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– ARTICLE –

Polynesian Origins: a biodistance study of mandibles from the Late Lapita site of Reber-Rakival (SAC), Watom Island, Bismarck Archipelago

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ABSTRACT

Biological distance studies, especially those based on cranial and skeletal morphology, continue to provide physical anthropologists and bioarchaeologists with an exceptional set of mathematically based methods for understanding population relatedness and population history. Because of the demonstrated correlation between phenotypic and genotypic similarities, studies of cranial form, most notably cranial measurements, occupy a central role in modern biodistance studies. This paper examines the results of multivariate statistical procedures applied to measurements recorded in modern and prehistoric mandibles from the Pacific, including the largest sample of intact Lapita mandibles from the SAC site on Watom Island, New Britain, Papua New Guinea. The results of this analysis demonstrate that the Lapita-associated mandibles from the SAC site are morphologically most similar to mandibles from eastern Melanesia and the Polynesian mandible series are closest to mandibles from Southeast Asia. As demonstrated in earlier biological distance studies based on craniometric data, the results of this new biodistance study support an ancestral Polynesian homeland in Wallacea and not one within geographic Melanesia.

Keywords: biodistance, multivariate statistics, Lapita skeletons, Reber-Rakival (SAC) Site, Bismarck Archipelago

INTRODUCTION

The first human occupation of Remote Oceania (Figure 1), a region that extends east, north and south beyond the main islands of the Solomon Islands chain, including eastern Melanesia, Polynesia and Micronesia (Green 1991), commenced *ca.* 3200 calBP (Green *et al.* 2008). This event is associated with an eastward expansion of Austronesian-speaking people and the Lapita Culture Complex, a cultural tradition recognized by its distinctive dentate-stamped pottery and the introduction of horticultural plants, domesticated animals (pigs, chickens and possibly dogs) and commensal rat species (Kirch 2000, Petchey *et al.* 2011, Summerhayes 2007). Following its immediate origins in the Bismarck Archipelago in Near Oceania, *ca.* 3300 calBP (Summerhayes 2007), the Lapita culture spread through the Solomon Islands chain and other islands in eastern island Melanesia, eventually reaching Fiji, and then Tonga and Samoa in western Polynesia approximately 600 years later (Petchey *et al.* 2011). After a pause of approximately one thousand or more years, these early Pacific navigators went on to inhabit the rest of the islands of Remote Oceania.

Because the Lapita culture is tied to the initial human colonization of Remote Oceania (Green 2003), skeletons associated with the Lapita culture are viewed as important sources of information for investigating the origins, health, and lifestyle of the earliest inhabitants of Remote Oceania and Polynesia (Pietrusewsky 2012a). More specifically, the study of human skeletons found in Lapita sites provides direct biological evidence for identifying the ancestors/origins of Polynesians. However, given the temporal and regional variation in Lapita across the Pacific and whether, for that matter, 'Lapita people' represent a cohesive biological entity, reconstructions of biological history need to be approached cautiously (Matisoo-Smith 2007).

In this paper we apply multivariate statistical procedures to measurements recorded in mandibles from the Reber-Rakival (SAC) site on Watom Island in the Bismarck Archipelago, one of the largest series of mandibles associated with Lapita culture now available for examining bio-

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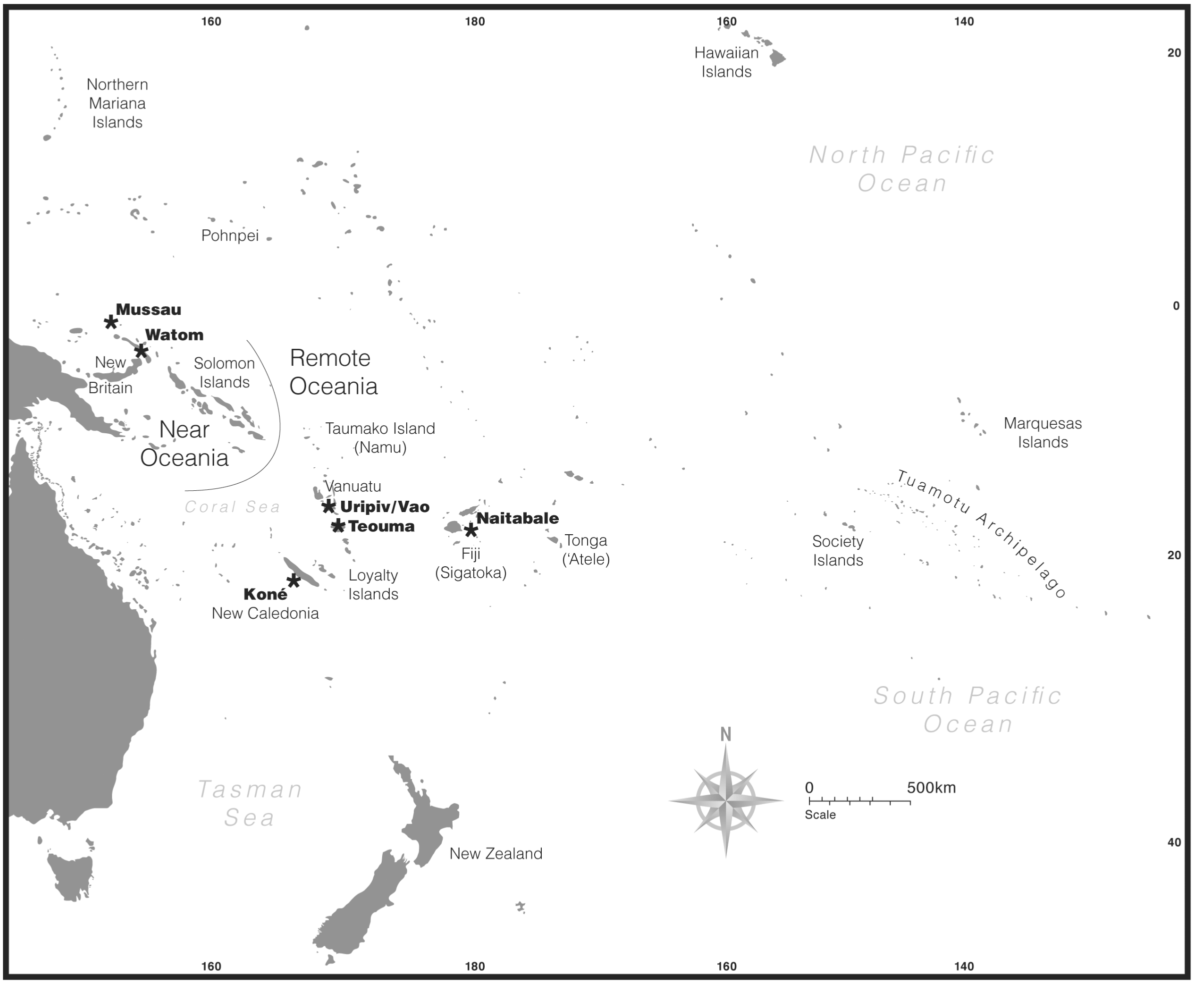

Figure 1. Map showing the approximate locations of the Lapita sites with skeletons (in bold) and the samples of Pacific mandibles used in this study.

logical origins of Lapita people and Polynesians.

BIOLOGICAL DISTANCE STUDIES

As observed by W.W. Howells, the biological characteristics of modern and ancient Polynesians are rich in clues regarding their origin and history, clues that were often misinterpreted in the past (Howells 1979: 271). The earliest studies in physical anthropology, including studies of skeletons from the Pacific, were frozen in a typological paradigm that relied on comparisons of measurements and indices and univariate statistics (Howells 1969: 312; Pietrusewsky 2006: 323). The transition to population-based studies of biological variation, based on historic and evolutionary processes and significant improvements in quantitative analysis, heralded a new era in physical anthropology.

Because of the demonstrated correlation between phenotypic and genotypic similarities and their demonstrated genetic basis, biological distance studies based on skeletal and dental variation provide a way to assess relatedness and affinities among past populations. Traditional measures of biological distance (biodistance) have generally relied on the application of quantitative methods to metric and nonmetric categories of skeletal and dental variation (Buikstra *et al.* 1990). More recent applications include ancient DNA (aDNA) and other biochemical and geochemical traits.

Studies of skull shape, most notably craniometric studies, continue to play a central role in biodistance studies and have been used to reconstruct population history in the Pacific. Although some aspects of cranial morphology [i.e., face and nose (Hubbe *et al.* 2009)], are susceptible to climatic adaptation, numerous studies have demonstrated that phenotypic distance and global patterns of craniometric variation, on average, correlate with neutral genetic distance globally and are consistent with neutral traits under an isolation by distance model (Harvati & Weaver 2006; Relethford 2004; Roseman 2004; von Cramon-Taubadel 2009; Betti *et al.* 2010).

A further attraction of this category of variation is its amenability to multivariate statistical analysis. There is now an emerging consensus that craniometric data can be used as a proxy to genetic data strengthening the use of phenotypic and craniometric variation in biodistance studies (von Cramon-Taubadel 2009). Likewise, the fact that craniometric variation is geographically structured allows high levels of classification accuracy when crania from different parts of the world are compared (Relethford 2009).

Both model-free and model-bound approaches are used in biological distance studies. The former focuses on tracing biological relationships, temporally and spatially, for reconstructing past population history while model-bound approaches allow the investigation of microevolutionary processes (e.g., gene flow, genetic drift, and selection) and the influences of geography and other isolating mechanisms on the observed patterns of biological variation (e.g., Relethford & Blangero 1990; Roseman 2004; Smith 2011).

