Prehistoric Population Estimates for the Tolaga Bay Vicinity, East Coast, North Island, New Zealand

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ABSTRACT

In temperate New Zealand, the widespread tropical crop, sweet potato (*Ipomoea batatas*), was stored in roofed semi-subterranean pits. These pits offer a unique chance to model the volume and weight of crops stored over time, and to interpret these in terms of population of specific sites and whole catchments. A figure of 0.84 persons (range 0.38–1.39, 95 percent confidence limits) per cubic metre of storage is derived. The smallest and largest defended sites (pa) had populations of 10 and 250 respectively, with a mean figure for defended sites of 50. In the Mangaheia Valley, some 270 ha of well drained silt alluvium supported a population of 170 (range 80–280, 95 percent confidence limits) at the end of the prehistoric period. In the whole of the Uawa catchment, the population would have been 420 (range 200–690), based on alluvial soils of some 660 ha. A figure of 250 (range 130–410) is tentatively suggested for an important sector of hill gardening in the same catchment. Apparently extensive areas of garden at Anaura Bay in 1769 suggest either very low crop productivity, a high risk of crop failure, or heavy consumption before storage.
Keywords: MAORI, DEMOGRAPHY, NINETEENTH CENTURY, STORAGE PITS, SOCIAL ORGANISATION, CHIEFTAINSHIP, NGATI POROU, JAMES COOK, GARDEN AREAS, PA, CROP PRODUCTIVITY, INTENSIFICATION.

INTRODUCTION

Settlement on the East Coast of the North Island has usually been regarded as based on dispersed hamlet- or household-sized settlements of about 5–30 people (Davidson 1981: 12; Jones 1983a). The interpretation is based on the nineteenth century records from the visit of the *Endeavour* in 1769, which entered Anaura Bay and Cook's Cove in the area with which this paper is concerned (Fig. 1). The settlement pattern is often contrasted with subsequent observations from the *Endeavour* of quite large defended settlements in the Bay of Plenty, where villages of 100 or so houses were described.

This apparent contrast is one of many that have provided fertile ground for the analysis of regional variation in New Zealand's prehistory (Prickett 1982; Salmond 1984). Little attention has been devoted to a fuller interpretation of these eighteenth century documents in the light of nineteenth century reports from the East Coast. These suggest that the Tolaga Bay vicinity had a population of some 1200 (Williams 1974: 15, 101–3), that there was considerable variation in the ranking of chiefs in the area (Dumont D'Urville 1950: 117–120), and that it was the place of residence of the "paramount" chief of Ngati Porou, Te Kani a Takirau (Polack 1838: 116–141; Smith 1910: 171–176). The eighteenth century documents in themselves give reason for caution in their interpretation. Fairly general comments, such

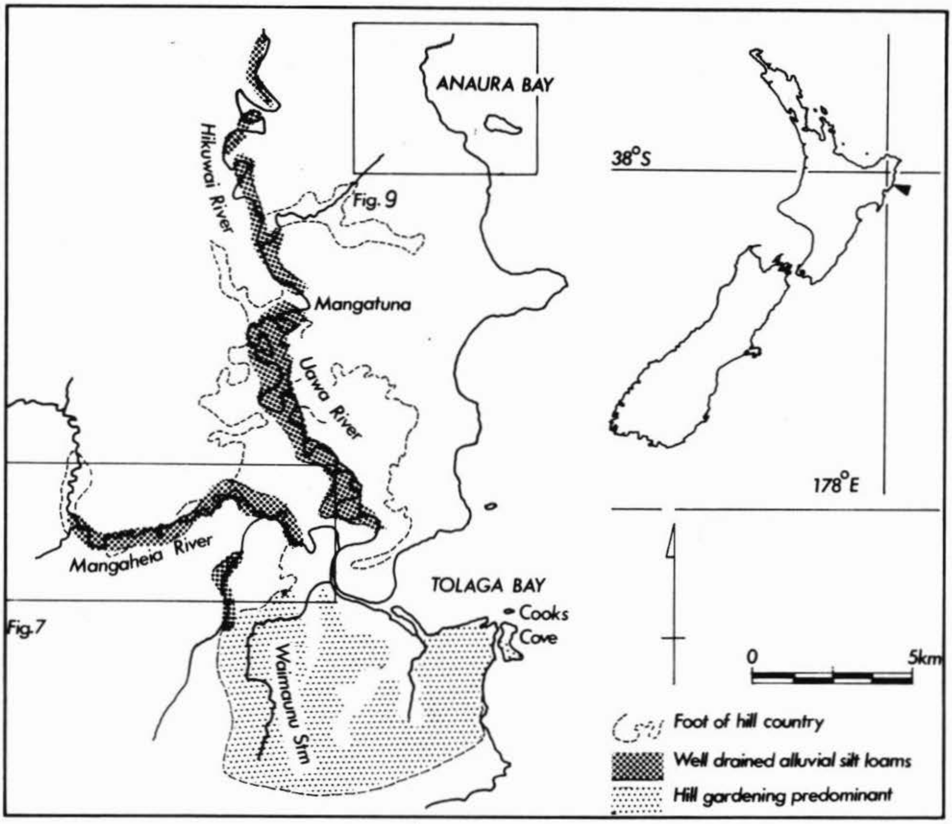

Figure 1: Locality of places mentioned in the text.

as those of Banks (1958: 61), mention abandoned houses in valleys, and areas of crops notably in excess of those needed by the population sighted. A recent archaeological survey (Jones 1986) indicates that a substantial proportion of the settlement was in and around the major river system of Tolaga Bay, in areas apparently not visited by and out of sight of the hill tops in the vicinity of the *Endeavour*'s anchorage at the entrance to Tolaga Bay (Jones 1983b).

There is therefore considerable variance between the accepted interpretation of the eighteenth century evidence, and what we know from archaeological survey and the nineteenth century accounts. Indeed, there are difficulties in the eighteenth century accounts themselves that should require caution. Can field archaeology help in resolving the matter?

This paper attempts to interpret the results of a recent extensive survey of surface archaeological evidence in the Uawa catchment in terms of prehistoric population, both populations of specific sites, and overall populations of parts of the catchment. These are compared with the horticulturally productive soils in the vicinity of the sites, and with the eighteenth century evidence of population sizes. Comment is made on the question of chieftainship and intensification of crop production.

THE INTERPRETATION OF PREHISTORIC POPULATION NUMBERS

The study of population size in prehistory is controversial (Weiss 1978; Guilbert 1981; Ross 1985). However, the effort is needed, since many of the "processual" goals of archaeology will depend on an understanding of changes and increase in population and its effect on resources. Competition within and between prehistoric communities is often cited as a cause of warfare without any grounds as to the nature of the resource base or the pressure on it (Vayda 1960; Groube 1977: 82–83). Methods of determining prehistoric population have been considered in New Zealand. The usual method is inference back from historic records (Pool 1977). This method lends itself to an assessment of settlement sizes, and of the overall population of an area. Considerations of middens and harbour or coastline productivity played a large part in the population interpretations made by W. Shawcross (1967a, b), Terrell (1967), and Anderson (1979).

Models for determining population based on a balance between "welfare" production and labour inputs (Bayliss-Smith 1980) have not been adopted here. These two parameters can not be as directly determined in the New Zealand archaeological record as areas of land or volumes of pit storage (Law 1969; Law and Green 1972; Fox 1983). The latter has so far been applied only to individual pa and has not been used to assess the population of an area. The unstated reasons for this are a lack of confidence in the thoroughness of survey, and lack of chronological control.

Analyses of prehistoric population undertaken in Eastern Polynesia other than New Zealand are relatively few. Bellwood's (1972) study of Hanatekua Valley, Marquesas, was able clearly to identify areas of cultivated and cultivable land, and found close parallels in modern-day practices on which to base inferences. In New Zealand, by contrast to Central Polynesia, there is considerable difficulty in defining areas of productive horticultural land because of the relatively undemanding fertility conditions and variety of cultural practices under which the principal crop, kumara (*Ipomoea batatas*) was grown (Jones 1986). These difficulties have been considered by Leach (1976: 181–2, 212–214) in estimates of prehistoric populations for Palliser Bay, southern North Island, and will be discussed later in the paper.

The lack of chronological control is an abiding problem in much settlement pattern archaeology (Smith 1978: 499; Cordy 1984: 24–26; Guilbert 1981: 112; cf. Lightfoot and Feinman 1982: 70–71). This problem is easy to define in theoretical statements, but field and dating practices to solve the problem have yet to be devised. The extensive site surveys interpreted in this paper certainly do not allow any analysis of settlement in the one time plane (except in the nineteenth century). Nevertheless, the broad evidence of chronology available for this study was used to model an accumulation of centuries of evidence. Qualitative and quantitative mathematical models are adopted which produce satisfactory conclusions about population sizes.

The procedure adopted first examines the definition of pa as it may be applied on the East Coast. A group of larger pa are then examined to define the largest possible size of population in the catchment. Population for any one pa is defined on the basis of number of terraces, length of occupied ridge, and volume of kumara storage pits associated with the pa. Although Fox's (1983) study of pa population found a useful footing in numbers of terraces, and numbers of pits, these criteria cannot be applied without modification to Tolaga Bay, since pa size and even definition are not straightforward. Moreover, whereas terraces are not always readily recognised as discrete units to be counted, pits are probably relatively well preserved. The procedure followed here requires an analysis of pit storage volume per pa site. The total volume of pit storage for all sites in the Mangaheia Valley is then calculated, and the assumption made that the maximum population for the valley is represented by the population defended by its largest pa.

The figures for population size through time are then defined numerically and graphically, and the total population multiplied by years of occupation is compared with the archaeological evidence of accumulated pit storage. Figures for maximum population can be derived, which are then compared with the areas of well-drained alluvial soil in the valley, and likely prehistoric crop productivity.

The assumptions and methodological procedures followed will be stated more fully in the following section.

FROM PITS TO PEOPLE

Throughout the world, the function of pits has been a matter of some controversy (Winter 1976: 27–29; Guilbert 1981: 108–112), as indeed pit function was controversial in New Zealand some decades ago. A quantitative study of pit storage in the Mogollon region of the American South-west compared crop storage between households, interpreted as one of the parameters of status (Lightfoot and Feinman 1982). Such approaches follow from the use of pits as indicators of agricultural wealth, directly in the form of stored crops and indirectly in the area of fertility of the gardens controlled and the labour available to till them. In New Zealand, this approach has been used on defensive sites which are divided into units, suggestive of social divisions where the status of each sub-group of the group which constructed the whole site can be assessed. A site at Kohekohe in South Auckland showed interesting divisions by these means (Law 1969: 20). Within a unit or a single-unit site, the distribution and the sizes of the pits can suggest patterns of social and economic organisation as was shown at Ongari Point (W. Shawcross 1966: 68) and this can also be shown at Kohekohe. The major focus of this paper, however, will be the modelling of pit storage in a whole catchment, and its interpretation in terms of population and horticultural productivity in that catchment.

