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REVIEW

Leviathan's Revenge: Seafaring Simulations, Deep History and the Rise of Computational Modelling

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To sailors of lore, the sea was both knowable and unknowable—a medium that could be manipulated but was also mercilessly destructive, equally exhilarating and horrifying. One might even say that these sentiments have endured ever since humans began crossing water millennia ago. A healthy respect for what lies above and beneath the water's surface provided the impetus for aquatically connected people to build watercraft, however technologically simple at first, and hone their skills by developing wayfinding and other techniques to successfully move from one place to another across the fluid and often unpredictable watery realms. While these events happened around the world at different points in time, what is clear is that whenever humans have found themselves near water, they have exploited its resources, harnessed its power, and continually used it in new and innovative ways. The history of humans and watercraft is one where the first foray into a non-terrestrial environment, a feat unto itself, eventually led us to reach the most remote parts of the planet across almost unimaginable distances. The impact of these milestones through time cannot be understated. Among other actions, this eventually spurred us to pursue new technological advancements in transportation, namely boats that were also submersible but ultimately aircraft and spacecraft. But that is a story for another time.

The stories found in these collections of papers are intriguing because the deep history of watercraft, from the initial seagoing technologies (e.g. rafts, drifting) to seafaring strategies (e.g. more adept movement with well-designed boats and an objective in mind), and then ideologically driven voyaging (e.g. sailing long distances) using progressively more advanced techniques (see Broodbank 2006) are extremely challenging to examine. The general lack of actual vessels—or even related components like paddles in the archaeological record—is primarily due to preservation issues, though people rarely placed watercraft in contexts where they would in fact be preserved; Viking ship burials and boats found in Egyptian tombs are notable exceptions. Unfortunately, these kinds of direct evidence are

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few and far between. In fact, over the thousands of years that people have moved across the Caribbean and Pacific—covering millions of square kilometres—there are only a handful of canoes (mostly incomplete) that testify to pre-contact seafaring activities. As such, for centuries we have been at the mercy of deciphering sometimes erroneous or exaggerative accounts by early sailors, using comparative analogies and ethnographic descriptions of boat building, and testing theories through replica experimentation of historically known traditional watercraft (e.g. *Kon Tiki*, *Hōkūle'a*). These are all valuable pursuits in their own right but lack broad based analysis using fine-grained datasets. That is, until more recently, where increasingly sophisticated computer modelling and simulations have dramatically changed the optics, providing new and powerful ways to investigate how humans harnessed the sea.

As many of the papers here demonstrate, the development of seafaring simulations dates back to some of the earliest uses of computers in the Levison et al.'s (1973. Levison et al.'s (1972) work was the first to do this for examining how Polynesian settlement may have occurred, coming at a time when some scholars were still debating whether these voyages were actually purposeful or accidental (e.g. Andrew Sharp's (1963) misguided treatise). Other attempts were made over the next 30 years, including Irwin's (1992) seminal tome in which he suggested that Pacific Islanders employed the strategy of first going upwind, then across, and finally downwind to maximize successful landfall and a safe(r) return home. Both studies were important in establishing a foundation for answering some of the lingering questions in the Pacific about intent, potential migration strategies, and the limitations and advantages of computers to model these processes. My goal here though is not to review the evolution of past modelling pursuits; the papers included in this issue certainly do an admirable job. I would like to point out, however, that as with all new attempts to explain complex human processes, whether related to maritime movements or not, there are those who question their efficacy and reliability. Rightly so, perhaps, as this is the backbone of the scientific method. But the altered perspectives that seafaring simulations offer may not always dovetail with theories engrained in scholarly discourse. I return to this issue below.

Importantly, the papers here demonstrate just how far seafaring simulation and computer modelling techniques have come, often in lockstep with advances in spatial software, data availability (e.g. satellites), and statistical analysis. That archaeologists, geographers, historians, and other scholars have gravitated more toward maritime modelling is encouraging and opens up a new array of options and opportunities for analysing what were some of the most pivotal events in human history. So, as part of my synthesis, I would like to first review some of the more interesting facets of computer simulations of seafaring that I have been involved with to highlight why they can be such exceptional tools to model human maritime behaviour. I then discuss some of the more poignant issues addressed in the papers found in this collection. Lastly, I suggest some additional thoughts that I believe should be considered when moving these practices forward.

