

1 The Evolution of Migration: the case of Lapita in the southwest Pacific

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Abstract:

Migrations have occurred across the history of the genus *Homo* and while the movement of pre-modern humans over the globe is typically understood in terms of shifting resource distributions and climate change, that is in ecological terms, the movement of anatomically modern, and specifically Holocene, populations is often explained by human desire to discover new lands, escape despotic leaders, forge trade relationships and other culture-specific intentions. This is a problematic approach to the archaeological and behavioural explanation of human migration. Here an evolutionary and ecological framework is developed to explain various movement behaviours and this framework is applied to the movement of human groups from the inter-visible islands around New Guinea to the widely dispersed archipelagos of the southwest Pacific about 1000 BC. Labelled the Lapita Migration, this movement is explained as a selection-driven range expansion. The development of evolutionary and ecological theory to explain human movement facilitates empirical testing of alternative hypotheses and links different histories of human movement through shared explanatory mechanisms.

Key words:

dispersal, Lapita, Oceania, migration, range expansion, selection

40 Movement is a constant characteristic of human life, occurring along a continuum of distances and  
41 durations. Major migrations have occurred multiple times in our history from the first hominid movements out  
42 of Africa (Lahr and Foley 1994), to the spread of archaic and modern humans in Eurasia (Haak et al. 2015;  
43 Skoglund and Jakobsson 2011), later population movements in the Americas (Frachetti and Spengler III 2015),  
44 as well as historically documented migrations in the colonial (Barquera and Acuña-Alonzo 2012) and modern  
45 (Abel and Sander 2014) eras. Smaller migrations, more limited in duration or population numbers have occurred  
46 countless times throughout the world (e.g., Burley 2013; Snow 1995; Stark et al. 1995).

47 One of the most impressive feats of human movement in the ancient world occurred three millennia  
48 ago in the southwest Pacific. After more than 40,000 years of human occupation in the inter-visible islands  
49 around New Guinea, voyagers moved east, into the open ocean where islands can be separated by weeks-long  
50 sailings. Between 3000-2750 cal BP, these groups colonized the distant and unoccupied archipelagos stretching  
51 from the Reef and Santa Cruz Islands to Sāmoa (Fig. 1), lying within approximately two million square  
52 kilometres of the southwest Pacific Ocean. The voyagers made and used a distinctively decorated pottery, called  
53 Lapita, which is the archaeological signature for the first cultural deposits in these archipelagos. The changing  
54 climatic conditions, navigational skills, and canoe technology that are correlated with the eponymous Lapita  
55 migration have been topics of research for decades (e.g., Anderson et al. 2006; Bell et al. 2015; Di Piazza et al.  
56 2007; Irwin 1989; Montenegro et al. 2016), but aside from these possible triggers of migration, comparatively  
57 little research has focused on the processes that explain why some, but not all, individuals moved to Remote  
58 Oceania when they did, and why this movement stopped at Tonga and Sāmoa, without further successful  
59 eastward landfall for another 2000 years. In short, 3000 years ago in the southwest Pacific, given the ability *to*  
60 migrate, *why* migrate?

61 The few answers to this question have focused on human motivation in the social and cultural context  
62 of Oceanic societies (Finney 1996). For example, Bellwood (1996) argues that groups with Lapita pottery were  
63 part of a larger population of similar Austronesian language speakers with an ideology that included the right of  
64 primogeniture. Individuals who might benefit less from primogeniture, second and later sons for example, could  
65 voyage to new lands, claim them, and thereby gain economic power and social status. Earle and Spriggs  
66 (2015:522) make a similar argument based on individuals' desire for power and control of voyaging knowledge,  
67 and see Lapita maritime culture "as a competitive and rather accessible political forum that was the engine  
68 driving rapid colonization of the Pacific Islands." Terrell (2014:11) has argued that Lapita movement to Remote  
69 Oceania was a prestigious activity, but not "singularly intentional and premeditated". Irwin (1992) mentions

70 these same individual motivations, and adds the thrill of adventure and a desire to explore the unknown, but  
71 suggests archaeology is poorly equipped to investigate these possibilities. Lilley concurs, and while agreeing  
72 that individuals have agency, adds that “the agency of individual social actors and ... social relationships ... are  
73 irrelevant at the level of geographical and chronological resolution we are dealing with here. We are considering  
74 the processes of population movement entailed in the settlement of vast areas over tens of generations” (Lilley  
75 2008:83-84).

76         These examples, except Lilley’s minority dissent and a few others (e.g., Kuhn et al. 2016), apply emic  
77 or common sense<sup>1</sup> concepts and human motivation to explain past population movements (e.g., Anthony 1990;  
78 B. J. Baker and Tsuda 2015; Burmeister 2000; Leppard 2014; Richards 2008), at least amongst anatomically  
79 modern humans (cf. Winder et al. 2015). This is a product of the dominant explanatory framework in  
80 archaeology and anthropology where human volition, agency, or some fundamental force in people—vitalism  
81 (Mayr 1997; Sellars 1962)—is used to explain cultural, behavioural and artefactual variation. Despite its  
82 dominance, there is a clear problem with this framework: there are no consistent expectations for empirical  
83 patterns that distinguish different vitalistic processes. If we want to evaluate competing explanations for why  
84 some individuals migrated across the Pacific, how would the archaeological patterns expected to result from a  
85 particular Polynesian habitus (Richards 2008) differ from patterns produced by social action (Leppard 2014), or  
86 chiefly control (Earle and Spriggs 2015)?

87         The approach presented here is different, and has the goal of proposing explanations of the  
88 archaeological record of population movement that may be evaluated and compared on empirical grounds. This  
89 necessitates an evolutionary and ecological framework where transmission, selection and other processes  
90 generate definitive empirical expectations relative to particular phenomena (e.g., artefacts), socio-natural  
91 environments, and ecologies. This framework has been developed over the last 35 years and is applicable to any  
92 phenomena conceptualized as exhibiting variation produced in part through both inheritance (cultural or genetic)  
93 and differential persistence (Bettinger 1991; Pigliucci and Muller 2010; Cavalli-Sforza and Feldman 1981;  
94 Atkinson and Gray 2005; O’Brien and Lyman 2000; Boyd and Richerson 1985; Dunnell 1980; Laland et al.  
95 2015; Lycett 2015; Mesoudi 2011; Shennan 2002; Whiten et al. 2011). A small sample of studied phenomena  
96 includes human and non-human artefacts and behaviours (e.g., Lipo et al. 2006; Whiten 2005), social trends  
97 (e.g., Bentley et al. 2004), ethnographic material culture (e.g., Tehrani and Collard 2002), manuscripts (e.g.,  
98 Spencer et al. 2004), languages (e.g., Gray and Atkinson 2003; Kandler et al. 2010), ancient games (e.g., de  
99 Voogt et al. 2013; de Voogt et al. 2015), monuments (Cochrane 2015; Neiman 1997) and many other domains.

100 The necessary evolutionary, ecological and archaeological concepts are developed in the next section, which  
101 also includes procedures for both describing relevant archaeological variation and generating expectations for  
102 the patterning of this variation given a set of proposed explanatory processes. The second major section  
103 summarizes current archaeological knowledge of the Lapita migration to Remote Oceania and presents two  
104 competing hypotheses to explain it. The strongest hypothesis to explain this movement is a selection-driven  
105 range expansion triggered by one or more proximate processes. The concluding section summarises the  
106 arguments, sketches related explanations for other significant migrations, and offers a further argument for the  
107 evolutionary understanding of the human past.

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## 109 EVOLUTION AND MOVEMENT

110 Movement behaviours vary within and between populations. In humans and many other animals  
111 (primarily birds, see Mueller et al. 2013) movement behaviour is culturally transmitted, entails costs in energy,  
112 time, and other resources, and may expose individuals to unfamiliar environments (R. R. Baker 1978; Bonte et  
113 al. 2012; Cox 1968; Travis et al. 2012). Given these characteristics, and the observation that large-scale  
114 movements have occurred independently multiple times over human history, selection and other sorting  
115 mechanisms are reasonable processes to investigate when explaining variation in movement behaviour.

### 116 **Definitions and Preliminary Matters**

117 With considerable variation in both ancient and modern human movement behaviours, a necessary first  
118 step is to define different movement types whose temporal and spatial distributions are likely explained by  
119 different processes (contra Anthony 1990:897). In previous archaeological studies several movement types have  
120 been proposed including military invasion, economic migration, return migration, and others (e.g., Anthony  
121 1990; B. J. Baker and Tsuda 2015; Wells and Stock 2012), but because these concepts were not designed to  
122 identify portions of the archaeological record it is unclear what archaeological observations define each  
123 movement type (Cochrane 2008); the types lack empirical sufficiency (Lewontin 1974). The attraction of such  
124 movement types may lie in their seeming ability to explain the archaeological record by naming it with natural  
125 language nouns that most archaeologists understand similarly due to shared common-sense. For example, once  
126 some portion of the record is labelled using a term like military invasion, the explanation of what happened in  
127 the past appears to many to be self-evident (Dunnell 1982:13).

128 Ethologists and other biologists are also interested in explaining movement and they must contend with  
129 the empirical sufficiency of their concepts when trying to explain the record of animal behaviour. Lidicker and

130 Stenseth (1992) defined animal *dispersal* as “one-way movements of individuals away from their home ranges”  
131 (Lidicker and Stenseth 1992:22), but like the movement types above, this definition can be difficult to  
132 unambiguously apply to the animal behaviour record (see also Hengeveld 1989:6-7). They also defined three  
133 related behaviours under the heading quasi-dispersal: *nomadism*, *excursions*, and *shifting* (Lidicker and Stenseth  
134 1992; Matthysen 2012). Nomadism is practiced by individuals without a home range. Excursions include short-  
135 term movements outside of home-ranges, perhaps searching for mates or other resources. Shifting involves  
136 moving the home range by adding territory in one part of the range, while subtracting it from another. As  
137 suggested by Lidicker’s and Stenseth’s movement types, *range* is another relevant concept and refers to a  
138 species’ spatial span of settlement (Hengeveld 1989:7). Finally, *range expansion* is another movement type and  
139 denotes a total spatial increase in range, different from shifting or dispersal (Figure 2).

