. Advanced Type of Political Organization:
(1) The "confederacies" of New South Wales: 3 tribes (Kamilaroi, Wiradjuri and Wongai-bon): 5.200 0.192
TABLE I (continued)

<table>
<thead>
<tr>
<th>Area ratios</th>
<th>Density ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>(b) Eastern side: 21 unaffected tribes (Kalibamu through Ramindjeri):</td>
<td>0.728</td>
</tr>
<tr>
<td>(c) Western side: 17 affected tribes between points A–B in Fig. 7. (Work-abunga through Maljangapa):</td>
<td>0.286</td>
</tr>
<tr>
<td>(d) Eastern side: 13 unaffected tribes between points A'–B' in Fig. 7. (Kukatji through Wiljakali):</td>
<td>1.002</td>
</tr>
<tr>
<td>(e) Western side: 12 affected tribes (Work-abunga through Ngandanjara):</td>
<td>0.318</td>
</tr>
<tr>
<td>(f) Eastern side: 8 unaffected tribes (Kukatji through Wadjalang):</td>
<td>1.334</td>
</tr>
</tbody>
</table>

rivers provide locally uneared ecological resources. Tindale (1940, p. 150) indicated that the fisher-folk of the Murray River enjoyed special food advantages. A quantitative analysis strikingly extends the meaning of his statement. In figure 5, the nine tribes of the lowest portion of the Murray have been plotted as hollow triangles in their appropriate positions. As compared to the basic curve, these riverine tribes show drastically reduced area ratios with the mean value of but 0.058. Their mean density is 17.33 times that expected from the local rainfall regimes.

Since all the tribes in the drainage of the Murray and Darling Rivers were eliminated from the basic series, it will be well to examine their position as a group. In figure 6, the area ratios of the tribes bordering on these two rivers have been plotted against their distance from the mouth of the Murray. The trend in the unaltered data was clear, but fluctuated sufficiently so that for plotting purposes the data were smoothed out by calculating the value of the area for each tribe from a moving 3-point average. Thus treated, the data show a consistent reduction in the size of the area ratios from the Pangerang tribe near the headwaters of the Murray to the Wariki at its mouth.

In a similar if less striking fashion the area ratios of the tribes along the Darling diminish from the Koamu tribe near its headwaters (in actuality, on the Balonna River, a major tributary of the Darling), to the Maraura tribe situated at the junction of the Darling with the Murray. The curves shown in figure 6 were drawn freehand merely to indicate approximate trends, and a more detailed future analysis may modify their form considerably. The data show a consistent decline from the initially higher than normal values of the area ratios at the headwaters of the two rivers to the extraordinarily low values at the Murray mouth. While the data do not lend themselves to exact curve fitting, certain regularities show through. Those few tribes which include but one bank of the Murray in their territory uniformly show
higher area ratios than those which include both banks. The three tribes nearest the Murray mouth show disproportionately low area ratios, perhaps as a consequence of bordering upon ecologically rich Lake Alexandrina. The five tribes nearest the mouth have an average area ratio of but 0.026, and the spectacular mean density ratio of 38.46. Since the population estimates available for these tribes, as summarized by Kryzwicki (1934) indicate that they have exceeded our assumed constant of 500 persons per tribe, it must be concluded that here the ecological effect of the unearned surface water of the Murray is responsible for aboriginal densities perhaps 40 times that to have been predicted from local rainfall values.

An ecological analysis of the Murray-Darling tribes cannot be attempted in detail at this time, but the region is obviously superior in its food resources. The waters of the river directly contribute a number of important food fish, shell-fish, and waterfowl. Indirectly the forested banks of the river increase the supply of birds and arboreal marsupials. The rich bottom lands offer a greater abundance of food plants. The ecological variables operating to increase human densities along these rivers cannot be identified in detail but it is obvious that such density ratios are not
primarily determined by rainfall alone. The volume of water flow and its reliability may prove to be fair ecological indices. On the other hand, stream gradient appears to be correlated with aboriginal density and may be the primary factor. It may be postulated that the younger, steep-sided valleys of the upper waters would provide less abundant food for the aborigines than would the mature, broad valley lands of the lower river. These points involve research for the future and are of no further concern here. The available evidence validates the exclusion of the Murray and Darling River tribes from the basic series on the grounds that unequal surface waters markedly alter their area ratios and hence density ratios.

INSULAR POPULATIONS

Insular tribes represent another category in which deviations from a primarily terrestrial economy are a cause for disqualification. On a priori grounds all tribes residing completely or partially on islands were excluded from the total series, and hence from the basic series. This decision was based on several factors. The very configuration of islands, with a long coastline enclosing a relatively small area of land, indicates that abundant marine foods should be available. Further, unlike mainland tribes, the area of land available to a given tribal population is determined by variations in the topography of land and eustatic sea level rather than by a complex of social interactions between groups of people. Thus the area
of islands bears no functional relationship to our assumed constant of 500 persons per tribe, save in the cases of islands large enough to support a greater population than this, or so close to the mainland that a single tribal population can maintain an adequate level of internal cohesion across the straits. An insular environment may operate both to increase aboriginal densities as compared to terrestrial standards, or to limit the size of a population in the case of very small islands lying well offshore. Both factors may be operative in many cases.

Despite these complexities, it is of some interest to compare the position of the insular tribes with the basic series. In figure 5 the positions of 13 tribes wholly insular are plotted with solid circles, and 5 tribes occupying islands and portions of the adjacent mainland are shown by half-solid circular symbols. In the latter cases the islands provide from 20 to 65 per cent of their total domain. Data for nine additional tribes even less insular in nature are given in table 1. The plotted positions for the tribes in the first two categories show the expected deviations from the basic curve in the direction of higher density ratios. A single exception, the Tiwi tribe of Melville and Bathurst Islands, has a much larger population than the assumed constant of 500 persons, and this may partially explain its position above the curve.

