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# Reports

## A Test of Communication and Cultural Similarity in Polynesian Prehistory[1]

PER HAGE, FRANK HARARY, AND DAVID KRACKHARDT
*Department of Anthropology, University of Utah, Salt Lake City. Utah 84112/Department of Computer Science, New Mexico State University. Las Cruces. N.M. 88003/Carnegie Mellon University. Pittsburgh. Pa. 15213. U.S.A.* 2 VI 98

In every field of anthropology one comes up against the problem of determining whether two (or more) networks defined by different relations over the same set of groups or individuals are significantly correlated. The networks may be defined by relations, say, of genetic similarity and geographical distance between pairs of villages, kinship distance and exchange transactions between pairs of individuals, or lexical differentiation and spatial distance between pairs of languages. Such networks can be correlated, but the problem is to find a test of statistical significance. The solution is to use a powerful statistical method invented in medical research known as the Mantel test (Mantel 1967) and more recently as the quadratic assignment procedure (Hubert 1987). Our purpose is to show how this method can be used to test network hypotheses in archaeology.[2]

In an innovative and influential contribution to Oceanic archaeology, Irwin (1992) proposes that the prehistoric exploration and colonization of the Pacific Islands was rapid, purposeful, and systematic. Irwin's study is timely given the accelerating growth of knowledge in Pacific prehistory (Allen 1994, Bahn 1993, Green 1993, Thorne 1993) and the increasing recognition that most islands in the Pacific were joined in various types of social and linguistic networks (Hage and Harary 1996, Kirch 1988). Drawing on computer simulations, studies of experimental voyaging, and practical sailing experience, Irwin argues that early voyagers in the Pacific adopted a cautious strategy of exploring first upwind in order to ensure a safe return to their point of departure. By this he means sailing east using summer and winter westerlies and returning west with the resumption of the prevailing easterly tradewinds. Then, with improving navigational skills and expanding geographical knowledge, they sailed across the wind and, finally, riskiest of all, downwind. In general, the archaeological evidence supports the hypothesis that islands from which it was easiest to return were settled first.

Irwin also hypothesizes that island communities did not necessarily become isolated after settlement but remained in communication and, depending on their degree of "mutual accessibility," continued to influence each other. Mutual accessibility is defined as the product of closeness and angle of target size between island pairs. In support of his hypothesis, Irwin generates an interisland accessibility network which he then compares with networks showing the cultural, linguistic, and biological similarity between pairs of islands in Polynesia. The cultural network consists of a mapping of Polynesia into cultural areas as drawn by Burrows (1938): the linguistic network is a phylogenetic tree of the Polynesian languages, and the biological network is a dendrogram showing the similarity between populations based on shared physical traits (Pietrusewsky 1971, Howells 1979). Irwin sees "close correspondences" between accessibility and all three of these networks. These correspondences contradict the traditional view of "islands as laboratories in which the inhabitants worked out their human inheritance alone, in a range of different circumstances" (Irwin 1992:206). They would, for example, support the idea, derived from Renfrew and Cherry's (1986) peer polity interaction model, that social stratification in eastern Polynesia was the result of elite interaction in a network of societies rather than a modification of an already stratified ancestral Polynesian society as hypothesized by Kirch and Green (1987).

There is a serious difficulty with Irwin's analysis because he has no method for comparing these networks. All that can be said is that the networks appear to correspond, but we really do not know if accessibility has a statistically significant relation to cultural, linguistic, and biological similarity. To appreciate the problem, one may compare Irwin's network of interisland accessibility in figure 1 (the higher the numbers on the lines, the greater the accessibility between island pairs) with Burrows's diagram of culture areas in Polynesia in figure 2.[3] How significant is the match? It is difficult to say.



2. Applications to cultural anthropology include Nakao and Romney's (1984) test of competing cognitive models of kinship classification and Schweizer's (1997) analysis of embeddedness in gift-giving networks. For applications to physical anthropology see Dow and Cheverud (1985) and Smouse and Long (1992). An application to primate studies is given in Schnell, Watt, and Douglas (1985).

3. The islands in figure 1 are a subset of those in figure 2. Tongarava, Rakahanga, and Manihiki in figure 2 are included in the Northern Cooks in figure 1.