140         Simply identifying movement types is not an explanation. In addition to defining movement types and  
141 identifying them in populations, biologists studying animal movement propose both proximate and ultimate  
142 processes to explain the variable frequencies of movement types within and between populations (Lidicker and  
143 Stenseth 1992:24). Proximate processes or explanations focus on the events that might trigger movement and  
144 include genetic interactions, phenotypic plasticity and contingencies such as the behaviours of other animals.  
145 These triggers are equally applicable to humans (Wells and Stock 2012). Ultimate processes or explanations use  
146 selection and other sorting processes, along with the differential fitness of behaviours, to explain the evolution  
147 of movement types. The evolution of movement types refers to the variable frequencies of different movement  
148 types over time and space. Ultimate processes are also applicable to the range of variation in human movement.

149         Proximate processes and ultimate processes underlie related, but different kinds of explanation (Mayr  
150 1976; Lyman and O’Brien 1998), focusing generally on how-questions in the first case—how do particular  
151 artefacts facilitate human movement—and why-questions in the second—why has selection, drift, or other  
152 sorting processes resulted in a particular distribution of movement types over time and space. And while they  
153 may often be analytically separated in particular research (e.g., Feathers 2006), proximate and ultimate  
154 processes are both part of dynamically sufficient evolutionary theory applied to different questions (Laland et al.  
155 2011). Importantly, proximate and ultimate processes explain variation in the distribution of movement types  
156 with reference to the measurable natural and social environment, the relative cost of movement, and potential  
157 fitness differentials. The subsequent sections outline processes and related concepts that are most relevant to  
158 explanations of archaeologically recorded human movement.

## 159 **Saturation and Pre-Saturation Dispersal**

160 Under what conditions might the distribution of different movement types be explained by selection?  
161 Lidicker (1975) was the first to address this and proposed two sets of contrasting conditions to explain dispersal:  
162 saturation dispersal may occur when a population is near carrying-capacity, and pre-saturation dispersal may  
163 occur when there is no such population-pressure (Hamilton and May 1977; Stenseth and Lidicker 1992). The  
164 relative fitness advantage of saturation dispersal is easy to understand. In this situation, dispersal and non-  
165 dispersal behaviours exist in a population. Non-dispersal may incur increasing costs associated with competition  
166 for dwindling resources, and dispersal, while also incurring costs, can open new environments to exploitation. If  
167 dispersal exhibits a relatively greater rate of increase than non-dispersal, and dispersal out performs non-  
168 dispersal in terms of costs and benefits, then selection is the likely process accounting for dispersal variation  
169 (Travis et al. 2012; Johnson and Gaines 1990; cf. O'Connell and Allen 2012; Keegan 1995).

170 In contrast to saturation dispersal, pre-saturation dispersal may have less obvious explanations. Why  
171 would organisms, including humans, engage in costly behaviour such as long-range dispersal in the absence of  
172 population density effects? Pre-saturation dispersal is often explained by proximate triggers, and Lidicker  
173 (1975) suggests they fall into three broad categories, economic, tactical and social. Proximate triggers are linked  
174 to particular contingent histories and some triggers are likely more relevant than others to human dispersal.  
175 Economic triggers, for example, might include declining foraging efficiency or other indicators of possible  
176 future resource depression that dispersers could observe (e.g., Grant 1978). Tactical triggers promote behaviours  
177 that place individuals in positions whereby they can more easily take advantage of likely future events (e.g.,  
178 Ostfeld 1992). Social triggers of pre-saturation dispersal can be numerous, including for example territoriality  
179 (e.g., Sinervo and Clobert 2003) and disruption caused by immigrants (e.g., Healey 1967). Of course,  
180 archaeologists and other social scientists have also investigated economic (e.g., Kelly 1983), tactical (e.g.,  
181 Aswani and Graves 1998) and social (e.g., B. J. Baker and Tsuda 2015; Fortunato and Jordan 2010) triggers of  
182 movement. In some of these cases the proximate process, the explanation, is equated with an ancient  
183 individual's personal intention (e.g., Earle and Spriggs 2015) and it is difficult to think of an empirical test that  
184 could distinguish between different intensions as explanations for archaeological variation. This difficulty  
185 reminds us that while some proximate triggers might be used to explain contemporary behavioural records they  
186 might suffer from a lack of empirical sufficiency when applied to the archaeological record (Cochrane 2009).

187 The characteristics of ranges can influence dispersal costs and therefore interact with both saturation  
188 and pre-saturation dispersal. Biologists typically describe the edges of ranges as areas where populations are

189 more vulnerable, as it is near the edges where suitable habitats are more likely to be discontinuous. Thus the  
190 fitness of dispersal behaviours in a population may be greater at the range margins than in the range core.  
191 Dispersal behaviour may vary throughout a range due to a number of other factors as well, including  
192 behavioural plasticity and parental effects, frequency-dependent influences on the fitness of behaviours,  
193 environmental variation and patchiness (Benton and Bowler 2012; Levin et al. 1984), and cooperative versus  
194 individual dispersal (Koykka and Wild 2015; Plantegenest and Kindlmann 1999; Ridley 2012).

### 195 **Range Expansion**

196           Range expansion (see Figure 2) differs from dispersal in that individuals do not leave their home range  
197 and settle at a new one, discontinuous from the first, but simply enlarge their home range. Like dispersal,  
198 particular aspects of range expansion can be explained by either proximate or ultimate processes, and much  
199 research considers the proximate process of climate change, because this shapes the distribution of suitable  
200 habitat to a large degree. However, selection processes are also used to explain range expansion (e.g., Duputié  
201 and Massol 2013; Kubisch et al. 2013). For example, Simmons and Thomas (2004) argue that the margins of  
202 static ranges often comprise discontinuous and occupied habitat patches, so that non-dispersal and within-patch  
203 biological reproduction outcompetes movement between patches, which entails costs and curtails reproduction.  
204 If climate change (or other processes) opens up new, unoccupied habitat outside the previous range, movement  
205 to the new unoccupied habitat may now outcompete non-movement. As the new habitat is colonized by  
206 increasing numbers, the selective advantage of founding new populations is reduced and cost of movement may  
207 make it a less effective strategy. Simmons and Thomas make two more points relevant to human movement.  
208 First, individuals who successfully move during range expansion (and dispersal) will most likely be habitat  
209 generalists as they are more able to exploit newly encountered and potentially unfamiliar habitats. Second, they  
210 point to various research demonstrating the reduction of genetic diversity in sub-populations that have engaged  
211 in range expansions, such as that which occurred across countless species, including humans, during the  
212 Quaternary interglacials (Hewitt 2000). This might occur through the bottleneck effect of small numbers of  
213 individuals (relative to previous range population) colonizing newly opened habitat (Williamson 1996:169-170).

### 214 **Demographic Processes and Movement in Time and Space**

215           Variation in both dispersal and range expansion can be influenced by population size, structure,  
216 growth, and distribution (Carmichael 2016). A prominent method for understanding the relationship between  
217 these demographic variables and movement is the reaction-diffusion system formalized in the Fisher-Skellam  
218 model (Fisher 1937; Skellam 1951; see also Kolmogorov et al. 1937). This model has been used to explain the



219 distribution of human genes (Cavalli-Sforza et al. 1994), cultural traits (Russell et al. 2014), and languages  
220 (Cavalli-Sforza and Wang 1986). The Fisher-Skellam model estimates changes in local population density based  
221 on a non-linear population growth function (the reaction) and a linear population dispersal function (the  
222 diffusion) (Steele 2009). The Fisher-Skellam model proposes a wave-front region during population movement  
223 where the population density changes from relatively high at the inner margin of the wave front to low at the  
224 outer margin. The model also indicates that the width of the wave-front region and the speed of population  
225 movement is a function of maximum population growth rate and mean movement rate (Steele 2009). As the  
226 Fisher-Skellam model is rather simple, it may not accurately capture the historical contingencies of particular  
227 events and quantitative biogeographic stepping-stone models (Mac Arthur and Wilson 1967) would be an  
228 improvement in the Lapita case. Steele (2009), however, discusses additional considerations to increase the  
229 Fisher-Skellam model's complexity and realism, including several that are relevant here: the Allee effect, time  
230 delay, and advection.

231           Named after Warder Allee (Allee et al. 1949), the Allee effect describes a positive correlation between  
232 population density and growth rate, such that small populations may suffer low growth rates or extinctions. The  
233 Allee effect has three general causes (Courchamp et al. 1999): genetic inbreeding and lowered reproductive  
234 fitness, demographic stochasticity at low population numbers with greatly skewed sex ratios being one example,  
235 and reduced chances for cooperative interactions with conspecifics. This third cause of the Allee effect is often  
236 exemplified through reduced chances for mate encounters, but also refers to cooperative social interactions  
237 involving, for example, defence, raising of young, and subsistence behaviours that contribute to population  
238 viability. When added to the Fisher-Skellam model, a strong Allee effect can slow dispersal front speed.

239           The growth rate and diffusion terms of the Fisher-Skellam model may be temporally and spatially  
240 variable. Clearly, if these vary over the geographic range of a population, estimated mean front speed might be  
241 affected. Time delay between biological reproduction and dispersal can also modify the speed of a dispersal  
242 wave-front. Steele (2009) argues it is sensible to add a time-delay function to the basic Fisher-Skellam model  
243 when estimating the front speeds of agricultural populations, but it is not clear how time-delay should be  
244 estimated for hunter-gatherers, or indeed, seafaring hunter-gatherer-horticulturalists such as the Lapita  
245 colonizers of Remote Oceania.

246           Lastly, the Fisher-Skellam model assumes an equal probability of diffusion in any direction. This is an  
247 obvious oversimplification. Advection is the process where populations might preferentially move along a  
248 particular route related to differential carrying capacity or a resource gradient. When resource gradients are

249 considered in the Fisher-Skellam model, movement will be speedier along the resource gradient and slower off  
250 the gradient (e.g., Grollemund et al. 2015).

### 251 **Applying Evolutionary Theory of Movement to the Archaeological Record**

252 Evolutionary theory applied to the movement of organisms has been developed in the context of plants,  
253 insects, birds, and other non-human animals, although there are a few exceptions dealing with humans (e.g.,  
254 Keegan and Diamond 1987; Winder et al. 2015). To explain the movement of human populations as evidenced  
255 in the archaeological record requires both new theory to be built and modification of previously developed  
256 concepts. The next sections discuss the identification of movement types in the archaeological record and the  
257 use of evolutionary processes to explain archaeological variation.