Table 1 presents an interesting trend in terms of insular density ratios. The total series of 27 wholly or partially insular tribes have a mean density ratio of 2.49, and if the Tiwi are omitted, the ratio rises to 3.07. For 13 completely insular tribes, the density ratio is 2.86, a value which rises to 5.58 with the exclusion of the Tiwi. Five tribes whose domain is from 65 to 20 per cent insular show a mean density ratio of 4.56. Eight tribes with 10 per cent or less of their territory on islands show a mean density ratio of but 1.53. Despite the small size of these samples, and the ecological variations along the different coastal regions of Australia, it is perhaps fair to infer that marine food resources do importantly alter aboriginal ecology and hence density. The detectable trend for density ratios to increase in passing from slightly to completely insular tribes is taken as confirmation, even though changes in population size may also be involved. As mentioned earlier, tribes with a foothold on the mainland have potential room for expansion to our assumed constant of 500 individuals per tribe via give and take adjustments with neighboring peoples, but totally insular groups may have their numbers limited in part by available land area. Despite their limitations the data do justify the decision to eliminate on ecological grounds both completely and partially insular tribes from the total and the basic series.

THE COASTAL POPULATIONS

The ecological position of the mainland coastal tribes is one further aspect of the problem posed by the addition of marine foods to the aboriginal diet. The available data consist of 119 tribes totally unselected, save that four gaps occur along the northern coast as shown in figure 1. The average
area ratio for the series of coastal tribes is 0.751 and the mean density ratio reaches 1.33. On a gross level access to the coast may be interpreted as increasing density by one third over the value predicted for inland tribes by the basic rainfall equation. Thus the systematic exclusion of the coastal tribes from the basic series seems justified, since there is no evidence to suggest that their tribal populations are smaller in numbers than that assumed for the whole continent.

But a regional examination of the coastal tribes indicates a complex pattern of variation which implies that much is yet to be learned of their ecology at a detailed and local level. It is convenient to survey briefly these tribes, beginning at Eyre Peninsula and going around the continent in a clockwise direction, lumping together groups of tribes which show generally consistent deviations from predicted density ratios. The 119 tribes have thus been divided into 12 subgroups which are listed in table 1 under the subheading, I-C. The first local group, C-2, extends from the Eyre Peninsula westward across the shores of the Great Australian Bight, around Cape Leeuwin to Geographe Bay. This group is characterized by the surprisingly low density ratio of 0.70. For the tribes along the Bight this low ratio may be explained by the total lack of even transient streams, the limiting factor of very scarce surface water in the form of springs and soaks, and a lack of watercraft. But it is more difficult to account for the continuance of these low density ratios into the well-watered southwestern corner of the continent. A detailed study of the marine fauna might provide a partial answer.

The second group of tribes, C-3, extends northward from Geographe Bay around Northwest Cape to Nickol Bay and shows the inexplicably high mean density ratio of 2.21. This coast has low rainfall and intermittent streams and rivers. At first sight it would seem to offer few advantages for aboriginal life. Yet Grey (1841), traversing much of this coast on foot under forced marches, concluded that parts of this region were the most densely settled he had seen in aboriginal Australia. He noted valleys rich in yams and lagoons abundant in their marine life and waterfowl. Further, marine turtles extend as far south as Shark Bay, so that this coastal country may have been more attractive from the native point of view than rainfall values suggest.

The next group, C-4, consisting of but two tribes along the Eighty Mile Beach, shows a mean density of 1.61, which reduction may be accounted for by the poor country and lack of streams. A fourth group, C-5, consisting of tribes along the Dampier Land coast, shows a mean density ratio of 5.44, the highest value for any of the coastal regions. Unless an abundance of turtle and dugong make this an ecologically rich coast, it may be suspected that the size of the tribal populations here falls below our assumed constant, and results in an apparent increase in the density ratio. Neither aboriginal food resources nor population estimates are obtainable in detail to determine this point.
There are at present no data for the tribes of the Kimberley coast, so that the next group, C-6, consists of scattered tribes along the coast of Am-hem Land. Here the mean density ratio falls to a more normal value of 2.45 which may be more representative of the tropical coastal regions. After a short break, group C-7, lying along the lowland stretch of the southern shore of the Gulf of Carpentaria, shows a mean density ratio of 1.12, a value which needs explanation in terms of both local ecology and population sizes. After another break and beginning at the tip of Cape York Peninsula a block of 15 coastal tribes extend down to the northern margin of the rainforest. They comprise group C-8 and show a mean density ratio of 1.71. Some of these tribes are essentially marine rather than terrestrial in their mode of life, owing to the dugout canoe, a trait diffused from New Guinea, which allows increased efficiency in the exploitation of marine foods.

Group C-9 includes eight rainforest tribes with a mean density ratio of 0.96, a value slightly below that predicted for inland tribes having no access to the sea. A breakdown of this group reveals that the four northern members, all of whom use the dugout canoe, have a mean density ratio of 1.63, whereas the four southern tribes, limited to less efficient watercraft, average but 0.76 for their density ratio. It would be tempting to consider that these differences in density ratio are a measure of the ecological contribution of the dugout, but present data are insufficient to allow this conclusion. With more information it may be possible to evaluate the contribution made by this cultural factor to the ecology of a coastal people for whom turtle, dugong and other marine foods are of great importance.