Because skeletal series represent only samples of past biological populations, which often span considerable periods of time and may be biased in their representation, extreme caution should be exercised when skeletal (cranial) samples are used in biological distance studies. Using relatively large samples that are free of systematic bias helps to alleviate some of the concerns. Likewise, the selection of traits that are less susceptible to environmental and cultural influences further insures that the results of biological distance analysis more faithfully estimate genetic relatedness. Several studies have suggested that some bones of the neurocranium, such as the temporal bone, because of their stronger correlation with neutral genetic data might be more reliable for reconstructing human population history than other cranial bones (e.g., von Cramon-Taubadel 2009; Smith 2011). A quantitative assessment of human mandibular shape, using geometric morphometrics, found that human mandibular shape exhibits considerable geographic patterning (Nicholson & Harvati 2006). More recently, it was shown that the mandible may reflect subsistence strategy rather than neutral genetic patterns although surprisingly it was determined that the mandible does pattern geographically albeit not as strongly as the cranium (von Cramon-Taubadel 2011). This is reassuring given that the mandible is often the only bone of the skull complete enough to allow biodistance investigations involving Lapita and post-Lapita skeletons.

LAPITA ORIGINS AND POLYNESIAN ANCESTORS

Several models, based mainly on archaeological and linguistic evidence, have been advanced to explain the spread of Lapita culture and the origins of the first inhabitants of Remote Oceania, including Polynesians. The prevailing paradigm, the 'Out of Taiwan' model, argues that the ultimate origin of the Lapita culture is linked with the spread of Austronesian-speaking agriculturalists, fueled by population growth, who left present day southern China or Taiwan 5000–6,000 years ago (Bellwood 2005; Spriggs 2007).

Variants of this model include the 'Express Train to Polynesia', which suggests a rapid migration from Taiwan to Polynesia with little or no contact with the indigenous peoples in Southeast Asia and Near Oceania along the way (Diamond 1988). Other models allow for interaction between these new maritime migrants and the descendants of the first inhabitants (as well as intrusion and independent development) within the 'Voyaging Corridor', a region that extends from eastern Indonesia to the Bismarcks and Solomon Islands (Green 2003; Irwin 1992; Terrell 2004). The 'Slow Boat' model, proposes that the ancestors of Polynesians emerged within Island Southeast Asia, people who then moved slowly eastward into Remote Oceania with significant admixture with the indigenous inhabitants of Wallacea and Near Oceania (Richards *et al.*, 1998; Oppenheimer and Richards 2001a, 2001b). Other models focus on demographic processes that are linked to climatic change and sea-level rises in late glacial and post-glacial periods, rather than the spread of farming and population growth (Oppenheimer 1998; Soares *et al.* 2008). Solheim proposes the origin and spread of Austronesian-speaking peoples is linked to a trade and communication network that first appeared in the Asia-Pacific region 5000 BC (Solheim 2006). Finally, the 'Indigenous Development' model posits that the Lapita cultural complex developed in Near Oceania with no input from outside this region (Allen 1984).

Evidence from Physical Anthropology

While the primary support for the Out of Taiwan hypothesis has been based on archaeological and linguistic evidence, evidence from physical anthropology has also made contributions to investigating the origins of Polynesians. Beginning with the earliest descriptions of the Pacific Islanders by European explorers and later more disciplined studies in physical anthropology involving anthropometric and skeletal studies; there has emerged a general recognition of a Polynesian phenotype. This phenotype includes features of the skull (high pentagonal-shaped cranial vaults, wide cranial angles, and rocker jaws, etc.), body proportions (relatively tall robust individuals with long bodies and short legs), and teeth (shovel-shaped incisors) found in high frequencies among Polynesians. Features, which some believe were the consequence of sea-related activities associated with voyaging and fishing (Houghton 1990).

Previous Multivariate studies

Multivariate craniometric analyses of the indigenous inhabitants of Near and Remote Oceania and surrounding regions have demonstrated a strong differentiation between the inhabitants of Australia and geographical Melanesia and those who occupy Polynesia and Micronesia (e.g., Pietrusewsky 2005, 2006, 2008a, 2008b, 2008c, 2008d). This marked separation suggests separate origins for the people living in these two regions and little or no admixture between the ancestors of the Polynesians and the indigenous inhabitants of Melanesia or the Bismarck Archipelago region of the Pacific. Similar results were obtained in biological distance studies that used dental metric and nonmetric data (e.g., Turner 1986; Hanihara 1992).

Previous multivariate craniometric analyses further demonstrate a close connection between several of the Polynesian cranial series and those from island Southeast Asia, most notably the Lesser Sunda Islands, Sulawesi, and the southern Moluccas in eastern Island Southeast Asia. The close relationship between New Zealand and the Southern Moluccas, like that seen in the dendrogram based on distances (Pietrusewsky 2005: 210), highlights this association. Likewise, this earlier work demonstrated that the Polynesian cranial series do not form close associations with any of the cranial series from Melanesia or a single aboriginal series from Taiwan, the Atayal. Overall, the craniometric results are more consistent with an ancestral homeland for Polynesians in Southeast Asia rather than one in adjacent geographic Melanesia or more distant Taiwan.

Initial studies of Lapita and post-Lapita skeletons demonstrated a suite of dental, cranial, and infracranial skeletal traits (e.g., shovel-shaped incisors, rocker jaws, flattened upper femoral shafts, oval-shaped fovea capitis, costo-clavicular sulci, relatively tall stature, etc.) not unlike other Pacific Island and Polynesian skeletons (Pietrusewsky 1989a, 1990; Pietrusewsky *et al.* 1997, 1998). As well, a number of features clearly differentiated the Lapita skeletons from other Pacific skeletons. Most notably, Lapita mandibles were described as possessing short bodies, broad and bilaterally divergent rami; skeletons had generally slender long limb bones and small teeth.

Previous multivariate analyses using mandibular measurement data recorded in Lapita and Post-Lapita mandibles and other more modern Pacific Island samples (e.g., Pietrusewsky 1985, 1989a, 1989b) failed to produce a consistent pattern of biological relationship. Given the imperfect preservation of the Lapita skeletal remains and the fact that many are now known to post-date the Lapita horizon (Petchey *et al.* 2011), it is not surprising that these mandibles showed affinities with more modern inhabitants of eastern Melanesia (Pietrusewsky *et al.* 1998; Pietrusewsky 1989a, 1989b). Preliminary, some extremely so, studies of individual Lapita and post-Lapita skeletons from the Y2–25 site on Waya Island, Fiji (Pietrusewsky *et al.* 1997), WKO-013B from Koné, New Caledonia (Pietrusewsky *et al.* 1998) and the Naitabale site on Moturiki Island, Fiji (Katayama *et al.* 2007) have noted similarities with skeletons from the Pacific and Southeast Asia. Studies that focus on biological relationships of the other Lapita skeletons presented in Table 1 have yet to appear.

SUMMARY OF BIOLOGICAL EVIDENCE

In summary, the dental and cranial evidence based on modern and near modern skeletons from the Pacific and neighboring regions provides little or no support for an origin within geographical Melanesia for the ancestors of Polynesians. Previous multivariate analyses of craniometric data support a homeland in southern Wallacea for the initial inhabitants of Remote Oceania and very little support for admixture between ancestors of the Polynesians and the inhabitants of near Oceania and eastern island Melanesia.

OBJECTIVES OF PAPER

In this paper multivariate statistical procedures are applied to measurements recorded in mandibles from the Reber-Rakival (SAC) site on Watom Island in the Bismarck Archipelago, the largest Lapita burial ground in the Bismarcks now available for examining biological origins of Lapita people and their relationships with other Pacific and Asian series.

MATERIAL AND METHODS

Lapita and post-Lapita skeletons

Thus far, there are six sites (two in the Bismarck Archipelago of Near Oceania and four in western Remote Oceania) with skeletons associated with the Lapita culture (Table 1 & Figure 1). The Teouma site in Vanuatu, and several different sites on Eloaua, Emananus, and Mussau in the Mussau Islands, New Ireland, may have skeletal remains that date to the Early Lapita phase. The skeletons from the other four sites (Watom, northern Vanuatu, Koné, and Naitabale) date from the middle to Late Lapita phase. Other skeletons, previously reported to be associated with Lapita, have been determined to post-date, some substantially, the Lapita phase (Petchey *et al.* 2011).

While studies of the Early Lapita skeletons from the Teouma cemetery on Vanuatu, one of the largest Lapita assemblages discovered thus far, have begun to appear (e.g., Bentley *et al.* 2007; Buckley 2007; Buckley *et al.* 2008; Scott *et al.* 2010; Shaw *et al.* 2010), there have been no biodistance studies of the limited number of crania and mandibles from this site. Of the skeletons excavated thus far from the Teouma site, only seven adult crania and five adult mandibles are sufficiently preserved and intact to allow the recording of measurements (Valentin personal communication). In addition to poor preservation, another contributing factor that accounts for the rarity of Lapita cranial and mandibular remains such as those from the Teouma site, is the complex mortuary practices of removing certain bones, especially the skulls, after body decomposition (Valentin et al. 2011: 51). For many of the other Lapita sites with human skeletons, very few have intact adult crania (Table 1). The absence of complete adult crania remains an overwhelming obstacle to undertaking biodistance studies involving Lapita skeletons, which are crucial to studies of origins.

Reber-Rakival (SAC) Site, Watom Island, New Britain, Papua New Guinea

After the Teouma site in Vanuatu, the largest number of burials, at least thirteen, associated with the Lapita culture is from the Reber-Rakival (SAC) site on Watom Island, located off the northeast coast of New Britain in the Bismarck Archipelago, Papua New Guinea. There is evidence of extensive occupation by people associated with Lapita along the coastal flats of Watom Island (Green & Anson 1987, 1991). Earliest occupation of the site is estimated to span the Middle to Late Lapita periods (Anson *et al.* 2005).