### 258 Identifying Portions of the Archaeological Record with Movement Types

259 Some intellectual input, the definition of concepts, is required to identify movement in the  
260 archaeological record and the definition of movement types should be specific to particular research questions  
261 and the precision of empirical measurement. While skeletal morphometric, isotopic, and genetic analyses are  
262 often used to identify ancient population movements (e.g., Bentley et al. 2008; Hofmanová et al. 2016;  
263 Pietruszewsky 2008), potentially the most abundant data on human movement is provided by artefacts.  
264 Observation of the human and non-human behavioural and archaeological records suggests movement varies  
265 along several dimensions, with space and time being two dimensions that are archaeologically measurable.  
266 Temporal and spatial variation across archaeological assemblages sharing homologous similarity defines several  
267 types of movement into *unoccupied* regions (including a null or default non-movement type, *range*). In Table 1  
268 these have been labelled using the terms discussed above; the labels themselves are convenience and are  
269 themselves not explanations. The dimension Spatial Distribution comprises sets of categorical options that  
270 describe the spatial patterning of homologous similarity and the options can be archaeologically identified through  
271 techniques such Kernel Density Estimation or other spatial statistics (e.g., Morrison 2012) applied to  
272 assemblages. Likewise, the dimension Assemblage Chronology describes the patterning of homologous  
273 similarity over time and can be identified as synchronic or diachronic using a variety of techniques from  
274 Bayesian modelling (e.g., Burley et al. 2015), to spatio-temporal probability analyses (e.g., Crema et al. 2010),  
275 and archaeological seriation (e.g., Cochrane 2002b) applied to assemblages. By identifying the archaeological  
276 record with movement types we can better predict the kinds of explanatory processes most likely relevant (e.g.,  
277 proximate climate change) and design research accordingly.

		Spatial Distribution		
		Continuous	Core-centred	Discontinuous
Assemblage	<b>Synchronic</b>	<i>range</i>	<i>excursion</i>	<i>nomadism</i>
Chronology	<b>Diachronic</b>	<i>range-expansion</i>	<i>shifting</i>	<i>dispersal</i>

Table 1. Spatial-temporal distribution of homologous artefacts and associated movement concepts.

Ideally, identifying a portion of the archaeological record as a particular movement type should be a quantitative exercise, the results of which can be evaluated with statistical tools. As an alternative to this approach, or to augment it, principles from comparative biogeography (e.g., Brooks and McLennan 1991; Parenti and Ebach 2009) can facilitate identification of movement types. Briefly, the comparative biogeographic method applied to the identification of movement types involves three-steps: first, geographic areas (e.g., islands separated by water-gaps) are used to divide putative homologously related artefacts; second, the defining criteria of artefact classes in each geographic area are examined; and third, depending on how artefact class criteria are (un)correlated with different geographic areas, different movement types are identified in previously unoccupied areas. Cochrane (2008), applying a cladistic technique developed by Slatkin and Maddison (1989), used this method to propose post-Lapita movement or cultural transmission between Fiji and Vanuatu, although subsequent research has questioned his conclusions (Reepmeyer and Clark 2010).

When using artefacts to investigate movement into *occupied* regions observation across multiple dimensions of archaeological variability may be required to identify movement types due to the added difficulty of distinguishing between artefact distributions resulting from human movement and distributions resulting from predominantly artefact movement (typically termed trade or exchange) or cultural transmission of artefact manufacturing information (e.g., Pétrequin 1993; Winter et al. 2012). To exemplify one possible procedure, we can examine Zedeño's (1995) work in the American Southwest. She suggests that in this long-populated region, surface treatment similarities on Anasazi pottery of the AD 1200s are easily copied and reflect only the transmission of ideas between local populations, not movement. Toward the end of the century, however, similarities in manufacturing techniques appear across different ceramic assemblages and these similarities, she argues, cannot be copied from simple observation and therefore result from the movement of individuals experienced in particular techniques. In the absence of these kinds of archaeological observations, the construction of language phylogenies is used to identify human movements associated with artefact distributions (e.g., Gray and Atkinson 2003; Gray et al. 2009; Holden 2002).

The Application of Selection and Fitness to the Archaeological Record

305           If selection or other sorting processes are to explain the distribution of movement behaviours in a  
306 population two assessments must be made. First, the fitness of movement behaviours must be measured,  
307 estimated, or modelled. Different movement behaviours within a population (including non-movement) must  
308 have different relative fitnesses if selection is a possible explanation. Measuring fitness in the biological world  
309 alone can be difficult and this difficulty is increased when explanation is focused on archaeology and the record  
310 of past human behaviours manifest in artefacts and other residues.

311           Madsen and colleagues' (1999) discussion provides a useful set of concepts for applying fitness  
312 measures to archaeological variation. They note that the typical notion of fitness in biology is that of individual  
313 fitness measured through biological reproductive success. However, there are scenarios where the individual  
314 fitness concept is unhelpful; individuals belonging to sterile castes within prosocial insect colonies is the  
315 archetypal example. The concept of inclusive fitness was developed to account for such scenarios, but both  
316 individual and inclusive fitness may not be relevant to all empirical variation explicable by selection (Nowak et  
317 al. 2010) such as that resulting from cultural inheritance or learning in complex society that creates emergent  
318 group-level traits (Smaldino 2014), or similar traits shared by all members of a group (Boyd and Richerson  
319 2002). A third type of fitness used in population genetics models refers to the rate of increase of a trait class, a  
320 statistical property of all trait classes in a population. The rate of increase of an archaeological trait class over  
321 time or across space depends, generally, on transmission processes (Boyd and Richerson 1985; Henrich 2001;  
322 Bettinger and Eerkens 1999; Tehrani and Riede 2008), population structure and environmental variation (Pérez-  
323 Losada and Fort 2011; Boyd and Richerson 2002; Lipo et al. 1997), innovation and trait-class frequencies  
324 (Neiman 1995; Eerkens and Lipo 2005), assemblage formation (Porčić 2015; Premo 2014; Dunnell 1970), and  
325 feedback effects between cultural and biological transmission (O'Brien and Laland 2012; Shennan 2000). When  
326 the empirical observations to be explained are the distributions of trait classes in the archaeological record,  
327 fitness as a variable property of classes is an appropriate fitness concept.

328           The second assessment required to evaluate selection as an explanation requires establishing  
329 performance differences between trait classes within relevant social, technological and natural environment  
330 contexts (e.g., Cochrane 2002a; Rogers and Ehrlich 2008). Trait classes that demonstrate greater rates of  
331 increase should also perform better than alternative trait classes in a given context, if selection-driven replication  
332 is not to be mistaken for some other processes such as trait-hitchhiking, or pleiotropic effects (McElreath et al.  
333 2003). Although performance differences are widely described in ancient technology studies (e.g., Feathers  
334 2006; O'Brien et al. 1994; Pierce 2005; Schiffer and Skibo 1997), the performance of different movement types

335 in the ancient world cannot be evaluated in a laboratory, but instead must be modelled or theoretically justified  
336 (cf. Shennan 2011). This is discussed in subsequent sections along with a description of data relevant to Lapita  
337 movement.

338

## 339 AN EVOLUTIONARY HYPOTHESIS OF LAPITA MOVEMENT TO REMOTE OCEANIA

### 340 **An Empirical Description of Lapita Movement**

341 Lapita movement to Remote Oceania is evidenced by a set of empirical patterns, foremost are the  
342 spatial and temporal distributions of artefacts appearing in previously unoccupied Remote Oceanic archipelagos.  
343 Although these artefacts are unambiguous signifiers of human movement, there has been over 40 years of debate  
344 about the explanation of this movement, typically with reference to genetic and linguistic data (Groube 1971;  
345 Green 1979; Allen 1984; Spriggs 1984; Green 1991a; Kirch 1996, 1997; Terrell and Welsch 1997; Green 2003;  
346 Kirch 2010; Sheppard 2011; Carson et al. 2013). The strategy followed here is to produce a description of the  
347 archaeological record of Lapita in Near and Remote Oceania and then generate an explanation of this record that  
348 is compatible with proposed explanations of related genetic and linguistic variation across the regions. However,  
349 the correctness of the archaeological conclusions is not judged by its fit with genes or languages. This is not a  
350 return to the empirical record of Lapita for its own sake, however fruitful this might be (Specht et al. 2013), but  
351 rather a recognition that descriptions of variation in these records often use incompatible units (e.g., alleles and  
352 decorative motifs) and that transmission mechanisms relevant to the explanation of one record may not be  
353 applicable to another (Cochrane 2009; cf. Matisoo-Smith 2016).

### 354 Site Dates and Population Distributions

355 New Guinea was first colonized approximately 50,000 years ago by modern *Homo sapiens*. The  
356 earliest archaeological sites are located in the highland valleys and the Huon Peninsula (O'Connell and Allen  
357 2015; Summerhayes et al. 2010), with the first sites along the north coast and offshore islands of the Bismarck  
358 archipelago dating after this, to about 40,000 years ago (Leavesley et al. 2002; Torrence et al. 2004). The eastern  
359 movement of people among the circum-New Guinea islands during the Pleistocene stopped at Buka in the  
360 northwestern Solomons, colonized about 30,000 years ago (Wickler and Spriggs 1988). Based on several  
361 decades of archaeological research (Sheppard and Walter 2006), no other areas in the Solomons were occupied  
362 until approximately 6,000 years ago at Vatuluma Posovi cave on Guadalcanal (Roe 1993).

363 Between the Solomons and the Reef/Santa Cruz Islands north of Vanuatu lies a large water gap, a  
364 biogeographic boundary between Near and Remote Oceania (Green 1991b) (see Figure 1). Near Oceania

365 comprises New Guinea, the Bismarcks, Admiralties, and the Solomons, all (except for Manus) inter-visible and  
366 likely forming a relatively safe region within which sea-faring skills developed over approximately 40 millennia  
367 (Irwin 1992; Terrell 2004). Remote Oceania comprises the islands and archipelagos to the east of this boundary  
368 including the Reef/Santa Cruz Islands, Vanuatu, New Caledonia, Fiji, Tonga, and Sāmoa. Here archipelagos are  
369 separated by multi-day to multi-week canoe voyaging distances.

