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– ARTICLE –

Mapping Prehistoric Open Sea Sailing Routes to Lizard Island and Beyond

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ABSTRACT

Migration and exchange, as well as the circulation and diffusion of cultural, material and linguistic traits are dependent on the technical means, the environmental conditions and the human capacity to actually navigate and reach distant islands and coastal areas. Simulations of the navigational travel potential of Pacific Islanders have been undertaken in 1973 (Levison, Ward and Web) and 1992 (Irwin). However, these were lacking comprehensive wind data, were too approximate in methodological respects and did not calculate travel speed of vessels in relation to force and direction of winds. Based on new simulation software developed by one of the authors (Anne Di Piazza), to which mapping and geographical representation software was added by the other author (Laurent Dousset), this paper illustrates the potential for extensive human circulation to and from Lizard Island into the Solomon Sea in open sea voyages. The simulations show that the Coral and Solomon Seas were (or even must have been) places of dense but specific and interlinked navigational networks, and demonstrate that voyages from the Massim area and even from the Solomon Islands to the coast and islands of Queensland were not only possible, but were likely.

Keywords: Pacific, Oceania, Island Melanesia, Australia, Lizard Island, navigation, simulation, network

INTRODUCTION

Understanding ancient navigation is necessary to appreciate the dynamics of colonisation and circulation in the Australia-Pacific region. The gigantic continent of Sahul was separated from Sunda by the Wallace Line among other biogeographical frontiers, which runs through Indonesia, between Borneo, Sulawesi and the Lombok Strait, and is a water gap impassable for most land species without watercraft even during low sea level periods. Humans crossed and occupied most of Sahul within a period of 5,000 to 10,000 years (*e.g.* Birdsell 1977) at least 50,000 years ago and possibly 65,000 years ago (Clarkson *et al.* 2017), and populated the Bismarck Archipelago by at least 44,000 years ago and the Solomon Islands by 34,000 years ago (*e.g.* Shaw 2017). The populations were and remained for millennia hunters-fishers-gatherers, probably also nomads, possibly sea nomads. Modern humans were capable of sea travel as they colonized Sahul, and were in possession of advanced maritime skills as indicated by pelagic fish remains (particularly *Scombrids*) in Timor dating back more than 40,000 years (Bednarik 2003, O'Connor, Ono & Clarkson 2011).

Millennia later, a new wave of migrations considerably altered this already complex human and social landscape. Archaeological and linguistic evidence suggest an expansion of Austronesian languages and speakers from Taiwan to the Philippines 4,500 to 4,000 years ago, to the Indo-Malayan archipelago 4,000 to 3,000 years ago, and to the Bismarck Archipelago 3,400 years ago (Bellwood 1985; Kirch 2000). Further, as the Lapita cultural complex developed, migrants reached the Solomon Islands, Vanuatu and New Caledonia 3,100 years ago, apparently avoiding Australia (*e.g.* Blust 1980; Kirch 1997; Spriggs 1997; Denham *et al.* 2012; Galipaud, Wu & Di Piazza 2014). Yet a third wave of migrations has been suggested by biological anthropologists and geneticists. A new 'Melanesian' wave of migrants reached as far east as Vanuatu 2,500 years ago, gradually adding itself or partly replacing the already established so-called Austronesian population (Skoglund *et al.* 2016; Posth *et al.* 2018; Valentin *et al.* 2016). The word 'Melanesian' is placed between quotes because its definition is, in this context in particular, difficult. It is worthwhile recalling that Rivers (1914) or Riesenfeld (1950) distinguished three cultural complexes in the area: the Papuans who are the descendants of the original migrants to Sahul, the Austronesians originating in Taiwan, and what they define as the Melanesians who are groups in which Papuan and Austronesian characteristics have amalgamated. It is difficult to clarify if this new wave of migrants 2,500 years ago was undertaken only by 'Papuans' or by 'Melanesians' in Rivers' or Riesenfeld's terms, or indeed by both.

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To make a long story short, the Pacific is – as are many other regions of the globe – a place of successive and complex colonisations, movements, migrations and circulations; a scenario in which grasping the capacity for, and analysing the technology of navigation are fundamental to understanding the deep-history of the region itself. In this paper, we therefore aim at analysing the technical and meteorological feasibility of open sea navigation in the Australia-Pacific area with a particular consideration of travel between the Australian continent and the so-called Melanesian islands of the Solomon Sea. Considering the widely praised capacity of Austronesian seafarers for long distance and complex travels across seas, the hypothesis according to which they may also have reached the coast of Australia seems rather obvious, despite the fact that some archaeologists (*e.g.* Sheppard 2015) believe there is little patterning linking both sides of the Solomon Sea. Here we aim to surpass what has so far remained an undemonstrated intuition and discuss possible open sea connections (and not simply coast-line navigation) in the Coral and Solomon Seas using real-world and empirical data applied to computer-based simulations of maritime voyages. The paper will demonstrate that open sea navigation between Lizard Island, which is taken as an ideal typical anchorage of the Australian continent, and the islands of the Solomon Sea is technically feasible, and that the probability that such voyages have taken place in prehistoric times is indeed very high. The fact that Lizard Island is the only locale on the Australian east coast on which prehistoric pottery sherds have been found (Felgate *et al.* 2010; Tochilin *et al.* 2012), is the principal reason for having selected this island as being potentially representative of Australia-Island Melanesia prehistoric connections. Other studies have investigated possible external contacts on the north-eastern Australian coast and the Torres Strait (McNiven *et al.* 2006; Rowland 2018). The longest 'accepted' voyage refers to 'natives of Waraber and Coconut Island [Torres Strait Islands] sailing as far south as Lizard Island to obtain 'club stone'. And these islanders used that same stone as an article of barter when trading with the Murray Islanders' (Laade 1969: 159). However, none of these have studied the possibility for open sea voyages across the Solomon and Coral Seas to the Australian continent. An exception is the comparative stylistic analysis of stone arrangements whose attributes express multiple cultural influences. The authors of this study conclude that '… although Lizard Island Group stone arrangements are predominately of Aboriginal authorship, some arrangements exhibit cultural influences from neighbouring areas' (Fitzpatrick *et al.* 2018: 1); these neighbouring areas include the Trobriand Islands, Roviana in the Solomon Islands as well as the Sivai region of Bougainville in Papua New Guinea.

Taking seasonal variation into account, we will illustrate several main navigational routes in the area and expose the arguments for an increased consideration of the circularity of voyages. Although not reaching as far as discussing the social, economic or demographic consequences of these potential voyages, the paper confirms old and opens new hypotheses with regard to the complex cultural multilayering (pluri-ontologies) that characterizes the broad region of Island Melanesia.

The first part of the paper will review previous attempts to simulate navigation in the Pacific. We then detail the technical particularities and improvements undertaken in our recent analysis, which are intended to generate a more accurate and a more general overview of seafaring to the north-eastern Australian coast and beyond in the Western Pacific. The second part of the paper will present the islands we have selected to be possible anchorages or crossroads, followed by a general discussion of the conditions for voyages between all of these islands. The third part will move into more complex and specific terrain and consider in detail possible connections between Lizard Island and the Solomon Sea, including the Papuan Tip. Finally, the last part of the paper will evaluate voyages as a circulatory practice, taking multi-anchoring points or multi-stopover voyages as scenarios of possible connections between Lizard Island (or Australia more generally) and the Solomon Sea in terms of nodes and crossroads.

SIMULATIONS OF SEAFARING IN THE PACIFIC

There have been several attempts to simulate and reconstruct prehistoric navigation through the Pacific (see Di Piazza *et al.* 2007). The earliest model was proposed by Levison, Ward and Webb (Levison *et al.* 1973), testing Sharp's (1956) thesis of unintended drift voyages as accounting for settlement of many Polynesian archipelagos. Rejecting Sharp's hypothesis, they concluded that the settlement of Polynesia required systematic exploration. Since that time, other models, also analysing drift voyages, were developed for understanding voyaging in the Caribbean (Callaghan 2001). The most comprehensive simulation was conducted by Irwin and colleagues testing strategies of intentional voyaging, which highlighted potential discovery voyages eastward against and eventually across the trade winds and allowed for safe return to the homeland (*e.g.* Irwin 1989, Irwin *et al.* 1990). A few years later, Evans (1999, 2008) proposed a new simulation using improved data on canoe performance based on a reconstructed Hawaiian double-hulled canoe and incorporating actual synoptic weather data. His goal was to undertake a digital simulation of the actual voyages of Hokule'a. Evans demonstrated that simulated courses using synoptic weather data were closer to Hokule'a's actual track than those based on monthly randomized weather data, as applied in earlier simulations.