The tribes of the central Queensland coast, C-10, show the inexplicably low mean density ratio of 0.79. Since this region is well watered, with permanent rivers, and both terrestrial and marine foods are abundant, one is at a loss to explain the low density ratio in ecological terms. It may be that this value reflects a systematic increase in population size; present data suggest but do not allow this as a final decision. The next group, C-11, roughly extends from Brisbane to a little north of Sydney and yields a mean density ratio of 0.95. This low value may reflect the disappearance of turtle and dugong along the coast in combination with mountains which in many places approach the sea and may reduce the exploitable terrestrial resources. Another group, C-12, stretches from just north of Sydney to a little east of Melbourne and gives a mean density ratio of 1.65. Here again mountains encroach upon the sea, but the coast is broken by numerous deep bays, estuaries and lake-like lagoons which, through their lengthened shoreline and ecological variation, probably confer advantages not to be predicted from mean annual rainfall as the sole determinant of density. On the other hand, early population estimates (Kryzwicki, 1934) suggests that here the size of the tribal population falls below the assumed value of 500 persons, and thus may cause an apparent increase in the density ratios. The relative contributions of these two factors cannot yet be determined.
The final group, C-13, extending from Melbourne through to Yorke Peninsula, and including the coastal tribes at the mouth of the Murray River shows an average density ratio of 1.65. This value is of little significance because of the ecologically heterogeneous nature of the tribes which contribute to it.

The foregoing rapid survey of the regional variations in the average density ratios among Australian coastal tribes provides but few useful generalizations. As might have been anticipated from the relative contribution of marine foods, the coastal tribes have density ratios intermediate between the insular and purely terrestrial inland tribes. Beyond that, it seems safe to infer that density ratios run higher along tropical than temperate coasts. Here the sea turtle, and to a lesser extent the dugong, may contribute importantly to the difference. Evidence from the Bight indicates that a lack of free surface water may act as a limiting factor of even coastal peoples. There are hints that technological improvements, such as the dugout canoe, may measurably influence the extractive efficiency of a people in a given environment, and hence directly change their density. It is quite evident that the ecology of coastal peoples becomes sufficiently complex so that most of the observed variations cannot be explained in terms of rainfall alone.

A detailed ecological investigation of the coastal tribes cannot be undertaken at this time, but certain of the steps necessary for a solution can be predicted. Systematic deviations in the size of tribal populations, if they occur, must be determined. The relative contributions of marine and terrestrial food resources must be evaluated, for rainfall will be of predictive use only for the latter. Further, there are some cultural hints that coastal peoples do not exploit the available terrestrial foods as intensively as do interior tribes. Along the rugged southeastern coast the encroachment of mountains will require corrective factors for differences in altitude and land gradients, for these will affect the types of land resources available and the intensity with which they can be exploited. Finally, the ecology of the marine contributions must be defined in detail. Differences between cold and warm water biota must be established. The contribution per running mile of deep water shorelines, sandy shoal water, brackish bay and lagoon, and mangrove swamp will require determination for different sections of the coastline. The task is a formidable one, but some predictive formulae, although clearly complex ones, can be derived to take the more important variables into account. Such an analysis would be facilitated if ethnologists, who have provided much useful qualitative information, would go further and obtain quantified data concerning the important foods used in a full seasonal cycle.

POPULATIONS EXCLUDED ON CULTURAL GROUNDS

The preceding sections validated the exclusion of categories of tribes which for ecological reasons had densities deviating from those predictable from the basic rainfall equation. There remain two cultural factors to be
justified as grounds for elimination. Since they operate to change the size of the tribal population, it will be convenient to use the area ratios for comparison. The first factor concerns the influence of a more advanced type of political organization characterized by matrilineal descent. The three excluded tribes, the Wiradjuri, Kamilaroi and Wongaibon, showed area ratios of 8.46, 5.03 and 2.10 respectively. The three tribes together show a mean area ratio of 5.02. It may be inferred from this that tribal populations in this region approximated 2,500 persons, as against the value of 500 assumed for the continent. The early observers quoted by Kryzwicki (1934) gave even higher estimates for the first two tribes. Thus it may be concluded that these three tribes on cultural grounds should not be included in the basic series.

FIGURE 7. Boundaries of circumcision and subincision initiation rites.

A second cultural factor considered as a basis for exclusion in the basic series is involved in the spread of the initiation rites of circumcision and subincision. These ceremonies seem, in terms of age-area theory, to have originated in the center of the continent, and hence at the outer boundaries of their distribution they appear to be recent acquisitions among the affected tribes. The distribution of the rites are given in figure 7, in which an eastern, a northern, and a western set of boundaries can be identified. On its eastern limits, the boundaries of the two ceremonies coincide from the Gulf of Carpentaria southwards until a point of bifurcation is reached;
then the limits of circumcision pass in a more easterly direction to ultimately reach the Gulf of St. Vincent, while the boundary for subincision proceeds in a more westerly direction to terminate at the head of Spencer's Gulf. This eastern set of boundaries shows the phenomenon of fragmentation most clearly since larger numbers of tribes are available along its limits, and coastal ecological disturbances are minimized. It is our thesis that the recent acquisition of either or both of these initiation rites operates in some as yet unknown fashion to produce tribal units with fewer than the 500 persons assumed as our continental constant. In short, the advent of these ceremonies is associated with tribal fragmentation.