On the block diagram (Fig. 2), various economic quantities are shown adjacent to other quantities to which they are related. For example, the weight of the stored food is closely related to the volume of the storage available. If all the interrelationships and conversions are known, and a value in some part of the system is also known, the remaining values should be amenable to calculation. Several of the quantities can be determined by archaeological investigations. The volume of storage in a site is the value which is most often available but for some parts of New Zealand, usable areas and garden areas may be known from studies of field systems, improved soils marked by gravel additions, or considerations of topography (Jones 1986). Occasionally, too, populations may be estimated from house plans, but this method has limited utility owing to the character of New Zealand sites. Bellwood decribes an exceptional site where this is possible (Bellwood 1969: 48), but unfortunately pits were not present on this particular site. The only method by which all the other information can be reconstructed is to recreate the links between the quantities. There are several methods by which this may be done.

In the present study, garden areas are associated with pits and the link between quantities 1 and 4 is explored. Several studies are available from New Guinea which may aid in the reconstruction of the links from 2 to 8 for kumara agriculture by ethnographic analogy. Historical records can be of use for the links from 1 to 5 and from 2 to 9 and virtually all

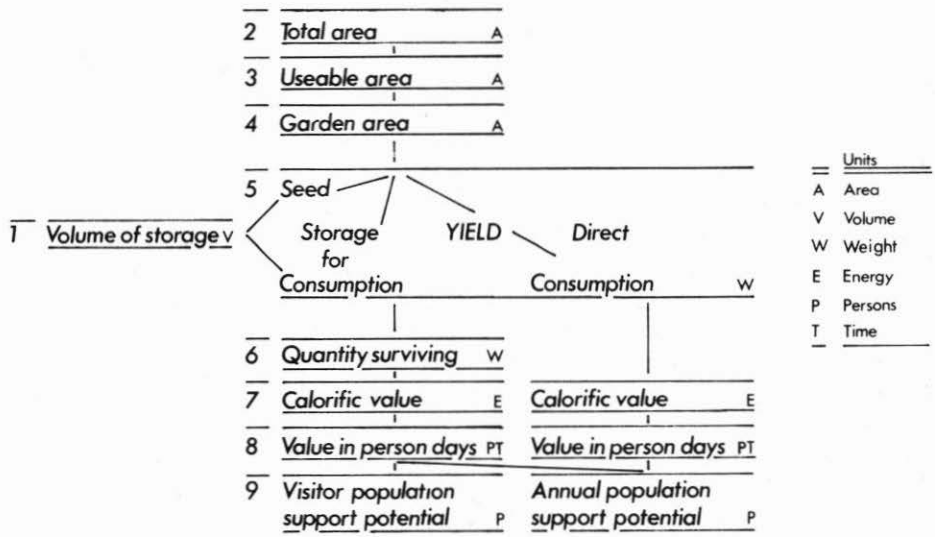

Figure 2: Block diagram showing relationship between harvested kumara, stored kumara, and consumption.

the links except perhaps 8 to 9 are susceptible to modern experiment and analogy from modern agricultural practices.

The links 2 or 3 to 9 have been made for archaeologically defined gardened areas (Law 1968: 72; Groube 1970; Leach 1976). The links 1 to 8 or 9 have been used by Law (1969; 1970; 1972), Law and Green (1972), Fox and Cassels (1983), and Jones (1983a) in the interpretation of single sites.

Inevitably, in following somewhat long chains of conversion, errors arise. Error estimates will be given for each section and these will be combined for the final figures. Error ranges will be 95 percentile, or two standard deviations each side of the mean for normally distributed variables.

Pits in New Zealand have been the subject of much archaeological investigation. This account concentrates on the semi-subterranean roofed pit (Fox 1974). The field evidence for this pit consists of partly infilled rectangular depressions from 1 and 2 m to 8 and 10 m in plan and from 1.5 m to 10 cm in apparent depth. The pit may or may not have a raised rim, the function of which is still open to various interpretations.

Another broad class of pit is the rua, an underground bell-shaped pit, with a narrow-necked opening to the surface (Best 1916: 87–88). Because of the hard sandstone substrate, this type of pit has not been identified on the East Coast of the North Island, although it is the most common type in the neighbouring Bay of Plenty where airfall ash subsoil is common (Jones 1986).

Athough the actual volume of a pit may appear self evident, on some sites in New Zealand, subsequent prehistoric cultivation and modern farming have truncated the soil profile leaving the depth of the pits in doubt. Also, on sites with renewed activity there is a possibility that the pits formerly possessed raised rims which have subsequently been removed. The methods suggested here may not be possible or valid where alterations like those above are suspected. Strictly speaking, "apparent pit volume" would be the best description, but for reasons of economy the term "volume" or "pit volume" will continue to be used. As the volume of pits can usually be determined accurately, no arbitrary error margin will be included.

CONTEMPORANEITY AND DURATION OF PIT USE

The difficulty of exactly associating pits within a site is commonly raised as an objection to the sort of volumetric analysis proposed, but it should be stressed that the models to be offered are not site-specific, but apply to wide areas over a considerable span of time. On some New Zealand sites there has been no soil build up but rather the reverse, and the only stratigraphic control is pit intercutting. Even where pits are stratigraphically contemporary some doubt must exist as to whether they are absolutely contemporary.

Duration of pit usage continues to be a matter of some controversy. Pits which are used for too many seasons are said to become infected with fungus and the tubers stored in them are very liable to rot. This has been suggested as the reason for the deliberate pit infilling observed archaeologically on some New Zealand sites. Some archaeological evidence, however, would suggest re-working or re-construction of the same storage space (Fox 1978: 17, 30), and even the deliberate fumigation of pit spaces (McFadgen and Sheppard 1984: 58–59).

On a site with a long sequence of apparently continuous occupation and with a known beginning and end date, by assigning some span of use to the pits encountered, an average population supported on kumara can be determined. This treatment concentrates on this approach but allocates several assumed spans of use for certain classes of pit.

PIT USAGE FACTORS

Some ethnographic material is available describing the filling of pits. Store pits were commonly lined, split tree fern trunks being a favourite material (Best 1916: 71), but other woods were occasionally used (ibid.: 75). The walls of rua were apparently lined with rushes (ibid.: 84). Pits lined with tree fern (*Cyathea* spp.) have been archaeologically identified at Harataonga Bay (Law 1972), Taniwha Pa (Law and Green 1972), Pari Whakatau (Duff 1961: 280), Tolaga Bay (Jones 1983b) and Kawerau (Lawlor 1983).

The inclusion of this lining must reduce the amount of space in the pit available for storage. On the floor of the pit, Best mentions coverings of gravel (Best 1925: 90), tea tree (*Leptospermum scoparium*) branches and fern fronds (*Pteridium aquilinum* var. *esculentum*) (Best 1916: 95), and fern fronds alone (Best 1916: 76). The first has not been encountered archaeologically and the last two would normally leave no trace. On the method of filling the pits, several sources gathered by Best agree that the tubers were sorted into sizes and stacked in the pits by hand. No sources show their being stacked in kits, other than early photographs dating to the late nineteenth century.

Best quotes two sources describing pits with a narrow passage down the middle with kumara stacked on either side (Best 1916: 78, 94) stating that the faces of the stacks were vertical. This is mechanically unlikely. It is doubtful if the face angle even of a face of elongated tubers could exceed 60 degrees, regardless of how carefully they were stacked. Although this passage is plausible for larger pits, on smaller pits such a passage would occupy most of the pit and complete filling is more likely. Best (1916: 96) mentions stacks up to 5 feet (1.5 m) high, which must place considerable pressure on the lowermost tubers, increasing the risk of bruising leading to decay. It is likely that 1.5 m is a maximum height for stacked kumara tubers rather than a typical figure. Pits only rarely exceed this in depth. It has been suggested in discussion that the pits in which a forest of postholes is encountered (Lawlor 1983) had formerly held racks on which kumara had been placed. This has not been recorded ethnographically and the suspicion must always be that the holes are not contemporary but represent reconstruction, evidence for which has been encountered on many pits, or that the posts supported light walls dividing pits into bins or compartments (cf. Fox 1974). Another possibility is that the posts were needed to support very heavy earthed-over roofs with weak or short-spanned horizontal members.

On a fairly typical pit, a reasonable allowance for wall and floor lining reduces the below-ground volume by about 20 percent. This figure varies with the pit size and proportions. For the pit described by Best, the volume available for kumara was about 60 percent of the total. As these calculations are rather tenuous, it is proposed to adopt a universal mean figure of 50 percent as the volume of the pit actually filled with kumara and to assign this an error of ± 40 percent of the mean (i.e., the reduced figure not the total volume).

Fox (1983: 12) has criticised this figure in the belief that no more than 30 percent of the pit's below-ground volume would be filled. This is at the bottom of the range presented here. Against Fox's 30 percent figure there has to be weighed the fact that the smallest pits and all rua (bell-shaped pits) could have had no space for access. The space for access would simply be created as the pit was emptied. In the case of large pits, the work involved in construction only to fill 30 percent of the available space could only be an inefficient alternative to a larger number of small pits. The figure proposed here, of 50 percent of the pit actually filled with kumara, is therefore the more reasonable figure.

BULK DENSITY OF KUMARA

To convert the volume to weight it is necessary to estimate the bulk density of kumara. In experiments, one of us (RGL) measured the specific gravity of kumara flesh as 1.09. However, a cubic metre of volume contains air between the tubers as well as the tubers themselves and this reduces the bulk density to a figure below that indicated by the specific gravity. This bulk density can be expected to vary with the shape and the degree of uniformity of the size of the kumara. Ethnographic accounts agree on the Maori practice of grading tubers by size which leads to a lower bulk density. Densities used for calculating shipping volumes for potatoes suggest a figure of 0.29 for the void ratio (the ratio of voids to total volume). The figure adopted here of 0.30 is estimated to have an error of ± 15 percent, giving a bulk density of kumara of 757 ± 15 percent kg per cubic metre.

LOSSES AND SEED

Losses in storage of up to 30 percent have been experienced with pits in the USA (Conway 1958: 46). Most of the crop will not be stored for the full period so average losses will be less than this. Furthermore, a store beginning to deteriorate would be an obvious choice for immediate consumption. The percentage of the crop surviving will for this paper be taken as 85 percent ± 15 percent of the total stored.

The Maori propagation method was by planting whole tubers and growing only one plant from each tuber. Each plant seems to have produced about ten tubers, so only about one tenth of the crop was required for seed (Best 1925: 115). However, some would possibly be infertile. To allow for these losses and some margin for safety and expansion, probably some 20 percent of the crop would be required for seed. A difficulty arises here, for if a high proportion of the crop is eaten direct from the fields, the percentage of the store which is for seed could rise well above 20 percent even to 100 percent in extreme cases. For any given quantity of storage, if a high percentage of seed is assumed, the size of the total crop must be greater than if the minimum percentage is adopted. Taking a low percentage then minimises the importance of kumara in the diet. This is demonstrated graphically in Figure 3.