Jim Specht excavated the first three burials (Nos. 1–3) at the SAC site on Watom Island in 1965–1966 (Specht 1968), more than a half century after Father Otto Meyer's first discovery of dentate-stamped Lapita vessels in the same general location in 1908. The Watom burials were located in the lower most occupation zone, designated C2, which contains evidence of domestic habitation and Late Lapita style pottery. More recent radiocarbon determinations, based on human bone from the skeletons, indicated

Table 1. *Sites with Lapita skeletons mentioned in text (see Figure 1 for locations).*

Site	**Location**	**Completeness of Skeletal Remains**	**Number of Individuals**	**Calibrated age ranges or dates given in references provided**	**References**
Teouma	Efate Is., Central Vanuatu	Approximately 80 burials representing subadults and adults; varying states of completeness	~80	Early Lapita 3200–3000 calBP[1]	Bedford *et al*. 2006, 2009; Buckley *et al*. 2008; Valentin *et al*. 2010
Mussau	Several Lapita sites on Mussau, Eloaua, and Emananus Islands in the Mussau Group (St. Matthias Islands), New Ireland, Papua New Guinea	Fragmentary skeletal and dental remains representing several individuals from five midden sites	No complete individuals	Early–Middle Lapita *ca.* 3500–2500 calBP[2]	Kirch *et al*. 1989
Watom	Reber-Rakival (SAC) site on Watom Island, East New Britain Province, Papua New Guinea	Partial remains of eight adult individuals (6 male, 2 female) excavated by Specht in 1965–66, Green and Anson in 1987 & 1991, and six additional Lapita-age burials excavated by Buckley and Anson in 2008 & 2009	~13+	Middle–Late Lapita Burial 1: 2800–2730 calBP; Burial 3: 2670–2350 calBP[3]	Specht 1968; Green & Anson 1987; Houghton 1989; Pietrusewsky 1989a; Anson *et al*. 2005; Petchey & Green 2005; Petchey *et al*. 2011
Uripiv & Vao Islands	Small islands located off the northeast coast of Makakula Is., northern Vanuatu	Five burials from Uripiv (2 fetuses, 2 infants, 1 child) are associated with initial Lapita settlement; 1 adolescent and 2 adults burials from Vao are associated with later Lapita settlement.	~8	Lapita/Late Lapita 3000–2600 calBP[4]	Bedford *et al*. (2011)
Koné (Site 13B)	Foué Bay, west coast Grande Terre, Koné, New Caledonia	Partial remains of at least four burials	~4	Late Lapita 2970–2850 calBP[5] 2850–2820 & 2800–2740 calBP[6]	Valentin *et al*. 2004; Sand 2010
Naitabale	Moturiki Island, central Fiji	Skeleton of a 50–60 year old female	1	Late Lapita Post–2650 calBP[7]	Katayama *et al.* 2007; Kumar *et al*. 2004; Nunn *et al*. 2007; Petchey *et al*. 2011

1 The dates reported here are based on charcoal not identified to short-lived species; the burials from this site are currently being dated using bone and other materials (Petchey personal communication).

2 The dates reported for the Mussau burials are based on shell and charcoal. The majority of the human skeletal and dental remains come from site ECA on Eloua Islands, Mussau Islands, a site that was initially occupied 3500 calBP and abandoned 2500 calBP.

3 Dates for B1 and B2 are on bone gelatin and are from Petchey *et al*. (2011).

4 Dates are based on direct dating of the burials and associated shell (Bedford *et al*. 2011).

5 Beta-179504 (charcoal sample) reported in Petchey *et al*. (2011:13).

6 Beta-179505 (charcoal sample) reported in Petchey *et al*. (2011:13).

7 Date is on bone gelatin (Nunn *et al*. 2007; Petchey *et al*. 2011).

that Burial 1 is Middle Lapita (2800–2730 calBP) and Burial 3 is within the Late Lapita (2670–2350 calBP) for the Bismarck Archipelago (Petchey *et al.* 2011; Summerhayes 2007).

Later excavations at the SAC site in 1985 by Dimitri Anson and Roger Green (Green & Anson 1987, 1991) resulted in the excavation of Burials 4–8 from zone C2. Most recently, in 2008 and 2009, Dimitri Anson and Hallie Buckley recovered additional elements for Burial 8 and at least five more burials (Burials 9, 10, 11, 14 and 15) of Lapita age. Burial 11 may include the partial remains of as many as five individuals bringing the total number of individuals from this site to at least 13. Although late in the sequence, the burials excavated at the SAC site on Watom Island represent the largest Lapita burial ground in the Bismarcks.

This study uses measurements recorded in male mandibles from Burials 3, 6, 8, 15, and Mandible 2 (Figure 2). Mandible 2 was identified in the miscellaneous remains from the 1985 excavations (Pietrusewsky 1989a). Although at least one burial from the SAC site is dated to the Middle Lapita period, most of SAC locality at the Reber-Rakival site on Watom Island is generally assigned to the Late Period (between *ca.* 2750 and 2500 BP) of the Lapita culture complex in the Bismarck Archipelago (Anson *et al.* 2005; Green *et al.* 1989).

Other mandible series used in the present analysis

Measurements recorded in the mandibles from the SAC site on Watom Island are used in two separate analyses. In the first, Watom is compared to nine male Pacific Island series, five from Polynesia and two each from Micronesia and Melanesia (Table 2, Figure 1). While the majority of the skulls are from museum collections, three series (ʻAtele, Sigatoka, and Namu) represent excavated prehistoric skeletons. Because only five mandibles were available for the Watom series, the number of mandibles representing the comparative series was restricted in number. In the first analysis 10 measurements were available and in the second, four measurements were common to the series compared.

In the second analysis the Watom mandibles are compared to six male series from Polynesia, three from eastern Melanesia, New Britain (Figure 1), and five series from

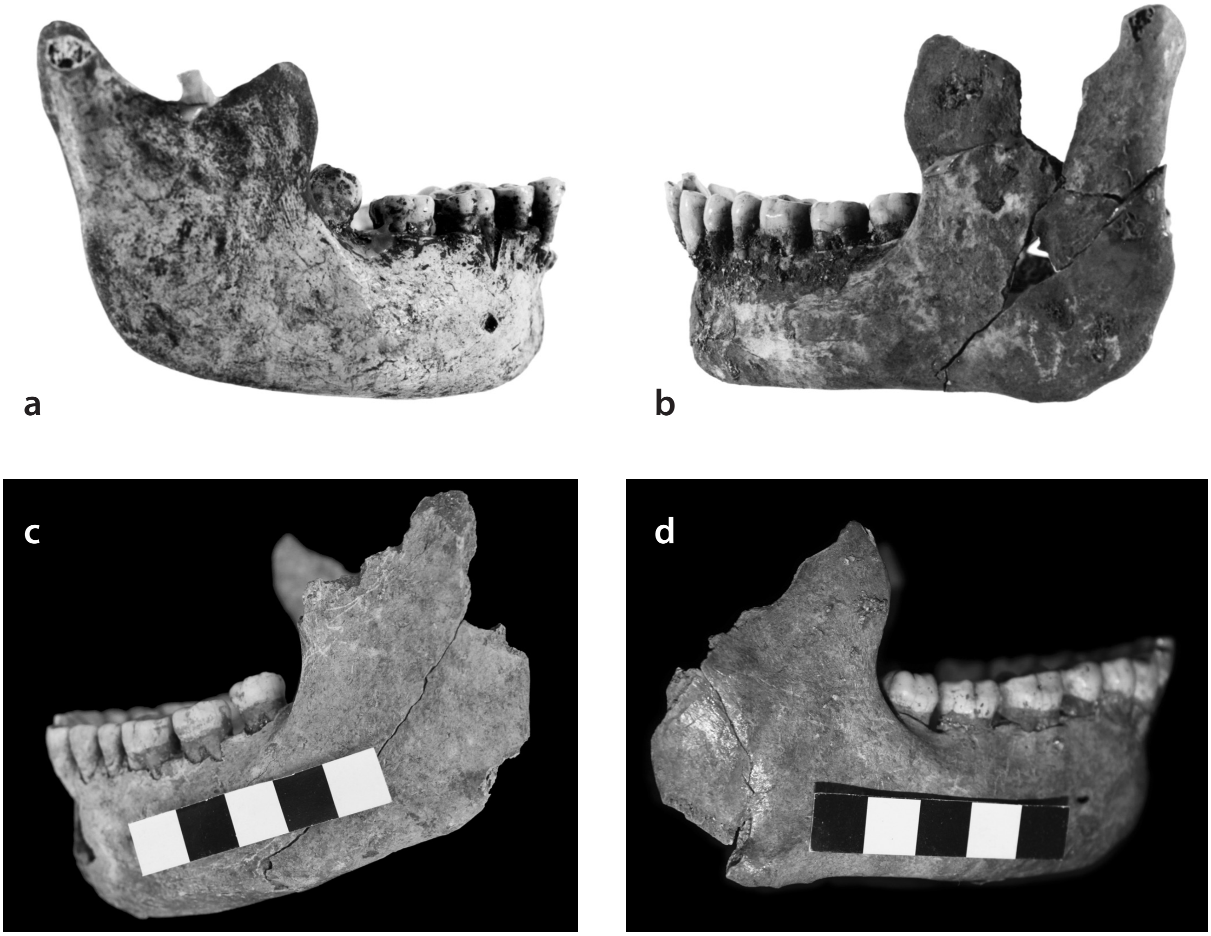

Figure 2. Some of the Lapita mandibles (lateral views) from the Reber-Rakival (SAC) site on Watom Island used in the study [a = Watom 3; b = Watom 6; c = Watom 8; d = Watom 15].