This hypothesis may be tested by comparing area ratios and early population estimates. As shown in table 1 subheading 2-B, the 25 tribes lying just west of the circumcision line have an average area ratio of 0.467, whereas the 21 tribes adjacent to the line on the east show a mean area ratio of 0.728. Thus as predicted from the basic rainfall equation, tribes lacking the circumcision ceremony have an area 1.56 times as large on the average as those tribes which have recently received the rite. The contrast would be even greater save for the fact that the coastal tribes do not follow this pattern as closely as do the interior tribes. A better basis for comparison can be obtained by eliminating the aberrant coastal tribes. When this is done, a transect of 17 non-coastal tribes lying between points A-B to the west of the circumcision line shows a mean area ratio of 0.286, whereas 13 tribes comparably situated to the east of the boundary have an average area ratio of 1.002. By this comparison, the unaffected tribes average 3.50 times the area of those which have newly taken over the rite. In figure 5, these 13 unaffected tribes are plotted as hollow squares, and it will be seen that they are distributed rather uniformly about the basic rainfall curve. The corresponding 17 affected tribes are plotted as crosses, and they consistently fall far below area values predicted from rainfall, thus demonstrating reduced tribal areas. A further disturbing factor arises from the presence of ecologically important unearned surface water from the Darling River in the territory of nine unaffected tribes lying to the east of the line. By further eliminating the tribes thus influenced, and their partners in comparison across the line, even more striking results are obtained. Thus 12 affected tribes west of the line show a mean area ratio of 0.318, whereas eight contiguous tribes to the east of the line give an average area ratio of 1.33. Even though the smaller numbers involved diminish the validity of the comparison, it is striking that the non-circumcising tribes have areas averaging 4.19 times larger than their western neighbors who have recently acquired the ceremony. This series of comparisons suggest that, in the absence of visible ecological factors capable of producing changes in densities, the tribes just to the west of the line are characterized by much smaller population sizes than the assumed constant of 500 persons. The population estimates for this region as summarized by Kryszwicki (1934) strikingly confirm this inference. There can be little doubt
that the diffusion of circumcision rites to the east has been associated with tribal fragmentation.

The above analysis was concerned with the rite of circumcision, either alone or combined with subincision. Since the most striking differences were found in a transect in which some of the affected tribes practiced subincision as well as circumcision, it will be of some interest to examine the effect of subincision alone as a differentiating trait. This can be achieved by comparing tribes just to the west of the subincision line, as shown between points C–D in figure 7, with corresponding tribes practicing only circumcision lying just east of this boundary between points C–D'. The six affected tribes to the west of the line have a mean area ratio of 0.185, whereas the five unaffected tribes across the line to the east show an average area ratio of 0.262. The tribes which practice only circumcision have 1.42 times as large an area on the average as those neighboring groups which perform both initiation rites. Despite the very small size of the samples involved, these data suggest that the rite of subincision when recently acquired tends to produce tribal fragmentation beyond that involved with the spread of circumcision alone. The available estimates given by Kryzwicki (1934) indicate very small tribal populations for the tribes here practicing dual initiation rites, and thus lend confirmatory evidence to the theory of fragmentation.

The evidence from the northern boundaries of circumcision and subincision is based upon very small samples, but it tends to substantiate the trends observed among the tribes along the eastern limits of the rites. Three non-coastal tribes lying just north of the circumcision boundary show an area ratio averaging 2.31. Five interior tribes positioned between the limits of circumcising and subincising show a mean area ratio of 1.56. It should be recalled that the Daly River tribes and the Murngin complex of north-eastern Arnhem Land, both coastal in location and lying between these lines, were remarked by Tindale (1940, p. 150) as showing fragmentation. Three interior tribes just inside the subincision boundary average 1.01 for their area ratio. These data are scanty but consistent with the suggestion of fragmentation following the acceptance of both circumcision and subincision that was noted along the eastern limits of these ceremonies.

The western boundaries of the rites coincide throughout their length. An examination of the area ratios on either side of this line does not confirm the trends found for the eastern and northern boundaries. The 19 unaffected tribes to the west of the line show an average area ratio of 0.534, whereas the 12 tribes practicing both rites just east of the line have a mean area ratio of 0.751. There are several local factors which may explain these discordant results. Information relating to the tribal groups in this region is less detailed than for most of the rest of the area used for analysis. Thus occasionally subtribal units may have been confused with tribal entities. The boundaries of most tribes are approximate rather than fully defined by the data. As noted earlier coastal tribes do not closely follow the pattern of fragmentation established for interior tribes: of the 19
tribes outside the boundary, no less than 11 are coastal in location. Further, this coastal stretch was characterized by unexpectedly low average area ratios. Unfortunately there are virtually no population estimates for these tribes to indicate whether their populations conform reasonably to the assumed constant of 500 persons.

Finally, a further environmental factor may have some influence here. The two areas of maximum rainfall variability in Australia, occur (modified after Gentilli, 1946), as might be expected, in arid regions. The largest is found centered in the Boulia region of Queensland, as shown in figure 7. Here the pattern of tribal fragmentation so closely follows the region affected by minimum rainfall reliability as to suggest that some causal relationship exists between the two. In these terms unreliable rainfall may increase the tendency toward fragmentation which also seems associated with the recent acquisition of circumcision and subincision. A second area of maximum rainfall variability centers in Western Australia along the Ashburton River, as indicated in figure 7, and extends over the broken highlands of the Hammersley Range to the north and the Barlee Range to the south. Again, maximum fragmentation seems to have coincided remarkably with the pattern of minimum rainfall reliability. For these various reasons it is considered that the negative evidence from the western boundaries of the initiatory rites does not vitiate the earlier conclusion that tribes which have recently acquired circumcision and subincision rites show a tendency toward fragmentation. The affected belts of tribes have therefore been properly excluded from the basic series.