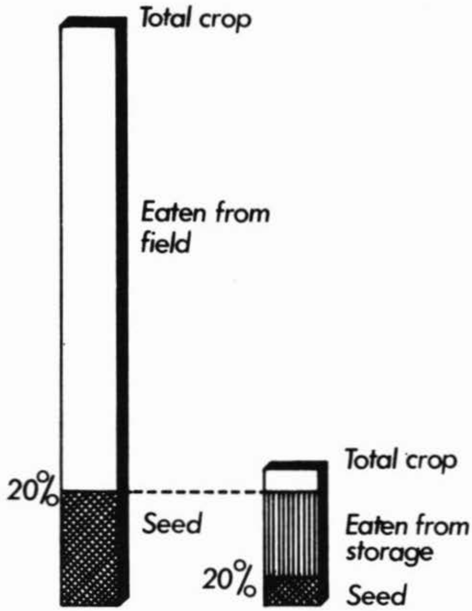

Figure 3: Function of storage for seed if (a) all the crop is eaten from the field; (b) most of the crop is eaten from storage. Twenty percent of crop is seed in both cases.

Some historical evidence suggests only damaged and small tubers were eaten direct from the harvest but this is almost certainly incorrect (see Firth 1929). A figure of 75 percent ± 10 percent of the full storage to be used for consumption will be adopted here as suitable for much of New Zealand but other workers may well consider varying this figure.

FOOD VALUE OF THE KUMARA

The most useful and basic measure is calorific value, for which there are seven apparently independent figures for kumara (Table 1). The figure of 119 Kcals/100 gm determined here is in close agreement with the value recently published by the South Pacific Commission (1983: 14) of 114 Kcals/100 gm.

An alternative approach to determining a calorific value is available from calorific value for carbohydrates generally. A high vegetable diet in New Guinea has been analysed to have the following calorie values: from protein, 2.90 cals; fats, 8.35 cals; total carbohydrate, 4.00 cals (Hipsley and Kirk 1965: 5). From the calorific point of view, kumara has very little protein or fats so the last figure is the most important. The percentage of the weight of a kumara tuber which is carbohydrate is the balance which is not water. Peters (1957) gives a substantial number of water-content determinations on kumara tubers. The

TABLE 1
CALORIFIC VALUES OF KUMARA

Source	Cals/100g
N.Z. Dept of Health n.d.	132
Massal and Barrau 1955	100
Barrau 1958	105
Hipsley and Kirk 1965	134
Peters 1957	90 (white)
	140 (yellow)
McKee 1957	125
	mean 119
	S.D. 33

average figure is 69 percent with a standard deviation of 5 percent for 27 values. Regarding the balance as carbohydrate, and allowing for a small amount of protein, this gives a mean calorific value of 127 cals/100 gm with a standard deviation of 200 cals/100 gm. These figures are encouragingly close to the first presented. Because of the lower standard deviation, the second figure is preferred to that of Table 1 for subsequent calculations. The authoritative South Pacific commission (1983) figure is close to this value but was not brought to the authors' attention until the conversion factors and subsequent analyses had been calculated. For the conversion factor, a figure of 1250 ± 24% Kcals/kg of kumara has been adopted. (The corresponding South Pacific Commission figure would be 1140 Kcals/kg with no estimate of error.)

Kumara can also provide useful, if small, quantities of protein as well as vitamins. Table 2 gives the quantities of these determined on one example of kumara. The values for protein content and beta carotene seem particularly variable.

TABLE 2
PROTEIN AND VITAMIN VALUES FOR KUMARA (AFTER MASSAL AND BARRAU 1955: 11)

	mg/100g	Requirement for moderately active adult male (mg)	% of requirement fulfilled when taking in 3,000 cals at 125 cals/100g
Water	70,800	–	–
Starch	25,000	–	–
Fat	300	–	–
Protein	500–2,800	70000 (animal prot.)	17–96
β Carotene (pro A)	13.7–34.8	5000 IU	100
Thiamine (B)	0.10	1.8	100
Riboflavine (B2)	0.05	2.2	55
Nicotinic Acid (B2)	0.70	18	93
Ascorbic Acid (C)	25	75	100
Niacin	0.70		
Ca	35	680	100

Beta carotene determines the degree of yellowness of the flesh which varies greatly with the variety of kumara. Maori varieties observed on Cook's first voyage were yellow (Banks and Solander n.d.). The significance of the intake of protein varies with the food value of the protein. Kumara protein has an experimental value of 74 (i.e., 100 parts of plant protein replace 74 parts of animal protein) (Massal and Barrau 1955: 11). This is very high for vegetable protein and comparable to dairy proteins.

Only about one third of beta carotene is converted to vitamin A. One IU (International Unit) is 0.6 microgrammes of beta carotene. The ascorbic acid content is sufficiently generous to cover losses in storage. It should be noted that vitamin D is necessary for the calcium to be used, and of the vitamins this is the most notable lack.

It is of interest that the high protein-content varieties can provide a very large part of the protein requirement. People can exist for long periods with low protein intakes and if kumara formed a total diet for part of the year probably no ill effects would result. Very small additions to a high kumara diet could add the other necessary constituents, notably phosphorous, iodine, iron, sodium and vitamin D. Fish would be an ideal partner for all but iron and could make up the protein deficiency at the same time (Mottram 1963: 45–114).

Kumara, then, has a lot to recommend it as a staple and there is no risk that very high intakes were necessary in order to gain other food requirements beyond calories.

Its importance as a Maori staple food has often been queried (e.g., K. Shawcross 1967) but in areas where soil fertility and condition, not to speak of climate, were suitable, it must have repaid any labour expended on its cultivation and can only have had great importance.

ETHNOGRAPHIC ESTIMATES OF KUMARA CONSUMPTION

Some data are available giving intakes for high kumara content diets (Table 3). The New Guinea Highlands are inhabited by a large population whose staple until recently has been sweet potato. It will grow all the year in this area and no storage is necessary or attempted. The situation is complicated by commensal pigs which are also fed on the crop, but some relevant measurements of production and intake are available.

Barrau (1958: 48) estimated the subsistence level of agriculture in the Highlands as communities with only 0.1 acres of garden per head. Sweet potato gardens mature in the Highlands in three to seven months and yield 3 to 6 tons per acre (7.5 to 15 tonnes/ha) (Massal and Barrau 1955: 10). Taking mean figures for the ranges above, suggests that a daily intake of 3 kg per head is subsistence level. Other foods could add another 10–20 percent to the calorific value of the food consumed.

Pospisil (1963: 376), studying a society in West New Guinea, found on a small sample of actual intake that the inhabitants of the area were eating 2.4 kg per day, this being the major part of their diet.

Brookfield and Brown, reporting data from several parts of the Eastern Highlands (Brookfield and Brown 1963: 115), give figures of 0.15–0.19 acres per head as the garden areas for crops for human consumption among the Enga. Other garden areas which include gardens for pigs have higher acreages per head. These figures suggest a daily intake of 4.6 to 5.8 kg per head. Again, other intake would be low. In a study of another Highlands group (Hipsley and Kirk 1965: 77), daily intake by groups of male and female adults was measured at 1.07 kg per day, with other food estimated at 385 calories.

Most of the sources mentioned above have used calorific values to convert the intake weight into a calorific intake. The figures used varied between 100 and 150 calories per 100 grams. It is not surprising in view of this variation that the daily calorific intakes in these sources also vary widely. The figure of 1250 ± 24% calories per kilogramme developed above is used in Table 3 which summarises this evidence.

TABLE 3

VARIOUS FIGURES FOR DAILY CONSUMPTION OR PRODUCTION OF KUMARA (BASED ON 1250 CALS/KG).

GROUP	WEIGHT CONSUMED OR PRODUCED (KG/DAY)	AREA UNDER CROP/PERSON ACRES (HA)	PERCENTAGE OF DIET FROM KUMARA	TOTAL INTAKE (cals)	POPULATION
CONSUMPTION					
Enga	1.07	-	78	1723 ± 321	adults
Chinese experiment	2.00	-	100	2500 ± 600	3 adults
Kapauku	2.75	-	80–90	4050 ± 1000	whole population
PRODUCTION					
General Highlands subsistence	3.0 ± 1.4	0.10 (0.04)	80–90	4410 ± 2030	-
Enga range	4.7 ± 2.1 –	0.15–0.19	80–90	6910 ± 3180	-
	5.8 ± 2.7	(0.06–0.08)	80–90	8540 ± 3920	-

These figures, calculated from garden areas for human consumption, show a very high daily intake, indeed higher than the measures of direct intake. For this reason they must be regarded as dubious. The error in the calculations may be in the assumption of the time to harvest or the yield, or it may indicate that gross waste of production exists in the Highlands either in subsistence, use of crops, or to pigs.

POPULATION CALORIE REQUIREMENTS

Calorie requirements of individuals vary with age, sex and, in the case of females, according to whether they are pregnant or not. Consequently the structure of the population determines the calorific requirement. For a moderately active population with a long life expectancy and positive real growth rate, a weighted average is about 2400 cals per head per day. Varying the life expectancy and growth rate can vary this figure. When very small groups are being considered, this average could be well wide of the mark; for instance, in a family group, all the children could be near-adult. Assigning an error to this is difficult. Diet surveys of well fed populations have indicated a standard deviation of 25 percent in individual intakes but averages are encouragingly close to the ideals. Class distinctions may widen the range for individuals. In famines, intakes in the low 1000s can be maintained for some time.

For large populations, an error figure of 15 percent is adopted. Where a population estimate is the outcome of the analysis, it is suggested an additional error be added of $\pm a\frac{30\%}{n}$ where n is the population estimate mean and a is the estimated proportion of the diet which came from kumara.

CONVERSION FACTOR

It is now possible to combine the various corrections and values above to produce the conversion factor from pit volume to person days:

K1 =	(0.50) ± 40% Non-used volume correction	×	(757) ± 15% Volume to weight conversion	×	(0.85) ± 17.6% Losses in storage correction	×	
	(0.75) ± 13.3% Allowance for seed correction	×	(1250) ± 24.0% Weight to energy conversion	×	$(\frac{1}{2400})$ ± 15% Energy to person days conversion	=	126 person days/m^3

While 126 is the best estimate for the value of K1, the uncertainties attached to its component parts mean K1 is likewise uncertain. The likely range can be found by "Monte Carlo" simulation. From 2000 trials, treating the multiplied variables as normally distributed, the 95 percentile range for K1 is 65 to 205 person days/m^3. That is, K1 varies from 126 by +63% and −48%. This result has been reported earlier as 130 ± 55% and 130 ± 65 (i.e., ±50%) person days/m^3. The value newly given here is the preferred one.