Table 2. *Mandible series used in the two analyses.*

Series Map No. & Name (abbrev.)	**No. of Crania**	**Location[1] & year examined**	**Remarks**
Analysis 1: 10 Male Mandible series and 10 Measurements			
1. Watom Island, New Britain, Papua New Guinea (WAT)	5	DUN-1987/2012	Five of the most complete mandibles from the SAC site on Watom Island, East New Britain Province, Papua New Guinea: Cat. Nos. 3, 6, 8, 15, & M2).
2. New Zealand (NZ)	15	DUN-1984	The majority of the skulls in this sample were collected in the late nineteenth century from known locations in the Otago region of the South Island of New Zealand. The following Cat. Nos. are included: B68, B139, B151, B168, B173, B174, B214, B342, B399, E21, E23, E41, E72, 202, and 319.
3. ‘Atele, Tongatapu, Tonga (ATE)	15	AIM-1984	The mandibles are from two prehistoric non-chiefly burial mounds, To-At-1, and To-At-2, excavated by Davidson in 1964 on Tongatapu, Kingdom of Tonga (Davidson 1969). The burial mounds were likely to have been in use over a considerable period of time *ca.* 1000–300 calBP.
4. Hawaiian Islands (HAW)	15	SIM-1990	The skulls were collected from Kauai Island. All specimens are presumed to be prehistoric.
5. Marquesas Islands (MRQ)	8	BPB-1992	All mandibles are from the Island of Ua Huka in the northern group, six are from the Hane Dune Site (Cat. Nos. 2843, 2845, 2848, 2851, 2896, 2897) and the origin of two more (Cat. Nos. 355 and 358) is identified as Ua Huka.
6. Society Islands (SOC)	11	BPB-1992	Mandibles are from the Tahiti Is. (Cat. Nos. 927, 940A, 940B, 940C, 940D); Moorea Is. (Cat. Nos. 924 and M5-3-Sk-4-4); Maupiti Is. (Cat. No. 2829); Bora Bora Is. (Cat. No. 3183A), and Society Islands (Cat. Nos. 219 and 220).
7. Pohnpei (Ponape) (PON)	9	TKO-1988	Eight burials are from Ponape (Cat. Nos. 2512-2526: 1, 2, 3, 4, 10, 12, 14, 15) and one is from Malem, Kosrae.
8. Northern Mariana Islands (MAR)	10	BPB-1987	Five skulls are from the House of Taga site on Tinian excavated by H. G. Hornbostel in 1925 (Cat. Nos. 874, 875, 878A, 881, 907); three more, also attributed to Hornbostel, are associated with latte structures on Tinian (Cat. Nos. 879, 889 & 905); two skulls are from Saipan (Cat. Nos. 890 and 904).
9. Sigatoka, Fiji (SIG)	15	DUN-1992	The burials from the Sigatoka sand dune site VL 16/1 on Viti Levu, Fiji, are generally assumed to belong to the Navatu phase (Level 2) that dates from 1700–1300 calBP (Anderson *et al.* 2006:146–147). Measurements were recorded in the some of the most complete mandibles from this site: Cat. Nos. 4C, 1/1, 1A, 1B, 1C, 2A, 10A, 10B, 10C, 13A, 16, 17A, 17B, 19, and 20.
10. Namu, Taumako Island, Solomon Islands (NAM)	16	DUN-1984	The burials are from the Namu site on Taumako Island, an island in the Duff (Taumako) Islands of the Santa Cruz Islands in the Solomon Islands. Human bone radiocarbon dates indicate the Namu burials range between 200–800 calBP (Leach & Davidson 2008:146). Measurements were recorded in 16 mandibles for Burial Nos.: 1, 13, 21, 34, 36, 73, 104, 126, 155, 164, 169, 179, 183, 184, 185, and 198.
Analysis 2: 16 Male Mandible Series and 4 Measurements			
1. Watom Island, New Britain, Papua New Guinea (WAT)	5	same as Analysis 1	
2. New Zealand (NZ)	20	AMS-1983; DAS-1984; DUN-1984; GOT-1983; PAR-1973/75; QMB-1983	The skulls in Dunedin were collected in the late nineteenth century from known locations in the Otago region of the South Island of New Zealand (Cat. Nos. B117, B129, B139, B151, B173, B175, B255, B388, E22, E23, E206). The remaining skulls, described as representing New Zealand Maori are from collections in Paris (Cat. Nos. 1148, 2615, 4861, 5341, 5371); Gottingen (Cat. No. 2919); Sydney (AMS: Cat. No. S249); DAS: Cat. No. 118), Queensland (Cat. No. 221).
3. Tonga (TOG)	20	BPB-1992; AIM-1984; SIM-1990	This series includes 6 Tongan skulls (Cat. Nos. 430, 431, 433, 435, 436, 440) were excavated by W. C. McKern during excavations on Tongatapu Island in 1920-21 as part of the Bayard-Dominick Expedition to Polynesia for the B. P. Bishop Museum. One more mandible from Tongatapu was examined in the B.P Bishop Museum (Cat. 2930). Eleven mandibles are from two prehistoric burial mounds, To-At-1, and To-At-2, on Tongatapu were excavated by Janet Davidson in 1965. Two mandibles are from Samoa the (B. P. Bishop Museum Cat. No. 2946) and the Natural History Museum (Cat. 25135).
4. Hawaiian Islands (HAW)	20	BPB-1969 onward	The Hawaii sample is from the Mokapu sand dunes on Oahu. The burials are presumed to be prehistoric.

Table 2 *continued*

Series Map No. & Name (abbrev.)	No. of Crania	Location[1] & year examined	Remarks
5. Marquesas Islands (MRQ)	20	AMS-1983; PAR-1973/1975; BPB-1992	The mandibles in the Bishop Museum are part of the Hane Dune series from Ua Huka Island (Cat. Nos. 2838, 2843, 2845, 2846, 2849, 2896, & 2897), two are from Ua Huka Island (Cat. Nos. 355, 358), and two are from the Marquesas Is. (Cat. No. 354 & 359). The mandibles in the Musée de l'Homme are from Nuku Hiva (Cat. Nos. 2725, 4854, 4719, 20553, & 112), Tahuata (Cat. No. 557 and 559), and Fatu Hiva (Cat. No. 7918). One mandible in AMS (Cat. No. 1220) is identified as coming from the Marquesas.
6. Society & Tuamotu Islands (SOC)	20	BPB, 1992; PAR-1975	The mandibles examined in the Bishop Museum are from various islands in the Society Islands (Cat. Nos. 220, 224, 940A, 940B, 7941, 2829). The mandibles in Paris are from Tahiti (Cat. Nos. 937, 6153, 5154, 4862, 4865, 4866, 4373); Moorea Island (Cat. Nos. 6717, 6720, 6724); Tuamotou Islands (6143, 6160, 6737, 6746).
7. Loyalty Islands (LOY)	20	PAR-1973/75	Most of the skulls are from Lifou Island, the main island of the Loyalty Island group. The majority of these were collected in the late nineteenth century.
8. New Caledonia (NCL)	20	PAR-1973/75	The skulls from New Caledonia were collected and accessioned by the Musée de l'Homme in the late nineteenth century.
9. Sigatoka, Fiji (SIG)	15	same as Analysis 1	
10. Vanuatu (VAN)	20	PAR-1973/75; SAM-1983; MMS-1983; NMV-1983.	The Vanuatu sample includes 15 skulls in Paris and 5 more in museums in Australia.
11. New Britain (NBR)	20	AMS-1983; DAM-1983; GOT-1983; SAM-1983	The New Britain sample comprises skulls from various locations including 7 that are from Ralum in the Gazelle Peninsula on the northeast coast of New Britain.
12. Java (JAV)	20	PAR-1975	The skulls, which were examined in the Musée de l'Homme in Paris, were collected from a number of locations in central and coastal Java in the late nineteenth century.
13. Sulu Archipelago (SUL)	18	PAR-1975	The specimens, which were examined in the Musée de l'Homme in Paris, are part of a larger collection of skulls and complete skeletons collected by Drs. Montano and Rey in an expedition to the Philippines and Indonesia in 1879.
14. Vietnam (VTN)	20	HCM-1989	Eight skulls are from the Van Dien cemetery in Hanoi and 12 are from dissecting room cadavers in Ho Chi Minh City. These collections were examined in the Faculty of Medicine, Ho Chi Minh City, in 1989.
15. Thailand (THI)	20	SIR-1989	Most of the skulls in this sample represent anatomical dissecting room cadavers in the teaching collections of the Siriraj Hospital in Bangkok.
16. Laos (LAO)	19	PAR-1973/75	The skulls represent recent Laotians in the Noël Bernard Collection that were registered in the collections of the Musée de l'Homme in Paris in 1920.

[1] AIM – Auckland Institute and Museum, Auckland, New Zealand
AMS – The Australian Museum, Sydney, Australia
BPB – B. P. Bishop Museum, Honolulu, U.S.A.
DAM – Dept. of Anatomy, University of Melbourne, Melbourne, Australia
DAS – Dept. of Anatomy, University of Sydney, Sydney, Australia
DUN – Dept. of Anatomy, University of Otago, Dunedin, New Zealand
GOT – Institut für Anthropologie, Universität Göttingen, Göttingen, Germany
HCM – Faculty of Medicine, Ho Chi Minh City, Viet Nam
MMS – Macleay Museum, University of Sydney, Sydney, Australia
NMV – National Museum of Victoria, Melbourne, Australia
PAR – Musée de l'Homme, Paris, France
QMB – Queensland Museum, Brisbane, Australia
SAM – South Australian Museum, Adelaide, Australia
SIM – National Museum of Natural History, Smithsonian Institution, Washington, D.C., U.S.A.
SIR – Dept. of Anatomy, Siriraj Hospital, Bangkok, Thailand
TKO – University Museum, University of Tokyo, Tokyo, Japan

island and mainland Southeast Asia (Table 2). Several of the Pacific Island series (e.g., Tonga, Marquesas Islands, Hawaiian Islands, Fiji) contain documented prehistoric skulls while the rest represent modern or near modern specimens examined in museums. Again, because only five mandibles were available for the Watom series, the number of mandibles for the comparative series was generally limited to 20.

Mandible Measurements and Sex Determination

The definitions of these measurements are provided in Tables 3 and 6. Using complete or nearly complete adult male mandibles, Pietrusewsky recorded the measurements. The methods for determining age at death and sex follow those described in Buikstra and Ubelaker (1994), Pietrusewsky and Douglas (2002), and White *et al.* (2012).

Multivariate statistics

The application of multivariate statistical procedures to craniometric data is the mainstay of biological distance studies in physical anthropology. Multivariate statistical procedures, a family of related statistics, allow the simultaneous analysis of multiple variables, such as cranial measurements, recorded in individuals from one or more groups (Pietrusewsky 2008a, 2012b). It is generally assumed that because the variables used in multivariate statistics are random and intercorrelated, their different effects cannot be interpreted individually in a meaningful manner. Cranial and mandibular measurements, because they are continuous variables, are ideally suited for multivariate analysis.