In 2007, one of the authors (Di Piazza *et al.* 2007) published with colleagues the results of a new computer simulation of navigation in the Pacific using both more precise and more accurate weather data. Previous simulations used monthly averaged wind force and direction for 5° × 5° wide cells, which approximately equate to 500 km

× 500 km units near the equator. Instead, we used weekly wind data for 1° cells. Winds experienced by the simulated canoes are extracted from probability matrices based on compass bearings from each cell, but actual winds are systematic, rather than random, and follow predictable patterns. In our model, the wind data is retrieved from actual recorded weather systems for the period January 1991 to December 1999. The model thus provides for a selection of sailing conditions: prevailing trade winds, summer and winter monsoons, El Nino westerlies, and other weather phenomena.

An additional improvement consists of the method of calculating the distance sailed by a canoe relative to the force and direction of the winds. Levison *et al.* (1973) varied canoe speeds solely on wind force and Irwin *et al.* (1989) had canoes sailing at constant speeds. In our model, canoe speed is based on the actual sailing performance of three canoes, for which data were available: a Micronesian outrigger voyaging canoe, a reconstructed Hawaiian double hulled canoe, and one of the author's reconstructed Tahitian double hulled canoe (Di Piazza and Pearthree 2004). For example, at a wind speed of 25 knots, canoes make their best speed (up to 4.6 knots) reaching across the wind between 80° and 130° off the wind. They slow down to 3 knots when sailing either downwind (140 to 180°) or close to the wind (75 to 80°). Their speed falls rapidly to 0 as canoes sail closer to the wind than 75°. In higher winds, canoe speed decreases and above 50 knots progress is effectively nil (see Di Piazza *et. al.* 2007: 1221).

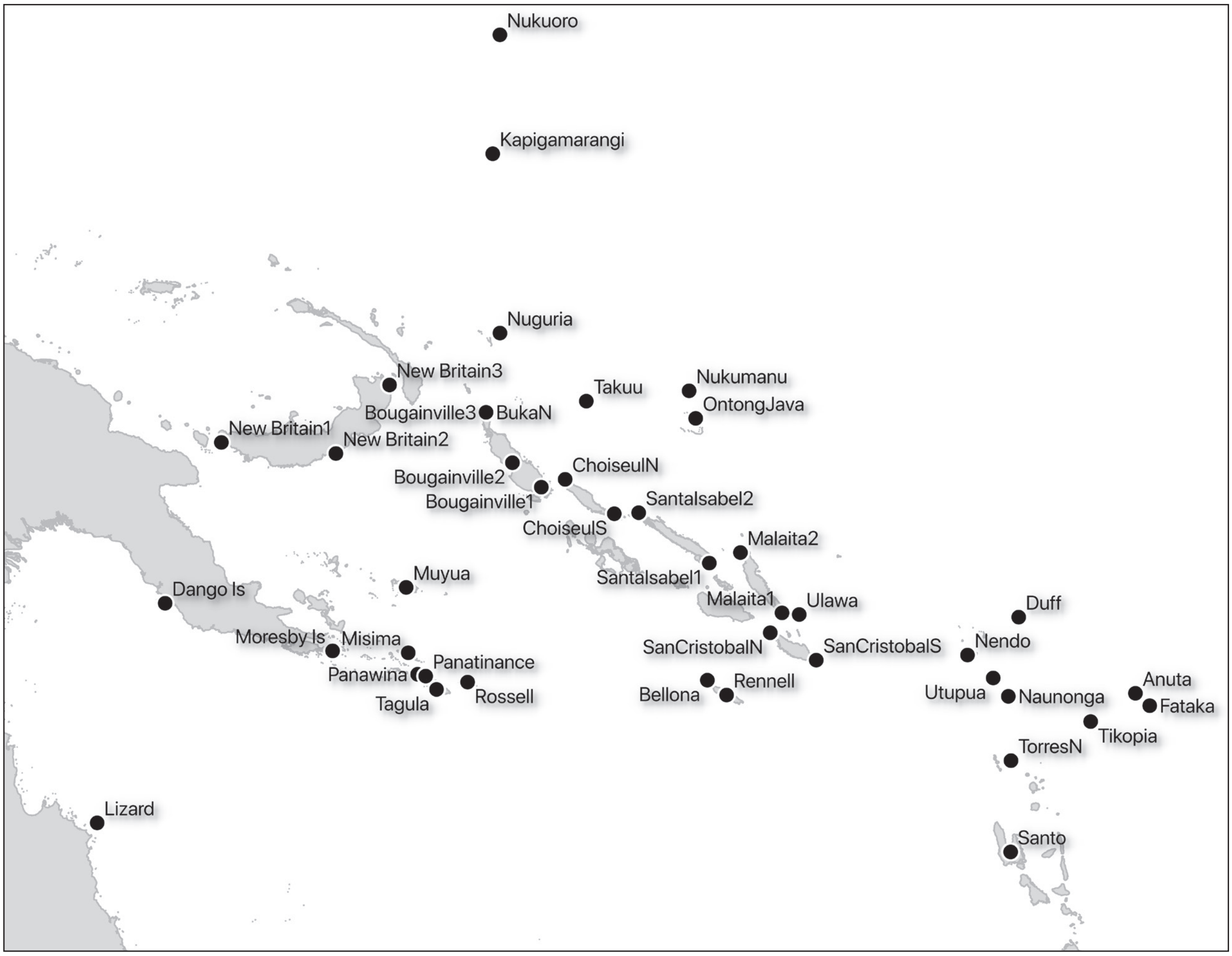
Recently, new sailing data have been published for a Melanesian voyaging canoe: the traditional *nagega* canoe of the Massim area in the Kula Ring (Irwin *et al.* 2019: 13). Speed recorded for the actual canoe by F. Damon (2017: 7–15), as well as the data obtained from the model of a similar sail tested in a wind tunnel indicate a substantially higher peak speed off the wind than the 24-hour averages used in our model. In any case, the polar plot of boat speed against the true wind direction is very similar to the data used in our simulations, with a canoe being able to sail efficiently up to an angle of 75–80° off the wind, and reaching its maximum speed just under 8 knots at 110–120° (Irwin *et al.* 2019: 13).

The rationale of our simulation is as follows. A canoe is sent out from an anchorage at every degree in all directions every week of the year. Theoretically, 360 canoes are therefore launched every week from every identified island. In fact, because a canoe cannot sail against the wind, the possible sector of departure is 210°. These canoes maintain their original bearing as closely as possible. In the case of head winds, a canoe is allowed to tack to continue to sail in the allowed sector (75° off the true wind). When head winds cease, the canoe regains its original heading. The distance sailed is calculated every 12 hours using a weighted mean of wind speed and direction of each of the four surrounding grids encountered by the canoe on a weekly basis. The canoes continue to sail until (and if) they reach a low island within half a day sail and a high island within 1-day sail distance. A canoe's voyage is interrupted if the duration exceeds 21 days of travel. Our simulations do not take currents into account because, while considerably complexifying the model, the relevant surface currents are generated by and follow the major wind system. Thus, the speed of a canoe is only slightly increased if these currents are taken into account and its general behaviour is not altered. Tides do not have any effect once a canoe is a few kilometres off the coast. If several of the 210 canoes launched reach the same island of arrival, the sum of all successful contiguous headings constitutes a sector which can be called *arc of departure*. This arc constitutes also what we will call in this paper the *arc of* success, because the more canoes reach an island, the greater the global success rate for such trips. For example, if 10 canoes launched the same week successfully reach the same island with headings from 15° to 24°, the arc of departure is 10°.

In 2018, Di Piazza and Dousset revived the former's simulation software to test, in the context of the Waves of Words Australian Research Council project, the feasibility of voyages to and from Lizard Island. Dousset programmed additional modules that could: statistically evaluate the results of the simulations; search, select and discriminate voyages according to particular conditions; reconstruct possible multi-stop-over voyages; and map the results into a QGis geographical framework. It soon became apparent that to test sea connections between Lizard Island and Island Melanesia, the general conditions for navigating in the Solomon Sea had to be analysed. To the anchor points intuitively selected in the vicinity of Lizard Island, we therefore added other islands to the simulation, stretching from the Bismarck Archipelago to Vanuatu, and allowed for circular or multi stop-over voyages.