POPULATION SUPPORTED PER ANNUM

The key assumption to examine here is the duration of use of kumara from store. The kumara crop was generally gathered and stored in April/May. The period when stored crops ran out is altogether less easy to define. It would be reasonable to assume that the stored crop would last *at least* until the period of new planting, because of the need for seed. Consumption from store would therefore last at least 4–6 months or $150 \pm 20\%$ days. As calculated above, a cubic metre is the equivalent of $126 + 63\% - 48\%$ person days (range: 65–205 person-days). The conversion factor, K2, from cubic metres of storage to population supported is:

$$\begin{aligned} K2 &= K1/150 \\ &= 126/150 \\ &= 0.84 \text{ persons/m}^3 \end{aligned}$$

This has 95 percentile error range of +66% to −52% or 0.38 to 1.349 persons/m^3.

The errors are not all estimation error, for in prehistoric New Zealand there could have been no one fixed value for conversion of food store volume to persons supported per annum. The method of filling the store undoubtedly varied from area to area and probably through time, so this variation is real, as is some variation in the fraction of the crop which was lost in storage. In addition, this will vary from year to year. The variation in the calorific value is probably also real, as the moisture content of the tubers can be higher in drought years or areas. So again some variation is expected, certainly from year to year and possibly from area to area. In calorific requirement people can make radical adjustments. If pressed, a population can survive on a much lower calorific intake, while if too much food is produced its disposal is obviously easy. Hence the variation in calorific intake must also have existed in prehistory. The existence of these variations is important when comparing sites. Differences between sites, particularly those in different areas, may be explicable in terms of these variations rather than in terms of population difference or differences in the importance of kumara. This part of the error is in fact a result, showing real variability rather than just a limitation to accuracy.

When comparing sites which are close together, it would be desirable to consider the reliability of the crop in this particular area, for this could induce considerable variation from year to year in the consumption of the crop and hence in the storage required.

Where yields were unreliable, any attempt to subsist on an uncertain food supply could have severe results. The only safe course would be to limit the importance of this food supply or greatly to increase the area of crops planted, hence minimising risk from poor cropping yield. Efficiency could be expected to fall in such a situation. Over some of New Zealand it is arguable that summer resources rather than winter resources were the population limiter. In this case, the efficiency of consumption of stored food could well be lowered.

The role of exchange of food in trade situations or prestige events has been ignored in this treatment. These certainly existed (see Firth 1929) but their effects are largely unpredictable within the framework advanced in this paper. It is not inconceivable, however, that archaeological modelling could be developed to deal with this important factor. In the Americas there has been a considerable amount of work on the Inca storage system. It is of some interest that a figure of 1.09 people per cubic metre of storage can be derived for this area (Browman 1985: 198–199), based on very large storage volumes and independently determined population numbers. This figure is close to that presented in the present study.

PA AND POPULATION IN TOLAGA BAY

The underlying geology of Tolaga Bay is sandstone, and semi-indurated mudstones on marine clays. The landform which results consists of rolling hill country in the south, on mudstone predominantly; steep-sided sandstone ridges in places in the south, more extensive in the centre and north of the catchment; and extensive alluvial flats with two meandering river systems, the smaller Mangaheia River, and the Uawa River (Fig. 1).

In many other parts of New Zealand, especially in areas with a soft substrate of volcanic origin, the artificial defences of settlements (pa) are quite pronounced, with ditches and banks up to 8 m high, large scarped terraces, and extensive defended areas. On the East Coast, artificial defences such as ditches are limited in size by the shallow depth of the sandstone base, except on alluvial sites. In many cases, no artificial defences are apparent, and pa may be identified by terraces and pits in clearly naturally defended areas. Good natural locations are relatively common, since wave action near the sea and slumping or faulting to form sandstone cliffs are quite common. Terracing on the crest of narrow ridges is common in most pa, and the terraces may have been narrowed by slumping after they were constructed.

Many pa have distinct groups of pits within them, or on nearby ridges. In some cases, pit complexes are butted up against clearly natural defensive features such as a ridge line with cliffed sides where the ridge line itself has no identifiable cultural evidence. Such "citadels" are common adjacent to cliff faces in the Hikuwai Valley, and the whole complex of cliff and adjacent pits is here classed as a pa.

The question of definition is of some importance, because pit storage complexes clearly need not be an integral part of the settlement unit and are likely to be a specialised site type associated with gardens. Furthermore, pits can occupy the same topographic positions as pa, i.e., on ridge lines, because they would only be built where surface run-off and ground water could be kept to a minimum. Ridge tops provide these conditions, as well as defensive positions. There will be many cases where a satisfactory division between the two classes of site is not possible. Indeed, it has been argued that some pa are primarily food stores (Law and Green 1972; Groube 1977: 83).

PIT DISTRIBUTION FROM ARCHAEOLOGICAL SURVEY

In general, the settlement data for hill country are regarded as more reliable than those for the alluvial flats. The alluvial flats, particularly the levee systems, are inferred to have supported substantial populations. The hill country nevertheless has to be considered closely, since it is the least altered remnant of the archaeological landscape on which a satisfactory examination of settlement size can proceed. However, the archaeological evidence for settlement on alluvium is largely indirect. The Uawa flats are now heavily settled and ploughed and are relatively wide with extensive tracts of back swamp, particularly towards the river mouth.

The main evidence of gardening on alluvium is the adjacent pit storage which occurs in large volumes where the levees are close by the hill country in the upper flats near Mangatuna, but very thin in the lower flats and where the levee soils are separated from the hill country by extensive tracts of backswamp or poorly drained alluvium (Jones 1986). The

Mangaheia Valley is smaller in scale, with large volumes of pit storage in the hill country close by, except in the lower reaches. However, in the lower reaches there are small hillocks close by the river, all of which have substantial settlement evidence, including pit storage.

POPULATION OF SETTLEMENT UNITS, ARCHAEOLOGICALLY DEFINED

From the survey of sites, figures are available for the length of occupied ridge at each site, the number of recognisable terraces, and both the number and volume of pits (Jones 1986). Measurements are based on careful estimates, tape and compass plans, plane table and alidade mapping, or measurements from aerial photographs at 1:25,000 scale. Because of the difficulty of assessing the width of the often-eroded ridges, site area is not regarded as a meaningful measure of settlement size in this particular case. Table 4 gives a matrix of the correlations between pairs of the above four variables. Clearly, it is possible to derive population figures for the sites solely from the surveyed (apparent) pit volumes.

TABLE 4
CORRELATION COEFFICIENT MATRIX FOR THE VARIABLE MEASURED

	LR	NT	NP	ln (VS)
LR	1			
NT	.63	1		
NP	.41	.50	1	
ln (VP)	.62	.35	.72	1

Lower half only is shown. LR: length of occupied ridge; NT: number of terraces; NP: number of pits; VS: pit volume from field survey.

However, in some pa, particularly coastal pa, pits are relatively few in number and volume. The pa at Cook's Cove (N89 & 90/643) or on Pourewa Island are good examples of this (Jones 1983c).

With these exceptions, pit volumes (not numbers of pits) are regarded as the best indicators of the population likely to have been supported in a pa. Because of the correlation between length of ridge (LR) and surveyed pit volume (VS) it is possible to give a secondary derived estimate of population from this variable. The regression equation between pit volume (VS) and the length of ridge (LR) is:

$$VS = 17.8 \times \exp(0.0047 \times LR) \quad (1)$$

This is shown graphically on Figure 4. The standard error of estimates from the regression is large. There are now two measures of pit volume in the analysis: one is pit volumes as surveyed in the field (VS), the other (VP) is an estimate derived from the correlation between length of ridge (LR) and VS. The population is best derived by averaging the sum of pit volumes (VS) and the measure derived from length of occupied ridge, i.e.,

$$Population = 0.5(VP + VS) \times K2 \quad (2)$$

$$\text{Taking } K2 = 0.84,$$

$$Population = 7.48 \times \exp(.0047 \times LR) + 0.42VS \quad (3)$$

Table 5 shows populations predicted by (3), pit volumes as surveyed, and length of occupied ridge for all pa in the study area.

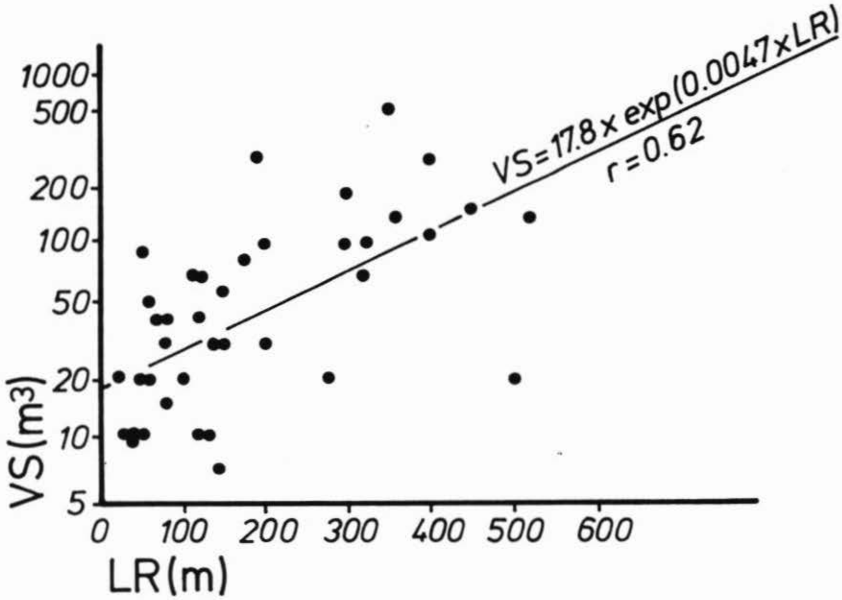

Figure 4: Regression equation of length of "occupied" ridge against pit volume. The correlation between the variables is statistically significant ($p < 0.001$).

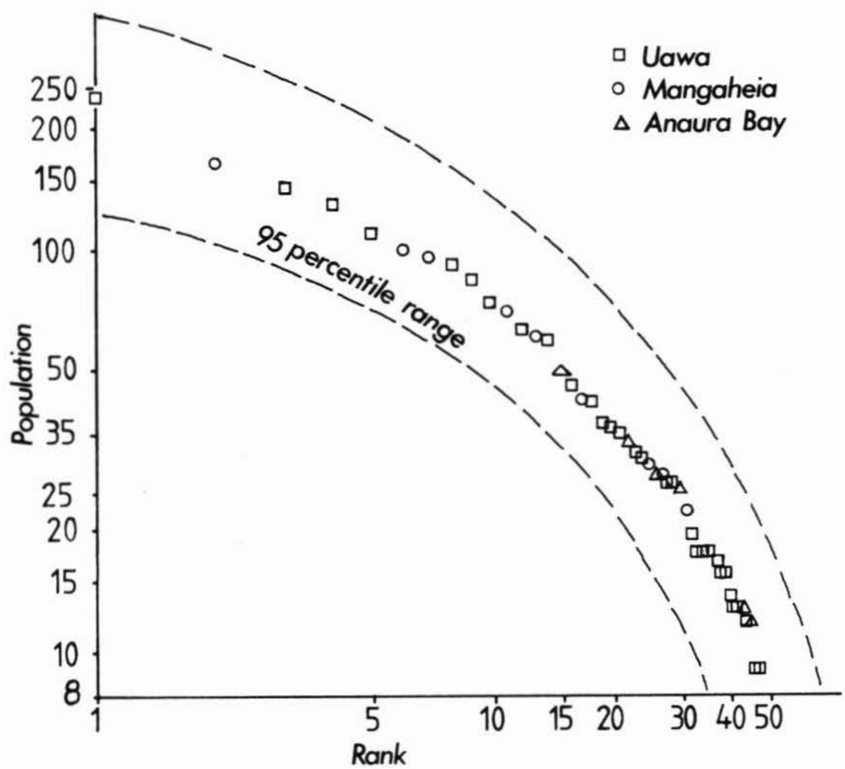

Figure 5: Sizes of population in pa plotted by the "rank-size" rule.