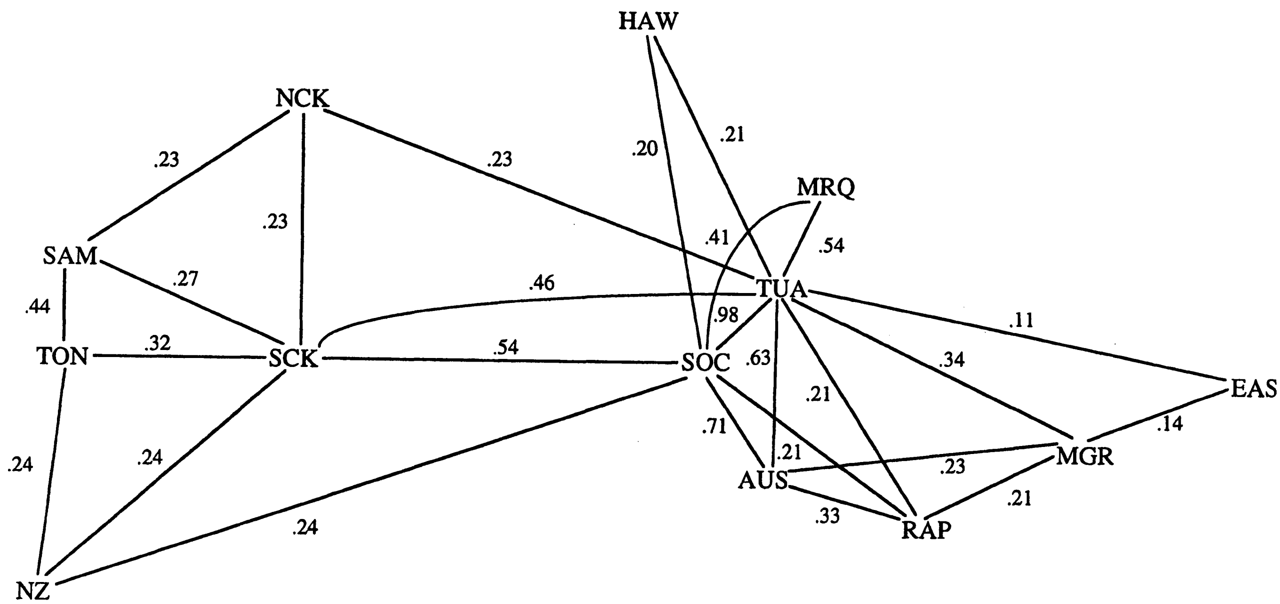


FIG. 1. *Irwin's (1992) mutual accessibility network of Polynesian islands.* TON, *Tonga;* SAM, *Samoa;* SCK, *Southern Cooks;* NCK, *Northern Cooks (Tongareva, Rakahanga-Manihiki, Pukapuka):* SOC, *Society Islands;* MRQ, *Marquesas;* TUA, *Tuamotus;* MGR, *Mangareva;* AUS, *Australs;* RAP, *Rapa;* HAW, *Hawaii;* EAS, *Easter;* NZ, *New Zealand.*

