Review

Human discovery and settlement of the remote Easter Island (SE Pacific)

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Abstract: The discovery and settlement of the tiny and remote Easter Island (Rapa Nui) has been a classical controversy for decades. Present-day aboriginal people and their culture are undoubtedly of Polynesian origin but it has been debated whether Amerindians discovered the island before the Polynesian settlement. Until recently, the paradigm was that Easter Island was discovered and settled just once by Polynesians in their millennial-scale eastward migration across the Pacific. However, the evidence for cultivation and consumption of an American plant, the sweet potato (*Ipomoea batatas*), on the island before the European contact (1722 CE), even prior to the Europe-America contact (1492 CE), revived the controversy. This paper reviews the classical archaeological, ethnological and paleoecological literature on the subject and summarizes the information into four main hypotheses to explain the sweet potato enigma: the long-distance-dispersal hypothesis, the back-and-forth hypothesis, the Heyerdahl hypothesis and the newcomer's hypothesis. These hypotheses are evaluated in light of the more recent evidence (last decade), including molecular DNA phylogeny and phylogeography of humans and associated plants and animals, physical anthropology (craniometry, dietary analysis) and new paleoecological findings. It is concluded that, with the available evidence, none of the former hypotheses could be falsified and, therefore, all possibilities remain open. For future work, it is recommended to use the multiple-working-hypothesis framework and the strong inference method of hypothesis testing, rather than the ruling theory approach, very common in Easter Island's research.

Keywords: islands, discovery, settlement, colonization, Easter Island, Rapa Nui, Pacific Ocean, Polynesians, Amerindians

1. Introduction

In general, any territory on Earth has been discovered once by humans but settled by different civilizations that have sequentially replaced one another. Besides unique, the discovery event does not necessarily involve permanent settlement, which means that a given place can be occupied temporarily by one or more cultures or civilizations before its full settlement. Therefore, we should clearly distinguish several forms of human presence, namely a unique discovery event, an intermittent occupation phase, the full settlement of the region and its sequential replacement by different cultural groups through history, without ruling out the possibility of temporary abandonments and further recolonizations. For more clarity, these processes will be called here (i) discovery, (ii) occasional occupancy, (iii) full settlement or settlement, (iv) historical turnover and (v) recolonization. Not all these phases should occur, or have occurred, in all regions but phases (i) and (iii) are mandatory in any colonization process.

Due to their remoteness and physical isolation, oceanic islands are particularly well suited to study discovery and aettlement processes [1]. Easter Island, located in the

South Pacific, has been included among the most remote inhabited places on Earth (Fig. 1). This, together with its more or less intermediate position between the Polynesian Pacific archipelagos and the South American continent, of contrasting cultural traits, has fostered the interest on when, how and by whom this tiny island was discovered and initially settled and whether it has experienced significant cultural turnover since then [2-5]. This paper is focused on the discovery (i) and settlement (iii) phases and, eventually, on the occasional occupancy (ii) between these two events. Post-settlement cultural developments and their possible drivers have already been reviewed by the author elsewhere [6, 7].

The paper shortly reviews the classical literature on the subject to present the main hypotheses that have been erected and the archaeological, ethnological and paleoecological evidence used to test them. The paradigmatic outcomes of these studies are then checked against new multidisciplinary evidence collected during the last decade, including genomics, which results have challenged and/or enriched former views. Finally, it is recommended that further studies adopt a multiple-working-hypotheses framework combined with the strong inference method of hypothesis testing, to adequately tacking the inherent complexity of the topic under study [8].

2. The island today

Easter Island is called Rapa Nui by its aboriginal inhabitants, the Rapanuis. The name Easter Island (Paasch Eyland, in Dutch) was coined by the first Europeans who arrived to the island, a Dutch expedition commanded by Jacob Roggeveen, the Easter Sunday (5^{th} April) of 1722. The name Rapa Nui (Big Rapa) originated later, in the 1860s, and was used by the Tahitian sailors to differentiate the island from a smaller one called Rapa (now Rapa Iti, meaning Small Rapa) (Fig. 1). According to the indigenous tradition, the first name of the island was Pito-o-te-Henua (the Navel of the World or the End of the World, depending on the source) but nobody uses this term. In Spanish, the official Chilean language (the island belongs to Chile since 1888), the name is Isla de Pascua. Easter Island is very small (164 km^2) and of triangular shape, owing to the coalescence of three volcanic cones: Terevaka (the highest elevation of the island with 511 m), Poike and Kao (Fig. 2). The island is located at about 27º 07’ 09” S and 109º 21’ 29” W, more than 2000 km apart from the nearest Polynesian islands (Picairn) and >3500 km far from the South American Pacific coasts (Fig. 1).