TABLE 5
PARAMETERS OF PA SIZE FOR TOLAGA BAY.

NZAA Site Number Yard Grid (N89 & 90/)	Length of Occupied Ridge LR (m)	Volume of pits VS(m^3)	Population by formula (3) in text	Rank by Population	Comment
3	340	unknown	37+	20	Taharangi, obscured by gorse
4	50	10	14	40	
6	100	–	12+	44	Parkinson sketch of Mitre Rocks
29*	120	70	43	17	Radiocarbon dates available
40	350	480	240	1	
44	50	90	47	16	Te Raroa Pa
107	40	10	13	41	
120	120	10	17	37	
273	–	–	–	–	Pa Oneone, destroyed
274	70	40	27	28	
276* & 277*	300	20	73	11	Includes adjacent pits (total 102 m^3)
280*	80	40	28	27	
285*	30	10	13	42	
294	50	–	9	46	
307*	400	280	167	2	Gardened natural terraces not included; includes pits N89 & 90/304–306
317*	320	70	63	13	
369*	140	30	27	29	
371*	120	40	30	25	
390	–	–	–	–	Destroyed
398	–	–	–	–	Marama Tawhaua, alluvial flats
400	520	140	145	3	Cliff top, includes adjacent pits N89 & 90/538–542 obscured by scrub
407	150	–	not in regression		
409	60	20	18	34	
434	150	54	38	19	Includes N89 & 90/435 (pits)
439*	80	30	23	31	
460	50	20	18	33	
462	50	–	9+	47	
463	–	–	–	–	Not mapped
468* & 469*	360	140	99	7	Gardened natural terraces not included
479*	100	20	20	32	
480*	130	10	18	36	
482*	20	20	17	38	
503	120	70	43	18	
504	–	–	–	–	Estimates not possible
505	200	100	61	13	
523	280	20	36	21	
570	200	30	32	23	
643	500	20	87	9	Te Kararoa, Cooks Cove
597	190	270	132	4	
610	60	50	31	24	
500	140	120	65	12	
515 & 516	400	110	95	8	
499*	300	180	106	6	Includes N89 & 90/396 (pits)
88–90	450	150	125	5	
45	325	100	76	10	Includes N89 & 90/250, 251 (pits)
94	80	15	17	39	
414	40	10	13	43	Anaura Bay
97	175	80	51	15	Anaura Bay
99	130	10 ?	18	35	Anaura Bay

103	200	30 ?	32	22	Anaura Bay
104	150	31	28	26	Anaura Bay
650	30	7	12	45	Anaura Bay
#	140	27	26	30	Anaura Bay
Means	176 (SD 135)			51 (SD 50)	

* Pa in the Mangaheia Valley
\# No site number

Figure 5 shows the populations of pa predicted by (3) plotted by the rank-size rule (Hodder and Orton 1976: 69–73). The object of this analysis is to display the relative sizes of settlements, and to indicate the hierarchy of settlement size in the Uawa catchment. Figure 6 shows a graphic representation of this data on a "tilted" map of the Uawa catchment.

The results show that the largest pa (defended settlements) at Tolaga Bay are an order of magnitude larger in size than the smallest defended settlements, with the largest settlement of the order of 200–300 people, and the smallest 20–30 people. The largest pa are at Cook's Cove, upper Uawa flats, lower Mangaheia Valley, and above Waihau Beach on the southern rim of the catchment. These locations are either coastal, *or* at the limits of canoe navigation and adjacent to significant large areas of well drained alluvial soils.

LIKELY POPULATIONS OF THE MANGAHEIA VALLEY AND ANAURA BAY

As noted above, the Mangaheia Valley is manageable in scale and has relatively well preserved surface evidence. It now forms the subject of closer modelling of population over time, and the results will be generalised to cover the whole of the Uawa catchment. The Mangaheia results will also be compared with the *Endeavour* (1769) observations of population and horticulture at Anaura Bay.

Based on the earlier interpretations of pa "size" and pit storage volumes, an attempt can now be made at estimating the population of the Mangaheia Valley (Fig. 7). The Mangaheia Valley is chosen for several reasons. First, there are C^{14} dates for two sites in the valley of 650 years B.P. and 550 years B.P. (Jones 1986). Second, in the middle and lower parts of the river there is a fair area of the well drained, alluvial silt loam Waihirere soils (Rijkse and Pullar 1978) available and stable (not subject to flooding) at the period of earliest dated settlement (Grant 1985: 89–91). Third, the middle valley is narrow and the settlement sites on its sides survive in good condition and are easily accessible from the river levees. In this respect, the middle Mangaheia contrasts with the Uawa flats where the valley sides are some distance from a good proportion of the well drained levee alluvial soils.

The procedure adopted to determine pit volumes associated with alluvial soils is as follows. Pit volumes for the immediate vicinity (within 1 km horizontal and 250 m vertical distance) of the middle valley alluvium are included, except where there are appreciable areas of north-facing, moderate slope. Such slope soils would have been usable for hill gardening and in the upper valley were the only soils available. The balance is inferred to be pit storage for crops grown on the alluvial soils, rather than hill slopes. Many pits occur on south-facing slopes on the steep north side of the valley, and these could not have been used for crop storage from slope gardens. There is a very high concentration of storage pits on the limited areas of elevated land immediately adjacent to the river levees in the lower part of the river. The swampy back flats in this lower part of the catchment are extensive, and pits are non-existent on the hills rising from the back flats. Pits in the lower

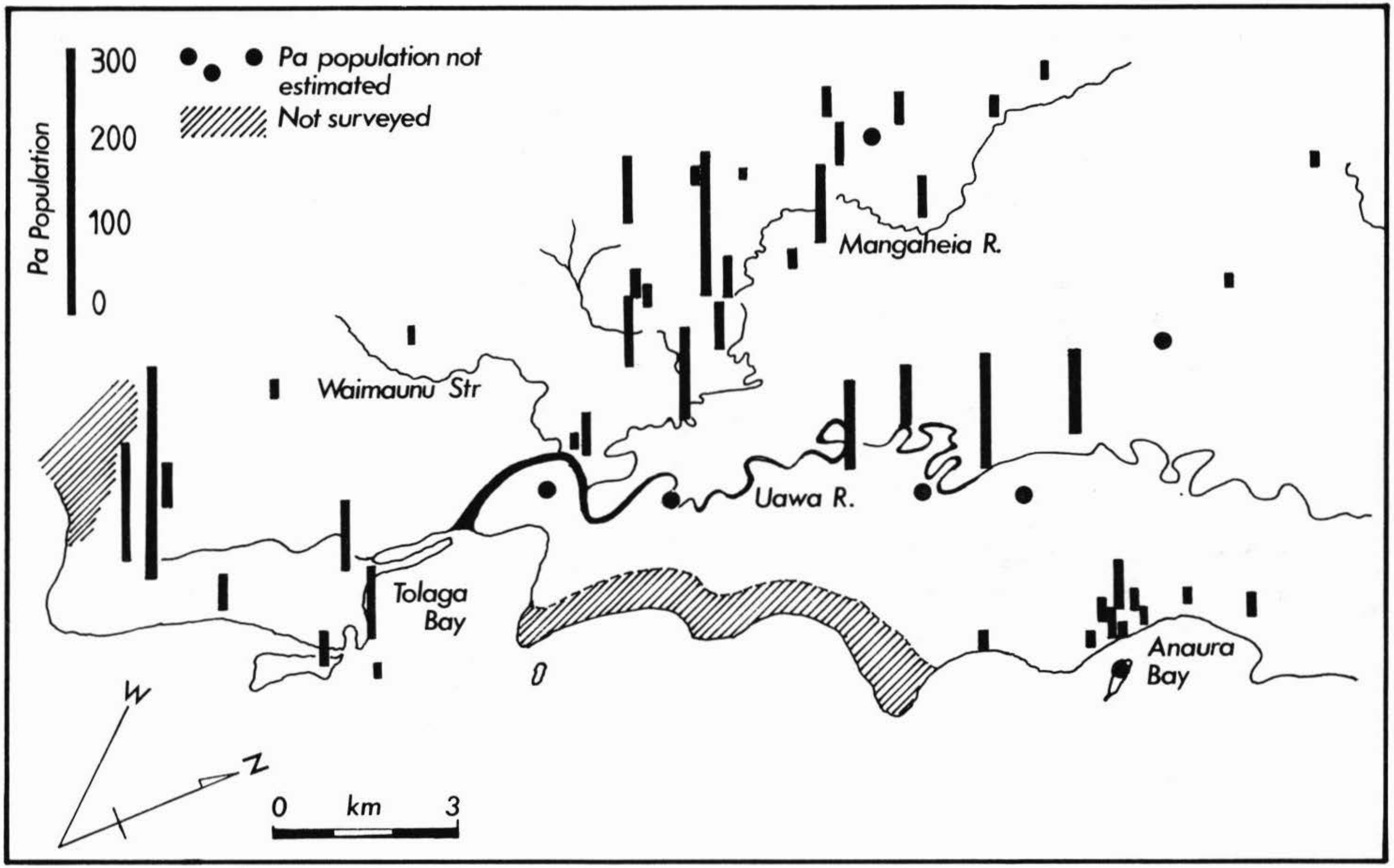

Figure 6: Populations of pa in the Uawa catchment calculated by a combination of pit volume and length of occupied ridge. The map base is tilted down to the north and west, emphasising the lower section of the rivers.