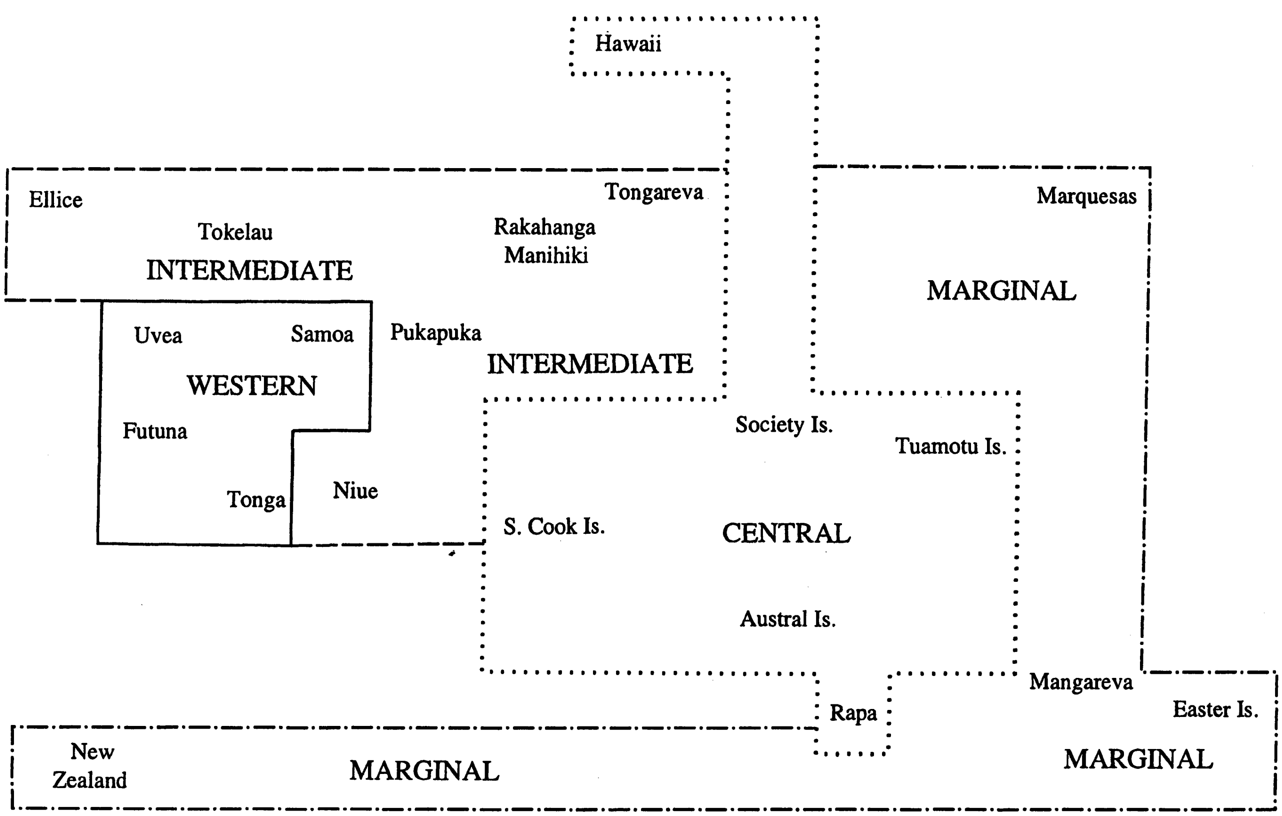


FIG. 2. *Burrows's (1938) distribution diagram of cultural groupings in Polynesia.*

**TABLE 1**
*Cultural Similarity and Minimum Accessibility Matrices for Polynesia Based on Burrows (1938) and Irwin (1992)*

| | TON | SAM | SCK | NCK | SOC | MRQ | TUA | MGR | AUS | RAP | HAW | EAS | NZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tonga (TON) | | 2 | 16 | 8 | 15 | 18 | 17 | 19 | 16 | 18 | 19 | 19 | 17 |
| Samoa (SAM) | .56 | | 16 | 9 | 16 | 18 | 17 | 18 | 18 | 19 | 19 | 19 | 17 |
| Southern Cooks (SCK) | .68 | .73 | | 8 | 3 | 7 | 6 | 10 | 9 | 10 | 8 | 14 | 9 |
| Northern Cooks (NCK) | .82 | .77 | .77 | | 9 | 11 | 9 | 12 | 11 | 14 | 13 | 15 | 12 |
| Society (SOC) | .78 | .83 | .46 | .77 | | 4 | 3 | 8 | 9 | 8 | 6 | 12 | 6 |
| Marquesas (MRQ) | .82 | .85 | .70 | .85 | .59 | | 7 | 9 | 9 | 10 | 5 | 12 | 8 |
| Tuamotu (TUA) | .76 | .83 | .54 | .77 | .02 | .46 | | 10 | 12 | 8 | 7 | 15 | 10 |
| Mangareva (MGR) | .91 | .90 | .86 | .89 | .78 | .80 | .66 | | 13 | 15 | 10 | 13 | 11 |
| Australs (AUS) | .84 | .81 | .62 | .82 | .29 | .66 | .37 | .77 | | 12 | 11 | 15 | 12 |
| Rapa (RAP) | .90 | .89 | .82 | .86 | .79 | .85 | .79 | .79 | .67 | | 11 | 17 | 13 |
| Hawaii (HAW) | .89 | .81 | .85 | .89 | .80 | .87 | .79 | .92 | .81 | .95 | | 12 | 11 |
| Easter (EAS) | .97 | .95 | .92 | .95 | .91 | .90 | .89 | .86 | .94 | .90 | .97 | | 14 |
| New Zealand (NZ) | .76 | .76. | .76 | .90 | .76 | .88 | .76 | .92 | .79 | .91 | .91 | 1.00 | |

We can answer this question if we go back to the data on which the networks in figures 1 and 2 are based and apply the statistical method known as the quadratic assignment procedure. This is a nonparametric permutational method for determining whether there is a statistically significant relationship between two "similarity matrices." A similarity matrix is a square matrix whose entries show the degree of similarity between pairs of elements. In the present case the entries in one matrix would show the accessibility between pairs of islands while the entries in the other matrix would show their cultural, linguistic, or biological similarity. We will use the quadratic assignment procedure to test Irwin's hypothesis concerning the relation between accessibility and cultural similarity in Polynesia. Tests for the relation between accessibility and linguistic and biological similarity must await the collection of more complete data. The linguistic data consisting of shared cognates in Polynesian languages from Clark (1979) are limited to eight of the societies in Irwin's analysis, while the biological data from Pietrusewsky (1971) are limited to eight of these societies with Samoa and Tonga not distinguished. To use the quadratic assignment procedure the matrices must be of the same order.