The two multivariate statistical procedures used to assess biological affinities in this study are stepwise discriminant function analysis and Mahalanobis' generalized distance statistic (Mahalanobis 1936). Both statistical procedures are explained in detail elsewhere (e.g., Pietrusewsky 2008a, 2012a, 2013: 151–152).

RESULTS

The results of applying multivariate statistics to two sets of data, one that uses ten mandibular measurements recorded in ten Pacific cranial series and the other that uses four measurements recorded in 16 cranial samples from the Pacific and Asia are presented separately.

Analysis I: 10 Pacific Groups, 10 Mandibular Measurements

Stepwise Discriminant Function Analysis

Stepwise discriminant function was applied to 10 mandibular measurements (Table 3) recorded in 119 male mandibles representing ten Pacific Island groups (Table 2, Figure 1).

A summary of the measurements (Table 3), ranked according to the F-values [tests of equality of group means using classical one-way analysis of variance] received in the final step of discriminant function analysis provides an indication of the discriminatory power of the original variables. Among the variables that contribute the most to the discrimination in this analysis are the mandibular length, bimolar-1 breadth, and bicanine breadth, and ramus breadth.

Table 3. *Summary ranking of mandibular measurements according to F-Values received in the final step of the first discriminant function analysis (10 male groups, 10 measurements).*

Step No.	Measurement[1]	F-Value	$d.f._B/d.f._W$[2]	p[3]
1	Mandibular length (O)	13.755	9/110	*
2	Bimolar-1 breadth (T-M1EB)	10.647	9/109	*
3	Bicanine breadth (T-CEB)	4.762	9/108	*
4	Ramus breadth (M-71)	4.194	9/107	*
5	Symphysis breadth (T-CBS)	4.550	9/106	*
6	Bigonial breadth (M-66)	2.739	9/105	*
7	Inferior length (M-68)	2.165	9/104	n.s
8	Alveolar length (T-BCAB)	0.806	9/103	n.s
9	Symphysis height (M-68)	0.593	9/102	n.s
10	Bimolar-3 breadth (T-M3)	0.465	9/101	n.s

1. The definitions of the measurements used in this analysis follow Martin and Saller (1957), Trinkaus (1978), and Olivier (1979). The numeric and alphabetical abbreviations (in parentheses) following the name of the measurement correspond to the original number or alphabetic code used by the authors in their descriptions of the how these measurements are recorded. 'O' = Olivier; 'M' = Martin and Saller; 'T' = Trinkaus.
2. $d.f._B/d.f._W$ = degrees of freedom between/degrees of freedom within.
3. * $p \leq .01$; n.s. = not significant.

The first four eigenvalues (table not shown), which provide an indication of the proportion of dispersion accounted for by each canonical variate, account for 94.2 per cent of the total variation in this analysis, indicating significant heterogeneity for these canonical variates.

The jackknifed classification results (Table 4) indicate that two of the Watom mandibles are re-classified as Namu and two more as the Northern Marianas. Three Namu

Table 4. *Jackknifed classification results obtained in the first analysis that applies stepwise discriminant function analysis to 10 mandibular measurements in 10 male groups, showing the cases re-classified at the end of the process (numbers in parentheses represent the number of crania originally assigned to each group). See Table 2 for explanation of abbreviations.*

Watom (5)		New Zealand (15)		'Atele (15)		Hawaiian Is. (15)		N. Mariana Is. (10)		Pohnpei (9)		Sigatoka (15)		Namu (16)		Marquesas Is. (8)		Society Is. (11)	
MAR	2	NZ	8	ATE	12	HAW	6	MAR	6	PON	3	SIG	6	NAM	7	SOC	3	MRQ	4
NAM	2	NAM	4	MAR	1	SIG	4	ATE	2	HAW	2	ATE	3	NZ	5	SIG	2	HAW	2
WAT	1	HAW	1	SIG	1	SOC	2	NZ	1	NZ	1	HAW	2	WAT	3	HAW	1	SIG	2
		PON	1	NAM	1	NZ	1	MRQ	1	ATE	1	SOC	2	HAW	1	MAR	1	SOC	2
		SOC	1			NAM	1			NAM	1	PON	1			MRQ	1	MAR	1
						MRQ	1			MAR	1	MRQ	1						

(Taumako Island) mandibles are misclassified as Watom. The Watom, Society Islands, and Marquesas Islands series have the poorest classification results in this analysis.

When the ten group means are plotted on the first two canonical variates (Figure 3) Watom (New Britain) and Namu (Taumako Island) form a cluster. A plot of the ten groups means on the first three canonical variates (Figure 4) accentuates the Watom and Namu affinity to which New Zealand is attracted. The two Micronesian series (Pohnpei and the Northern Mariana Islands) form an isolated cluster. The cranial series from the Hawaiian, Society, and Marquesas Islands and Fiji form a separate grouping. The 'Atele (Tongan) series is the most isolated series in this representation.

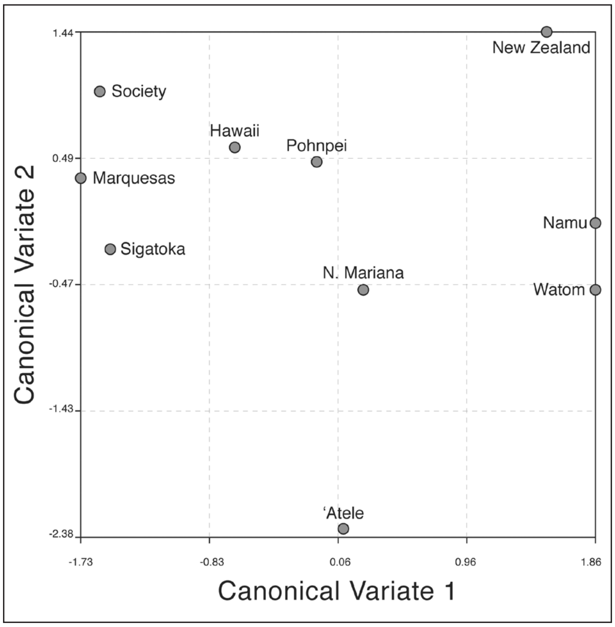

Figure 3. Plot of 10 group means on the first two canonical variates that results from the application of stepwise discriminant function analysis to 10 mandibular measurements. Abbreviations of the cranial samples are explained in Table 2.

Mahalanobis' Generalized Distance –D

The distances, obtained through the application of Mahalanobis' generalized distances to ten mandibular measurements are given in the Table 5.

The groups closest to Watom are Namu, Northern Marianas, and New Zealand. The groups with the greatest distances to the Watom series, indicating greatest dissimilarity, include Marquesas and Society Islands in Eastern Polynesia, Sigatoka (Fiji) and Pohnpei. The Watom series is not particularly close to any of the Pacific Island series investigated in the first analysis. Also of note is the association of the mandibles from the 'Atele burial mounds on Tongatapu, Tongan Islands, with the two series from Micronesia and those from the Sigatoka burial mound in the neighboring Fiji.

Applying the UPGMA clustering algorithm to the distances for ten groups results in the dendrogram shown in Figure 5. The Watom series forms a loose connection with the New Zealand and Namu series, which are well separated from the remaining series.

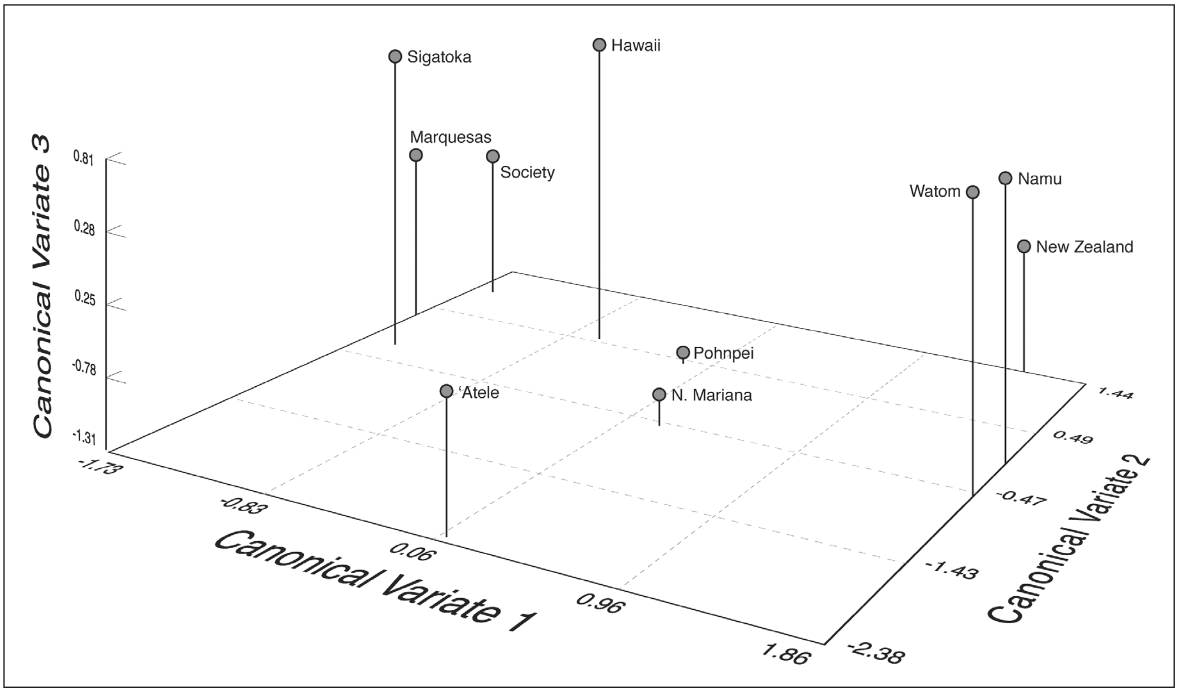

Figure 4. Plot of 10 group means on the first three canonical variates that results from the application of stepwise discriminant function analysis to 10 mandibular measurements. Abbreviations of the cranial samples are explained in Table 2.