Leviathan's Revenge

The leading title of my review is a bold one for what many might perceive as a straightforward review of papers on how computational modelling can be used to examine maritime travel. Often used by sailors to refer to larger, and sometimes mythical, sea creatures, the leviathan of which I speak is a digital disruptor of traditional praxis that alters interpretive

frameworks. It is a mechanism for mobilizing information, inputting those data into various modelling programs, and generating scenarios for answering questions related to our maritime past.

As a graduate student at the University of Oregon in the mid-1990s to early 2000s, I had experience working in both the Caribbean and Pacific, and I became fascinated by the ways in which peoples could have travelled across the world's seas and oceans. I began reading accounts of traditional Pacific seafaring such as Gladwin's (1970) well-known review of sailing in Puluwat, Micronesia; Lewis' (1994) review of wayfinding and the sidereal compass in the Pacific; and the famous Polynesian double-hulled voyaging canoe replica, *Hōkūle'a* (e.g. Finney 1979, 1991; Hovarth and Finney 1969; Low 2018), which through experimental means, illuminated and transformed our understanding of how Pacific Islanders travelled across vast distances of ocean. This also had the effect of helping to revitalize interest in traditional navigational techniques. These narratives ultimately led me to the aforementioned studies by Levison et al. (1972) and Irwin (1992) in the Pacific that tapped into my burgeoning interest in GIS and other aspects of spatial analysis and how they might be applied to maritime travel. Given the long-history of interest in how the Pacific was settled, it came as no surprise that more concerted efforts through experimentation and computer modelling to help answer these questions might be first found in this mighty ocean that covers one-third of the world's surface. But how might seafaring simulations be applied to other regions like the Caribbean, Atlantic, or Indian Oceans which also had deep histories of seafaring?

As someone who had worked in the Caribbean in the years prior to beginning my PhD, I became interested in the work of Richard Callaghan (1999, 2001, 2003) who began publishing a series of papers on how Indigenous groups may have first settled the region using a new computer simulation program he developed and later called "Seascape". To say I was intrigued in his results was an understatement. He was proposing a pattern of island colonization for the Caribbean that was completely contrary to the generally accepted premise, oft cited without any real supporting evidence. In short, archaeologists for decades had assumed that because similar pottery (termed Saladoid) had been found in both the Orinoco River Basin of Venezuela and across the Lesser Antilles to Puerto Rico, that these peoples had migrated northward from South America using the islands as stepping-stones (Fig. 1). From a biogeographical perspective this certainly made sense but had never been closely examined or tested. Using his new simulation program, Callaghan (1999, 2001) instead suggested that given what was known about Caribbean pre-contact watercraft technology (i.e. the use of dugout canoes without sails or outriggers) and the prevailing winds and currents that moved from east to west, the Caribbean was most likely settled in a direct "jump" from the South American mainland to the northern islands such as Puerto Rico. This was, to say the least, a completely new interpretation that in Richard Callaghan's own words, received ridicule and disdain from scholars when he first presented his results at the International Association for Caribbean Archaeology congress in Puerto Rico (Callaghan 1993).

Callaghan's (1999, 2001) subsequent publications on the issue of maritime movements in the Caribbean were so captivating that I began thinking of ways to test this using existing archaeological data. I started to compile radiocarbon dates from the literature for as many of the sites and islands as I could find. While not entirely comprehensive, I was able to collate more than 600 dates, identified those that were spurious using a chronometric hygiene approach, and used the remaining ones to develop a model of colonization to see how they compared with Callaghan's (2001) results and the stepping-stone model (Fitzpatrick 2006). To my surprise, the oldest Saladoid sites dating to around 2500 BP were found