AN OVERVIEW OF THE SIMULATED VOYAGES

The simulations include possible sea connections between a series of chosen islands in the Solomon Sea with the obvious extension to Lizard Island in the Coral Sea. The selection of these islands satisfies several criteria (Map 1). The first is to be either a representative island for a small island group or to be an entry point to other nearby islands. Such is the case for the Torres Islands in Vanuatu (marked as TorresN) which are considered to be a representative for other small islands of the region, namely, the Banks Islands. Another example is Santo which stands as an entry point for the islands of central Vanuatu, namely, Malekula, Ambae, Maewo, Pentecost and Ambrym. Navigation and exchange between Santo and these islands is largely attested and does not need to be confirmed. This does not preclude that an independent and fine-tuned simulation of voyages within the Vanuatu Island group would be interesting and possibly produce a more nuanced picture of what we have assumed here, in particular if the simulation was put in context with other studies such as Huffman's



Map 1. Map of islands/anchor points accounted for in the simulations.

map of the cultural and economic exchange system of north-central Vanuatu (1996: 192). Moresby Island has, for identical reasons, been selected to be representative of the Milne Bay area. Individualising each island would have produced unnecessarily complex simulations, maps and trajectories without producing any added value. We have thus – safely – assumed that if it is possible to reach Santo, for example, it is also possible (in the same or in further voyages) to reach proximate islands such as Malekula. On the other hand, distinguishing (rather than grouping) some islands in the proximity of Lizard Island, such as Rossel Island from Tagula or Panatinance (Pana Tinani) is useful considering that the inhabitants of the former speak a non-Austronesian language in an otherwise Austronesian-speaking region; however, local mythology of Rossell does mention the arrival of pigs, taro and a special canoe brought in by more 'light-skinned' ancestral figures (see Armstrong 1928).

The second criterion is not one that identifies islands as such, but that defines several anchor points for one single island. This is the case for New Britain, Bougainville, Santa Isabel, Choiseul and Malaita. Indeed, these islands are sufficiently large that the particular wind and seasonal conditions plausibly differ from one point of the island to another. These islands have therefore been split into several 'sub-islands' (Bougainville 1, 2 and 3, for example), even though one could also assume that reaching one point of the island should, in subsequent voyages along the coast, also enable reaching other points. In other cases, for example New Britain, a more fine-grained distinction within these large islands also allows considering linguistic differences; New Britain 1 and 2 are regions dominated by Austronesian languages, while New Britain 3 is primarily a non-Austronesian area.

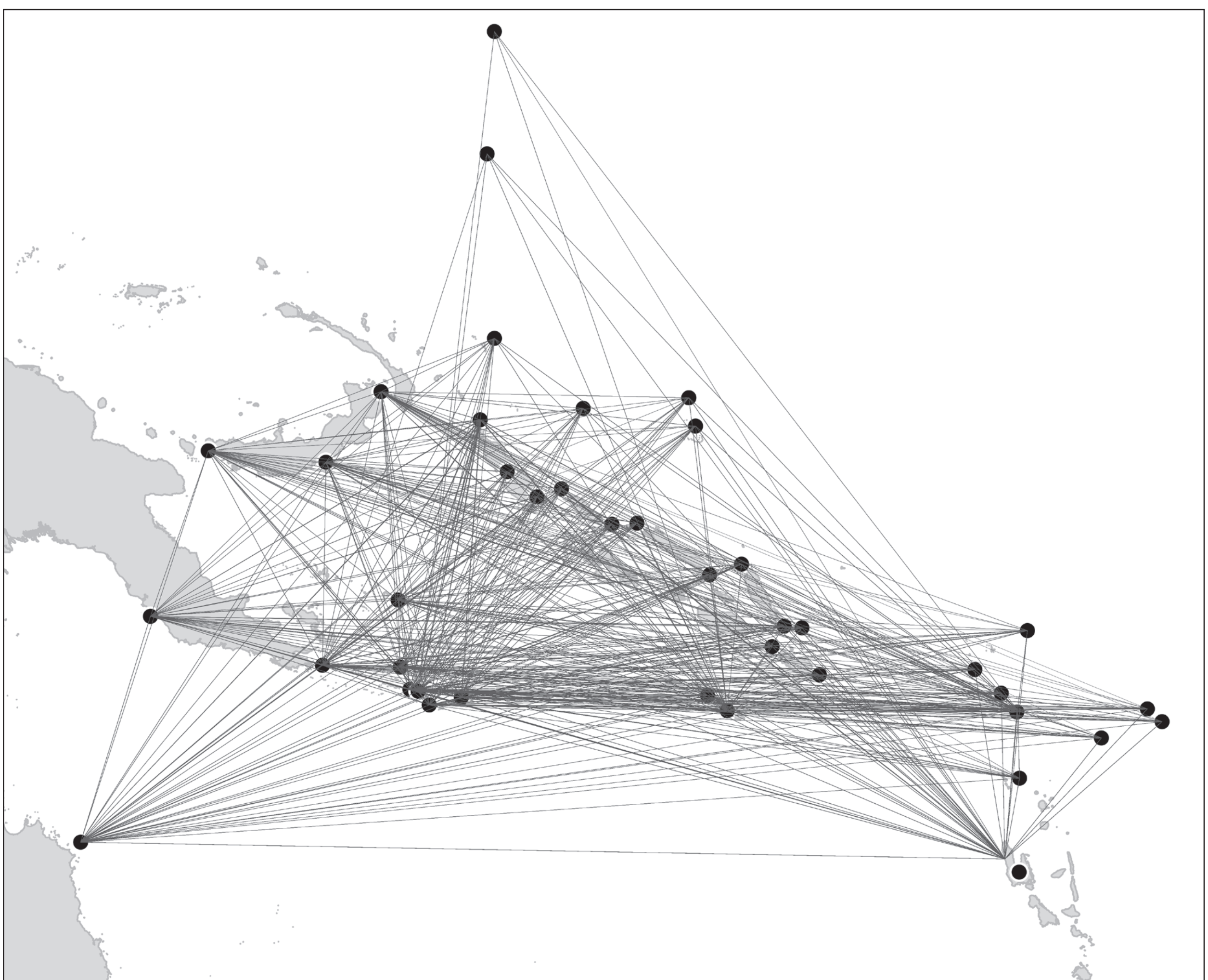
The simulations did envisage to include possible voyages between New Caledonia and Lizard Island as well. Preliminary results show that such voyages are in theory possible but rather limited. They can occur end of May leaving from North New Caledonia and would take 15.5 days, mid-July leaving central-north New Caledonia and would take 12 days, end of May leaving from central-south New Caledonia and take 15 days, and beginning of March leaving from south New Caledonia and take 13.5 days. We have not tested the arc of departure/success for these voyages, but they are likely to be very similar to those of Santo. For questions of readability of the various maps of this paper, and because of the unlikelihood of New Caledonia to have been a major anchor point for repeated open sea voyages between Lizard Island and Melanesia, we have decided not to address the potential New Caledonia connection in this paper.

Taking the 43 selected islands and sub-islands as possible points of departure, the software calculates 444,577 voyages over a year, of which 12,407 are unique and reach one of the other islands or sub-islands identified (Map 2). These successful courses represent 2.7% of all calculated routes. Evaluating this percentage in relation to the sector of navigation (210°), the mean arc of departure or success is therefore 5.8°.

The mapping of voyages as straight lines does not reflect actual trajectories and provides for some strange routes, such as the one between New Britain 1 and Lizard Island over the Papua New Guinean landmass. Displaying each change of tack in accord with the dominant winds would, however, have produced unreadable maps. The lines therefore need to be understood as possible connections between anchorages and not as actual sailing routes. Map 2 thus produces the representation of a geospatial network and not a travel map.

Several preliminary and very general conclusions can be drawn from this network.

1. The density of the network is considerable, linking most islands to all others. If intermediary stops are allowed, then all islands can be connected to all others. Islands on the periphery such as Nukuoro and Kapingamarangi are clearly isolates (even though they may be connected more strongly to other islands that lie beyond the evaluated region). Interestingly enough, Lizard Island, also on the periphery, is technically and meteorologically speaking a feasible point of access. This general conclusion will however be nuanced when we tackle more specific islands and open sea routes as well as thresholds. Indeed, Map 2 displays all voyages in an unnuanced way without discriminating their navigational feasibility (other than limiting the journey to



Map 2. The 12,407 simulated successful voyages (refer to Map 1 for identifying anchorages)

21 days) or their possible occurrences over several seasons of the year.