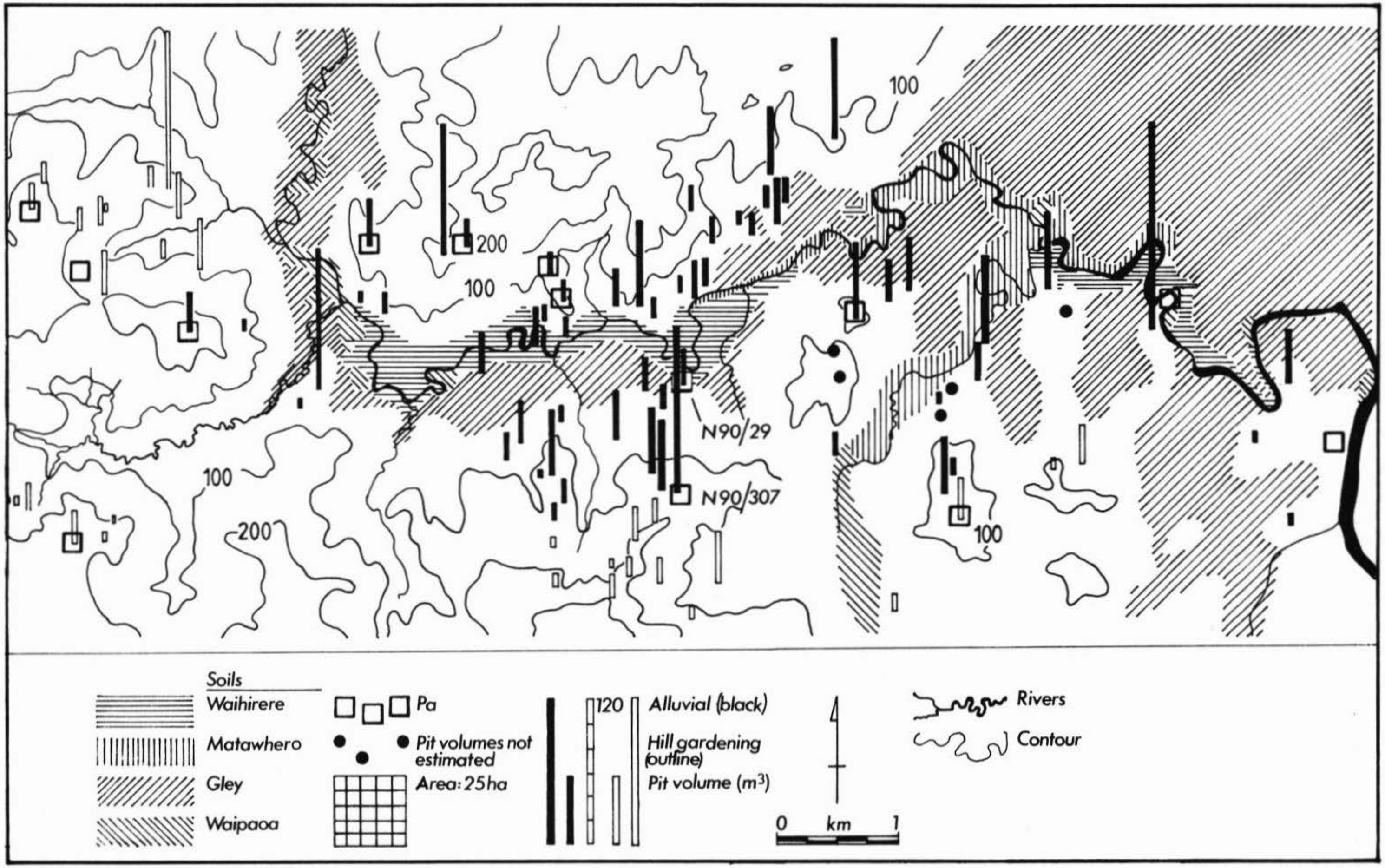

Figure 7: Mangaheia Valley, showing alluvial soil and surveyed pit volumes.

catchment may therefore be unambiguously identified as storage for crops from river levee alluvium.

The total volume of pits for the middle and lower valley area associated with the use of alluvial soils is 1800 m^3. The total population calculated by the formula for all pa in the middle and lower valley is about 600 people (see Table 5).

It cannot be assumed that all these were occupied at the same time, or that any site (pit or pa) was used for only one year or season. To deal with the factors of contemporaneity and length of occupation for any one site, the assumption is made that between one fifth and one third of the maximum population as defined by pa occupation are assumed to be in the valley in 1769, i.e., 120–200 people. It is reasonable to assume that maximum population would have been associated with a greater risk of opposition between social groups occupying the valley, even if they were related by kin ties.

All pits in the valley (whether associated with pa or not) are assumed to be used for 100, 40 and 10 years duration. These six possible variants are presented in the graph which shows a sigmoidal population curve (Kirch 1980: 42), starting low at A.D. 1000 and increasing rapidly to reflect the two known dates for the valley, and then levelling off (Fig. 8). The *area* under the curve is the product of pit volume and years used. For the 40-year duration assumption, this is (1800×40) 72,000 m^3.y; for the 100-year assumption, 180,000 m^3.y. For the range of assumed population in 1769 (120–200) the *area* under the curve has to match these figures. The results of the graphic analysis are shown in Table 6. For a 10-year pit life, the population figures are unacceptable since they are substantially less than the population of one of the large pa. For 40-year pit life, a continuing population of about 170 people for the valley is acceptable. (From the graph, the population figure is 170, with a 95 percentile range of 80 to 280.) A 100-year pit life approaches a population of 500 for the valley, which is unacceptable because it would suggest that all pa were occupied at the same time.

TABLE 6
POPULATION FIGURES FOR SIGNIFICANT OCCUPATION FROM A.D. 1110 IN THE MANGAHEIA VALLEY

Date	Duration of pit usage (yrs)		
(Years A.D.)	10	40	100
1100	0	10	20
1400	30	120	180
1800	50	170	420

Further evidence on the chronology of pa in the Mangaheia Valley is actively being sought, but the general picture for dating in the Uawa catchment (Jones 1986) does not suggest the remarkable late eighteenth century concentration of dates for pa in the Pouto Peninsula, North Auckland (Irwin 1985: 72).

From a particular sigmoidal growth curve the number of person-days represented can be calculated. Appendix 1 provides a mathematical calculation of population figures directly relating to population and population-years, using such a growth curve. As can be seen from the calculation and from the graph (Fig. 8), either very low 1769 population figures or a very short overall period of occupation has to be considered, if only a short duration of use of any one site is allowed (less than 10 years). For the middle and lower valley system, a short (less than 400 years) overall period of occupation is unlikely. One model not

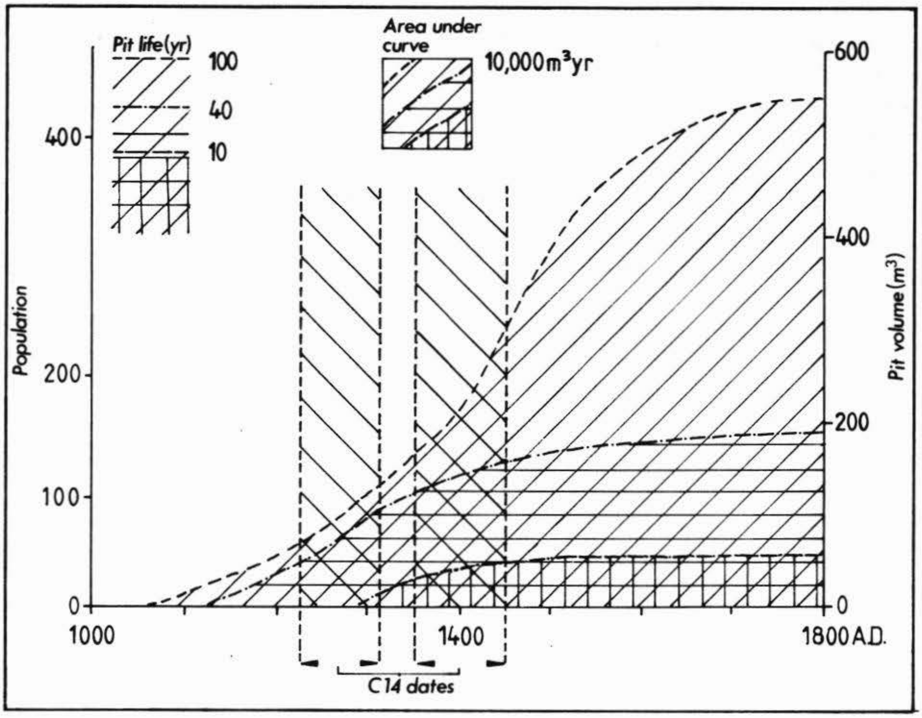

Figure 8: Graph of various assumptions relating to final population numbers and duration of pit use for the Mangaheia Valley.

presented here, which would be worth entertaining, involves major fluctuations in population over the centuries. This would allow a maximum population considerably higher than those shown, at as yet undefined periods, balanced by periods of very low population, but with the same accumulated volume of pit storage.

A model with varying durations of pit storage is also helpful in considering the balance of settlement between the river valley settlement and hill settlement in Tolaga Bay. In earlier work (Jones 1986), it was argued that hill settlement must have been as important as the valley settlement, in overall terms, and that some understanding of the relative chronology of these two settlement patterns was needed.

However, if the reasonable assumption of longer duration of use and re-use of pits near alluvium is made, hill settlement would become relatively unimportant. Duration of use under a hill swiddening pattern of horticulture could not have been long. The associated storage pits would have been abandoned and are unlikely to have been used again. An estimate of population based on hill gardening is made later in this paper.

ANAURA BAY

The visit of the *Endeavour* to Anaura Bay in October 1769 has provided a good deal of documentation of Maori gardening practice (Leach 1984: 64–66) and is also the source of the prevailing view of East Coast settlement pattern. The documents provide a useful check of the interpretations so far advanced, and also allow some inferences about areas in crop, and related population numbers. The possibility of using the Anaura Bay figures to calibrate the Mangaheia Valley system graph (Fig. 8) has been considered. The limits of the Mangaheia analysis were decided on other grounds. The Anaura figures allow more than a simple check, however, and further consideration will be given to implications for areas under crop in the Mangaheia and Uawa catchments.

Table 7 summarises the various sources on the question of population, planted areas, and the relative importance of sweet potato. The Monkhouse figure of 100 acres (40 ha) in crops, stated as though it were the result of much discussion, is the preferred figure.

TABLE 7
ENDEAVOUR OBSERVERS, 20–23 OCTOBER 1769, ON POPULATION AND CROPS OF ANAURA BAY.

Source	Population of Bay	Plantation area	Sweet potato
Banks 1958: 59	"did not see 100 people in all"	150–200 acres	
Cook 1955: 181–183	"two old men ... who from their garbe appeared to be chiefs"		"Pretty large plantations of these, but at present they are scarce"
Magra, in Cook 1955: 183			"Commonly occupy a considerable part of these plantations"
Monkhouse, in Cook 1955: 582–584	130 people around ship in 17 canoes, 2 chiefs; 60 at watering place	"It is agreed ... a hundred acres"	

Both Cook's and Magra's comments suggest that a large proportion of the planted area was in kumara. The drawing by Spoering (Lysaght 1979: 62) shows the plantations to be in the colluvial Waipaoa silt loams, and older yellow-brown sands of the mild slopes between the beach front and the steep hill slopes (Fig. 9). The total area of such soils, mapped by Rijkse and Pullar (1978) is 56 ha, or about 140 acres (this includes 6 ha or 14 acres of Matawhero soils). Allowing for an increase in colluvial soil area as a result of European farm practices, this area is notably close to those recorded as planted in 1769. The strips of cultivated land up the steep hill slopes shown by Spoering are here interpreted as extensions of the principal gardened areas in the colluvial slopes at the foot of the hill, such as those drawn by Taylor (1839) at Tokomaru Bay. The relative exaggeration of the steep-slope gardens in Leach's recent interpretation (1984: 64–66) appears to be unwarranted. These steep-slope gardens are better interpreted as minor extensions of the colluvial gardens, and could be either the result of pressure on garden space or some quirk of land tenure, or both.