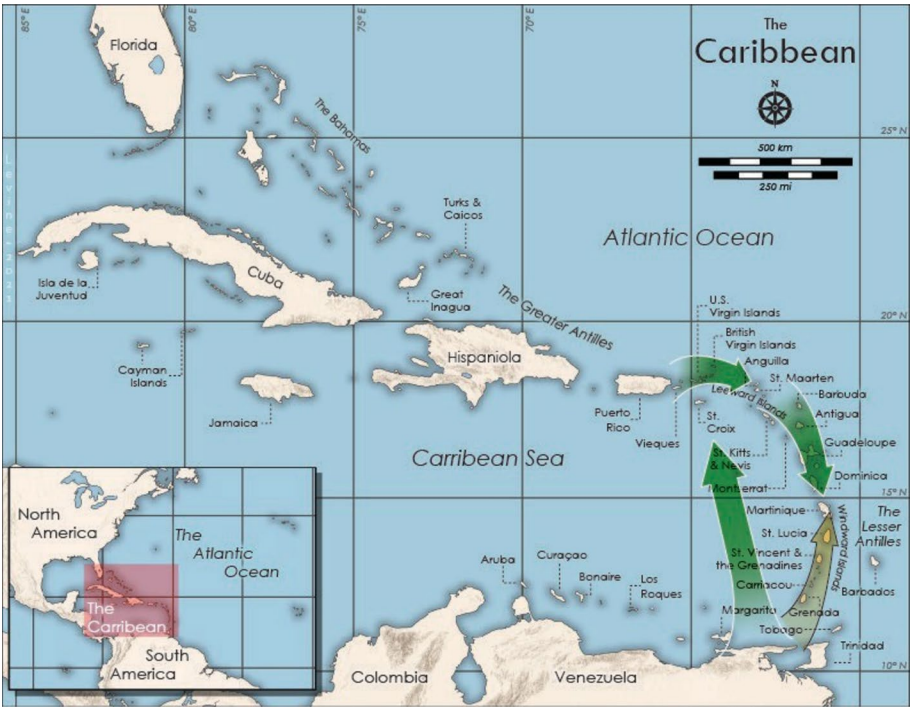

Fig. 1 Map of the Caribbean showing the traditionally accepted stepping-stone movement model (yellow arrow) versus the southward route hypothesis (green arrows)

in Puerto Rico and the northern Lesser Antilles and became progressively younger as one moved south. This led me to examine in more detail this and other chronological disparities in the Caribbean and propose a new colonization strategy couched within Callaghan's (2001) simulation framework termed the "southward route hypothesis" (Fitzpatrick 2013a, b, 2015; Fig. 1). Additional attempts to review even larger suites of radiocarbon dates using Bayesian statistics (e.g. Napolitano et al. 2019; Rodriguez Ramos et al. 2023) have continued to support this hypothesis (see also Callaghan (2008) and Slayton (2018) for additional voyaging simulation studies in the region). My main point in summarizing this conundrum in Caribbean archaeology is that Callaghan's (1993, 1999, 2001) early computer simulations were pivotal in identifying an alternative solution to a problem that most scholars were not even aware of or interested in answering.

Prior to assessing radiocarbon chronologies for the Caribbean (Fitzpatrick 2006), I had reached out to Callaghan to see if he was interested in collaborating on a suite of papers focusing on the Pacific Islands. I had been working in Palau, western Micronesia for my PhD, and was curious about its contact-era history. This large archipelago, consisting of hundreds of islands stretching for ca. 150 km, had remained virtually isolated from Europeans until 1783 when the British packet *Antelope* wrecked on its shores in a storm. This was in stark contrast to most of the other islands in Micronesia—along with the larger surrounding island groups of the Philippines, the Moluccas, and New Guinea—that had been contacted centuries before. Not only that, but the Spanish had actually heard about Palau from Carolinian sailors who had been lost and washed ashore in the Philippines and called

them the "Enchanted Islands." The Spanish Crown actually tried on multiple occasions to locate them from both Guam and the Philippines, but without success. Callaghan agreed to help and in two subsequent papers, we suggested that the confluence of strong winds and currents around the islands explained Palau's relative isolation that, in effect, spared it from colonial impacts for nearly 250 years (Callaghan and Fitzpatrick 2007, 2008).