370 Two Bayesian meta-analyses of Lapita deposit dates in Near and Remote Oceania have been conducted  
371 in recent years (Denham et al. 2012; Rieth and Athens in press), both producing generally similar results.  
372 However, Rieth and Athens (in press) demonstrate that unidentified charcoal dates for non-Mussau deposits  
373 used by Denham et al. (2012) contribute to older date ranges, thus Rieth and Athens' results for Near Oceania  
374 are presented here. According to their single phase analysis, Lapita ceramics appear first in Near Oceania on  
375 Mussau between 3535-3234 calBP (2 sd) and sometime between 3230-3085 cal BP (2sd) in the rest of the  
376 Bismarcks. Although not included in either of the meta-analyses, Lapita ceramic deposits in the Northern  
377 Solomons are later, dating at the earliest to 2850- 2150 cal BP (2sd) on Buka (Specht and Gosden  
378 1997:appendix 3) and to a similar time range in the Western Solomons, primarily on New Georgia and nearby  
379 islands (Sheppard and Walter 2006). Lapita ceramics have also recently been discovered on the southeast coast  
380 of New Guinea, near Port Moresby, and date to between approximately 2900 - 2500 cal BP (David et al. 2011).

381 Lapita assemblages are famous for their intricately decorated ceramics (Figure 3) with diverse vessel  
382 forms, some red-slipped and with lime in-filing, and likely used for ceremonial purposes, but also including a  
383 more utilitarian plainware component (for overview see Kirch 1997). This varied and intricate set of ceramics  
384 appears in Near Oceania without local precedent. There are no earlier, simpler forms in Near Oceania that we  
385 might expect to develop into Lapita. There are earlier and pene-contemporaneous ceramic assemblages in  
386 Taiwan and Island Southeast Asia, some stylistically similar to Lapita, and that are probably best characterized  
387 as a shared ceramic horizon (Spriggs 2011), but there is no uncontroversial ceramic evidence of a population  
388 movement from these regions that resulted in the Lapita assemblages of the Bismarcks<sup>ii</sup>.

389 Once Lapita pottery appears across the Bismarcks, there is a delay of 36-375 years (Denham et al.  
390 2012) before the transport of these ceramics into Remote Oceania by the first humans to reach those wide-  
391 spread archipelagos. Based on Sheppard and colleagues' (2015) Bayesian modelling, the earliest Lapita  
392 colonization deposits in the Reef Santa Cruz Islands have start dates of 2920-2793 calBP (95% HPD region). In  
393 Vanuatu the large Lapita burial ground at Teouma was also first used between 2920-2870 cal BP (probability  
394 not reported) (Petchey et al. 2015) and other Lapita sites throughout the archipelago date to a similar temporal

395 range, although a single site in Vanuatu, Makué, has a 3318-3008 cal BP (95% HPD region) start date  
396 (Sheppard et al. 2015). This is the oldest site in Remote Oceania, but because the seven charcoal dates  
397 comprising the Makué Bayesian analysis all derive from unidentified wood it is almost certainly too old. The  
398 earliest Lapita colonization sites in New Caledonia date to approximately 3000 cal BP and are found throughout  
399 the archipelago (Sand 2010), although there is yet no Bayesian chronological analysis to model start dates. Fiji's  
400 earliest Lapita site is found in the centre of the archipelago on Naigani and has an estimated start date of 3001-  
401 2790 calBP (95% HPD region) (Sheppard et al. 2015). Lapita colonization sites dated to a similar temporal  
402 range are found across the archipelago (Cochrane in press). In Tonga, first landfall by Lapita colonists was made  
403 on Tongatapu at 2838 +/-8 BP with the spread of Lapita occupations northwards up the archipelago within 70-  
404 90 years (Burley et al. 2015). Based on Lapita ceramic petrographic and geochemical analysis, the first colonists  
405 of Tongatapu probably arrived directly from northern Vanuatu, the Reef/Santa Cruz islands or even further west  
406 in Near Oceania (Burley and Dickinson 2010). Contrastingly, there is a single Lapita ceramic site in Sāmoa at  
407 Mulifanua. This site dates to approximately 2880-2750 cal BP (1 sd) (Petchey 2001) and a single Lapita sherd  
408 there has been petrographically sourced to Fiji (Dickinson 1998). Scattered plainware sites across the Sāmoan  
409 archipelago post-date Mulifanua, or are just contemporaneous (J. T. Clark et al. 2016), but Sāmoa generally  
410 seems to have had small isolated populations for the first 800 or so years of prehistory (Cochrane et al. 2016;  
411 Cochrane et al. 2013; Cochrane and Rieth 2016). Some suggest the lack of early sites in Samoa is due to lack of  
412 research aimed at uncovering deeply buried, inundated or otherwise displaced sites (Bedford 2015; Dickinson  
413 and Green 1998).

414 In summary, Lapita ceramics appear suddenly in the Bismarck Archipelago, without local precedent,  
415 and most likely between 3535-3234 cal BP. After a pause, the ceramics appear with the first human colonists in  
416 Remote Oceania across the Reef/Santa Cruz Islands, Vanuatu, New Caledonia, and Fiji contemporaneously  
417 about 3000 cal BP, but skipping most of the Solomons until their appearance in the Western Solomons around  
418 2600 cal BP (Sheppard 2011). Within 150 years of the first Lapita excursions into Remote Oceania colonists  
419 reach Tonga approximately 2850 cal BP and move quickly north up the archipelago. The oldest site in Sāmoa,  
420 and the only Lapita site, dates to approximately the same time as Tongan landfall (although likely a bit later  
421 based on decorative comparisons), but there are only a few additional archaeological sites in Sāmoa for the next  
422 several hundred years. This farthest eastern extent of Lapita pottery thus occurs between about 425-650 years  
423 after the ceramics first appear in Near Oceania. The first Remote Oceanic Lapita sites, with the possible  
424 exception of Sāmoa, all appear to be slightly earlier than the Lapita sites of the Northern and Western Solomon

425 Islands or the New Guinea south coast, even though the Remote Oceanic sites are farther from the geographic  
426 origin of Lapita in Mussau and the Bismarcks (Sheppard 2011).

427         The distribution of other artefact types are also evidence of movement from Near to Remote Oceania.  
428 Geochemically sourced obsidian from several sites in Near Oceania, such as Talasea on New Britain, is found in  
429 early Lapita deposits of Remote Oceania, from the Reef/Santa Cruz, to Vanuatu, New Caledonia, and Fiji, but  
430 not in Tonga or Sāmoa (Summerhayes 2009; Fredericksen 1997). There seems to be no evidence to differentiate  
431 between direct procurement of Near Oceanic obsidian by Remote Oceania residents (Sheppard 2011) and a  
432 down-the-line transfer of materials (cf. Reepmeyer et al. 2010). There are local sources of volcanic glass in  
433 Remote Oceanic too, and these were used, but Near Oceanic obsidian dominates initially. Within about 200  
434 years of Lapita movement to Remote Oceania, obsidian from Near Oceania is no longer transported to Remote  
435 Oceania.

#### 436 Pre- and Post-Lapita Environment and Subsistence in Near and Remote Oceania

437         The earliest Near Oceanic populations were predominantly hunters, gatherers, and fishers, although  
438 over the millennia they increasingly incorporated arboricultural resources and the management of other plant  
439 and animal life-cycles into their subsistence regimes. By 35,000 years ago, and likely somewhat earlier,  
440 populations were exploiting shellfish resources on New Ireland (Allen 1996) and stone tools used on aroids are  
441 present by about 30,000 years ago (Specht 2005) with later stone tools showing aroid and yam processing by  
442 about 11,000 years ago (Barton and White 1993). Phalangens (marsupial possum) were translocated from New  
443 Guinea to the Bismarcks by about 20,000 years ago (Leavesley et al. 2002), as was likely the case for *Canarium*  
444 and other nut trees by at least 10,000 years ago. In the New Guinea highlands agriculture including modifying  
445 fields through mounding and ditching began 6950-6440 cal BP (2 sd) (Denham et al. 2003) at sites of 2000 m  
446 elevation. *Colocasia esculenta* (taro) was likely grown in these fields, but there is evidence for its earlier  
447 presence beginning about 10,000 years ago. Taro in these highland agricultural systems was likely initially  
448 transported from its native lowland habitat along the coast. A diverse suite of domesticated nut species dating to  
449 5,600 years ago have been recovered from archaeological sites in the Sepik-Ramu basin of New Guinea  
450 (Swadling et al. 1991). These nut species are also found a bit later in the Bismarcks, but prior to Lapita. In  
451 summary, before Lapita pottery appears in Near Oceania, populations there had a long history of hunting and  
452 gathering, mid-Holocene agriculture and arboriculture, along with tuber and aroid use beginning in the  
453 Pleistocene. After the appearance of Lapita in Near Oceania these subsistence practices continue at new Lapita



454 occupations and at locations with both pre-Lapita and Lapita deposits (Kirch 1997:203-205; Lentfer and  
455 Torrence 2007).

456 A suite of domesticated Asian (mainland and island) animals appear in Near Oceania during and after  
457 the advent of Lapita pottery. Pigs are rare in Near Oceanic Lapita pottery contexts, as at Mussau, for example,  
458 but increase in abundance over time (Kirch 1997:211-212). Pig bones are found on Buka and Guadalcanal in  
459 Late Lapita and post-Lapita contexts (Specht et al. 2013). Small amounts of dog bone are also found in Lapita  
460 deposits in Near Oceania, but not in the earliest phase of Lapita pottery. Chicken occurs in Lapita contexts in the  
461 Mussau islands, but association with the earliest Lapita pottery is unclear (Specht et al. 2013).

462 The familiar flora and fauna of Near Oceania was left behind after voyaging to Remote Oceania, where  
463 Lapita populations encountered a never-before-seen world that added new plants, animals, and landscapes to the  
464 environments previously known. The flora and fauna of Remote Oceania are generally depauperate compared to  
465 Near Oceania. Bat species are the only native terrestrial mammals. There are only about 50 bird species in Fiji  
466 compared to more than 120 in the Solomon Islands. About one quarter of the seed-plant genera that exist in New  
467 Guinea and Island Southeast Asia are not found to the east of the Solomons (Green 1991b:494-495). New  
468 terrestrial animals and animal varieties were encountered by Lapita colonists, including crocodiles, megafaunal  
469 tortoises and birds in Vanuatu (Hawkins et al. 2016; J. I. Mead et al. 2002; White et al. 2010; Worthy et al.  
470 2015), New Caledonia (Anderson et al. 2010) and Fiji (Worthy and Anderson 2009b).