The climate is subtropical oceanic with annual average temperatures of 20-21 ºC and small seasonal variations (2-3 ºC). Total annual precipitation is 1200 mm in average, with a more humid period between April and June (120-140 mm/month) and a drier phase between November and January (70-90 mm/month). There are no permanent water courses on the island due to the high porosity of its volcanic rocks, the only freshwater reservoirs are the *ranos*, indigenous name to designate a volcanic crater with permanent water inside, in the form of a lake or a marsh [9]. The biggest one is Rano Kao, with a lake of >1 km diameter and ca. 10 m depth, followed by Rano Raraku (300 m diameter and up to 3 m depth) and Rano Aroi, with a marsh of ca. 150 m diameter (Fig. 3).

The vegetation is entirely anthropogenic and dominated by grasslands (85-90% of the surface), forest and shrublands are scare (5% each) and about 1% corresponds to crops and ruderal vegetation [10]. The flora is not very rich and most species are introduced. Indeed, of the >200 species of vascular plants known, less than a quarter are autochthonous and only four are endemic to the island [11]. This situation contrasts with palynological reconstructions that have documented an island mostly covered by dense and extensive palm-dominated forests during the last ˜40 kyr BP [12-14]. These forests would have been totally removed in 1400-1600 CE by Polyneisan colonizers, the fruit-eating rats they introduced to the island, or both [3, 15, 16]. This has been interpreted as the result of the overexploitation of island's natural resources and the main cause of the cultural collapse of the ancient Rapanui civilization [3], which has been considered a microcosmic model for the future of the entire planet under the current exploitation practices [17]. This ecocidal hypothesis has been paradigmatic for decades but further studies have challenged this view [5, 16, 18-20].

At present, Easter Island has about 6000 inhabitants (excluding tourists), most of them living on the capital, Hanga Roa. About 60% of the population is of Chilean origin and 40% are of Polynesian origin but the intense mixing between these two ethnic groups prevents to define a clear separation between them. The indigenous language of Rapa Nui is called *vananga* and is of Polynesian origin but is restricted to this island. The different cultures that have established on the island have influenced the original *vananga*, which has contribution from several languages, notably English, French, Spanish and Tahitian (21).

The main economic activity of Easter Island is tourism. The island is visited by up to 90,000 tourists per year, attracted by the abundant and enigmatic cultural heritage of the ancient Rapanui civilization that, according to the ecocidal paradigm, caused the socio-ecological demise of the island. The most iconic manifestations of this disappeared civilization are the >900 megalithic statues, called *moais* (Fig. 4), carved on the soft volcanic rocks (tufa) of the Raraku crater and transported, by unknown media, to almost all island's coasts [22]. But this is not the only legacy of that enigmatic civilization, as it has been estimated that a total of ˜20,000 sites and/or manifestations (in an island of <170 km^2!) of archaeological interest are still available in their places of origin, including several types of dwellings, petroglyphs, cultivation shelters or landmarks, among others [23]. The whole island has been considered an outdoor museum with many enigmas still to be elucidated.

3. The East-West debate

The intermediate position of Easter Island between South America, to the East, and Polynesia, to the West, has fostered a controversy on the geographical origin of Easter Island's discoverers and settlers from either one or another side of the Pacific Ocean. A brief historical account is provided at following on how this debate has proceeded using mainly ethnological and archaeological evidence. More extensive and detailed reviews are available elsewhere [2-5, 24-27].