TRIBAL FRAGMENTATION

The question as to why such fragmentation should occur is not to be easily answered. The spread of both initiation ceremonies is known to have been a gradual and essentially undramatic process. Neighbors were known to be practicing the rites, they were witnessed by visitors, and when introduced later with ceremonial sanctions, it is difficult to comprehend why diffusion should be accompanied by social shock-effects. The problem is further complicated by the fact that both the patterning of area ratios and the population estimates of early observers for tribes deep within the affected area strongly suggest that tendency toward fragmentation was transient, that tribes which had practiced the rites for longer periods of time tended toward reintegration so that tribal populations returned to the assumed constant of about 500 persons. It is on these grounds that a block of 20 tribes in the center of the area of initiating tribes have been included in the basic series. It is perhaps enough to indicate here that the area ratio method has served to identify the phenomenon of transient tribal fragmentation in Australia, to associate it with the diffusion of circumcision and subincision, and to note that the tendency seems heightened in areas of minimum rainfall reliability. The functional explanation will certainly be found in the realm of social forces and interactions, and thus will await further research by cultural anthropologists.
AUSTRALIAN ABORIGINAL POPULATIONS

AVERAGE SIZE OF TRIBES

Throughout the discussion the assumption has been used that the Australian tribe, in a broad statistical sense averages about 500 persons. In this assumption the existence of a marked central tendency is more important than the absolute size of the estimate. The calculations of Brown (1930), who systematically surveyed the problem, yield averages from 437 to above 523 persons per tribe. Kryzwicki (1934) comprehensively covered the available literature and reached similar values. He tabulated early estimates for 123 tribes with the following results: 70 tribes numbered less than 500 persons; 37 tribes numbered between 500 and 1,000; 12 tribes ranged between 1,000 and 2,500; and four tribes contained more than 2,500 individuals. From these figures Kryzwicki concluded that the tribe in Australia averaged about 550 persons, but he cautioned that his compilation contained inherent errors. The majority of his estimates originated from the correspondents of E. M. Curr, and Kryzwicki (1934, p. 305) provided the following evaluation of them:

...individuals, with but few exceptions, who were fundamentally far from any systematic scientific interest in the phenomena observed by them. In the best cases they were persons who were willing to relate what they had seen during their personal contacts with the natives. They saw, or rather encountered, a certain number of bands forming integral parts of tribes: this was usually enough for them, and more often than not they treated such bands as tribal communities... And so, more especially as regards tribes with a population of under 500 souls, the possibility is very great that we may have included in our list such names which are designations of portions of tribes.... Another difficulty to overcome is to ascertain where the limits of a tribe end and those of a nation begin. The category of tribes with over 2,500 head of population quoted in our table really embraces only nations.... We cannot issue any definite opinion whether these were really nations or only large tribes, on the basis of the material we have at hand. But we draw attention to this difficulty as also to the caution which is indicated and even essential when studying the data given hereunder.

Kryzwicki further warns that his list of 123 tribes represent poor regional sampling for the continent, and that Curr's informants tended to ignore the many small tribes, reporting on disproportionate numbers of large and very large tribes. He concludes cautiously that the typical population of an Australian tribe may be considered to range between 300 and 600 persons.

Of the 123 tribes listed by Kryzwicki it has been possible to identify 77 as corresponding to those defined by Tindale (1940). Most of the unidentified "tribes" are hordes by the latter's list, some cannot be equated with Tindale's nomenclature, and half a dozen required exclusion for other reasons. Although Kryzwicki was fully aware of the dubious accuracy of the estimates he quotes, the situation is further complicated by an epidemic which seems to have been smallpox, that spread through parts of eastern Australia in the early nineteenth century, and may have affected most of the continent. Depopulation clearly followed, but the magnitude of its impact cannot now be estimated. This factor may result in Kryzwicki's values, and our own, being underestimations.
COMPARISONS OF POPULATION ESTIMATES

Despite these difficulties it seems worth testing population data against our predictions for tribal population size derived from the basic rainfall equation. The method of estimating the size of tribal populations from the area ratio determined from the basic equation requires that the size of the populations approximates a statistical constant. In this case it has been assumed to be 500 individuals, but should later more accurate data indicate a changed value, it would not affect the method. Estimated population size will vary directly with the area ratio: thus an area ratio of 1.00 indicates a tribal population estimate of 500 persons; a ratio of 2.00 gives an estimate of 1,000; and a ratio of 0.50 an estimate of 250 persons. Since the method is applicable only to those groups of tribes in which the area is a direct and constant expression of population size, the following categories in which ecological factors modify tribal densities have been eliminated: (1) coastal and insular tribes; (2) tribes affected by unearned surface water.\footnote{The three large "confederacies" have been excluded to keep the coordinates of the diagram shown in fig. 8 within reasonable and convenient scale values. They should perhaps also be excluded as being probably affected by unearned surface water.} This leaves for comparative purposes the basic series plus those circumcising and subincising tribes which have not been excluded by the above criteria. From Kryzwicki’s list of tribes there are 45 which fulfill the necessary conditions. Figure 8 shows the population estimates of early observers plotted against estimates calculated from area ratios. Prior to plotting, the estimates by field observers were independently graded as to their validity as judged from cultural factors involving care of observation and internal consistency. Of the 45 estimates, 11 were judged as good (largely the data of modern anthropologists), 27 were considered as fair, and 7 were classed as poor in probable accuracy. These categories are shown by appropriate symbols in figure 8. It will be noted that the estimates considered to be poor give the greatest scattering, whereas those thought to be good give the least, thus suggesting that the independent judgments of the accuracy of these estimates was made with a basis of reason.

The relationship between the observer’s estimates of population size and the values predicted by the area ratio methodology can be tested in several different ways. One involves the coefficient of linear correlation, $r$, and merely gives the degree of association. The value for $r$ is 0.436 for the total series of 45 tribes, and 0.509 for the 38 tribes judged to represent good or fair estimates. In view of the scattering shown by the 7 estimates judged to be poor, it seems proper to ignore this category as representing inaccurate guesses by poorly qualified observers.