Table 5. *Mahalanobis' distances for 10 Pacific groups using 10 mandibular measurements. All distances are significant at p > .05 unless otherwise indicated (see Table 2 for explanation of abbreviations).*

	WAT	NZ	ATE	HAW	MAR	PON	SIG	NAM	MRQ	SOC
Watom	—	9.878	13.825	12.351	9.013	14.942	14.987	7.492	18.988	21.073
New Zealand		—	16.983	7.777	7.518	5.840	13.756	4.364	12.661	10.441
'Atele			—	10.760	6.966	9.722	9.497	9.915	11.541	14.309
Hawaiian Is.				—	7.829	5.410	2.583	7.143	2.631*	2.733*
N. Mariana Is.					—	4.979	7.964	9.043	6.737	8.497
Pohnpei						—	8.765	9.044	5.420	4.362
Sigatoka							—	13.158	2.294*	3.540
Namu								—	14.356	14.470
Marquesas Is.									—	1.137*
Society Is.										—

* = distance not significant at *p* > .05; significance of distances was determined according to Rao (1952:245) and Buranarugsa & Leach (1993:17).

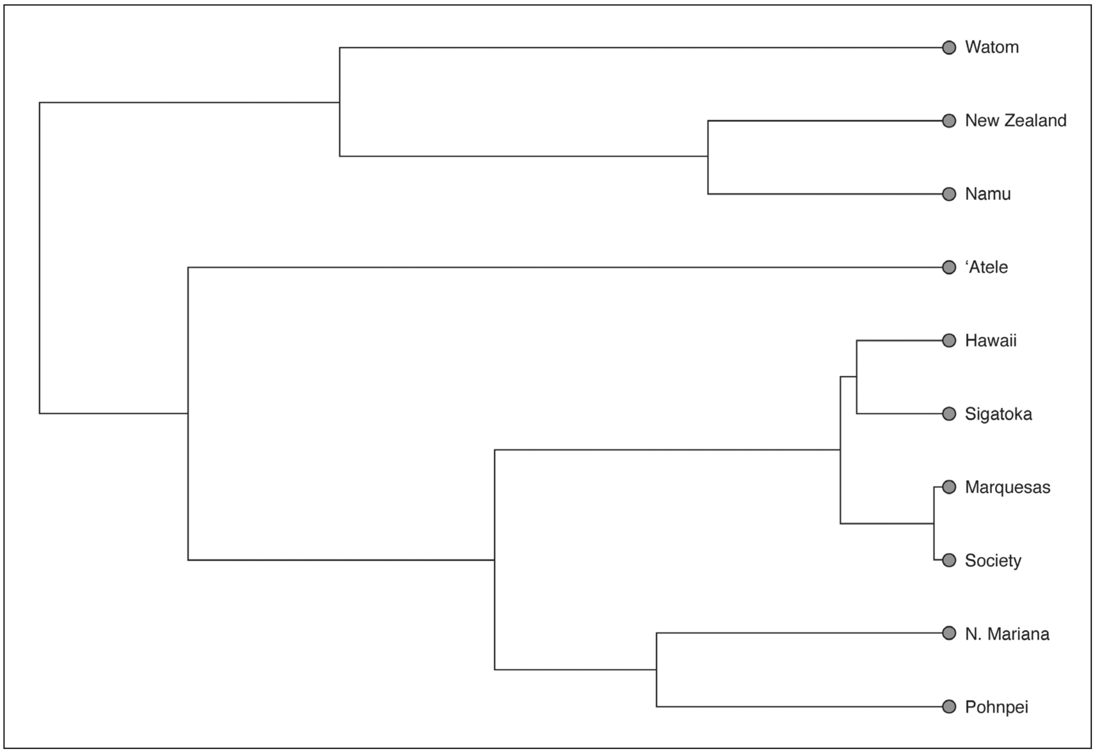

Figure 5. Dendrogram (or diagram of relationship) that results from applying the UPGMA clustering algorithm to Mahalanobis' distances using 10 mandibular measurements recorded in 10 male groups.

Analysis II: 16 Asia-Pacific Groups, 4 Mandibular Measurements

Stepwise Discriminant Function Analysis

Stepwise discriminant function was applied to four mandibular measurements (see Table 6) recorded in 297 male mandibles representing 16 Pacific Island and Southeast Asian groups (Table 2, Figure 1).

A ranking of the four measurements (Table 6), according to the F-values received in the final step of discriminant function analysis, indicates that ramus breadth contributes the most to the discrimination in this analysis.

Eigenvalues, which provide an indication of the proportion of dispersion accounted for by each canonical variate indicates that the first canonical variate accounts for 72 per cent of the total variation (table not shown). The first two eigenvalues account for 86 per cent of the total varia-

Table 6. *Summary ranking of mandibular measurements according to F-Values received in the final step of the second discriminant function analysis (16 male groups, four measurements).*

Step No.	Measurement[1]	F-Value	d.f.$_B$/d.f.$_W$[2]	p[3]
1	Ramus breadth (M-71)	15.331	15/281	*
2	Symphysis height (M-68)	2.791	15/280	*
3	Ramus height (M-70)	1.878	15/279	n.s.
4	Bigonial breadth (M-66)	1.809	15/278	n.s.

1. M = Martin and Saller (1957).
2. d.f.$_B$/d.f.$_W$ = degrees of freedom between/degrees of freedom within.
3. * p ≤ .01; n.s. = not significant.

tion; both are significant at the 1 per cent level, indicating significant heterogeneity for these canonical variates.

The correct and incorrect jackknifed classification results for each of the 16 groups (Table 7) indicates that two of the Watom mandibles are correctly classified and one each is re-classified as Hawaii, New Caledonia, and Sigatoka. Three of the Tongan and Loyalty Islands mandibles each are re-classified as Watom and two each of the Hawaiian Islands and Fijian mandibles are reclassified as Watom. New Caledonia, Watom, and Vanuatu are among the series with the best classification results in this analysis.

When the 16 group means are plotted on the first two canonical variates (Figure 6) Watom occupies a peripheral position. The series closest to Watom in this figure are Sigatoka, Loyalty Islands, and New Caledonia from eastern island Melanesia. A plot of the 16 group means on the first three canonical variates (Figure 7) reiterates the associations seen in the previous plot. With the possible exception of Tonga, all the Polynesian and Southeast Asia series are distant from Watom, Sigatoka, Loyalty, and New Caledonia, which form a loose association in one quadrant of this diagram.

Table 7. *Jackknifed classification results obtained in the second analysis that applies stepwise discriminant function analysis to four mandibular measurements in 16 male groups, showing the cases re-classified at the end of the process (numbers in parentheses represent the number of crania originally assigned to each group). See Table 2 for explanation of abbreviations.*

Watom (5)		Tonga (20)		Society Is. (20)		Marquesas Is. (20)		New Zealand (20)		Hawaiian Is. (20)		Loyalty Is. (20)		New Caledonia (20)	
WAT	2	TOG	4	VNT	6	HAW	3	NZ	5	NZ	4	NCL	5	NCL	10
HAW	1	WAT	3	NZ	3	VAN	3	THI	5	WAT	2	WAT	3	LOY	4
NCL	1	LOY	3	HAW	2	NBR	3	HAW	2	SOC	2	SIG	3	SIG	4
SIG	1	VAN	2	WAT	1	VNT	3	NCL	2	HAW	2	SOC	2	NZ	1
		VNT	2	TOG	1	SIG	2	NBR	2	LOY	2	LOY	2	VAN	1
		MRQ	1	VAN	1	WAT	1	WAT	1	SIG	2	VAN	2		
		NCL	1	NBR	1	SOC	1	JAV	1	SUL	2	NBR	2		
		NBR	1	SIG	1	MRQ	1	SUL	1	TOG	1	TOG	1		
		SIG	1	JAV	1	NZ	1	VNT	1	NBR	1				
		SUL	1	SUL	1	THI	1			VNT	1				
		THI	1	THI	1	LAO	1			THI	1				
				LAO	1										

Vanuatu (20)		New Britain (20)		Sigatoka (15)		Java (20)		Sulu (18)		Vietnam (20)		Thailand (20)		Laos (19)	
VAN	7	TOG	5	SIG	4	NZ	6	VAN	6	VNT	4	VNT	5	VAN	4
TOG	4	NZ	4	HAW	3	SOC	4	SOC	3	NZ	3	SUL	4	MRQ	2
NBR	2	HAW	2	NCL	3	SUL	3	VNT	3	VAN	3	NZ	3	NZ	2
WAT	1	VAN	2	WAT	2	HAW	1	NZ	2	SUL	3	THI	3	JAV	2
SOC	1	NBR	2	SOC	1	NCL	1	TOG	1	THI	3	NBR	2	SUL	2
NZ	1	SOC	1	LOY	1	VAN	1	HAW	1	TOG	1	WAT	1	THI	2
NCL	1	MRQ	1	VAN	1	NBR	1	SUL	1	SOC	1	TOG	1	SOC	1
JAV	1	LOY	1			SIG	1	THI	1	JAV	1	VAN	1	HAW	1
VNT	1	NCL	1			JAV	1			LAO	1			NCL	1
THI	1	JAV	1			THI	1							NBR	1
														VNT	1

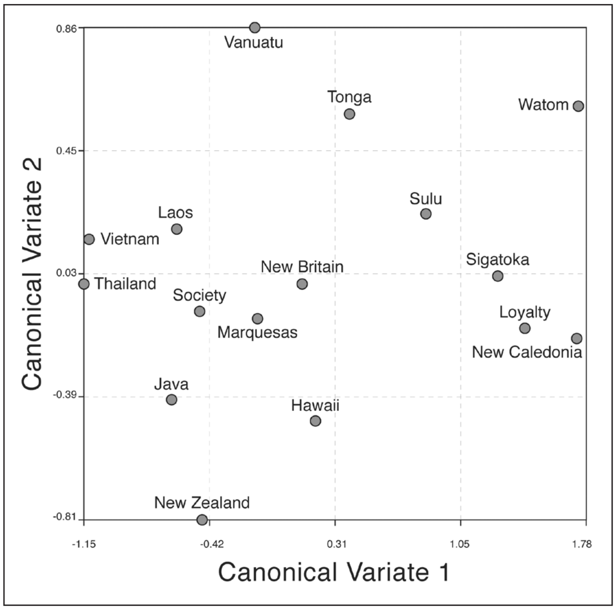

Figure 6. Plot of 16 group means on the first two canonical variates that results from the application of stepwise discriminant function analysis to four mandibular measurements.