3.1. Rapanui mythology

The first hypothesis on the origin of the Rapanui civilization emerged from Rapanui's oral tradition and, hence, it should be taken with great care [3]. According to the Rapanui legend, the founders of this civilization arrived from the west by boat and landed in the Anakena beach (Fig. 2). These pioneers were commanded by Hotu Matu'a and their homeland was a hypothetical Polynesian island called Hiva. These first colonizers brought all what they needed to settle the island (food, tools, plants, animals) and established near Rano Raraku, from where they spread across the island and founded the Rapanui culture. This legend does not specify a particular chronology for the arrival of the Polynesian settlers. As any legend based on oral tradition, there are several versions and a variable set of details according to the person who tells the story but there is a general agreement in the geographical origin. Earlier Easter Island's ethnologists such as

Katherine Routledge or Alfred Métraux, based also on the Rapanui oral tradition, situated the legendary island of Hiva in the Marquesas Islands or in the Gambier Islands, specifically on an island called Mangareva (Fig. 1) [24, 25]. It should also be noted that modern Rapanuis have an indisputable Polynesian origin and, hence, they refer to the origin of their own culture. In the Rapanui mythology, Hotu Matu'a and their followers were both the discoverers and the first settlers of Easter Island.

3.2. The American way

In 1803, the Spanish missionary Joaquín de Zúñiga suggested that the predominant winds and marine currents seamed favorable for navigating from South America to Polynesia. During the same century, several analogies were established between the Easter Island statues and those from Amerindian cultures of Bolivia and Peru [3]. These observations encouraged the Norwegian explorer Thor Heyerdahl to demonstrate that Easter Island was first discovered by Amerindians, before the arrival of the Polynesian culture that founded the Rapanui civilization. The famous *Kon-Tiki* expedition was launched for this purpose in 1947. Using a simple raft with a single sail, Heyerdahl and five other men navigated from Peru to the Tuamotu Islands in 101 days (Fig. 5) with the only aid of the winds and the marine currents, thus demonstrating the hypothesis of Zúñiga [28]. Heyerdahl concluded that Easter Island would have been discovered in this way by Amerindian cultures and organized a fieldwork campaign (1955-1956) to the island to collect evidence in support of this idea. He found, for example, that some plants (notably the sweet potato, *Ipomoea batatas*) were considered to be introduced from South America and their names were also of Amerindian origin. He also noted similarities between many tools and constructions, including the moais and the petroglyphs, with potential Incaic and pre-Incaic counterparts from South America [29].

The underlying hypothesis of Heyerdahl was that Amerindians were the discoverers of Easter Island by 400 CE and the Polynesians arrived later and eradicated the Amerindian culture. Heyerdahl linked this view with a Rapanui legend about a war between two groups called the "short-ears" and the "long-ears", where the first won and exterminate the enemies. The chronology was based on a single radiocarbon date and was called in question later and considered too old [30]. The scientific community did not take Heyerdahl's ideas too seriously arguing that he was so attached to his theories that he was neither objective nor rigorous in the analysis of evidence [3]. Perhaps the main merit of Heyerdahl was that, for the first time, he disentangled discovery from settlement, in a cultural sense, and introduced the possibility of arrival and interaction of both Polynesian and Amerindian cultures on Easter Island.

3.3. A unique Polynesian origin

Most evidence provided by Heyerdahl to defend his theory of Amerindian discovery was re-analyzed by Flenley and Bahn [3] to support the contrary hypothesis, that is, the Polynesian discovery and settlement, coinciding with the Rapanui legend. These authors highlighted that the winds and currents that favor the East-West navigation are not constant but vary seasonally. They also noted that the "El Niño" phenomenon, which occur every four years, stops or reverts the oceanic circulation thus favoring West-East navigation. Furthermore, navigation skills were very different at both sides of Easter Island. Polynesians were experienced sailors who have colonized most of the Pacific islands and archipelagos for millennia in a West-East direction (see below). Their boats were highly hydrodynamic and very efficient and were moved by wind but also by oars, very different to the rudimentary Heterdahl's *Kon-Tiki* raft.