Another outgrowth of this burgeoning collaboration was historical in nature: Magellan's crossing of the Pacific. While examining Palau's curious phenomenon, Callaghan and I had created a list of known contacts by Europeans with various Micronesian islands. While many have heard of Magellan, fewer are aware that the island he first reached was Guam in 1521, about 1300 km northeast of Palau. But this was ca. 2000 km away from his intended landing in the Moluccas. And his naming of the Pacific ("calm sea") was counter to known weather and oceanographic conditions around the tip of South America described by other sailors historically and those in the modern era. We wondered whether modelling Magellan's voyage using computer simulations would help us understand why this trip happened the way it did (Fig. 2).

So, we posed three questions about Magellan: (1) why did he encounter benign weather conditions after entering the Pacific?; (2) why did he travel so far north when he knew that the Moluccas lay along the equator and could estimate latitude, particularly when ship records indicated that the crew was starving?; and (3) why did he only see two uninhabited

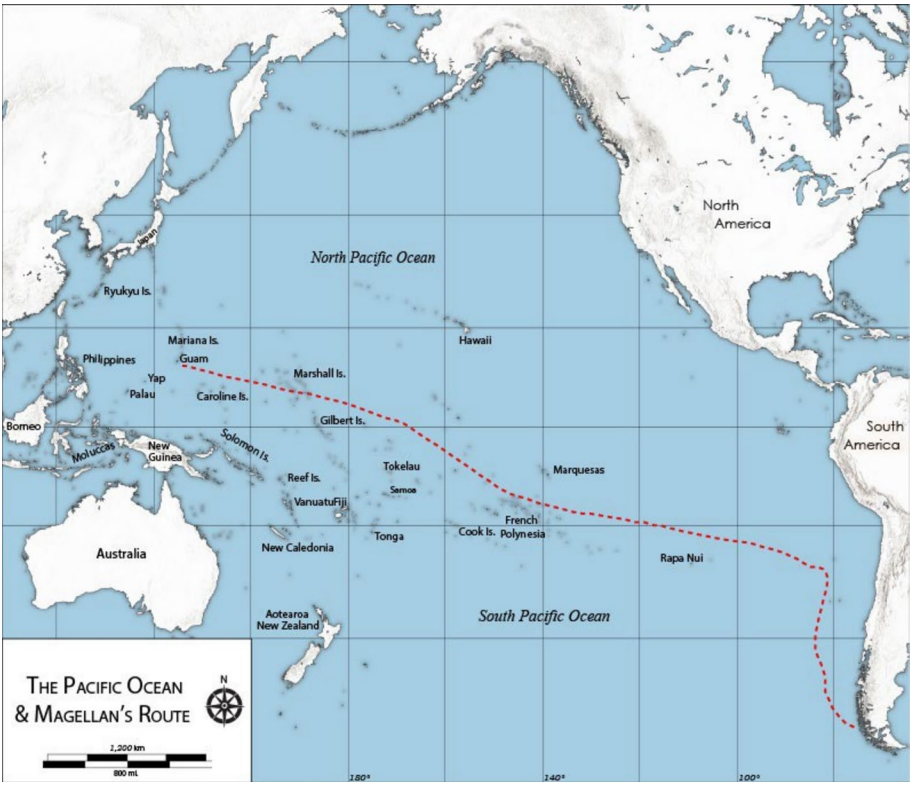

Fig. 2 Map of the Pacific showing Magellan's probable route based on historical records (adapted from Antonio Pigafetta, *The Voyage of Magellan*, trans. Paula Spurlin Paige (1969)