2. Some islands appear as concentrators of connections in the network. This seems to be particularly the case for Rossell, Panatinance, Panawina, Misima, Muyua, Bellona and Rennell, as well as TorresN. This preliminary visual impression will be investigated further below.

3. A large proportion of voyages (71%) take 10 days or less, and 39% of all voyages take 5 days or less (Figure 1). If we consider that shorter voyages involve less risk taking and thus have better success rates, then the figures suggest that navigation in the Solomon and Coral Seas appears, again in very general terms, to be highly feasible.

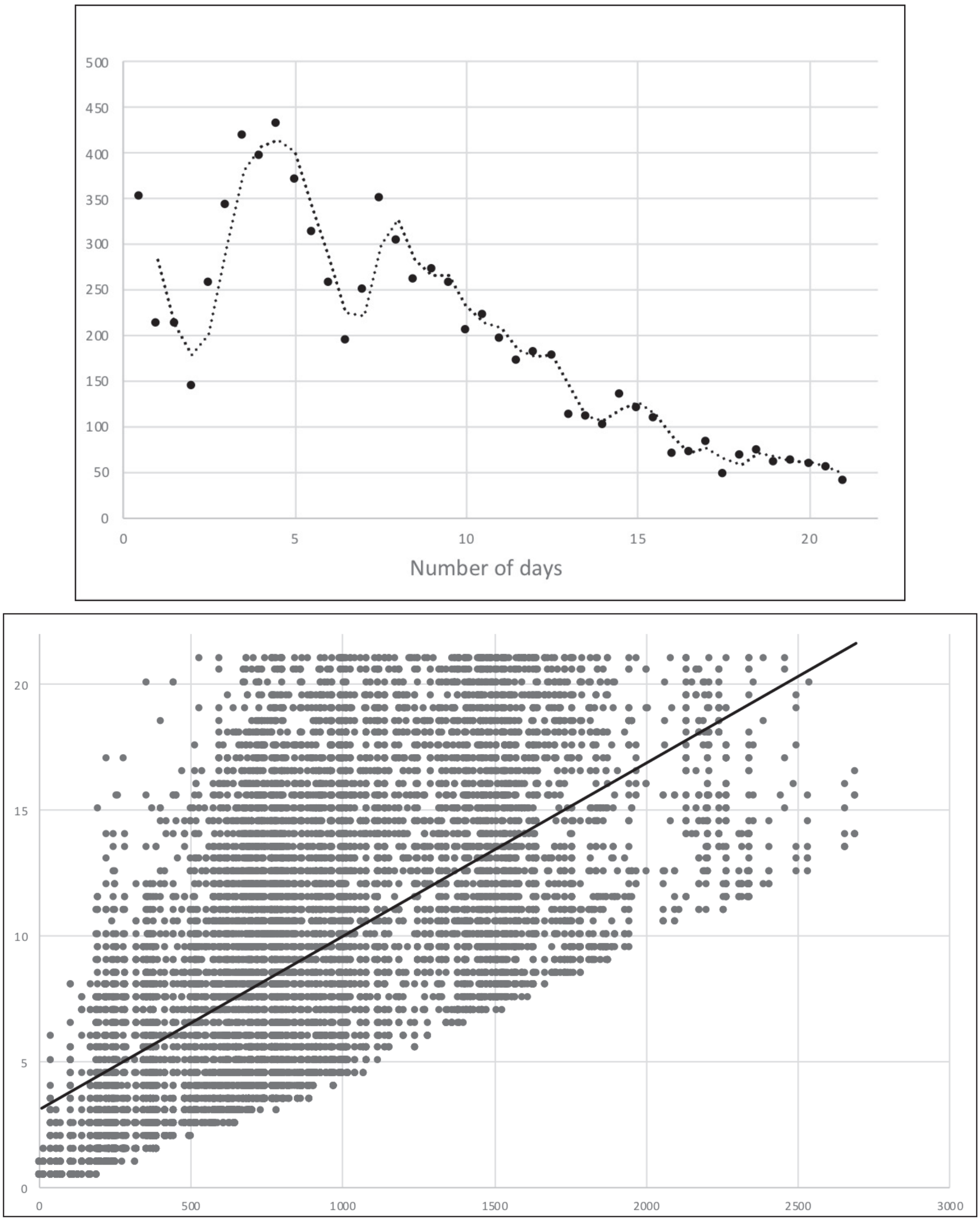


Figure 1. Distribution of the duration of voyages (top figure; Y axis: number of voyages, X axis: duration in days; the dotted line is the moving average calculated as Ft = (At + At-1 + At-2 +…) / n); and the relationship between duration of voyages and distance between islands (bottom figure; Y axis: days, X axis: distance as the crow flies in km between islands; the line represents linear regression).

TRAVEL TO AND FROM LIZARD ISLAND: FROM A FACTOR OF EFFICACY TO A NAVIGATIONAL THRESHOLD

Let us now consider in more detail travels to and from Lizard Island. The produced simulations are concerned with the potential to reach Lizard Island including possible stopovers on the way. In total there are 8,339 possible voyages to or from Lizard Island with however a wide range of arcs of success. While it is potentially possible to navigate from nearly all identified islands to Lizard, the feasibility of these voyages is uneven. To illustrate this feasibility, we have defined a factor of efficacy calculated as $(1/n)*a$, where n is the duration in days and a the arc of success (see Map 3), which has the advantage of linking the duration of a voyage with its arc of success. While intuitively the duration of a voyage and its arc of success seem related (the shorter the duration, the bigger the arc), this is in fact not systematically the case because the arc of departure is a consequence of the local wind system. Displaying the connections between islands proportionally to their factor of efficacy, the islands in the Massim area, including Panawina and Rossell, the Bellona-Rennell region, and the Torres-Utupa area appear as central nodes in the network.

The factor of efficacy does not solve the problem of defining a navigational threshold. It is a tool for representing rather than discriminating connections. Lewis (1975: 223–232), in analysing actual Micronesian and Polynesian voyages undertaken by traditional canoes, noted that most recorded inter-island voyages had an arc of landfall comprised between 11° to 18°, and that 7.5° might represent the limit of navigational feasibility. The arc of landfall is calculated as 2(Arctg) (r/d), where r is the radius of the indicator zone and d the distance between the two islands. Gladwin implies that a Carolinian navigator would expect his course to be within a sector of more or less 5° in relation to the position of the island (Gladwin 1970: 202 cited by Lewis 1975: 231). These different thresholds have been

Map 3. Direct and indirect voyages to and from Lizard Island. The size of the connecting lines is proportional to the factor of efficacy.

mostly estimated for the relatively isolated low islands of Micronesia and Polynesia. In the Coral and Solomon Seas, voyages do not require such a degree of accuracy. Most islands are high and constitute expanded targets. Dango Island benefits from a safety screen, the Papuan coast; Rennel and Bellona from the southern Solomon Islands; and so on.

If these arcs of landfall are indeed a good measure of the degree of navigational accuracy required to reach an island, they do not measure the relative ease or difficulty of actually sailing to it. This difficulty changes with the winds encountered, as well as with a canoe's performance.

Despite the arbitrary nature of a discriminatory factor, we have below defined such a threshold to be at 5° angle of departure. The most difficult voyages are thus eliminated, even though, because of the safety screen from which they benefit, they could in theory be considered possible.

Applying this 5° threshold to direct trips to and from Lizard Island, 237 voyages are simulated, of which 128 lead to Lizard Island (Map 4) and 109 leave from Lizard Island (Map 5). Interestingly, while numerically speaking there is a greater number of opportunities to reach Lizard Island than to leave it, the number of islands that allow for such direct trips to Lizard are fewer than those islands to which direct trips are possible departing from the Australian east coast. Reaching Lizard Island is therefore, proportionally speaking, easier than leaving Lizard Island, but this easiness is limited to a reduced number of islands of departure, as we will see below.