471 As Remote Oceanic archipelagos had never hosted humans prior to Lapita, bird, fish, and shellfish  
472 populations were naïve to human predation and Lapita populations targeted these rich resources, such that we  
473 might characterize the initial Remote Oceanic Lapita populations as hunter-gatherer-fishers, with a bit of  
474 domesticated plant use on the side. Numerous archaeofaunal analyses document the focus on marine and avian  
475 resources in the first generations of Remote Oceanic Lapita (Steadman et al. 2002; Nagaoka 1988; Irwin et al.  
476 2011; Worthy and Anderson 2009a; Burley 2012). Human bone isotope studies also confirm a lesser focus on  
477 vegetable based proteins (Valentin et al. 2010), even though plants, such as yams, bananas, and taro, that had a  
478 multi-millennia history of human use in Near Oceania were brought to Remote Oceania (Fall 2010; Horrocks  
479 and Bedford 2005; Horrocks et al. 2009; Horrocks and Nunn 2007). Lapita populations also brought  
480 domesticated animals, although their temporal and spatial distribution varies tremendously (Matisoo-Smith  
481 2007). Pig was brought to the Reef/Santa Cruz Islands and Vanuatu by Lapita populations (Green 1976;  
482 Matisoo-Smith 2007; cf. Anderson 2003), but not elsewhere. Chicken also appears in early Lapita deposits of

483 these archipelagos, and Fiji additionally. The Polynesian rat (*Rattus exulans*) is found in the earliest deposits  
484 throughout Remote Oceania, but dog is not a Remote Oceanic Lapita introduction.

#### 485 The End of Lapita

486 Those groups who left for Remote Oceania initially maintained contact with Near Oceanic populations  
487 as evidenced by obsidian transport (see above) and the similar, intricate Lapita pottery decorations repeated on  
488 locally-made pottery (Dickinson 2006) across both regions (see **Figure 3**). Lapita voyagers to different Remote  
489 Oceanic archipelagos also maintained connections for a time, as evidenced by shared pottery designs (Cochrane  
490 and Lipo 2010; Green 1979; S. M. Mead et al. 1973), and the transfer of Remote Oceanic volcanic glass and  
491 basalt (G. R. Clark et al. 2014; Reepmeyer et al. 2012). By approximately 2700 cal BP, however, this movement  
492 between populations had largely stopped, both within Remote Oceania and between the regions, as evidenced by  
493 the lack of artefact transport, and the replacement of commonly decorated Lapita pottery with different,  
494 archipelago-specific styles in Remote Oceania. Lapita pottery continued to be made in Near Oceania for another  
495 400 years or so (Specht and Gosden 1997; Summerhayes 2001), but the Lapita movement to Remote Oceania  
496 was over.

#### 497 **The Saturation Dispersal Hypothesis**

498 Given the movement types outlined in Table 1, what type accurately describes the Lapita  
499 archaeological record? The diachronic character of Lapita assemblages, with the earliest Near Oceanic  
500 assemblages pre-dating the earliest Remote Oceania assemblages (Sheppard et al. 2015), indicates that range-  
501 expansion, shifting, or dispersal are possible movement types. The spatial distribution of Lapita assemblages in  
502 Near and Remote Oceania is discontinuous, suggesting dispersal is the correct option of these three, but the  
503 discontinuous distribution is unavoidable due to inter-island water-gaps. Moreover, the evidence of Lapita  
504 design similarities and distribution of obsidians across Near and Remote Oceanic Lapita populations for the first  
505 200-300 years of Lapita movement indicates that homologous similarity across assemblages is continuously  
506 distributed from Near Oceania across the archipelagos of Remote Oceania. Therefore, range-expansion most  
507 accurately describes the Lapita record. Nevertheless, it is informative to first set range-expansion aside and  
508 compare the Lapita archaeological record to the empirical expectations of dispersal.

509 Saturation dispersal requires that there is increased fitness for dispersing relative to non-dispersing and  
510 this is typically measured as individual reproductive fitness in the context of ecological competition as  
511 dispersers remove themselves from competitive contexts. To explain observations of the Lapita archaeological  
512 record by saturation dispersal, the rate of increase of Lapita archaeological trait classes in Remote Oceania

513 should be greater than the rate of increase of similar trait classes in Near Oceania, the former range. Considering  
514 the relevant archaeological trait class to be a decorated Lapita ceramic deposit, the rate of increase of this trait  
515 class in Remote Oceania, identifying dispersers, is greater than in Near Oceania, representing non-dispersers.  
516 Although difficult to quantitatively compare, based on the most recent site inventories, and including the nine  
517 Caution Bay Lapita sites (Anderson et al. 2001; Bedford and Sand 2007; David et al. 2011), there are about 23%  
518 more spatially discrete Lapita deposits of any temporal range in Remote Oceania compared to Near Oceania (n  
519 = 132 and 102), this despite the fact that the time period over which Lapita ceramics were made in Near Oceania  
520 is three times that of Remote Oceania. Of course, simply counting deposits is a blunt measure of differential trait  
521 increase; the deposits differ in size and temporal range for example, and a host of processes contribute to the  
522 differences between Near and Remote Oceanic Lapita deposits (e.g. research intensity, local geomorphic  
523 processes). A better measure would be to compare deposits of similar age ranges in Near and Remote Oceania  
524 corresponding to the time of movement, about 3000-2800 cal BP. Again, the data are not robust, but using the  
525 same inventories there are 24 temporally discrete Lapita deposits (i.e., not continued deposition from an earlier  
526 non-Lapita deposit) in Near Oceania whose estimated date ranges fall within 3000-2800 cal BP, and there are 44  
527 deposits in Remote Oceania, about twice as many, within this same date range, a number also generated by  
528 Anderson (2001:Table 1) using slightly different methods and older site inventories. Finally, with the data  
529 available to him in 2001, Anderson also calculated the rate at which new Lapita deposits were created in Near  
530 and Remote Oceania using the median intercepts of calibrated age ranges to place deposits in 100 year intervals.  
531 Given the (in 2001) conservative total Lapita time spans of 900 years in Near Oceania and 400 years in Remote  
532 Oceania, 9.7 Lapita deposits were established in Near Oceania per 100 years, while 23.8 Lapita deposits were  
533 established per 100 years in Remote Oceania (Anderson 2001:17-18). While it seems that there was a greater  
534 rate of increase of decorated Lapita archaeological deposits in Remote Oceania compared to Near Oceania, both  
535 overall and during the approximately 200 hundred year period of most frequent movement, dating analyses  
536 focused on the duration and rate of deposit formation are required to thoroughly demonstrate this (e.g., Lipo et  
537 al. 2005). Nevertheless, the greater rate of increase of Lapita deposits in Remote Oceania relative to Near  
538 Oceania suggests selection or another sorting process is a profitable hypothesis to explore.

539         If selection explains the proposed greater rate of increase of Remote Oceania Lapita deposits, what is  
540 the relative advantage conferred to Remote Oceanic Lapita groups? In other words, why is there differential trait  
541 increase? Saturation dispersal connotes increased competition for resources within the original range compared

542 to a lessening of competition for dispersers, providing them an advantage (see Groube 1971). What is the  
543 evidence for increasing competition for resources at approximately 3000 cal BP in Near Oceania?

544         There are very few quantitative studies relevant to resource competition in Near Oceania around the  
545 time of Lapita movement to Remote Oceania. Archaeofaunal analyses examining possible resource depression  
546 provide one window on competition, assuming that human overexploitation or predation-driven depression is  
547 correlated with competition. Wickler's (2001:226-233) work on Buka molluscs addresses this issue. He  
548 recorded similar amounts of marine shell in midden deposits in pre-ceramic, Lapita, and post-Lapita layers. In  
549 fact the amount of shell increases after Lapita and Wickler concludes that "there is no evidence for human  
550 overexploitation of molluscs from the Buka sites" (Wickler 2001:233). A lack of vertebrate faunal deposits  
551 between 5000 and 2500 calBP precludes additional insights from the Buka materials. On nearby Nissan Island,  
552 Spriggs (1991) also generated data on shellfish and other fauna. The data do not allow fine grained analysis, but  
553 from the pre-Lapita (3650-3200 BP) to Lapita phases (3200-2500 BP) at site DFF, Spriggs notes a decrease in  
554 the weight of deposited shell, from approximately 7 kg to 6 kg (Spriggs 1991: table 4). The same terrestrial  
555 vertebrate and fish taxa are also present in the assemblages across these phases, with the exception of the  
556 Polynesian rat (*R. exulans*) that is found only in the Lapita deposits (Spriggs 1991: table 7). Additionally,  
557 Steadman (Steadman et al. 1999; Steadman 2006) notes that although specimen counts are low, there is no clear  
558 record of resource depression or extinction of birds in any Near Oceanic sites around the time of Lapita  
559 movement to Remote Oceania.

560         Increasing competition might be observed in other subsistence realms, such as arboricultural resources  
561 and other plant foods, but the nature of the prehistoric record in Near Oceania (e.g., absence of data on plot  
562 cultivation) seems to preclude analyses of variation in plant food yields or intensification that might signal  
563 competition. There is, however, evidence for sustained use of plant foods throughout the prehistoric sequence of  
564 Near Oceania (see above), and productive lagoon habitats on the New Guinea north coast after approximately  
565 6000 calBP (Swadling 1997; Terrell 2002). Pope and Terrell (2008) argue, however, that the abundance of these  
566 productive lagoons and reefs along the New Guinea coast may have declined in the middle to late Holocene  
567 such that a "likely environmental cause of the Lapita expansion was resource scarcity, which drove people to  
568 search for new, more productive habitats" (Pope and Terrell 2008:13). While possible, this proposal does not  
569 accord with the other evidence of resource use summarized above, and Pope and Terrell's argument is  
570 contradicted by their radiocarbon data that indicates the early stages of a rebound in lagoon and reef abundances  
571 from the 5000-4000 BP period to the 4000-3000 BP period. This rebound is before and during Lapita movement

572 to Remote Oceania, although the fact that there are only two Lapita sherds from New Guinea's northern  
573 coastline (Bedford and Sand 2007:table 1), and the rarity of other pene-contemporaneous cultural deposits along  
574 the north coast, suggests that population sizes there may have been small (Golitko et al. 2016).