islands after crossing such a vast distance of ocean over a period of three months and more than 16,000 km? (Fitzpatrick and Callaghan 2008). What our simulation analysis showed is that Magellan's entrance into the Pacific was indeed unusual in terms of weather conditions. Although we surmised that certain elements of the voyage were related to various decisions Magellan made to alleviate suffering of the crew while still moving gradually westward, what we discovered was that "ENSO-related phenomena across the Pacific between 1518 and 1521 may have been largely responsible for structuring the route and extent of what many consider to be the world's greatest voyage… and that Magellan's voyage itself is probably the earliest historical record of ENSO phenomena" (Fitzpatrick and Callaghan 2008, pp. 164–165). In essence, what our computer simulations of seafaring showed was that the world's largest ocean—in contrast to the name Magellan bestowed: "the calm sea"—was actually the result of episodic weather conditions. Because he was the first European to enter the Pacific, there can be no earlier written account of ENSO. This was an astonishing and unexpected discovery and one that only computer modelling could help decipher.

What I would like to reiterate here is that seafaring simulations, structured across a mosaic of data sets and analytical instruments, have proven themselves to be indispensable tools for answering important questions about our maritime past. They are not fanciful toys or computer games that scholars play in their off time. They are highly advanced instruments that can accomplish these goals when nothing else is capable of doing so. The major drawback,

however, is something that Slayton et al. (2025, 'Seafaring and Modelling') note, which is that "spatial analysis tools have been primarily developed with a land-based perspective in mind and may not reflect the experiences or practices of past peoples who actively engaged with the sea." But as the papers here attest, this is quickly changing and truly becoming leviathan's revenge.

Seafaring, Modelling and Deep Historical Events

The papers in this collection embody a range of interests, skills and personal experiences. In terms of the latter, I really enjoyed the dialogue between the workshop organisers and Yapese master canoe carver, Larry Reigetal along with Alson Kelen, Director and co-founder of Waan Aelon in the Marshall Islands. Having met Larry before in Yap and learned about Waa'gey (the local canoe building association), it is apparent that these kinds of traditional voyaging revitalisation movements are indispensable for maintaining and passing on knowledge of canoe building and navigation (wayfinding) as it was practiced for millennia. They also reinforce the recognition and importance that Micronesians had in early efforts to revive these skills as part of the Polynesian Voyaging Society's construction of *Hōkūle'a* and showing that travel between Hawai'i and Tahiti (and later, many other places) was possible. This could not have been done without help from the famous Micronesian navigator, Mau Piailug, from the small island of Satawal. In fact, it was the atoll inhabitants of Micronesia, many of whom were engaged in inter-island exchange networks as part of the *sawei* (but also less formalized ones within the Marshalls and beyond), that continued the tradition of long-distance voyaging when others in Polynesia had ceased or declined (Fitzpatrick and Napolitano 2025). What Larry and Alson describe is a humanised, more complete picture of the painstaking time required to build canoes, train

apprentices, provision and travel, elements of which can potentially be incorporated into different iterations of computational modelling.

The paper by Borreggine et al. (2025, 'State of the Field') does an excellent job of summarising the history of computational archaeology and some of the primary issues relevant today when approaching seafaring simulation. Of relevance are decade-long gaps between Levison et al.'s (1973) and Irwin's (1992) work in Polynesia and those that came after (notwithstanding a few select others).

Research over the last 20 years or so has accelerated significantly, however, and with it, a much greater variety of approaches. The authors point out a pandemic jump related to the inability to conduct fieldwork in which scholars, museums and various agencies began pivoting to new ways of analysing and disseminating data. One example is Montenegro et al. (2023) who moved beyond the more common pursuit of identifying success rates of voyages over long distances (in this case, Hawai'i and New Zealand that are situated in more temperate climes) as dependent solely on winds and currents by including thermodynamics of the human body. Identifying energetic demands and requirements of the voyagers themselves is an important component to consider and likely influenced survival rates. In sum, Borreggine et al. (2025) describe how the future might be shaped both technologically (e.g. artificial intelligence, machine learning) and socially (e.g. collaboration, traditional knowledge). To me, one of the most important aspects of this is their recognition of the need for interdisciplinary research as it relates to climate science and archaeology. As they note, computer modelling shows great promise across a spectrum of issues, ranging from assessing threats of climate change on the archaeological record to gauging how peoples in the past were affected by environmental changes. These issues absolutely deserve greater inclusion in future studies.