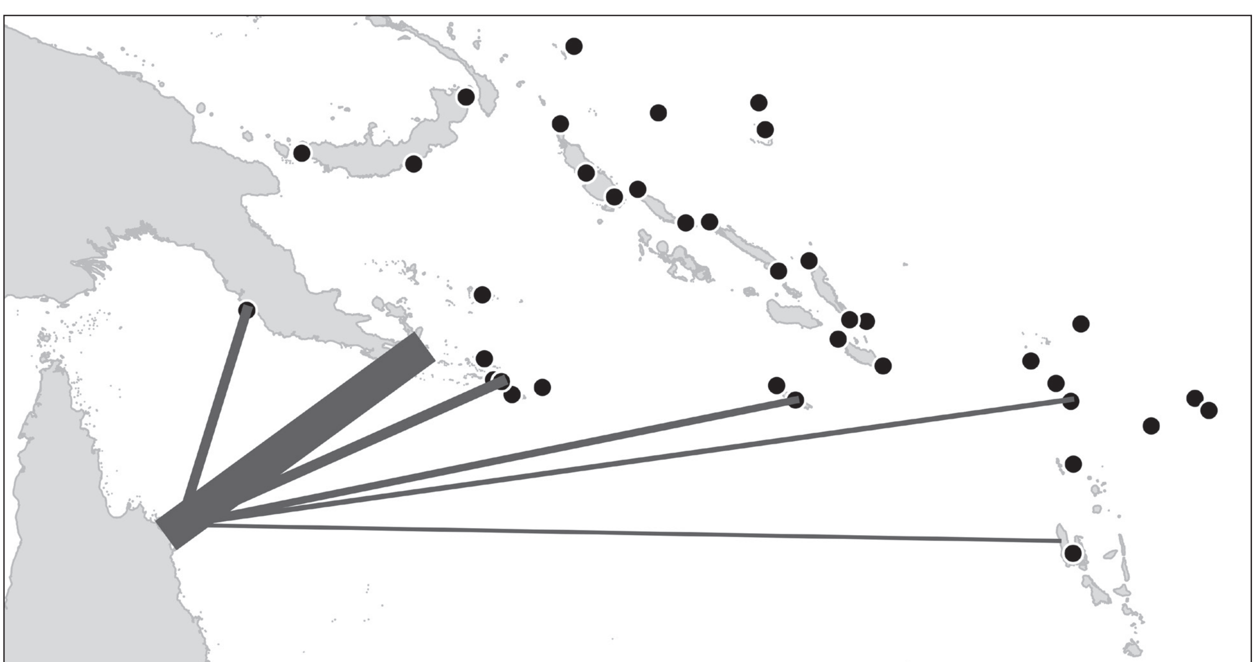
Let us have a closer look at the possible voyages to Lizard Island and organize these with respect to region and season. Note that there are minor differences in winds over the years. For illustrative purposes, the discussion below takes the wind data for 1998, because this is also the year for which the data is the most complete.

From the Massim area / Papuan Tip to Lizard Island

Voyages from Moresby Island and Panatinance can take place any time during the year with a few rare exceptions, such as the second week of June (henceforth Jun2), Jul2 or Aug3. The trips from Moresby Island and Panatinance take anything between 3.5 and 15.5 days. The fastest voyage is leaving Moresby on the third week of May, the slowest on the fourth week of February. The arcs of success range between 5°, which is here our threshold, and 55°. August seems to be a somewhat particular windy month, since either the voyage is impossible (3rd week) or highly successful (1st week; 7.5 days, 55°). If we apply the factor of efficacy, then the following voyages arrive at the top of the charts:

PNG south-eastern coast

Voyages from Dango Island to Lizard Island are much more difficult than from the Papuan Tip. They are seasonally limited to January and February, July and a few weeks in the period of October to December (oct2, nov2 and dec4). Moreover, voyages in July are slow with 17 and 18 days of travel with arcs between 5° and 10°. The most efficient voyages are possible on the last week of January and the first week of February, with respectively a duration of 7.5 and 4.5 days, and arcs of departure of 14°.



Map 4. Voyages to Lizard Island with equal or more than 5° arc of success. The size of the connecting lines is proportional to the arc of success.

Table 1. *The most efficient voyages from the Papuan Tip/Massim to Lizard Island. fE is the factor of efficacy and is the relationship between duration of voyage and arc of success. An fE of 2 and more can arbitrarily be considered to be representing voyages with a good feasibility. The very high arcs of 55° and 32° for aug3, may2 and jul1 are associated with longer travel times, and may be explained by contrary winds encountered during the voyage. Canoes are obligated to deviate from their original headings into the allowed sector, before paralleling again their original course, leading them to discover the target relatively fortuitously.*

Period	Departure	Days	Arc	fE
aug3	Moresbyls	7.5	55	7.3
may2	Moresbyls	7.5	32	4.3
jul1	Moresbyls	7.5	32	4.3
oct3	Moresbyls	3.5	13	3.7
may3	Moresbyls	3.5	11	3.1
feb1	Moresbyls	4.5	13	2.9
jul1	Panatinance	4.5	12	2.7
apr1	Moresbyls	6.5	17	2.6
jul3	Panatinance	4.5	11	2.4
sep1	Moresbyls	4.5	11	2.4
sep4	Panatinance	4.5	11	2.4
may1	Moresbyls	5.5	13	2.4

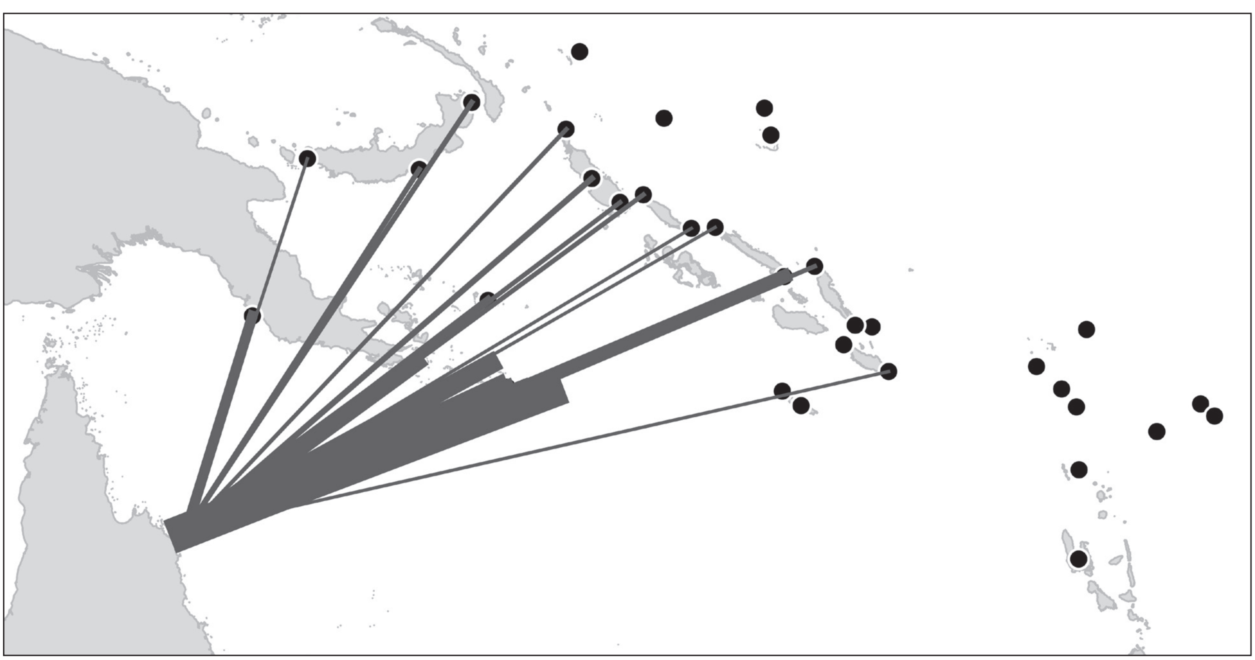
Period	Departure	Days	Arc	fE
may3	Panatinance	4.5	10	2.2
sep1	Panatinance	4.5	10	2.2
apr4	Moresbyls	5.0	11	2.2
apr4	Panatinance	5.5	12	2.2
aug4	Panatinance	5.5	12	2.2
nov2	Moresbyls	6.0	13	2.2
sep1	Moresbyls	4.0	8	2.0
apr2	Panatinance	4.5	9	2.0
aug1	Panatinance	5.5	11	2.0
jun1	Moresbyls	6.0	12	2.0
may1	Panatinance	6.5	13	2.0

Southeast Solomon Islands

Direct voyages from Rennell Island to Lizard Island are possible, but remain difficult if not very difficult. The most efficient voyage departs Rennell on the first week of January with an arc of 11° and reaches Lizard Island after 17 days of navigation. The fastest trips take 8 days at the end of June and beginning of July, as well as in September, but the arcs of success do not exceed 7°.