Mahalanobis' Generalized Distance -D²

The distances obtained through the application of Mahalanobis' generalized distances to four mandibular measurements are given in Table 8.The groups closest to Watom are Sigatoka, Loyalty Islands, New Caledonia, and Tonga. The groups with the greatest distances to Watom include Thailand, Vietnam, New Zealand, Sulu, and Java. Again, with the possible exception of Tonga, the Watom series is not particularly close to any of the Polynesian series investigated in the second analysis.

Applying the UPGMA clustering algorithm to the distances for 16 groups results in the dendrogram shown in Figure 8. The Watom series joins Sigatoka, Loyalty Islands, and New Caledonia, all series from eastern island Melanesia, This grouping is well separated from the remaining samples in this analysis.

DISCUSSION

Previous research on Lapita mandibles from Watom Island (Pietrusewsky 1989a, 1990) demonstrated a number of features, which when compared to other Pacific skeletons, clearly differentiated the Watom skeletons. Most notably, the Watom mandibles possessed short bodies, and broad and divergent rami compared to the mandibles of people now living in Polynesia, Micronesia, and Melanesia (Pietrusewsky 1989a). Multivariate analyses involving mandibular measurements (e.g., Pietrusewsky 1989a, 1990) failed to produce a consistent pattern of biological rela-

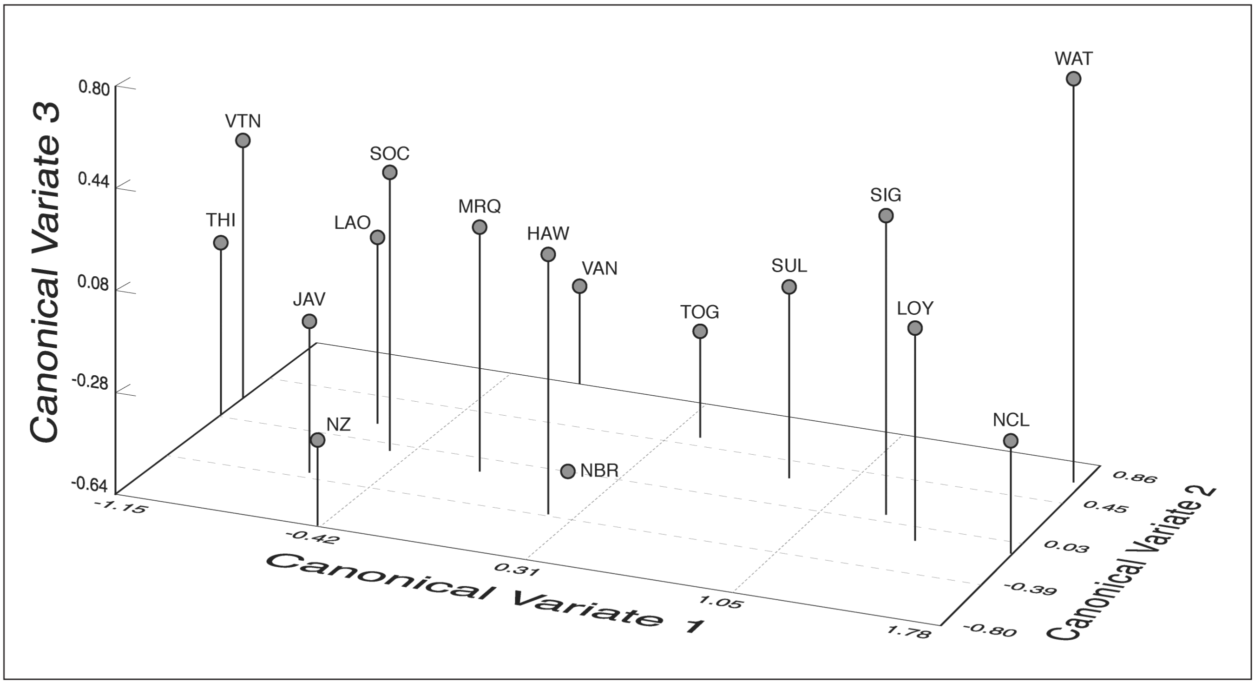

Figure 7. Plot of 16 group means on the first three canonical variates that results from the application of stepwise discriminant function analysis to 4 mandibular measurements. Abbreviations of the cranial samples are explained in Table 2.

Table 8. *Mahalanobis' distances for 16 Pacific-Asian groups using four mandibular measurements. All distances are significant at p > .05 unless otherwise indicated (see Table 2 for explanation of abbreviations).*

	WAT	TOG	SOC	MRQ	NZ	HAW	LOY	NCL	VAN	NBR	SIG	JAV	SUL	VTN	THI	LAO
WAT	—	2.997	5.673	4.377	8.059	3.652	1.380*	2.397	4.973	5.072	0.709*	7.523	7.544	9.039	9.675	6.434
TOG		—	1.687	1.001	2.599	1.402	1.976	3.100	0.571*	0.546*	1.557	2.111	1.85	3.170	3.013	1.346
SOC			—	0.177*	1.046	0.682*	3.720	5.677	1.380	1.536	3.206	0.334*	0.363*	0.575*	0.654*	0.204*
MRQ				—	0.910*	0.261*	2.611	4.400	1.265	0.865*	2.061	0.503*	0.711*	1.303	1.262	0.377*
NZ					—	0.985	4.187	5.715	2.938	1.095	4.245	0.324*	1.460	2.052	1.402	1.158
HAW						—	1.687	3.281	2.277	1.110	1.351	0.975	1.776	2.485	2.394	1.221
LOY							—	0.382*	3.717	2.594	0.503*	4.304	5.447	6.756	6.752	4.389
NCL								—	4.929	3.713	1.657	5.964	7.447	8.928	8.763	6.248
VAN									—	1.275	3.455	1.786	0.966	1.763	1.775	0.789*
NBR										—	2.424	1.218	1.650	2.981	2.370	1.174
SIG											—	4.244	4.842	6.247	6.408	3.863
JAV												—	0.490*	0.781*	0.461*	0.353*
SUL													—	0.239*	0.190*	0.061*
VNT														—	0.145*	0.442*
THI															—	0.369*
LAO																—

* = distance not significant at p > .05; significance of distances was determined according to Rao (1952:245) and Buranarugsa & Leach (1993:17)

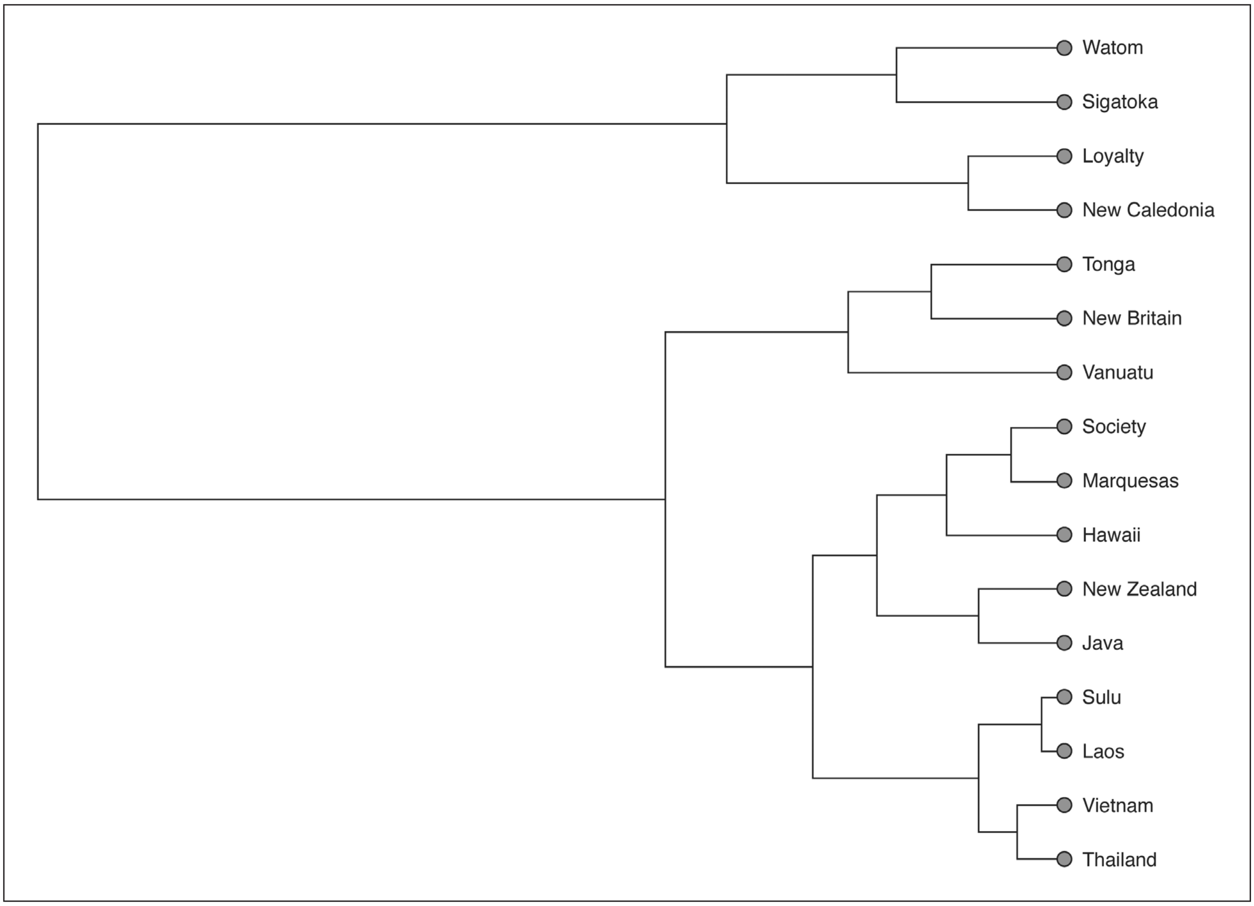

Figure 8. Dendrogram (or diagram of relationship) that results from applying the UPGMA clustering algorithm to Mahalanobis' distances using four mandibular measurements recorded in 16 male groups.

tionship, although the Watom and post-Lapita mandibles were well differentiated from Polynesians and generally closest to mandibles from eastern Melanesia. Recent redating of some of the skeletons used in this earlier work determined that some of the mandibles combined with those from Watom Island post-date the Lapita phase, some by a considerable degree (Petchey *et al.* 2011), thus weakening the conclusions of this earlier study.