Total pit volume for all of the Anaura Bay catchment is about 1000 m^3, much of this concentrated on steep-sided ridges 50–150 m in altitude above the colluvial soils or sandy soil areas. Sites that could not be attributed to storage of crops from colluvium were not included in the analysis.

Anaura Bay therefore provides an opportunity to test the assumptions of pit volumes, population, cultivated area, and crop productivity, brought forward for the Mangaheia Valley.

Figure 10 shows the graphs of population levels and pit volumes for Anaura Bay. The figures fit well with the observations of 1769 (Table 7), showing low population levels of about 70 in 1769 for 40-year duration of pit use. (From the graph, the population figure is 70, with a 95 percentile range of 30–110.)

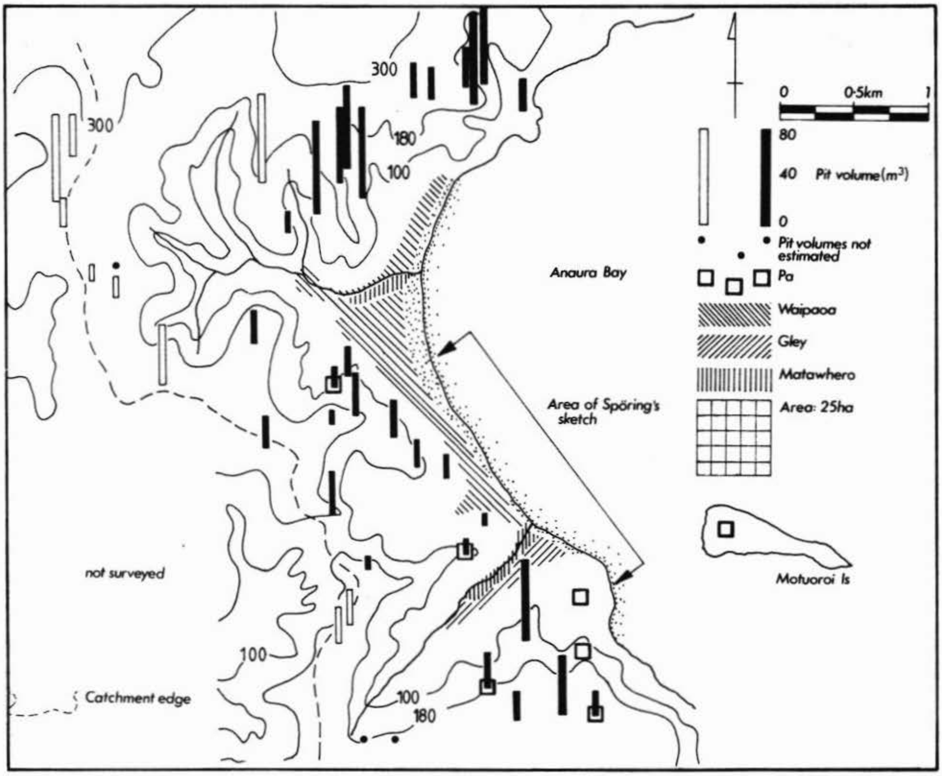

Figure 9: Anaura Bay, showing area of colluvial soils and surveyed pit volumes.

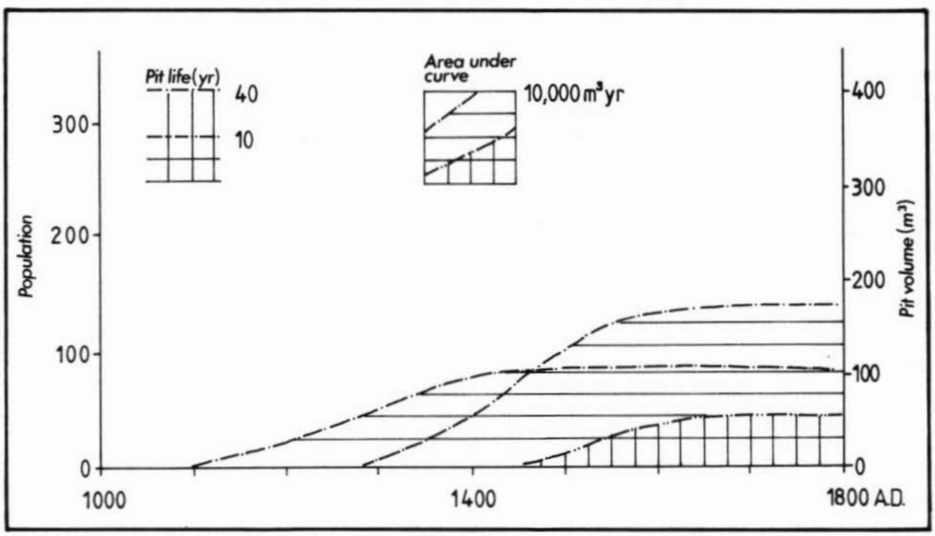

Figure 10: Graph of various assumptions relating to final population numbers and duration of pit use for Anaura Bay.

What is puzzling about Anaura Bay is the area of crops, which seems to be much more than that needed by the population. If we assume that the productivity is a relatively low 1.5–2.5 tonnes per ha, the 40 ha that appear to have been planted would provide 60–100 tonnes before storage. However, the consumption from storepits for 70 people at 185±60% kg/person is 5–20 tonnes, or well under half the crops that could have been grown from the historically observed area of crops. This is a serious departure from the archaeologically derived figures already discussed, which could be explained by several factors:

(i) Severe wastage or risk of crop failure before storage, to which the response was considerable over-production.

(ii) Conspicuous consumption in the period between harvesting and storage (see Fig. 3). Historically, such practices have been documented (Firth 1929: 308–338).

(iii) Storage other than in pits for a considerable period.

(iv) A high volume of trade in kumara or kumara products such as fermented paste.

(v) Very low productivity for the area under crop compared with ethnographically recorded cropping yields such as Barrau (1958).

(vi) The population seen by Cook was at a seasonal low point. This seems relatively unlikely, since the highest seasonal demand for labour would have occurred in the season of the *Endeavour*'s visit (i.e., spring).

(vii) The figure offered for consumption out of store (185 kg per person per year) is rather too low. Yet Cook (Table 7) records sweet potato availability as scarce in October, some 4–5 months before the new harvesting season. It could reasonably be argued that the assumption is rather too high.

If factors 1 to 5 are accepted in explanation, then the implications for the wider Uawa catchment are considerable.

THE WIDER UAWA CATCHMENT

Taking 170 (range 80–280) as an acceptable figure for population based on 270 ha of silt alluvium in the Mangaheia Valley, a range can be established for the population of the Uawa Flats, not so far considered because of the isolation of much of their alluvium from any elevated country on which pits could be dug. The total area of land in the Matawhero and Waihirere silt loam soil classes is 369 ha and 295 ha, total 664 ha (Rijkse and Pullar 1978: 62, 64). The total population which could be supported is:

$$\frac{664}{270} \times 170 \text{ (range 80–280)} = 420 \text{ (range 200–690)}$$

This figure takes no account of the extensive areas of rolling hill country in the south of Tolaga Bay, which contain significant and well preserved volumes of pit storage (Connor 1980; Jones 1986), as does the Mangaheia periphery. It was earlier suggested that hill country pit storage would have been in use for a shorter duration than pit storage associated with silt alluvium, and hence would contribute less to overall population aggregates. The surveyed volume of pits for the catchment of the Waimaunu Stream and the area east to the sea, an area which includes the Cook's Cove vicinity and the areas likely to have been seen by the *Endeavour* observers in 1769, is some 6,000 m^3. This is the most important area of hill gardening and provides a very considerable volume compared with surveyed pit volume associated with alluvial soils. Taking a 40-year apparent duration of use as the norm for alluvial soils, an apparent duration of use for hill soils of half that, or 20 years, is reasonable. Graphic analysis of pit volume, starting with negligible population and peaking at A.D. 1550, shows a population of 250 for a 20-year duration of use, and 500 for 40-year duration of use. Of these, the lower figure of 250 (range 130–410) is preferred.

Areas in cultivation in a valley such as the Mangaheia must have been extensive, even with populations as low as one to three hundred. An area of crops three times that of Anaura Bay, or 110 ha, would be not unreasonable. Taken as a proportion of the 270 ha of suitable alluvial soils available in the eighteenth century, this would amount to 45 percent of the area of desirable soils being in use.

This percentage of the available area under cultivation is not a generally acceptable one for swidden cultivation, where soils might be cropped in no more than one year in five (or a maximum of 20 percent of the available area cultivated). The need for fallowing would be less on the alluvial soils, since these have good natural fertility (Rijkse and Pullar 1978: 59, 63, 65). Nevertheless, the extensive nature of the gardening suggests that territorial pressure on alluvial soils must have been considerable (the population figures advanced here are by no means the maximum that could be entertained) and the value of gardening on hill soils can be readily explained.

Elsewhere (Jones 1986), it has been argued that climatic factors would also have had an influence on the incidence of hill gardening, and that there may have been a shift in the balance between hill gardening and alluvial gardening over time. It has been argued in the wider Polynesian context that the alluvial soils formed by man-induced erosion led to an intensification of cropping on these soils (Spriggs 1982; Kirch 1984: 123–192). There is no evidence to suggest such change in the eastern North Island, where the eighteenth century evidence is quite unambiguous on the existence of extensive hill gardening. Indeed, an equally plausible case could be made that gardening initially proceeded on alluvium and subsequently developed on the hill country. Overall, it would appear that an acceptable balance between low productivity and high reliability of product was being sought in a highly labour-intensive gardening regime. This applies to season by season considerations and over a longer span of time.

It seems doubtful that pressures were so acute as to lead to forms of intensification (other than labour intensification) that would result in greater density of population.

The Anaura Bay population density figures compare only with the lower range deduced for thirteenth century Palliser Bay, where a total population of 319 is derived, based on some 84–90 ha of swidden gardens and an annual cropping area of 12 ha (Leach 1976: 180). This general result is twice that of Anaura Bay, which is based on the eighteenth century records, and the population per annual cropping area is some 10–20 times that of Anaura Bay. Again, bigger crop areas, a shorter fallow period and lower crop productivity are indicated by the eighteenth century evidence. The question of duration of occupation must also be considered, since there is only poor evidence that the Palliser Bay gardens were used for several centuries with permanent abandonment. The majority of the dates for the Palliser Bay stone row gardening systems lie in the thirteenth century A.D. (Leach 1976). Variability between these dates is well within the range of the inbuilt errors of charcoal-based dates. A distinct set of later dates (fifteenth and sixteenth century A.D.) is presented for stone rows at the Washpool and Black Rocks (Leach 1976) where there is independent evidence of a long duration of occupation not necessarily related to gardening (Anderson 1979).