A better method of measuring the agreement between the two sets of estimates is given by $r_1$, the coefficient of intra-class correlation. This more exact way measures the deviation of the data from exact agreement, represented by the dotted line. Its calculation involves the duplication
FIGURE 8. Correlation between tribal population estimates from early observers and those calculated by area ratio methodology.

of the data by reflection about this axis of agreement. The value for $r_1$ for 45 tribes is 0.400; for the 38 tribes judged to represent good to fair estimates it rises to 0.504. Although not high, the degree of agreement indicated is fairly satisfactory considering the dubious nature of the tribal estimates by early observers. With accurate estimates from modern observers and a refined predictive equation, a much closer measure of agreement should result. Even in its present form the result suggests that the assumption of 500 persons per tribe is close to a proper figure. More im-

FIGURE 9. Frequency distribution of tribal populations as estimated from area ratio methodology.
portantly, the result validates the area ratio methodology, and suggests that when the basic equation has been refined to include the full set of ecological variables it will become more accurate than the population estimates quoted by Kryzwicki, and hence a useful demographic instrument for aboriginal Australia.

VARIATION IN POPULATION SIZE

If it will be granted that the validity of the assumed average of 500 persons per tribe has been demonstrated as a statistical abstraction, it becomes feasible to investigate the variance of the size of Australian tribal populations. Estimates for the 123 tribes of the basic series were made from their area ratios and the results were seriated. Using group intervals of 100, the distribution is shown in figure 9. It will be noted that the frequencies for the extremes of the distribution seem to show a deficiency in numbers. Thus of the 123 tribes, but 6 cases fall below 200 and only 15 occur in the unlimited range above 900. Consequently there appears to be a more than expected clustering tendency for tribes to average between 200 and 900 in population. It is unfortunate that the total series is too small in numbers to allow a statistical demonstration of the significance of this clumping. The mean value of the frequency distribution lies at 575, but this value is an artefact resulting from the use of arithmetic mean rather than the geometric mean. (The proper calculation was precluded by limitations of time in preparing for two years' further field work in Australia.) Thus the calculated mean is higher than the true mean, which by the nature of the area-ratio method is dependent upon the value assumed for the size of the tribal population and should have approximated 500. The mode falls between 400 and 500, giving a measure of the skewness of the distribution. The standard deviation is 300, and since it would presumably be of the same general magnitude for the proper calculation using the geometric mean, the corrected values can be estimated as a mean of 500 with a range from 200 to 800 as defined by plus and minus one standard deviation. Despite the evident inadequacies of the data, it may be claimed that Kryzwicki's earlier analysis is essentially confirmed.

The validation of 500 persons per tribe as a statistical constant of approximately correct magnitude allows the conversion of the basic equation expressing the relationship between tribal area and mean annual rainfall into a new form expressing density, D, as a function of rainfall:

\[
D = \frac{0.0703037}{X - 1.58451}
\]

where X is mean annual rainfall, (as indicated in figure 4).

DISCUSSION

In the early stages of this investigation it was assumed, in the absence of adequate data for the size of the Australian tribal population, that in the basic series the size of the tribal territory is an inverse measure of the
density of the population, through the interlocking assumption that there tribes average about 500 persons in size. The high degree of curvilinear correlation between mean annual rainfall and the size of the tribal area confirms both of the intervening assumptions. The lack of functional validity in either case would have resulted in a low value for rho, save for the improbable instance in which one unrelated assumption somehow systematically compensated for the uncorrelated vagaries in the other. The value of 0.81 for rho is ample evidence that both of these independent assumptions hold true with a reasonable degree of validity.

A brief examination of the variance of the size of tribal populations in this correlation is revealing. With rho equal to 0.81, the explained variance of the dependent variable amounts to 65 per cent of the total, the unexplained variance to but 35 per cent. It is understood that the explained variance is expressed not only in terms of mean annual rainfall, but also in terms of such other variables as may prove to be partially correlated with the former. The unexplained variance must be considered to contain deviations due to the following types of errors which diminish the value of rho:

(1) Errors of verification: the nature of the tribe as an entity; location of tribal boundaries; instrumental errors in planimeter values for tribal areas; type of map projection; assignment of mean annual rainfall values tribally; and unrecorded microgeographical variations in rainfall.

(2) Errors of space: assumption that basic series ecologically represents complete regional homogeneity.

(3) Errors of time: assumption that no shifts in rainfall values through time have affected recorded tribal boundaries.

(4) Errors of culture: assumption that with broad cultural uniformity in Australia no small regional differences exist which might affect extractive efficiency.

(5) Errors of the environment: use of mean annual rainfall as the sole environmental variable. It must be expected that the following variables will also influence aboriginal densities; (a) rainfall reliability, (b) rainfall intensity, (c) seasonality of rainfall, (d) humidity, (e) evaporation rates, (f) temperature, (g) length of growing season, (h) altitudinal differences, (i) soil variations including trace mineral deficiencies, and (j) other unspecified factors affecting the biota.

(6) Errors in population size: appreciable deviations from assumption that tribal populations approximate 500 persons as a constant will occur, whether systematic or erratic in nature.

In addition to the above specified sources of error, the value of rho is dependent upon the causal relationship between mean annual rainfall and size of the tribal population. The exact contribution to the unexplained variance can be evaluated for none of these types of errors, but each of the first four categories must have affected it slightly, while the last two must have increased it substantially. Thus it must be inferred that a very close causal relationship exists between rainfall and the size of tribal territory; that the densities of Australian aboriginal tribes are rigorously subject to environmental determinism.