Related to this, Jarriel et al. (2025, 'Disaster, Risk, and Resilience') address how disaster, risk and resilience factor into modelling in small island and other coastal community contexts. This is of special relevance in the age of rapid anthropogenic climate change in which sea level rise and increased and/or more intense storm activity disproportionately affect those who live in low-lying coastal zones such as atolls. Archaeological and anthropological research can be foundational parts for examining how peoples in the past adapted to both swift and long-term changes, particularly when used in conjunction with traditional knowledge gleaned from modern day communities. Jarriel et al.'s (2025) suggestion of combining multiple epistemologies: archaeology, ethnography, historical accounts, ancestral knowledge, oral histories, and environmental and paleoclimatic data (essentially, an historical ecology approach) to identify emerging patterns is key (pun intended) in this regard. Among other pursuits, the authors home in on differences between Western notions of risk and disaster and what is deemed acceptable or different to peoples today or in the past. As they note, computational modelers should be cautious about introducing their own preconceptions of space as they relate to settlement patterns, migration strategies and a slew of other variables. The Pacific Islander perspective that boats remain stationary while the islands come to them is contradictory to Western belief systems of movement across water and one of only many such muses. Given the propensity for volcanism in the Pacific Basin and Lesser Antilles, one also wonders whether these or other kinds of natural events may have discouraged settlement of different islands at certain points in time.

As Leidwanger et al. ('Launching CAST') describe in their introductory paper, there is both a need to build a community of practitioners across the social and natural sciences and to sustain this collaboration. The inclusion of traditional Pacific Island voyaging experts like Larry and Alson is critical to this endeavour and attests to many more opportunities to do the same in other parts of the world as part of the emergent "blue

humanities" movement. As the authors emphasize, there can be a tendency to approach modelling as purely economic (e.g. travel time, success rates), in a sense, presenting the sea as either a barrier or resource. But this obscures the social aspects of human engagement with the sea for which other facets of daily life were also critical. In sum, this is a refreshing perspective for how the modelling of seafaring should occur in the future and will lead to more enriching experiences and outcomes for everyone.

Following these views, Farr et al. ('Navigating the Narrative') also note that: "… to construct useful models, we need to understand the ways in which the sea can be used and understood, and somehow incorporate the intellectual, spiritual, emotional and physical realities of mariners' lives within them." The authors readily admit that this is not an easy task, in part because evidence from our past is largely known from the remains of material culture recovered in the archaeological record. The quality of these data can be fraught with preservation issues and in the case of seafaring, may not be found at all. This harkens back to what I have called the "seafaring paradox", where we will really only find evidence for a successful voyage when land is reached, but never an unsuccessful one (and as we have seen historically, there were many such ill-fated ventures) (Fitzpatrick 2018). And so, the authors here, similar to what others in this collection of papers have pointed out, indicate the need for greater interaction between theory, experiments, ethnographic and historical research, and traditional knowledge. While I generally agree with Farr et al. that "computational modelling is best used to inspire further inquiry rather than provide absolutes", I do see opportunities to examine unique historical events such as Magellan's voyage, for example, to answer specific kinds of questions (Fitzpatrick and Callaghan 2008). Overall, the three key foci described by Farr et al. that most maritime modelers share are important principles to follow: (1) how people engaged with their environment (both landscape and seascape); (2) examining and understanding maritime technologies; and (3) employing the rich history and traditional knowledge held by practitioners into the different systems of analysis.