Irwin's accessibility network is constructed from two preliminary matrices, one of which gives the geographical distance and the other the minimum angle of target size between islands in Polynesia. The entries in these matrices are percentages of greatest distance and greatest angle of target size. These two matrices are combined in a single mutual accessibility matrix by calculating each cell's geometric mean, that is, by multiplying the two corresponding values for each cell and taking the square root of the product. On the basis of this similarity matrix, Irwin constructs a network in which islands are joined to some of their more accessible neighbors as shown in figure 1. We have subtracted the entries in Irwin's (symmetric) matrix from 100 so that the lower the number the greater the accessibility between pairs of islands. The result is shown in the lower diagonal half of table 1.

Irwin defines cultural similarity in terms of Burrows's (1938) classic study in Polynesian ethnology. On the basis of a distributional analysis of cultural traits, including artifacts, aspects of social organization, and religious ideas, Burrows identified the four subgroupings shown in figure 2. From Burrows's tabulation of cultural traits in Polynesia we have constructed a matrix showing the number of traits shared by pairs of islands.[4] The maximum number of shared traits between any pair of islands is 18. We have subtracted this number from 20 so that the lower the number the greater the degree of cultural similarity. This (symmetric) matrix occupies the upper diagonal half of table 1.

We now have two similarity matrices that we wish to compare: one in the upper triangular half of table 1 showing the degree of cultural similarity between pairs of islands and the other in the lower triangular half of table 1 showing their mutual accessibility. Such matrix comparisons have been difficult in the past because standard statistical analyses require, as a critical assumption, that the observations be independent of one another. In the present case, we have $13 \times (13 - 1)/2 = 78$ observations derived from pairing the 13 island communities. These observations are clearly not inde-

4. In constructing this matrix, traits classified by Burrows as "slightly developed," "exceptional," "recent," "few examples," "rare," "localized," and "questionable" were counted as absent; traits classified as "present but not prevalent" were counted as present. "Primal gods" were counted if all four were found. Traits in Burrows's diagrams 2, 4, and part of 15 pertaining to barkcloth, the kava ceremony, and bonito hooks were omitted because of environmental limitations. Sail types in diagram 11 were omitted because it was not always possible to determine the aboriginal type. A trait was counted as present in the Northern Cooks if it was found on at least one of the three islands.

pendent, since they share islands in their comparisons. Krackhardt (1988) has shown that such row or column interdependence in these matrices can bias standard tests of significance to a pronounced degree: Samples drawn from a population for which the null hypothesis is true have a 70% chance of appearing "significant" using standard parametric methods with a moderate amount of autocorrelation in the data.

Fortunately, an approach to performing reasonable statistical tests on matrix comparisons such as these has been developed. Mantel (1967) was the first to propose a permutation method as a test of significance for such cases. Hubert, who coined the term "quadratic assignment procedure" to refer to this permutation approach, has applied it to a wide array of problems (Hubert 1987, Hubert and Golledge 1981, Baker and Hubert 1981, Hubert and Schultz 1976). Krackhardt (1987, 1988) proposed that this philosophy could be applied to multiple regression problems wherein the data were in matrix form. A clear advantage of this approach and its multiple-regression cousin, as Pattison (1988:405) points out, is that it "provides a means of testing formal hypotheses . . . which are expressed in familiar general linear model terms."

The quadratic assignment procedure is straightforward. Each variable being correlated takes the form of an $N \times N$ matrix rather than a vector as is normally the case in correlational analysis. The first step is to calculate the traditional correlation based on the $N \times (N - 1)$ observations contained in the matrices (the diagonals are ignored). Then the rows and columns of the dependent variable matrix are permuted to give a new "random" matrix. The correlation is recalculated on the basis of this new permuted matrix. This procedure is repeated a large number of times (999 in our case), resulting in a distribution of correlation values based on these randomly permuted matrices. This distribution of values becomes the reference distribution against which the observed correlation is compared. If less than 5% of the correlations derived from the permuted matrices are larger than or equal to the observed correlation, we say that the correlation is significant at the .05 level (one-tailed). If less than 1% of the correlations are larger than or equal to the observed correlation, we say that the correlation is significant at the .01 level. If we were performing a multiple regression form of quadratic assignment instead of a bivariate correlation, we would use the same procedure to test each of the beta coefficients in the regression (Krackhardt 1987, 1988).[5]