Anthropologists have been so impressed with the bewildering variability of cultural expression that they have tended to deny the possible operation
of environmental determinism. Historically this is understandable, for the early proponents of the latter concept claimed so much that their position was easily discredited. Our claim here is merely that on the simplest cultural levels the densities of human populations are primarily determined by the variables of the environment. Since man, like other living things, must extract his energy from the environment there are good ecological reasons for such determinism. In economies higher than the hunting and collecting level, the environmental control of densities will become less rigorous and hence less visible. The same will be true for cultures changing their form rapidly in time, especially at the technological level. But as long as man extracts his energy from the environment by crude means his population density will depend to some extent upon such determinism. For man in the Pleistocene, and much of our evolutionary interest in him centers in this period, the environment must have determined his population density as completely as it did for the Australian aborigines.

It follows as an important corollary of environmental determinism of aboriginal densities that these populations must have been in essential equilibrium with their environment. This idea will not be new to biological students of natural populations, for it is a major premise in the structure of evolutionary thinking, but it has remained foreign to most anthropological conceptualization. Although utilized in a qualitative form, either explicitly or implicitly, by Kaberry (1939), Kryzwicki (1934), Steward (1938), Tindale (1940), and Wolfe (1933) among others, it has not received widespread anthropological acceptance. It is not claiming too much to insist that studies of the population dynamics of man at a hunting and collecting level of economy, whether Pleistocene or modern, must start with the premise that such groups are usually in equilibrium with their environment.6 A more detailed discussion of the utility of this concept will be found in Bartholomew and Birdsell (ms.).

The present study has a number of applications to research in aboriginal Australia. The finding that the size of the tribe approximates 500 persons in a statistical sense validates one of the primary simplifying assumptions used by Birdsell (1950) for the construction of simple gene flow models used in exploring the dynamics of aboriginal populations. Even in the present tentative form of the basic equation, the area ratio method allows for the construction of considerably improved gene flow models compared to those previously published. In the latter devices such as “accelerators” were used in the Boulia region, and “inhibitors” in the region of the New South Wales “confederacies,” to partially adjust for suspected deviations from the tribal norms. It is now evident that these adjustments were much too conservative and that other regions may need alteration. It

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6Exceptions occur among such peoples as the salmon fishermen of the Northwest Coast and the bison hunting horsemen of the Great Plains of North America. Technically both belong with the hunting and gathering peoples but in each case these more complicated cultures are based upon special circumstances. Among culturally simple groups the concept should hold with considerable regularity.
is now possible to start with Tindale’s tribal map and to make the corrections required for those areas in which the average size of the tribal population systematically deviates from the statistical mean of 500 persons. Sporadic deviations from this mean may also be corrected by the area-ratio method. Thus an idealized grid of genetic isolates can be created for modern aboriginal Australia which is superior for gene-flow models to the actual tribal map.

In a like way the high correlation between mean annual rainfall and the size of the tribal area will allow the construction of idealized genetic isolate grids for any time point in the Recent or terminal Pleistocene for which paleoclimatological estimates for approximate rainfall can be provided. Such data now are too scanty to be used, but recent strides in the natural sciences in Australia suggest that they may become available within the next decade. Then it will be possible to construct gene flow models, to determine the distribution of aboriginal densities, and to take an approximate census for a given period of prehistory. When the paleoclimatological variables can be defined for the now sunken Sahul Shelf, which formerly connected Australia with New Guinea during glacial periods of eustatic lowering of sea-level, the same techniques can be applied to that submerged land surface, an area which is of some importance in the reconstruction of population dynamics in prehistoric Australia.

The basic curve in figure 4, which depicts the relationship between mean annual rainfall and the size of the tribal territory, suggests that the apparently simple material culture of the aborigines is in fact surprisingly adaptable. While the curve is a statistical artefact, the data show a remarkable smoothness in their distribution around the curve from one extremity to the other. This may be interpreted as indicating that, despite the relative uniformity of their material culture throughout the continent, the aborigines maintain the same high level of extractive efficiency (for a hunting and collecting people) from the most arid environment to the wettest regions in Australia. Thus no breaks occur in the distributional pattern of the data as one passes from spinifex and sandhill country at one extreme through the various types of desert scrub lands, mallee country, grassland and open forest, dense eucalyptus forest, finally to the nearly impenetrable rainforests of the Cairns tableland region. Both the flora and fauna change drastically in abundance and in type in such a transect and the pattern of the data is witness to the constant level of cultural adaptedness of the aborigines. One qualifying statement must be made at this point. If densities were substituted for the size of tribal areas in relationship to rainfall, the picture might change slightly. This conversion is dependent upon the absence of systematic regional variations in the average size of the tribal population.7

7As stated earlier, there is little evidence for such variation save possibly in the region of the tropical rainforest. Tindale informs me that an examination of his genealogies for the tribes of this region suggests that the nuclear 11 tribes may have had considerably smaller populations than the 500 considered generally valid
The broad generalizations resulting from this investigation are applicable to other culturally simple hunting and collecting peoples in different places and in different times. But it must be stressed that the specific variables and the detailed constants for the Australian equation are not transferable to any other people. The equation relating human population densities to a given environment will depend in each instance upon three major categories of variables:

1. The variables of the environment in terms of climatic, soil, and topographic factors;
2. The variables influencing the phylogenetic history of the local biota;
3. The variables in culture which determine a people's extractive efficiency.