575 In summary, the faunal data, evidence of plant use, and productive New Guinea environments,  
576 considered against a backdrop of relatively small populations checked by endemic malaria (Groube 1993) all  
577 suggest that competition for limited subsistence resources was not present in Near Oceania just before and  
578 during Lapita movement to Remote Oceania (see also Irwin 1989). As saturation dispersal is not currently a  
579 viable hypothesis, pre-saturation dispersal may be an alternative. Pre-saturation dispersal occurs without  
580 concomitant resource competition and is typically explained by proximate economic, tactical or social triggers.  
581 Social triggers are perhaps most relevant here with disruption caused by a possibly intrusive population in Near  
582 Oceania (Green 1991a), and territoriality of particular groups in the region (Finney 1996; Kirch 1997:65-66;  
583 Anderson 2006) being the most widely accepted possibilities (cf. Bell et al. 2015). Possible proximate triggers  
584 are discussed below within the context of range expansion.

#### 585 **The Selection and Range Expansion Hypothesis**

586 The Lapita movement into Remote Oceania is most accurately identified as range expansion (see table  
587 1) as movement resulted in a larger, continuous home range for the populations that deposited Lapita ceramics  
588 and moved between the previously separated regions of Near and Remote Oceania. Range expansion is typically  
589 explained by the proximate mechanism of climate change that opens up new territory with movement into that  
590 territory structured by demographic processes described by a reaction-diffusion system (e.g., Crozier and Dwyer  
591 2006; Shigesada and Kawasaki 2002). Other proximate mechanisms relevant to the Lapita range expansion  
592 include social triggers and technological changes. Finally, range expansions in particular environmental contexts  
593 have also been explained by selection that accounts for the differential rate of increase of movement and non-  
594 movement behaviours.

#### 595 Proximate Mechanisms of Lapita Range Expansion

596 Anderson and his colleagues (Anderson 2001, 2015; Anderson et al. 2006) have argued that the Lapita  
597 movement to Remote Oceania, and other population movements in the Pacific (Goodwin et al. 2014), were  
598 triggered by the increased frequency of ENSO events and other climate phenomena. ENSO events reduce the  
599 strength of the predominant easterly trade winds and are combined with westerly wind-reversals. Anderson and  
600 his colleagues suggest that Lapita voyaging craft had little windward capability, but that the ENSO influenced  
601 wind reversals would allow downwind sailing from west to east and lessen the time at sea without the need to

602 tack over great distances (Anderson et al. 2006). Their ENSO frequency data are generated from sedimentation  
603 records in the Laguna Pallcacocha (Ecuador) core and indicate an increase in ENSO frequency about 3100  
604 calBP, correlated with Lapita movement to Remote Oceania.

605         While ENSO variability likely acted as a proximate mechanism of range expansion through lowered  
606 movement costs, changes in sailing skills may also have contributed a similar trigger. Irwin and his colleagues  
607 (Irwin 1992; Bell et al. 2015; Irwin 2008; Irwin and Flay 2015) have long argued that Lapita movement to  
608 Remote Oceania was predicated upon a search and return strategy, the ability to engage in open-ocean sailing  
609 beyond site of land, and safely return to a starting point, whether or not new islands are discovered (Irwin 1989).  
610 Sailing east from Near Oceania, against the prevailing southeast trade winds, then returning safely home  
611 requires a variety skills, including latitude sailing, dead reckoning of position, maintaining a course, and reading  
612 weather, animal, wave and current signs of unseen islands (Irwin 1992). Several of these skills might have been  
613 developed by Near Oceanic and Island Southeast Asian populations during the 40 millennia or more of human  
614 occupation in a “voyaging nursery...an island corridor which runs from Island South-east Asia to the end of the  
615 Solomon Islands” (Irwin 1989:168) that is between northern and southern cyclone belts and within which  
616 islands, with few exceptions, are inter-visible. Given that these skills would be required to sail to Remote  
617 Oceania at the speed indicated by dated Lapita deposits, it is likely that these skills coalesced within Near  
618 Oceania Lapita populations at least by approximately 3000 calBP and also acted as a proximate trigger. A  
619 related study by Bell et al. (2015) supports this proposal. Using a Bayesian model-choosing framework, they  
620 found that colonization models privileging both the latitudinal error within which a vessel can make a course  
621 that reaches land (i.e., angle of target), and sailing into the wind for a safe return home, were the most power  
622 predictors of Remote Oceanic colonization times. The angle-of-target and safe-return-home models performed  
623 better than models privileging habitat quality and the effects of social hierarchy (e.g., primogeniture) and  
624 territoriality.

625         Canoes and sails, the artefacts that of course facilitated voyaging, are absent from the Lapita record, so  
626 there is no direct evidence of ancient canoe technology. Linguistic reconstructions of canoe parts (Pawley and  
627 Pawley 1994), engineering analyses of hulls and sails (Irwin and Flay 2015), and the aforementioned speed of  
628 movement into Remote Oceania indicate Lapita populations likely used single-outrigger canoes with sails, but  
629 whether the invention of these craft were a proximate mechanism triggering movement, or whether they were  
630 invented earlier is unknown (cf. Anderson 2015).

631 Evolutionary Mechanisms of the Lapita Range Expansion

632           The likely greater rate of increase of Lapita deposits in Remote Oceania relative to Near Oceania  
633 suggests selection or other sorting processes are relevant to explaining this population movement. As  
634 demonstrated in research on humans and other animals (see above), variation associated with range expansions  
635 may be explained by selection processes in the context of kin competition, spatial heterogeneity of resources,  
636 and population dynamics described by reaction-diffusion systems. Here, the focus is on resource distributions  
637 and population dynamics as these scenarios include concepts that are measurable in the archaeological record.

638           The patchiness of habitats at range margins may promote selection-driven range expansion. Simmons  
639 and Thomas (2004) note that if the margin of a static range comprises discontinuous, occupied habitat patches,  
640 movement between patches (which entails a cost) may exhibit decreased fitness relative to non-movement.  
641 However, when proximate processes open new habitat, movement to unoccupied, virgin resource patches may  
642 become relatively less costly, and exhibit increased relative fitness compared to non-movement.

643           Paleoenvironmental data for the Solomon Islands are available to examine habitat characteristics along  
644 the eastern margin of the Near Oceanic Lapita range (Grimes 2003; Haberle 1996; Powell 1976), prior to range  
645 expansion. These studies conclude that secondary forests and disturbance taxa prevailed in the region over the  
646 Holocene and that this environment may have been caused by either human activity, volcanic and other tectonic  
647 processes in the region (see e.g., Dunkley 1986), or a combination of these. Grimes' (2003) detailed  
648 investigation of the New Georgia Group in the western Solomons indicates large-scale forest fires after 3500  
649 BP, likely intentionally set to promote the growth of economic plants such as breadfruit. The pre-Lapita  
650 archaeological record of the Solomons (Miller and Roe 1982; Sheppard and Walter 2006) reveals a sparsely  
651 inhabited group of islands, compared to the Near Oceanic Lapita range core in the Bismarcks. In short, the  
652 Lapita-era Solomons seem to be characterized by the discontinuous, occupied resource patches that promote  
653 selection-driven range expansion.

654           Simmons and Thomas (2004) also argue that individuals who successfully move during range  
655 expansion will most likely be habitat generalists as they are better able to exploit newly encountered and  
656 unfamiliar resources. Likewise, the selection and range expansion hypothesis predicts that Lapita movement to  
657 Remote Oceania will be correlated with generalist subsistence regimes that exploit a variety of newly  
658 encountered resources. The record of archaeofaunal remains, fishing strategies, plant microfossils, animal  
659 translocations, and human skeletal isotopes indicate that initial Lapita populations in Remote Oceania did  
660 engage in generalist subsistence practices focused on pristine faunal resources, a spatially variable set of

661 domesticated animals, and with relatively less contribution from horticultural crops compared to Lapita  
662 populations in Near Oceania.

663 Numerous faunal assemblages representing the first Lapita populations in Remote Oceanic  
664 archipelagos document a subsistence focus on high-return prey, including taxa never encountered before.  
665 Megafaunal tortoises were driven to extinction in Vanuatu by the first Lapita colonists (White et al. 2010).  
666 Terrestrial faunal remains from the earliest Lapita site in Fiji indicate humans there drove reptile species and a  
667 megapode to extinction (Irwin et al. 2011). On Tonga, 14 species of birds were hunted to extinction within 200-  
668 300 years of Lapita settlement (Steadman 1989). Generalized fishing strategies also contributed to Remote  
669 Oceanic Lapita subsistence such that “the same eight fish families comprise the bulk [88%] of Lapita fish faunas  
670 of sites distributed from the Reef-Santa Cruz Islands to Western Polynesia [i.e., Tonga and Sāmoa]” (Butler  
671 1988:109). Plant microfossils and faunal remains demonstrate that transported animals and agricultural plants  
672 also contributed to the Lapita diet with, for example, introduced taro, banana, pig and chicken present in the  
673 Lapita deposits of Vanuatu (Horrocks et al. 2009; Horrocks et al. 2013; Matisoo-Smith 2007), taro, yam and  
674 chicken in Fiji (G. R. Clark and Anderson 2001; Horrocks and Nunn 2007), and taro and chicken in Tonga (Fall  
675 2010; Steadman et al. 2002). It is unclear at what time Lapita populations in Remote Oceania became  
676 increasingly reliant on growing food, but in a unique study, Roos and colleagues (2016) examined the  
677 stratigraphic record of charcoal and stable carbon isotopes in Fiji’s largest river valley and concluded that  
678 swidden farming and removal of native forest did not begin in parts of the valley until 1000 years after Lapita  
679 colonization.

680 While analyses of fauna and plant microfossils suggest a generalized diet for Lapita populations in  
681 Remote Oceania, a comparison of Remote Oceanic Lapita isotopic diet with Near Oceanic Lapita isotopic diet  
682 also conforms to predictions of the selection and range expansion hypothesis. The converse expectation to  
683 Simons’ and Thomas’ (2004) proposal that range expanding individuals are resource generalists is that  
684 conspecifics who do not move will be more specialized in their resource use within the pre-existing range (see  
685 also Cox 1968). In the only current comparison of Lapita isotopic diet from Near and Remote Oceanic sites,  
686 Kinaston et al. (2016:450-451) note that the Lapita population at Teouma, Vanuatu, one of the earliest  
687 populations in Remote Oceania, “consumed protein resources from higher trophic levels than plants and  
688 displayed the most variation in diet compared with the other skeletal samples [in their study].” Skeletal samples  
689 from Lapita deposits at their other Remote Oceanic Vanuatu sites indicate a diet “mostly consisting of low-  
690 trophic level marine...and terrestrial foods, mostly horticultural plants, nuts, and fruits” (Kinaston et al.