Relationships Between Watom Lapita and Polynesians (Analysis 1)

The results of the present multivariate analysis, which uses five Lapita mandibles from Watom Island and nine other Pacific series (Analysis 1), indicate similarities between the Watom and Namu mandible series and little or no similarity to the Polynesian series. The jackknifed classification results (Table 4) in this analysis show that three mandibles from the Namu site on Taumako Island, in the eastern Solomon Islands, are misclassified as Watom, and two of five Watom mandibles are re-classified as Namu. The canonical plots (Figures 2 & 3) in this analysis also reveal that Watom is closest to Namu. Likewise, the results of the Mahalanobis distance analysis indicate that the group closest to Watom is Namu.

Taumako Island, located in the Southeast Solomon Islands, is the largest island of the Duff (Taumako) Islands, which are part of the Outer Eastern Solomon Islands. Radiocarbon dates based on human bone suggest the burial mound at Namu, from which the mandibles used in this analysis were obtained, was in use between 200–800 calBP (Leach & Davidson 2008: 146). The first inhabitants, who began to arrive approximately 3000 years ago, were people associated with the Lapita culture. Although the first human settlers probably came from some part of the wider Solomon Islands area, it is quite likely that later cultural influences from Polynesia occurred early on in the sequence of occupation. Today, the current inhabitants of the Taumako Islands speak a Polynesian language, but in many other respects their culture is more closely associated with the Santa Cruz Islands area (Leach & Davidson 2008: 323). This reflects a long history of interaction and contact with several places both near and farther afield from these islands.

A previous multivariate craniometric analysis (Pietrusewsky 2008d) demonstrated that the Namu crania were most similar to cranial series in neighboring eastern Melanesia (Santa Cruz, Fiji, and Loyalty Islands) and were most differentiated from Polynesian cranial series. Univariate comparisons of female craniometric data in the same study found that the female crania from the Namu site were almost identical to a post-Lapita female skeleton (WKO-013B) from Koné in New Caledonia (Pietrusewsky *et al.* 1998). This new analysis, using mandibular measurements, reaffirms the previous results and demonstrates that the skeletons associated with the Lapita culture in the Bismarcks are most similar to people now living in island Melanesia, who are biologically very different from Polynesians. The results of an isotope and trace element analysis suggested that the Late Lapita people on Watom Island were relatively mobile, including one possible migrant female, Burial 9 not included in this study (Shaw *et al.* 2010).

It is worth mentioning that the cranium assigned to Burial 15 from Watom, whose mandible is included in this study, exhibits cranial modification very similar to that seen in the adult crania of the Arawe people of southwestern New Britain (Brown 2010). This type of cranial modification has not been observed in Polynesian crania.

The cumulative evidence, based on biodistance studies using mandibular and cranial measurements, suggests the people buried in the Lapita burial ground on Watom Island are phenotypically more similar to the indigenous inhabitants of near Oceania and the western region of Remote Oceania (e.g., Vanuatu, Loyalty Islands, New Caledonia) than they are to Polynesians. Although it is somewhat naïve to believe that biological, linguistic and cultural traits are necessarily transported through time as bundles (Addison & Matisoo-Smith 2010: 1), the expectation that skeletons associated with the Lapita Cultural Complex, Early or Late Lapita, biologically resemble the modern-day inhabitants of Remote Oceania is not supported by this study. The evidence presented in this and previous biodistance studies challenges the prevailing orthodox view that the origin of Polynesians is associated with Lapita culture.

If the skeletons associated with the Lapita culture, like those excavated on Watom Island in the Bismarcks, represent the ancestors of the people who would eventually go on to colonize Polynesia and other parts of Remote Oceania not part of geographical island Melanesia, then the observed dichotomy between Lapita and Polynesian skeletons requires explanation. Is the appearance of a Polynesian phenotype the result of an intrusion of new people from elsewhere or is it the result of transformative processes that take place in western Polynesia (Tonga and Samoa) similar to archaeological and linguistic evidence that suggests the distinctive Polynesian culture developed there (Green 1967)? Given the very shallow time depth available for this to occur, a thousand years or less, intrusion may be a more likely explanation. Of course, this scenario challenges the orthodox view that the origin of Polynesians was solely Lapita-derived. Alternative explanations for the appearance of a Polynesian phenotype include serial founder effect, genetic bottleneck, and other stochastic events associated with ocean voyaging (Kirch & Green 2001: 73–74; Howells 1979; Lum *et al.* 2002). The association of Micronesian and Polynesian mandibles in the first analysis (as well as in multivariate craniometric analyses by Pietrusewsky previously cited) may provide support for Micronesia as a possible alternative route for the ancestors of the Polynesians, an idea earlier championed by Howells (1973) and more recently by Addison & Matisoo-Smith (2010).

Watom Lapita, Pacific Islanders, and Southeast Asians (Analysis 2)

The second analysis, which applies multivariate statistical procedures to four mandibular measurements recorded in 16 Asian and Pacific Island groups, again shows that Watom mandibles are most similar to those from eastern geographical Melanesia and highly differentiated from those in Polynesia.

Previous multiple craniometric multivariate analyses of Pacific and Asian series (Pietrusewsky 2005, 2006, 2008a, 2008b, 2008c, 2008d) indicated the presence of two major divisions, one comprising Melanesian and Australian series and a second that includes Polynesian and East and Southeast Asian series. Results of this earlier work further demonstrated a close connection between several of the Polynesian and Island Southeast Asian cranial series, most notably the Lesser Sunda Islands, Sulawesi, and the Southern Moluccas in Island Southeast Asia. A recurring connection in these analyses was that between New Zealand and the Southern Moluccas. Although no mandibular series from the southern Moluccas was available for the present analysis, several mandibular series from eastern Polynesia group closely with those from island and mainland Southeast Asia, most notably New Zealand and Java.

Studies of mt-DNA, Y-chromosome, and genome-wide studies of modern humans and commensal species provide additional context for interpreting the results of the present analysis involving the Late Lapita mandibles from the SAC site on Watom Island (e.g., Friedlaender *et al.* 2008; Hill *et al.* 2007; Kayser *et al.* 2001, 2008; Matisoo-Smith 2009; Wollstein *et al.* 2010). Genetic studies of modern humans generally favor Polynesian origins in the Bismarck Archipelago region with probable ultimate origins in Island Southeast Asia, well in advance of the time of dispersal predicted by the Out of Taiwan model (e.g., Soares *et al.* 2011). Likewise, the results of genome-wide studies indicate that while the Polynesian autosomal gene pool is of distinctively Island Southeast Asian origin, there has been substantial admixture between the ancestors of the first people to colonize Remote Oceania and the indigenous inhabitants of Near Oceania (e.g., Kayser 2010).

The results of the present study support craniometric and genetic evidence demonstrating a connection between Polynesia and Southeast Asia, particularly Island Southeast Asia. Unlike the genetic evidence however, the mandibular and cranial evidence finds little or no admixture between Polynesians, or their presumed ancestors, and the inhabitants of Near Oceania and geographical Melanesia. Likewise, the skeletons associated with Lapita Cultural Complex in the Bismarcks, although contemporaneous with the earliest inhabitants of western Remote Oceania, the immediate ancestors of the Polynesians, are most similar to the people living in geographical Melanesia.

The sharp differentiation between Polynesians and the indigenous inhabitants of New Guinea (including Watom Island) and island Melanesia (including Vanuatu, New Caledonia, and Fiji), indicated in these results, suggests separate population histories for these two regions. While the evidence from this new biodistance study does not fit any of the currently proposed models for Polynesian origins entirely, it does support models (e.g., 'Voyaging Corridor' and 'Triple-I' models) that suggest an intrusion of new people and culture from a region outside Near Oceania (in Island Southeast Asia or Wallacea), and/or cultural innovation, possibly coupled with the effects of sampling error to account for a Polynesian phenotype. There is little or no evidence for integration or admixture between the ancestors of the Polynesians and the people they encountered on their journey through Near Oceania in the results of the biodistance analyses presented in this paper.

CONCLUSIONS

While the sample from Watom Island used in the present study is small and represents skeletons associated with the Late Lapita phase in the Bismarck Archipelago, the results of this new and previous biological distance analyses allow some tentative conclusions regarding biological relationships of these skeletons and the origins of Polynesians.

- The mandibles associated with Late Lapita culture in the Bismarcks are biologically similar to those of the modern or near modern inhabitants of Near Oceania and western Remote Oceania and most dissimilar to Polynesian mandibles.
- Modern and near modern Polynesians are biologically closest to people living in Island Southeast Asia.
- If the ancestors of Polynesians passed through island Melanesia on their way to Polynesia, there is little or no phenotypic evidence of admixture between these people and the indigenous peoples they encountered.
- The results of this new biodistance analysis do not support Late Lapita people as ancestors of Polynesians.
- As suggested in previous craniometric analyses, an ancestral Polynesian homeland located somewhere in Island Southeast Asia or Wallacea is indicated by these results.

One of the greatest challenges to biodistance studies is the availability of adequate samples of well-preserved crania. Larger samples of well-dated skeletons associated with Early Lapita culture, which include relatively complete and well preserved crania and mandibles, will facilitate future work in this area and contribute to our understanding of biological relationships and the origins of Pacific Islanders, including the Polynesians.

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