A reasonable interpretation of the Palliser Bay results, consistent with a labour-intensive, short or no fallow regime, would involve: initial burning and clearance of climax coastal forest; building of stone rows as windrows, and for shelter and land demarcation; a five to ten year period of use with labour-intensive cultivation and generally low productivity of 2–5 tonnes/ha; and eventual permanent abandonment caused by wind erosion of top soils and other environmental problems.

In this case, it is worth recalling Brookfield's (1962: 252) comment:

> Many systems employing land rotation contain more technical elaboration than some so-called "permanent" systems ... it might be more productive to pay closer attention to techniques, and to assess any agriculture by its success in maximizing output while retaining an equilibrium in the ecosystem.

The major contrast between Palliser Bay and Anaura Bay/East Coast horticulture would be the latter's relative permanence of settlement allowed by a combination of mature top-soils of high fertility, constantly re-juvenated flood plains and colluvial slopes, and hill gardening, in which an "equilibrium in the ecosystem" was clearly maintained.

SOCIAL ORGANISATION IN TOLAGA BAY

In the introduction to this paper, a number of apparent discrepancies were noted between the nineteenth century historical evidence of social organisation and archaeologists' interpretation of the eighteenth century *Endeavour* records. This section reviews likely settlement size, social organisation, and total population of the area in prehistory, and re-assesses the eighteenth and nineteenth century observations in the light of these results.

For the Uawa catchment, Tolaga Bay, a population of about 670 is suggested, based on 660 ha of silt alluvium and a largely unknown usage of hill soils. Defended settlements for any one period had an archaeologically defined minimum size of about 10 people, with a maximum of 250 and a mean size of 50.

The archaeologically derived figures for Anaura Bay fit well with the 1769 *Endeavour* observations for the same place. The Anaura Bay figures also suggest very substantial areas planted in crops, as much as one half ha for every person. If these figures can be relied on, area of soil usage for silt alluvium in the whole catchment must have approached the limits of soil availability, even with a relatively small population of 500–1000.

Population of the whole of Tolaga Bay would have been a minimum of five times that of Anaura Bay, with correspondingly larger social units than those observed in 1769, which form the basis of conventional views of settlement patterns on the East Coast of the North Island. Seasonal variation in the size and location of these units along the length of the principal river systems must also have occurred. For example, outside the growing season, smaller settlements could have been vacated with the crops relatively well secured in pits and brought to larger settlements as needed. Intensive use of alluvium in the nineteenth century was reviewed in an earlier paper (Jones 1986: 24-25).

The small, 1–3 extended family units defined by the rank-size analysis (Fig. 5) were undoubtedly the most frequently occurring social unit in prehistoric Tolaga Bay. This is further emphasised by the likely under-representation of this size of site in the present analysis, since the majority of "undefended" sites are of this size (Jones in press: Fig. 3). Overall, the distinction between defended (included in the present analysis) and undefended sites (not included) seems difficult to sustain, and not only for the small-sized units. The adaptive value of this unit for the bulk of subsistence activities, such as gardening, fishing or gathering, is generally recognised.

In the South Island, variants of the kin-based *whānau* (extended family) and *hapū* (sub-tribe) social aggregates had extremely variable population numbers and modes of identifying social relationship and affinity (Anderson 1980). The size of these units would fit well with the lower end of the range of social aggregates of 10–250 people defined in this study. From the Anaura Bay observations of 1769, the small hamlet of three or four houses in an enclosure and one or two extended families was the most common settlement type (Banks 1958: 135). This pattern is often contrasted with the neighbouring Bay of Plenty where apparently much larger settlements were seen (Davidson 1981: 12). No landings were made except in the far north-west of the Bay of Plenty, so this very high figure for settlement size must be treated with scepticism.

It has been argued that societies need "... to be organised as competitive cultural entities, with the ability to maintain and defend the boundaries of their support areas ... although a dispersed pattern of small settlements would represent an optimum solution to the problem of energy capture" (Smith 1978: 488–493). The smaller subsistence units of settlement would have aggregated into large units of 50–100 people for the purposes of defence or seasonally for other communal purposes, such as the pa N89 & 90/40, or 307 (Table 5, Fig. 8). These units need not only have existed for defensive purposes. In the nineteenth century, they existed for trade (Polack 1838) and were attached to mission stations (Williams 1974). Although no evidence can be brought forward for Tolaga Bay, it seems likely that extended family units may have come together as part of the seasonal round. These larger units must also have represented the principal self-maintaining kin unit or *hapū* (sub-tribe).

The range of settlement size and variety of cultivation methods and soil types used in Tolaga Bay suggest parallels with results of recent work in the Valley of Mexico. In the "Formative" period, i.e., before state formation, "polymorphic settlement configurations" are described as "predictable adaptive strategies", where land tenure or resource distribution prevent consolidation of land holding, and where "there is a considerable risk in the predictability of harvests either through climatic variability or imperfect adaptation of the cultigen to the environment where it is grown" (Hirth 1984: 137). This description of land tenure and subsistence provides a reasonable parallel with those of Tolaga Bay.

The prehistoric maize varieties were determined to have a productivity of 2,400–3,200 kg/ha with a population of 19 people/ha based on a consumption rate of 160 kg/person. Lower prehistoric yields have also been determined (Sanders, cited by Denevan and Turner 1985: 167). Even at these low levels of productivity, the population supported at comparable levels of consumption to the present New Zealand examples seems high.

CHIEFTAINSHIP

If we are to seek evidence of pre-state formation, then close consideration needs to be given to evidence of institutionalised leadership. This can to some extent be recognised as a consequence of settlement size.

In Tolaga Bay, the very largest prehistoric settlements are in the range of 200–300 people: units that would need a high degree of co-ordination and various methods of recognising and reinforcing communal interest, such as oral traditions of ancestry (*whakapapa*), and the central meeting house which was itself an elaborate metaphor of communally recognised ancestry. Such behaviour was described by the *Endeavour* observers in 1769 (Banks 1958), and named individuals occupying a range of positions of authority occur in the nineteenth century records. Settlements of this size, particularly at the upper end of the range, are clearly candidates for "scalar stress" (Johnson 1982) in which leadership needs to be institutionalised and reinforced for the benefit of the whole community.

These larger settlements also match the figure of 150–300 people used as the upper limit for a New Guinea social unit "possessing a coherent system for the maintenance of internal order", at which point it is likely to segment into two or more further descent groups (Forge 1972: 371). A corollary to Forge's argument could well be that, for this scale of settlement to continue in a stable form, there needs to be stratification of leadership of the kind evident at Tolaga Bay from the nineteenth century historical records.

The *Endeavour* observations of chieftainship can be re-interpreted in the light of these theoretical views, particularly with reference to the reinforcement of leadership. At Anaura Bay, 100–130 people were seen with *two* chiefs (Table 7). Elsewhere on the East Coast, chiefs with "a kind of Ensign of distinction" (a carved stick) were seen "in their War Canoes one, two or three, according to the size of them" (Banks 1958: 144).

> When ever we were Viseted by any number of them that had never heard or seen any thing of us before they generaly came off in the largest Canoes they had, some of which will carry 60, 80 or 100 people .... In each Canoe were generaly an Old man, in some two or three, these use'd always to direct the others, were better Clothed and generaly carried a halbard or battle ax in their hands or some such like thing that distinguished them from the others (Cook 1955: 281).

In general, these figures suggest as few as 20–30 men per chief, with a possible total population per chief of 50–70. The reference to the largest canoes being used in first contact is also of interest, since that contact would be one in which a competitive framework with the newcomers was established. The earliest historical references for the nineteenth century also clearly indicate ranking between chiefs.

Dumont D'Urville in Tolaga Bay in 1827 witnessed a display of this pattern of power, when he attempted to restrict access on to his ship. The first arrivals showed distinct deference to the second chief to arrive. The second arrival wanted Dumont D'Urville to shoot a third arriving chief but when he arrived on board he was accorded deference by the earlier chiefs.

> As in all other parts of New Zealand, the natives of Houa-Houa (Uawa) live in small independent tribal groups, each under the direction, or rather, under the protection of its own chief. Doubtless those who came on board first only belonged to weak tribes without any prestige, while those from the last canoe came from a powerful tribe ... (Dumont D'Urville 1950: 120).

Where there were accessible and reasonably productive tracts of soils, it must have been possible to have permanent settlements of greater than 100 people. The alluvial silt loams and some of the hill country could provide this opportunity.

A well established system of chieftainship implies a degree of control over the storage of crops for the purposes of reciprocity and prestation. Of Te Kani a Takirau, recognised as the "paramount" chief of Ngati Porou in the nineteenth century, it was said "all the food planted by the tribe was for his benefit alone, such was the law of the tribe" (Ropata Wahawaha, cited by Smith 1910: 173). Significantly, the first ten ranked pa in Table 5 have considerably higher mean values of pit volume than do the last ten pa. This evidence warrants closer consideration than is possible in this paper, in the light of the results of work by Law (1969) and Shawcross (1966).

Social units of the size and flexibility identified for Tolaga Bay would provide a kinship-linked "competitive cultural entity" consistent with many dynamic tiers of leadership at *whānau* (extended family), *hapū* (sub-tribe), and "paramount" chieftainship—in this case the Ngati Porou tribal grouping of the whole of the East Coast.

The present study has sketched in an interpretation of the archaeological field evidence of this society. In particular, it can be concluded that the 1769 observations of the society seen at Anaura Bay have previously been made to bear far too heavy a burden of interpretation. Compared with the Uawa catchment, Anaura Bay is a comparatively simple and small component of a wider system of settlement. Rapid changes in the size and location of settlement, and in the earned or ancestral ranking of individual leaders, both played a part in that settlement system.

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APPENDIX 1
"SIGMOIDAL" POPULATION GROWTH MODEL

T = Time in years from start of growth
N = Population size
$N0$ = Population size at start, i.e, $T = 0$
$N1$ = Population size at time $T1$
$N2$ = Population size at time $T2$
I = Initial population increase, % per annum
L = Limit population
ln(y) logarithm by its base e
exp(y) e raised to a power y
P = integral of N through time between T1 and T2

$$\begin{aligned} \text{let } R &= \ln \frac{(100+I)}{100} \\ \text{then}: N &= N0 \frac{(L \times \exp(R \times T)}{L - N0 + N0 \times \exp(R \times T)} \\ \text{and}: P &= L \times (T2 - T1) - (L/R) \times \ln(N2/N1) \end{aligned}$$

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