691 2016:449). In contrast with these Remote Oceanic Lapita diets, the isotopic diet of Near Oceanic Late Lapita  
692 individuals interred on Watom Island off the west coast of New Britain included “substantial amounts of  
693 terrestrial foods, probably horticultural/arboricultural products, native animals and domestic species coupled  
694 with marine foods” (Kinaston et al. 2016:449). Additional archaeological and paleoenvironmental research on  
695 Watom specifically (Lentfer and Green 2004), and Near Oceania generally (Kirch 1997), also suggests a greater  
696 focus on horticulture and arboriculture by Near Oceanic Lapita populations, and pre-Lapita populations  
697 (Torrence 2012), compared to the first Remote Oceanic Lapita populations.

698         Simons and Thomas (2004) note that the selection processes that explain movement during range  
699 expansion often influence the genetic diversity of populations. Simply put, sub-populations or demes that  
700 engage in range expansion should show less genetic diversity through bottlenecking. Estimating the genetic  
701 diversity of Lapita colonists is difficult as ancient DNA has been successfully retrieved from only four Lapita-  
702 age individuals, three from Vanuatu and one from Tonga (Skoglund et al. 2016), and there are no similarly aged  
703 Near Oceanic samples for comparison. Analyses of modern DNA, however, note a decrease in genetic diversity  
704 moving east from Near to Remote Oceania (Friedlaender et al. 2008; Kayser et al. 2006), consistent with the  
705 range expansion hypothesis, although uneven sampling across the Lapita range may contribute to this result.

706         Finally, using the Fisher-Skellam reaction-diffusion model it should be possible to describe the  
707 demographic characteristics of Lapita populations undergoing range expansion, including the direction of  
708 movement and variation in population density across Remote Oceania. In its most basic form the Fisher-Skellam  
709 model predicts a linear population diffusion, but it is now clear that Lapita colonization of Remote Oceania is  
710 not accurately described as a linear wave of advance from the Bismarck archipelago to successively more  
711 eastern islands (Sheppard 2011). While the colonization dates for Vanuatu, New Caledonia, and Fiji are  
712 essentially contemporaneous at 3000-2900 cal BP, the petrography and geochemistry of the earliest Tongan  
713 Lapita pottery at approximately 2838 +/-8 BP suggest a direct colonization from Near Oceania or the Vanuatu  
714 region (Burley and Dickinson 2010), not Fiji as west to east linear diffusion would predict. A possible  
715 explanation may be selection promoting variation in the distances of range-expansion movements. For example,  
716 occasional very long moves, as in Lévy-flight models, are a more efficient range-expansion and foraging  
717 strategy under some conditions (Humphries and Sims 2014; Lilley 2008). Once the first Lapita populations  
718 arrive in Tonga further colonization of the archipelago follows the expectations of advection, diffusion along  
719 resource gradients, as groups moved north up the island chain (Burley et al. 2015). Given that the date of the  
720 single Lapita deposit in Sāmoa, and several immediately post-Lapita plainware ceramic deposits in the Sāmoan

721 archipelago are contemporaneous with northern Tongan Lapita sites (J. T. Clark et al. 2016), the colonization of  
722 Sāmoa may be generally described as the last stop on the advection influenced diffusion of Lapita populations  
723 from the south.

724 Sāmoa has a unique Lapita record, and one that should be explicable by the selection and range-  
725 expansion hypothesis, and the Fisher-Skellam model. The Lapita era record of Sāmoa comprises a single Lapita  
726 deposit and a handful of immediately post-Lapita plainware ceramic deposits throughout the archipelago,  
727 contrasting with extensive Lapita and post-Lapita deposit distributions of Tonga and Fiji. Two hypotheses have  
728 been proposed to explain the Sāmoan Lapita record: the Lapita record is more extensive than currently known  
729 as it has been destroyed or displaced through geological processes (Dickinson and Green 1998; Green 2002), or  
730 the Sāmoan Lapita record is an accurate reflection of a sparse founding population compared to other Remote  
731 Oceanic archipelagos (Cochrane 2013; Rieth et al. 2008; Cochrane et al. 2016; Cochrane and Rieth 2016). If the  
732 latter hypothesis is correct, and Sāmoa's earliest populations were small and isolated, a possible explanation for  
733 the continuation of this demographic pattern is the Allee effect (Courchamp et al. 1999). A reduction of  
734 cooperative interactions between individuals seems the most relevant process leading to inverse density-  
735 dependent growth and might involve, for example, subsistence and child rearing. The possibility that Sāmoa's  
736 coastline lacked, relative to Fiji and Tonga, numerous habitable beach ridges (Cochrane et al. 2016; Rieth et al.  
737 2008) would also promote the Allee effect.

### 738 Testing the Selection and Range Expansion Hypothesis

739 The selection and range expansion hypothesis to explain Lapita movement to Remote Oceania is  
740 currently supported by all relevant empirical observations. While climate change and innovation in voyaging  
741 technology lowered the cost of movement for Lapita populations, selection processes related to environmental  
742 variation and demography explain the relatively greater rate of Lapita deposition in Remote Oceania. There are  
743 several observations that would refute this hypothesis: if the rate at which Lapita deposits are generated in Near  
744 and Remote Oceania is, in fact, similar, or the rate is greater in Near Oceania, then selection is not a viable  
745 explanation for the differential distribution of Lapita deposits in Near and Remote Oceania; if subsistence  
746 practices in Near and Remote Oceania are similar, then again, support for the range expansion hypothesis is  
747 eroded; if the environment and Lapita-era demography of the eastern range margin of Near Oceania is not  
748 considerably different from the range core of the Bismarck Archipelago, then the proposal that range expansion  
749 is partly explained by environmentally-based selection is questionable.

750           Given the complexity of the selection and range expansion hypothesis, a single smoking-gun  
751 falsification is unlikely, but the combined force of multiple research results could lead to the rejection of this  
752 hypothesis. Additional tests of the hypothesis could profitably be conducted through simulation. Agent based  
753 simulations such as Turchin and colleagues' (2013) employ environments, behaviours and cultural transmission  
754 rules that vary within likely parameters, as well as realistic geographies to determine if hypothesized processes,  
755 such as the evolution of costly cooperative institutions in their study, produce model results that match observed  
756 empirical patterns. Model based testing of the selection and range expansion hypothesis can proceed similarly:  
757 would simulation results match the empirical patterns of Lapita populations in Near and Remote Oceania, given  
758 the geography of Near and Remote Oceania, environmental differences, the variable cost and performance of  
759 movement under different technological and climatic regimes, and culturally transmitted subsistence and  
760 voyaging strategies?

761

## 762 CONCLUSION

763           At this point, some readers may be saying to themselves, "so what?" After all, it is fairly obvious that  
764 the Lapita movement into Remote Oceania was facilitated by the abundant resources in these untouched islands,  
765 likely innovations in maritime technology, and climate changes. How does the account given here improve on  
766 the obvious? It improves our understanding of Lapita movement into Remote Oceania in two fundamental ways.  
767 First, the development of an evolutionary theoretical framework facilitates, for the first time, empirical testing of  
768 proposed explanations for Lapita movement. Second, by use of this framework, the generation of cumulative,  
769 linked knowledge of evolutionary histories is possible, where previously largely disconnected, incommensurate  
770 studies exist.

### 771 **A Little Metaphysics**

772           This subheading is taken from Neiman's (1995:29) seminal article that uses evolutionary theory to  
773 explain decorative variation in North American Woodland pottery. Particularly important in Neiman's argument  
774 is the concept of selectively-neutral variation, in place of our common-sense notion that decorative variation is  
775 explained by personal choice, identity negotiation or other intentions. Neiman, drawing on the work of others  
776 (Dunnell 1992; Sellars 1962), notes that the difference between the two approaches, using a theoretically driven  
777 approach or a common-sense one, is encapsulated in two distinct metaphysics (see also Carroll 2016; Conant  
778 1951; Eddington 1928): we choose to explain the relationships between empirical phenomena with invented  
779 mechanisms, concepts explicitly designed to solve particular research problems; or we choose to explain the

780 relationships between empirical phenomena, such as the differential distribution of Lapita assemblages across  
781 regions, with the common-sense or intentional language of persons, concepts such as ambition, choice, need. Of  
782 course, both metaphysics employ concepts to explain empirical observations, but concepts in the theoretically-  
783 driven approach are openly evaluated and modified, kept or discarded, by their ability to explain empirical  
784 relationships through comparison of observations with deductively generated expectations. That is, explanations  
785 that eschew the intentional language of persons are imminently more open to empirical testing. When using  
786 concepts from the language of persons it is not possible to generate consistent expectations for empirical  
787 archaeological patterning. If we use ambition to explain human movement what empirical patterns would we  
788 expect? How would these vary over different environments, population sizes, and time periods? As Neiman  
789 (1995:30) concludes: “There is simply no way to produce a formal model by which the implications of common  
790 sense notions ... for empirical variation ... might be deduced.” Rendering our explanation of the Lapita  
791 movement to Remote Oceania using theoretically-driven concepts such as selection, transmission, replication,  
792 and pleiotropy (and possibly others) allows us to deduce the expectations described above and compare them to  
793 archaeological observations.

794         For many, however, the intentional language of persons is the preferred explanatory framework in  
795 archaeology and anthropology. Explanation cast in these terms is obvious and needs little explication (Osgood  
796 1951). Long-distance movement is explained by the *desire* to acquire prestige goods. *Rivalry* between  
797 individuals explains the search for new lands. The *need* to maintain contact with an ancestral home causes  
798 repeated, two-way voyaging. These kinds of explanations make intuitive sense because they are cast in the  
799 language we use to explain our own lives. To ensure there is no misunderstanding, I am not arguing that  
800 individuals in the past behaved randomly, lacked personal motivations, or understood their lives without  
801 recourse to goals (however conceived). I am arguing that it is a choice, not a given, to explain human behaviour  
802 and its material results using the intentional language of persons, or purpose-built and integrated theoretical  
803 concepts with linked empirical methods. Crucially, the latter facilitates testing and the generation of cumulative  
804 knowledge<sup>iii</sup>.