Santa Cruz / North Vanuatu

Similarly, voyages from Vanikoro and Santo are difficult, if not very difficult, but remain technically feasible. Departure from Vanikoro can take place during a few weeks between February and August, and departures from Santo a few weeks between February and June, with an additional week in September. The shortest voyage leaves Vanikoro on the first week of July and reaches Lizard Island after 12



Map 5. Voyages from Lizard Island with equal or more than 5° angle of success. The size of the connecting lines is proportional to the arc of success. Note that the lines do not represent actual travel routes, but represent the weighted connection between anchor points.

days of sailing. But the arc of success is at the threshold of 5°. Similarly, the shortest trip from Santo departs on the first week of September and reaches Lizard Island after 13 days with 5° arc. The voyage with the greatest arc (8°) leaves Vanikoro on the first week of June and reaches Lizard Island after 17 days.

The voyages leaving Lizard Island back to the north and northeast reflect similar and different characteristics at the same time. Here again, Moresby Island is the most reachable destination with voyages taking place during April and March, with 3.5 days travel time and an arc of success of 13°. The longest voyage reaches Buka Island in 20.5 days with only 5° of arc of success. Let us here again summarize these voyages with respect to destination and season.

To the Massim area / Papuan Tip

The islands that can be reached in this area are multiple: Tagula, Rossell, Muyua, Misima, Panawina, Panatinance, and Moresby Island. However, all voyages are limited to the period January to May. The shortest voyages are to Moresby Island (3.5 days at 13°), Panawina (4.5 days at 5° in March or 5.5 days at 13° in April), Misima (5 days at 10°), Tagula (5.5 days at 7°) and Panatinance (5.5 days at 15°). The most efficient voyages are to Moresby Island in the first week of May (6 days at 27°), to Rossell Island on the second week of April (8 days at 50°), and to Tagula on the second week of April as well (7 days at 53°).

PNG south-eastern coast

As with all voyages from Lizard Island to the north and northeast, trips to Dango Island are limited to the January-May period. The shortest trips take 4 days at arcs ranging between 9° and 16°, with the most efficient departing on the first week of May.

New Britain and Bougainville

Direct voyages to New Britain and Bougainville are possible, but remain very difficult. The most efficient voyage to Bougainville departs on the first week of May and arrives after 15.5 days with an arc of 9°. Voyages to New Britain are similarly difficult, if not worse. The shortest voyage leaves in the second week of May and takes 10 days to the southwest coast of New Britain, but has an arc of success of only 5°. The voyage with the greatest arc (8°) leaves on the last week of January and takes 19.5 days to reach central New Britain.

Solomon Islands

The islands that can be reached from Lizard are Choiseul, the northern part of Malaita, and Santa Isabel between March and May. The most efficient voyages are to Santa Isabel on the second week of April (17.5 days at 21° arc) and the second week of May (15.5 days at 14°). Voyages to the Solomon Islands are generally speaking more efficient and feasible than voyages to New Britain and Bougainville.

To sum up the seasonality of voyages (see Figure 2), the most efficient voyages to Lizard Island take place during the tropical trade wind season of the southern winter (favourable months are from April to October). Voyages leaving Lizard Island back north to the Papuan tip can only take place between January and March during the tropical monsoon season of the southern summer. These conclusions, and the fact that the highest probability to reach a destination is towards Moresby Island, invite us to consider two possible scenarios, which are not mutually exclusive.

1. *Travels to Lizard Island must have been followed by at least a temporary stay (or settlement) along the Australian coast.*

Because of the narrow seasonal window during which voyages can be undertaken from Lizard Island, but also due to the time lag for favourable conditions for return voyages to Lizard, sailors would have to remain on the latter until the monsoon wind system establishes before undertaking north and north-eastern courses. There is indeed research that could be associated to, or that could even confirm such temporary settlements on Lizard Island. Pottery shreds were discovered on Lizard (Felgate *et al*. 2010; Tochilin *et al*. 2012; see also Lentfer *et al.* 2013), which is the only locale on the Australian east coast from which prehistoric pottery is known (Tochilin *et al.* 2012), and some have suggested that ancient pottery discovered in Roviana in the Solomon Islands could have been made from temper that originated in the Lizard Island area (Felgate & Dickinson 2001). Tochilin *et al*. (2012), however, show that the Roviana pottery could not have derived from Lizard Island temper, and that the latter's pottery contains local quartz-calcite temper. Whether Lizard Island temper was traded is not a question of significance in the context of our simulations. It is probably sufficient to consider that the discovery of local pottery could be partial confirmation of the presence of navigators. Rather, let us reverse the statement: the fact that the most efficient direct voyages to Lizard Island are from the Papuan Tip/ Massim area could account for an Austronesian origin of the local prehistoric pottery techniques.

2. *Routes of navigation were more complex and circular, connecting in one longer trip several anchorages before returning to the departure island (or before navigating to any other island).*

Such a scenario reflects the possible existence of trading networks with stepping stones on the way. This is also the conclusion Wood (2018) reaches in his analysis of Austronesian loan words in Cape York. The author suggests that there must have been several contact sequences between Papuan Tip Oceanic languages and southeast Cape York Peninsula, also introducing Austronesian outrigger

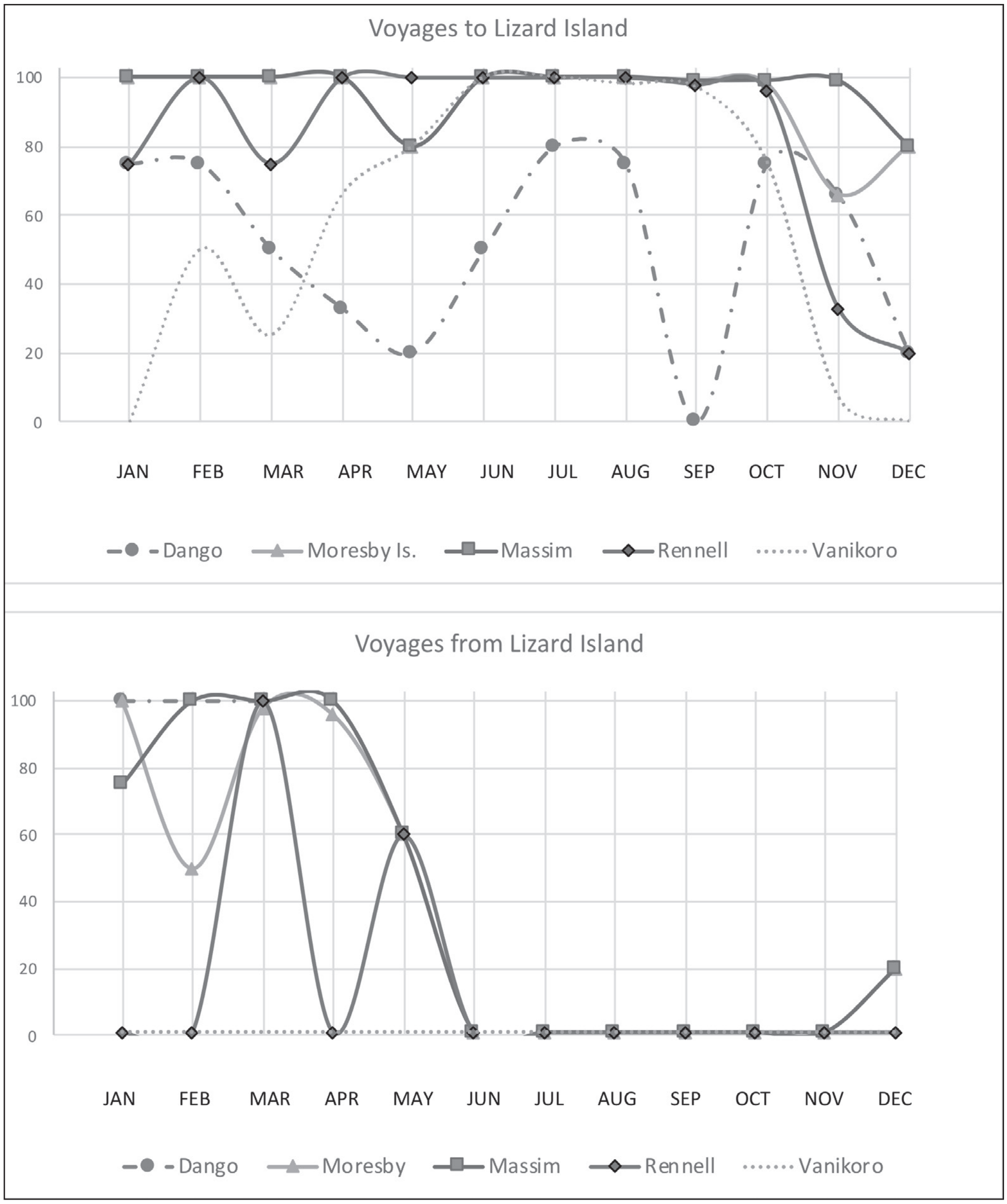


Figure 2. Seasonality of voyages to and from Lizard Island (Y-axis: relative number of possible voyages in %). Note that some of the islands have been clustered into groups of islands in these figures (also see below). Massim: Tagula, Rossell, Panatinance, Panawina, Misima, and Moreby Is; Rennell: Rennell, Bellona; Vanikoro: Vanikoro, Tikopia, Anuta, Fataka, Naunonga, Utupua, Nendo, Duff.