In Australia mean annual rainfall at this preliminary level of analysis gives reasonably accurate predictions for population densities, and the same may hold true for other interior temperate and tropical populations. On the other hand, a people such as the Eskimo living in the Arctic would show densities conditioned by other variables such as temperature, length of the growing season, and the various factors which affect the marine fauna upon which they are dependent for winter survival. In general those variables which influence the local biota most importantly can be expected to be the ecologically important variables of the density equation.8

Even regions which seem environmentally to be approximately equivalent to portions of Australia will not show similar human densities or density equations for peoples at about the same level of extractive efficiency. The Shoshoni of the Great Basin in the United States, and the Bushmen of the Kalahari Desert of South Africa have been shown by Vorkapich (ms.) to have quite different densities from the Australians for the same rainfall regimes. Aschmann (ms.) shows even more striking density differences for the hunters and collectors of the middle region of Baja California. With similar environments, and extractive efficiency differing but little among these four peoples, the disparities in their densities must be attributed primarily to differences in the local biota and food chains. The Australians are dependent upon a unique flora and a marsupial fauna. The trophic levels these comprise will not be duplicated elsewhere. The Shoshoni have specialized of necessity as seed and root gatherers; game is of but

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8While the Australian data lent themselves to an analysis primarily based upon the size of tribal territories, it must not be presumed that the relative constancy of size of the Australian tribal population will be met with among all other peoples. In terms of cultural analogy, the assumption of similar sized population groups in the Pleistocene makes an attractive working hypothesis, but among modern peoples it seems likely that similar investigations will have to deal directly with data for densities.
little importance to them. The Bushman can depend more upon grazing animals which are more abundant in his environment than in those of the other three peoples. For Baja California human densities were markedly conditioned by the presence of a wealth of starchy plant food in the form of half a dozen species of agave. These brief examples are sufficient to indicate that the phylogenetic history of the local biota of a region is of prime importance in the formulation of the human density equation; constants derived from one region cannot be applied to another biotic province. The fact that the Indians of middle Baja California with lower rainfall and no higher extractive efficiency show more than 50 times the density that Australians do in roughly equivalent climatic conditions highlights the importance of the biotic variable. Its evaluation will require detailed and quantitative ecological research upon the composition of food chains and trophic levels as they affect man.

The efficiency with which a people extract energy from their environment will vary with the content and complexity of their culture. Forms of social organization may contribute to efficiency, but for simple hunting and collecting cultures the techniques for the fabrication of primary and secondary tools will usually be of greater importance. It is unfortunate that to this late date ethnologists have provided little quantitative data on the relative efficiency of extractive devices used at this cultural level. Without such information, and there remains but little time in which to collect it, it will remain impossible for archeologists to evaluate the extractive efficiency of the various populations in the Pleistocene which are necessary to our understanding of human evolution. In view of the magnitude of the task remaining to be accomplished in this field it is perhaps fortunate that of the three categories of variables influencing the human density equation that referring to cultural variation appears to be the least important. For most simple hunting and collecting peoples, a surprisingly large proportion of the total food supply is probably obtained through the use of the unaided hands, a digging stick, and the simple spear or bow.

SUMMARY AND CONCLUSIONS

(1) For the Australian aborigines a simple exponential relationship exists between mean annual rainfall and the size of the tribal territory. For the total series of 409 tribes the equation takes the form of: \( Y = 615.00 X^{-0.98980} \) where \( Y \) is the size of the tribal territory and \( X \) is the mean annual rainfall.

(2) By the systematic exclusion of categories of tribes in which ecological factors change the population density, as compared to an inland terrestrial standard, and by the elimination of tribes in which cultural factors modify the size of the population from the assumed constant of 500 persons, the equation for the basic series becomes: \( Y = 7,112.8 X^{-1.58451} \).

(3) The validation of the ecologically and culturally excluded tribal categories through the area ratio method yields preliminary data toward the establishment of a quantitative human ecology in Australia. Densities are
increased measurably by the marine foods available to coastal and insular tribes. Riverine foods from unearned surface water may provide the greatest increase in density. Among the cultural factors, advanced political organization may result in a marked increase in the size of the tribal population, whereas the recent acquisition of either or both circumcision and subincision ceremonies, for reasons which have not been defined, is associated with a transient decrease in the size of tribal population.

(4) A comparison between the admittedly inaccurate early estimates for the size of tribal populations and estimates based upon the area ratio methodology confirms the assumption that statistically the size of the Australian tribe approximates 500 persons, with an effective range of variation between 200 and 800. This clustering tendency of tribal population size is apparently based upon territoriality, limited personal mobility, and absence of tribal authority as these factors operate through the forces of social cohesion to define and maintain an effective social entity.

(5) The value of 0.81 for the coefficient of curvilinear correlation of the basic equation results in an explained variance of 65 per cent and an unexplained variance of but 35 per cent. A listing of the categories of errors which have contributed to the unexplained variance indicates that the size of the tribal territory is causally and rigorously determined by the magnitude of the mean annual rainfall. This relationship validates the intervening, independent assumptions that for the basic inland tribes density is an inverse function of the size of the territory and that tribal populations approximate 500 persons in a statistical sense. Thus the basic equation can be rewritten in the form of an equation for density as follows:

\[ D = \frac{0.0703037}{X^{-1.58451}} \]

(6) The high degree of correlation between rainfall and density indicates that the Australian aborigines are subject to a rigorous environmental determinism of their densities. There is little reason to believe that most other Recent or Pleistocene hunting and collecting populations were not equally subject to environmental determinism of this nature. An obvious corollary is that such populations were in equilibrium with their environment, provided that culture, and hence extractive efficiency, was but slowly changing.

(7) The methodology here developed for Australia can be extended to simple hunting and collecting populations at other points of time or space, but the density equation will differ in terms of: (a) the variables of the environment critical for the biota; (b) the variables of the phylogenetic history of the local biota; and (c) the variables of culture which determine the extractive efficiency of a population.

(8) Applications of this study for Australia allow the correction of existing tribal maps to approximate an idealized distribution of genetic isolates for use in gene flow models. Similar genetic grids can be constructed for various points in prehistory when paleoclimatological estimates for mean annual rainfall in times past become available. Such instruments will al-
low the taking of prehistoric censuses and the determination of the pattern of distribution of prehistoric densities, even extending out onto the now submerged Sahul Shelf.

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