In a subsequent paper, Slayton et al. (2025, 'Seafaring and Modelling') outline the different variables that modelers often consider and incorporate into their simulations and analytical prose. This is a useful methodological playbook that nicely summarises the decision-making processes, the parameters used, differences in computational modelling, and processing outputs, including data sharing and storage. One of the most frequent questions I get when presenting simulation results is: how appropriate is it to use modern climatic data for examining past seafaring events? What modelers are confronted with, in most cases, is having to superimpose what is known of recently/historically collected data on winds, currents and anomalous weather conditions onto the fabric of the past. The major benefit here is the ability to use high-resolution modern data recorded from satellites, buoys outfitted with sensors, and that collected by the shipping industry, for instance. The assumption is that major ocean currents as we know them today are probably not that different now, at least since the end of the Last Glacial Maximum under which most major maritime activities have taken place. In some parts of the world such as Wallacea, detailed paleogeographic reconstruction of landforms during the late Pleistocene can help to overcome some of these analytical hurdles in modelling to address maritime migrations even deeper in time (e.g. Kealy et al. 2016, 2017). Nonetheless, Slayton et al. (2025) rightly note that there will also be limitations and challenges inherent in any kind of computer modelling which uses complex data sources. However, many of these issues are being addressed with improvements in computational capability, data quality, and cross-disciplinary communication, and are likely to be continually overcome as we enter the next phase of machine learning and

artificial intelligence, a point that many authors here have made in this special collection of papers.

Concluding Remarks

I sincerely thank the workshop organisers for the invitation to read and comment on their research. I have tried to provide some thoughts, albeit abbreviated, on the issues that inspired me and how this exciting subfield of study, well-articulated by the authors in this collection, might move forward into the future. There is obviously much more I could say but given space limitations I will simply end with a few concluding thoughts.

As computational modellers continue to explore maritime travel across time and space, I do think it is worth reiterating some important points by the well-known and respected archaeologist, Atholl Anderson (2004), who has probably published more extensively on the subject of voyaging in the Pacific and beyond than any other archaeologist. The first is that boats are not passive platforms—just because you have a boat does not mean that travel is ensured for everyone or will ultimately succeed. There are many factors at play, notwithstanding storms or other natural catastrophes that can wreak havoc on boats at sea. Having worked in different island regions for more than 30 years, it is evident to me that over the last few centuries, the pendulum has swung back and forth in terms of explaining the capabilities of ancient seafarers. Historically in the Pacific, the first Europeans marvelled at the prowess and expertise of traditional Polynesian sailors and their large double-hulled canoes that became the inspiration for modern day catamarans. Captain James Cook's utilisation of the remarkable skills of Tupaia, a Tahitian navigator, was well known, yet even this was not enough to dissuade Sharp's (1963) opinion that the Pacific was too vast and unpredictable to have been settled purposefully.

Archaeological research has clearly demonstrated that Remote Oceania was in fact first colonized by at least 3200 BP and not as the result of accidental drift voyages. However, this masks the realization here and elsewhere like the Caribbean (Fitzpatrick 2013b) that just because you have a boat does not mean you can do what you want when you want, or that a trip will always be successful. The pendulum has risen and fallen, but there must be the recognition that travel across the world's seas and oceans was also dependent on many factors that were outside of our control.

This brings us to issues surrounding the aquatic realm and the obvious need to consider things like winds and currents. But it also applies to the social realm. Anderson (2004) correctly notes that in the Pacific (and many other places worldwide), seafaring was in fact a male-dominated activity that excluded women in knowledge circles and sometimes in travel, particularly for exploratory ventures. As seafaring simulations continue to incorporate a broad range of other disciplines and data sources, new genetic data might help parse out how settlement patterns were structured and explain population diversity observed through time. Interesting questions might involve exploring how paternal or maternal lineages might have been affected as part of these voyaging strategies. As Anderson (2004, p. 267) notes, "…the important point is that the way in which seafaring developed technically, was operated socially, and interacted at the larger scale with the maritime environment constitutes a set of critical factors in island histories that deserves further consideration."

Overall, the papers in this special issue clearly support such sentiments. We are at an exciting time, rife with numerous challenges and opportunities in archaeology and computational modelling as they relate to maritime activities in the past and present. For me, this

is the leviathan rearing its head above the surface, providing a future pathway for study, understanding and collaboration.

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Author Contribution SMF wrote the main manuscript text and prepared Figs. 1 and 2.

Data Availability No datasets were generated or analysed during the current study.

Declarations

Competing interest The author declares no competing interests.

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