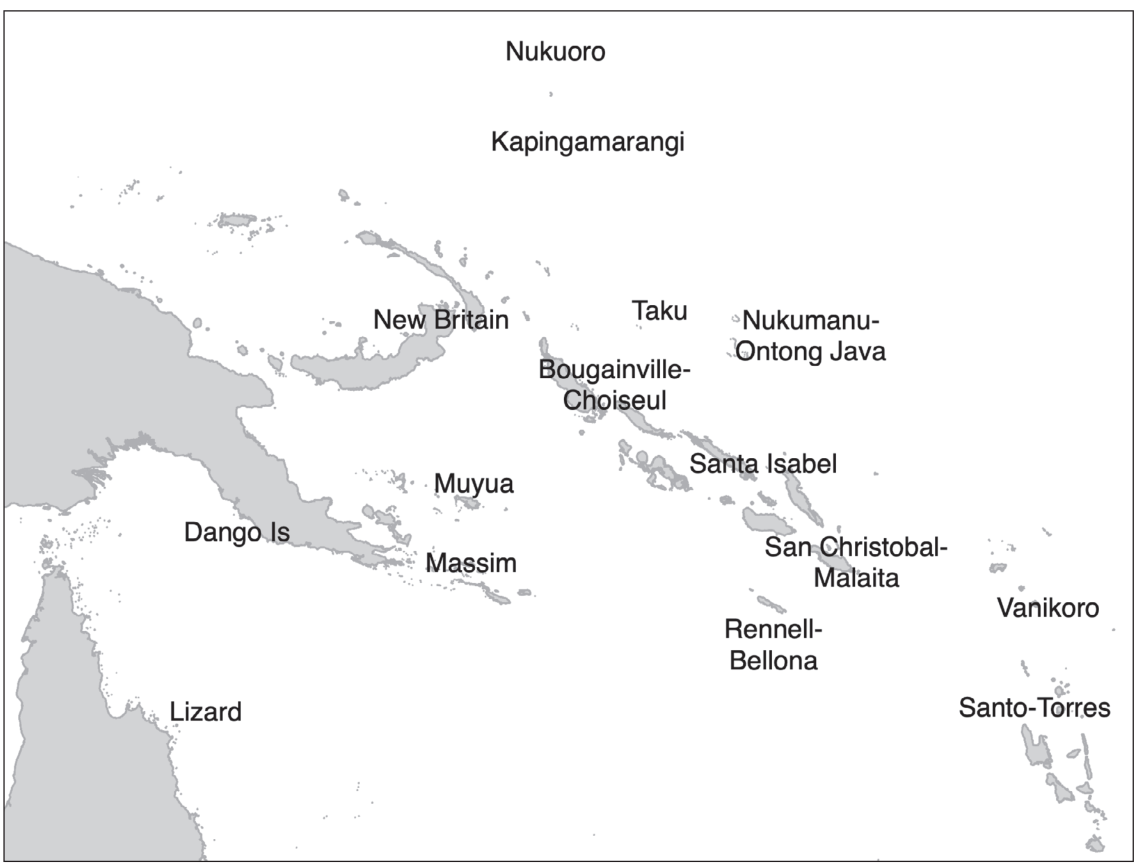
canoes to the area and probably involving sustained trade engagements or even small-scale colonization by Austronesian speakers. In this context, and in addition to scenario 1 above, it is possible to imagine open sea voyages from the Papuan Tip/Massim area to southeast Cape York and slower return trade trips that followed the coast up through the Torres Strait to Dango Island as being part of a more general exchange network. This is also a point Lilley (2019) makes in his recent paper. He suggests that the east-west interaction sphere that emerged in Lapita times between the Papuan Tip/Massim area and the main Solomon Island chain, and the increased use of the Great Barrier Reef islands that occurred in the same general period, are two linked processes. Further, Swadling and Bence (2016) show that the Kula ring, first reported by Malinowski, may have significantly changed in social and geographical scope over the centuries, extending at least as far west as Port Moresby, as suggested by the trade of boar's tusks. These are possible indications that Lizard Island may have been a landing point, or even a regular and long-term stopover in a vast system of circulation and exchange.

LOCATING LIZARD ISLAND WITHIN THE WIDER MELANESIAN NETWORK

Beyond mere exploration, repeated and regular navigation within the Solomon Sea relies on meteorological knowledge and the capacity to predict change in wind conditions depending on seasons. Indeed, the Solomon and Coral Seas are mostly affected by three wind patterns: the doldrums, the southeast trade winds, and the north-westerly monsoon (Irwin 1992). The doldrums or the Intertropical Convergence Zone (ITCZ) lie north of the Equator, between northern Australia and New Guinea. Typically, it is an area about 150 miles wide, with light and variable winds, calms, squalls, heavy showers and thunderstorms. It moves northwards in the southern winter and southwards in the northern summer. The southeast trade winds, limited to the north by the ITCZ, are usually steady, reaching close to gale strength one or two days per month. The north-westerly monsoon winds, generally moderate and commonly intermitted with strong squalls and heavy showers, affect the Queensland coast, the southern coast of New Guinea, and Island Melanesia in the southern summer. In the southern winter, these winds are replaced by southeast trade winds.

These wind patterns have direct implications for the timing and the nodes or crossroads involved in a circulatory network. Voyages from east to west, benefiting from the southeast trade winds, are feasible in the southern winter for the entire region, and as far north as the ITCZ moves in the southern summer. Voyages from west to east, benefiting from the northwest monsoon winds, are feasible in the southern summer for islands situated north of the ITCZ. The ITCZ and the northwest monsoon winds generally lie north of Lizard Island, making the southeast trades the predominant winds that pattern voyaging in this area all year-round. The remaining island groups discussed below benefit from the alternating south-eastern trades and the northwest monsoon winds, providing more opportunities for two-way voyaging among them.

To further understand the potential for circulatory or multi stop-over navigation as a delayed long-term exchange network taking seasonality into account, we have grouped certain islands (see Map 6), some of which already appeared as possible cross-roads in Map 2 and Map 3 above,



Map 6. Groups of Islands. These are Dango, Lizard, Massim (for Tagula, Rossell, Panatinance, Panawina, Misima, and Moreby Is.), Muyua, Rennell-Bellona, New Britain (for New Britain 1, New Britain 2, New Britain 3, Nuguria), Vanikoro (for Vanikoro, Tikopia, Anuta, Fataka, Naunonga, Utupua, Nendo, Duff), Santo-Torres, San Christobal-Malaita (for San CristobalS, San Cristobal N, Malaita1, Malaita2, Ulawa), Santa Isabel (for Santa Isabel1, Santa Isabel2), Bougainville-Choiseul (for Bougainville1, Bougainville 2, Bougainville3, ChoiseulN, Choiseul S, BukaN), Nukumanu-Ontong Java, Takuu, Kapingamarangi and Nukuoro.

into island groups and reanalysed voyages between these groups in terms of:

- the number of navigational opportunities depending on season; and,
- the number and nature of connections between island groups, excluding those within an island group.

Figure 3 compiles the total number of voyages possible for each specific island group, distinguishing voyages that leave from a specific island group from those that reach the island group. The Massim, Rennell-Bellona, Santo-Torres and Vanikoro groups clearly appear as important cross-roads or nodes within the network. However, only the Massim area allows for an approximately equal number of outgoing and incoming travels, while Rennell, Santo and Vanikoro number far more outgoing than incoming voyages.