The advantage of this simple procedure is that it is robust against varying (and unknowable) amounts of row, column, and symmetric autocorrelation in the dyadic data (Krackhardt 1988, 1993). If we draw a sample from an autocorrelated population for which the null hypothesis is true (i.e., there is no relationship between the independent and dependent variables), the probability that the sample will appear "significant" by this test is .05 (at the alpha = .05 level). This remarkable feature of the quadratic assignment procedure is the result of its being a conditional nonparametric test. Each permutation of the dependent variable retains the structure of the original dyadic data and therefore preserves all the autocorrelation (the lack of independence among observations) in each permuted correlation; the test is conditioned on the degree of autocorrelation that exists in the data.

The pairwise Pearson product-moment correlation between cultural similarity and mutual accessibility is $r = .496$ ($P < 0.001$). This result supports Irwin's theory that island communities continued to communicate and influence each other after settlement (1992:198): "With clear evidence of correspondence between human patterns and island accessibility, it must be accepted that Polynesian communities on different islands influenced one another in prehistory. Indeed, it seems that Polynesian societies were not as discretely divided as their islands, although they often appeared to be at contact." The next step would be to see, when the appropriate data become available, if these correspondences hold for linguistic and biological as well as cultural similarities using the same method of matrix comparison.

We conclude with three suggestions for improving Irwin's model. The first is to find more and better data on the distribution of cultural traits in Polynesian societies. Burrows's study was published 60 years ago, and data collected since then may enable one to clarify and add to the traits in his tables. The second suggestion is to use a larger sample of societies. Irwin's model uses only 13 societies, but Burrows's study is based on 18 societies, or 21 if the three islands of the Northern Cooks (Pukapuka, Manihiki-Rakahanga, and Tongareva) are distinguished, as they probably should be. Finally, an improved, more realistic measure of accessibility might use the inverse of geographical distance. This would have the effect of magnifying shorter distances and equalizing longer distances. This is commonly done in ecological studies in order to "reveal geographical patterns that are local in nature" as opposed to those involving "broader regional trends" (Schnell, Watt, and Douglas 1985:241). Placing greater weight on shorter distances would take account of the "close-contact zones" delineated by anthropologists (Lewis 1994 [1972], Lewthwaite 1967), the "regional homelands" and "prehistoric interaction zones" hypothesized by archaeologists (Green 1981, Kirch 1986, Weisler, Kirch, and Endicott 1994), and the "communalects" proposed by linguists (Pawley and Green 1984). For example, Tonga and Samoa are in the same close-contact zone and, as shown in table 1, are highly similar to each other, moderately similar to the adjacent Northern Cooks, and highly dissimilar to all other island societies.

5. The difference between the two is comparable to the difference between simple correlations and multiple regression analyses. Quadratic assignment is used to test the correlation between two square matrices. Multiple regression quadratic assignment is used to test the regression coefficients of each of the independent variables in a multiple regression where all variables are in the form of square matrices.

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# Possible Early Pigment Use in South-Central Africa[1]


LAWRENCE S. BARHAM
*Centre for Human Evolutionary Research at the University of Bristol, 11 Woodland Rd., Bristol BS8 1TB, England.* 20 IV 98


Four pieces of pigment (one limonite and three hematite) were recovered in 1996 during preliminary investigations of the late Middle Pleistocene archaeological site of Twin Rivers, central Zambia. The apparent antiquity of pigments here is significant in that it coincides with the shift toward composite tool technology which marks the transition from the Early to the Middle Stone Age. The systematic use of hematite is a feature of the Sub-Saharan Middle Stone Age after 130,000 b.p., but the presence of pigments at Twin Rivers suggests an early emergence of symbol use predating its full expression in the late Pleistocene.

The hilltop site of Twin Rivers (fig. 1), near Lusaka, central Zambia, was excavated by J. Desmond Clark in the 1960s (Clark 1971). A bone-and-artifact-bearing breccia was located beneath a layer of large dolomitic

1.  0011-3204/98/3905-0005$1.00. The 1996 season of research at Twin Rivers and Mumbwa Caves was funded by the National Geographic Society and the British Academy. Support in Zambia was provided by the National Heritage Conservation Commission, the Livingstone Museum, the British Council, and the American Embassy. Mark Roberts of the Open University provided the mass spectrometric dating, and his help is gratefully acknowledged. I am indebted to Desmond Clark for his continuing guidance and support of the current research program in Zambia. The comments of two anonymous referees were helpful in clarifying my thinking and the presentation of this report.