### 805 **Other Case Studies**

806         Some might see a hole in the selection and range expansion hypothesis presented here: what of the pre-  
807 Lapita population movement from Taiwan, through Island Southeast Asia and eventually into the Bismarck  
808 Archipelago by 3535-3234 calBP? The movement into Remote Oceania might be a continuation of a larger  
809 movement over a longer time that began in Taiwan or coastal China (Bellwood 2011; Green 1991a; Kirch

810 2010). Indeed, there is much evidence from linguistics, genetics, and archaeology suggesting population  
811 movements and interaction in Island Southeast Asia and Near Oceania prior to Lapita movement into Remote  
812 Oceania. The phylogenetic relationships of Austronesian languages typically give the most support to a single  
813 movement from Island Southeast Asia to Remote Oceania (Gray et al. 2009; Gray and Jordan 2000), but this  
814 proposal has never been subjected to the kind of analysis demonstrated here, using homologous similarity  
815 amongst archaeological artefacts and evolutionary and ecological mechanisms to generate empirically testable  
816 hypotheses (cf. Carson et al. 2013). Importantly, the agriculturally-fuelled increased population growth that is  
817 the assumed proximate trigger for movement from Island Southeast Asia to the Bismarck Archipelago  
818 (Bellwood 2009) has not yet been convincingly demonstrated (Zahid et al. 2015; cf. Bellwood and Oxenham  
819 2008; Matsumura and Oxenham 2014). Other evolutionary concepts and processes such as selection interacting  
820 with environmental variation, or additional proximate triggers should also be investigated.

821         It is the use of theoretical evolutionary concepts and a framework of empirical testing that allows us to  
822 both link research on Lapita movement to other population movements in a consistent and cumulative sense, and  
823 to generate cascading empirical implications of the explanatory processes we propose. Cumulative, in this  
824 context, means that research results are mutually compatible, and perhaps combinable in a way that leads to new  
825 insights. For example, advection is suggested in the movement of Lapita populations south to north across  
826 Tonga and perhaps into Sāmoa. This is compatible with analyses that explain Lapita assemblage decorative  
827 similarities using transmission and phylogenetic models which also suggest cultural relatedness between  
828 southern Tonga, northern Tonga, and Sāmoa (Cochrane 2013; Cochrane and Lipo 2010). Additionally, the  
829 proximate triggers and relative costs of canoe travel that began Lapita movement into Remote Oceania might  
830 also partly explain the end of Lapita movement in Sāmoa and Tonga. It is at this eastern boundary of Lapita  
831 Remote Oceania that the seascape changes, with many smaller islands and more widely separated to the east, so  
832 that the costs of canoe voyages must rise (Di Piazza et al. 2007). Later innovations in voyaging technology and  
833 perhaps climate change may have been a proximate cause of movement to East Polynesian beginning 1000-900  
834 cal BP.

835         Leaving Lapita and broadening to evolutionary research in other regions can lead to global insights.  
836 For example, advection likely explains the movement of Bantu speakers from West Central Africa who  
837 followed a route privileging savannah corridors (Grollemund et al. 2015), agricultural populations moving into  
838 Europe (Silva and Steele 2014), and Paleoindians in North America (Chaput et al. 2015). Although the  
839 movement types and proximate and ultimate mechanisms need to be proposed for each case, advection may be

840 fundamental process in human movement, and one that can help explain and predict modern population  
 841 movements as well (Abel and Sander 2014). This kind of insight derives from an evolutionary and ecological  
 842 approach to population movement built to explain variation amongst any phenomena that can be characterized  
 843 by both differential persistence and replication through transmission.

844

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846

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1531

1532 Figure captions

1533

1534 **Fig. 1** Map of the southwest Pacific showing major islands, archipelagos and archaeological sites (*italics*)

1535 mentioned in text. The dashed line separates Near Oceania to the west from Remote Oceania to the east. Some

1536 small islands removed from main map for clarity

1537

1538 **Fig. 2** Schematic depictions of dispersal phases, corresponding quasi-dispersal types, and range expansion.

1539 Circles are species ranges and solid lines indicate movement (adapted from Lidicker and Stenseth [1992])

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1541 **Fig. 3** Examples of decorated Lapita ceramics from Near and Remote Oceania deposits. Top to bottom, left to

1542 right: Anir islands, southwest New Britain (Specht et al. 2013); Santa Cruz Islands (The University of Auckland

1543 Photographic Collection); New Caledonia (Sand et al 1998); Tonga (Burley and Dickinson 2010)

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<sup>i</sup> I do not use the term “common sense” in a pejorative manner. By common sense I mean the often implicit, sometimes contradictory sense-making system we carry around in our heads as members of a society and which we use to make sense of our daily lives.

<sup>ii</sup> This is a contentious claim and deserves some elaboration. Carson et al. (2013) have proposed an often-cited argument that Lapita ceramics in the Bismarcks have their origin in earlier red-slipped and dentate decorated ceramics from Nagsaraban, Luzon, Northern Philippines. Carson et al.’s (2013:17) abstract presents the argument clearly:

Finely made pottery with a very specific decorative signature is found in multiple locations in the Philippines and western Oceania, constituting a shared cultural trait that can be traced, both geographically and chronologically, to a specific homeland. Especially important for human migration models, this decorated pottery is linked to a system of cultural origin, so the spread as a diagnostic tradition can be related to the spread of a cultural group. Even more important, this decorated pottery appeared with the first peopling of the remote Pacific Islands, thus providing a clear and datable chronicle of where and when people spread from one location to another. The pottery trail points to a homeland in the Philippine Neolithic about 2000–1800 BC, followed by expansion into the remote Mariana Islands 1500 BC, and then slightly later into the Lapita world of Melanesia and Polynesia.

The date range of 2000-1800 BC for the earliest ceramics at Nagsaraban is, however, open to question. In Hung’s PhD thesis reporting on the pottery (Hung 2008:159-161), the dates in order of depth below surface for the silty clay pottery layer from excavation pit 9 are: 800-740 BC (180 cm), 20-10 BC [a typographical error?] (160 cm), 3340-3000 BC and 800-510 BC (150 cm). Other excavation pits have similarly inverted ranges for depths and divergent ranges for the same depth. Carson et al. (2013:19) address this by stating:

As outlined by Hung et al. (2011 and supplementary data; see also Hung 2008), the early red slipped pottery was found within a thick deposit of silt that yielded basal dates of 2000–1800 BC and upper limits of 800–400 BC. Dating within the alluvial silt naturally is complicated by inter-mixing, but numerous portions retain integrity of large re-fitted potsherds and partly reconstructed vessels, indirect context with multiple cross-confirming radiocarbon dates. These identifiable masses within the larger silt unit are not always arranged in convenient vertical stratigraphic order, but each provides a datable

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sub-unit in its own right. Given these limitations, the earliest confirmable instance of the decorated pottery appeared about 1800 BC, yet conceivably it could have occurred as early as 2000 BC.

In Hung (2008) and Hung et al. (2011) there are no refitting data, or stratigraphic descriptions to support the above statement, nor is it clear what “indirect context with multiple cross-confirming radiocarbon dates” means. Given the dates above, and the remainder presented in Hung (2008:table 7.1), it is also not clear how the basal date range of 2000-1800 BC is derived, as no dated material returned this range. Mijares (2016) provides some depositional information noting:

There was minimal bioturbation activity in the lower silty clay layer [lower ceramics layer] that could account for any movement of materials from above layer into the lower strata. These can be seen in the blocky structure of the sediment as oppose to a crumbly or granular structure normally associated with bioturbation such as faunal (worm) activity [sic].

Mijares’ description does not seem to support Carson et al.’s (2013) description of the same deposit as “complicated by inter-mixing” or containing “identifiable masses within the larger silt unit”. Another excavator of the site, Tsang (2007:82) notes that the “stratigraphy is not complex.” Tsang also proposes dates for the lower pottery layer at Nagsaraban of 3700 to 2600 BP, although it is not clear why this date range is chosen from the data in the table of radiocarbon dates (Tsang 2007: 94), nor is contextual information for the dates given.

Of course, Nagsaraban is only one site among many Island Southeast Asian ceramic-bearing sites currently dated prior to 3000 cal BP. However, reading Spriggs (2011:515-516) one might think that the Nagsaraban and other Northern Philippines deposits are unambiguously earlier than Lapita deposits in the Bismarcks as he states: “It is now well-established that dentate-stamping on pottery to produce at least some of the simpler motifs found in later Lapita pottery does have a chronological priority in northern Luzon over its rapid development in the Bismarcks to become the classic design system of Lapita (Hung 2008)”. However, Spriggs’ (2011:Table 1) table of dates includes only four of the over 20 dates from Nagsaraban, and many of the dates from other sites have not been critically examined in terms of context or association and dated material. In summary, the current state of knowledge better suggests a red-slipped dentate, incised, and impressed pottery horizon throughout Island Southeast Asia, without any clear indication of an overall directionality for the spread of pottery or pottery-making ideas, or indeed, pottery-makers.

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In contrast, there is clear chronological priority for ceramics in Taiwan, with these appearing by perhaps 2700 BC. The earliest ceramics are buff to dark brown “globular jars with incised, everted rims decorated with wavy lines and short parallel strokes” (Kuang-Ti 2013:614). Interestingly, at about 1500 BC, pene-contemporaneous with the appearance of Lapita pottery in the Bismarks, a set of diverse pottery traditions arise in Taiwan with an increase in the number of archaeological sites (Kuang-Ti 2013).

<sup>iii</sup> A contrived example may help make my point. Individual and population-level Great Ape history and behaviour is explained using evolutionary and ecological theory including both cultural and genetic transmission, selection, and other mechanisms (e.g., Prado-Martinez et al. 2013; Whiten et al. 1999; Whiten 2005, 2014). Suppose through the future invention of some sophisticated translation instrument we could talk to Great Apes with a rich and nuanced vocabulary, and we asked them “why did you behave that way, what was your intention or goal”, would their answers become the ‘real’ explanation for Great Ape history and behaviour? Would evolutionary and ecological explanations of Great Apes then be viewed as incorrect or inappropriate? No, because the use of explanatory concepts derived from theory or derived from the intentional language of persons is a choice, not a requirement of the subject matter. However, the choice has ramifications for the characteristics of the knowledge we generate.