When distinguishing the potential for travel between islands groups with respect to season, the general picture depicted above is further confirmed. Figure 4 displays the evolution of the number of connected island groups over the year. For example, in mid-May, the Massim group can be reached from 12 other island groups and can reach 13 other groups.

Several conclusions can be drawn from Figure 4. While voyages are possible all over the year (except for Dango and Lizard), there are two peak seasons of navigational potential which are valid for most island groups. These are May and September – October, with another lower peak at the end of December and the beginning of January. Dango Island constitutes an exception with only one peak season in May. Further, the Massim Island group appears as a dominant crossroad through the year, followed by Vanikoro, Santo-Torres and Rennell-Bellona, which are seasonally more marked. In general terms, we may conclude that open sea voyages to Lizard Island (and voyages in general in the Solomon Sea) greatly increase their success rate if integrating a stop-over in the Massim area.

DISCUSSION

In this paper we have investigated the question of seafaring between Lizard Island and the Melanesian Islands of the Solomon Sea. More accurate climate data, better information on canoe performance and a refined rationale of simulation demonstrate that the potential for navigation in the Solomon Sea is extensive, and that sailing to Lizard Island not only is possible, but has most likely occurred. In addition, seasonal variations of wind conditions show that journeys to Lizard Island were followed by at least several months of visit or even settlement on the island before having the opportunity to return north or north-eastwards. These variations also demonstrate that the Massim area and the Papuan Tip appear as ideal connectors or stopovers in circular and indirect trips all over the Solomon Sea, but more particularly in voyages to and from Lizard Island. We therefore suggest that the material demonstration of the Lizard Island – Island Melanesia connection must proceed with the archaeological and linguistic analysis in the Massim area and the Papuan Tip of the potential traces navigators may have left or carried *en route* in a possibly vast network of circulation and exchange to the Australian continent.

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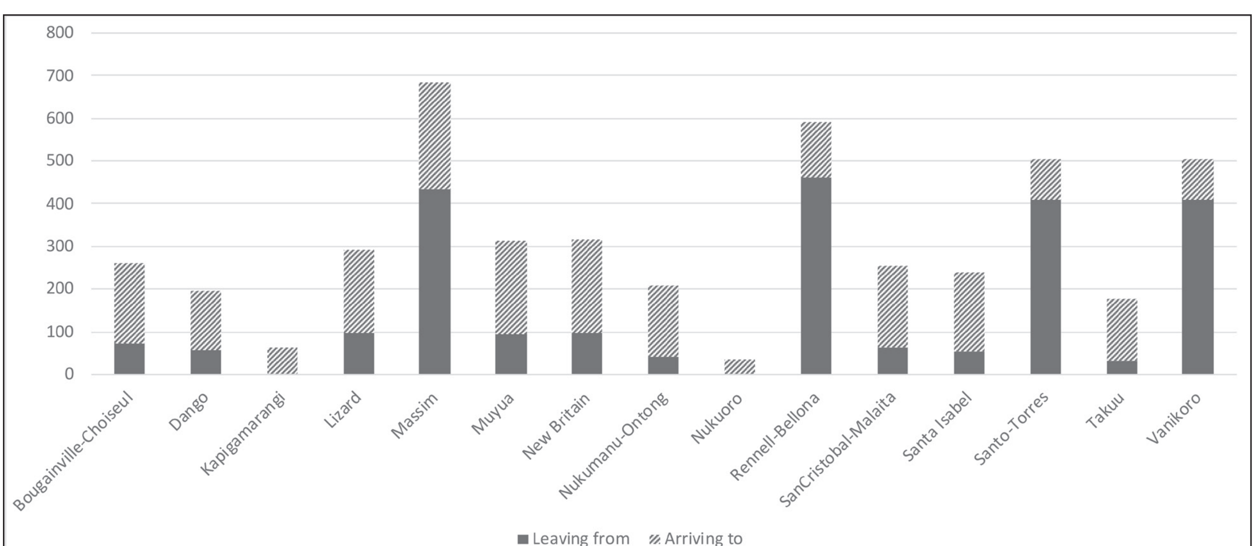

Figure 3. Number of possible voyages between groups of islands (no threshold).

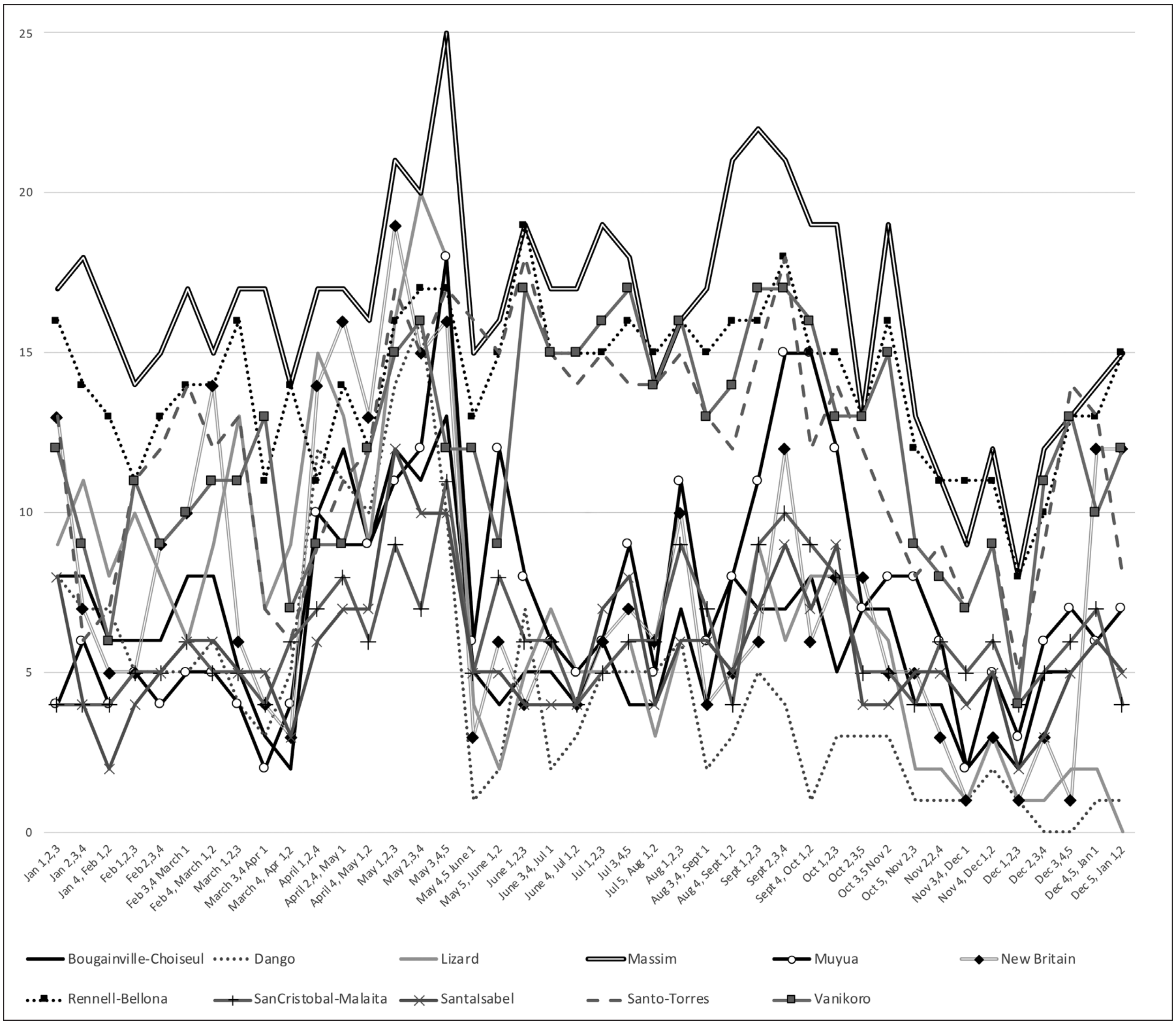

Figure 4. Number of interconnected island groups depending on season. To ease reading of the figure, we have not displayed certain minor and peripheral groups such as Takuu, Kapingamarangi or Nukuoro.

colleagues that participated at the workshop held at the Institut Pasteur, Paris, in February 2020 for their feedback, as well as Tim Denham for his comments on an earlier version of this paper. The wind data has been produced and made available by the Laboratoire d'Océanographie Dynamique et de Climatologie, Paris.

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