Regarding plants of South American origin and their names, these would have been introduced after the European contact. According to Flenley and Bahn [3], the Rapanui art can also be considered of Polynesian origin. For example, the moais and the tools used for their carving may be related to similar representations from Mangareva (the hypothetical Hiva of the Rapanui legend, see above) and adjacent islands. The same is true for the petroglyphs, whose images are common in other Pacific island, as for example Hawaii or New Zealand. Other evidence come from physical anthropology, specifically from skeletons found in the island's excavations corresponding to the ancient Rapanui civilization. The skull biometry and the dental patterns, two characters commonly used in human phylogeny, were also Polynesian in origin, probably from the Marquesas or the Tuamotu Islands (Fig. 1).

Flenley and Bahn [3] dismissed the Amerindian discovery and concluded that Easter Island was colonized only from Eastern Polynesia, probably from the Marquesas Islands, via Mangareva (Fig. 1). Based on palynological reconstructions using radiocarbon-dated lake sediments, these authors found that forests started to decline at about 800 CE and considered this as the indication of the initial Polynesian settlement, under the hypothesis of anthropogenic deforestation. Using archaeological evidence, other authors suggested that the initial settlement of the island took place between 800 and 1000 CE and ceremonial sites with worked stones were erected later, between 1100 and 1200 CE [30]. This view is consistent with the Rapanui mythology and also with the current conception of the human colonization of Pacific islands, which is briefly summarized at following.

3.4. Peopling of the Pacific

In a Pacific context, the colonization of Easter Island was one of the last steps of a West-East spreading process (Fig. 5) initiated when one or several groups of Taiwanese sailors colonized the Philippines by 5000 yr BP (3000 BCE) [31]. The next step was the colonization of the Bismark Islands, north of New Guinea, by 1500 BCE. This was a fundamental stage because it implied the disconnection from the original Taiwanese culture and the development of a new culture known as Lapita, which was the seed of all Polynesian cultures.

The Lapita culture experienced a rapid expansion reaching Tonga and Samoa (Western Polynesia) by 950 BCE, followed by a long pause of around 1000 years, before the expansion towards Eastern Polynesia. The archipelagos of Society, Tuamotu and Marquesas, as well as the Mangareva Island, were not colonized until 600 to 900 CE. The last expansion wave started from these archipelagos in three different directions: Hawaii (800 CE), Easter Island (800 CE) and Nez Zealand, the last Polynesian Island to be colonized, by 1200-1300 CE. Some authors propose later dates for this last colonization wave, including Easter Island, which would have occurred between 1200 and 1300 CE [32]. This coincides with the oldest dated archaeological materials from the Anakena beach (the landing site of Hotu Matu'a and his group, according to the Rapanui tradition), which resulted to range between 1200 and 1400 CE [33].

According to Nunn [34], the last colonization wave, including the discovery and settlement of Easter Island, took place during the Medieval Warm Period (750-1250 CE), characterized by warm and dry conditions with reduced storminess, low interannual variability and rising sea levels, perhaps above present-day ones. Aridity would have stimulated the search for new islands where to live and climatic stability and increased sea levels would have provided optimal conditions for long-distance navigation. This is supported by the larger amount of inter-island interactions documented during the Medieval Warm Period, in comparison with the Little Ice Age (1350-1800 CE), when long-distance voyaging ceased coinciding with increased variability in trade winds, increased storminess and perhaps increased dust from volcanic eruptions [34].

This general picture is the current paradigm but there are still some points that should be clarified before dismissing any Amerindian influence on Easter Island before the European contact, which signified the first worldwide exposure of the island and its inhabitants. Perhaps the most important of these pending issues is the presence, on the island, of the sweet potato (*Ipomoea batatas*), which was considered by Flenley and Bahn as "The only remaining possible botanical link between the island and the South American mainland…" [3] during the Rapa Nui prehistory, i.e. before the European contact.

4. The sweet potato enigma

The sweet potato –which, in Rapanui, is known by its Amerindian name: *kumara*- originated in tropical America and was domesticated >6000 years ago, owing to the nutritional properties of its tuberous roots. In theory, this plant should not have been on the Easter Island before the European contact (1722 CE) but there is evidence of its presence long before that date, even before Europe-America contact (1492 CE). The oldest Polynesian record of this plant consisted of carbonized soft tissues found on the Cook Islands (Fig. 1), dated to ca. 1000 CE [35]. The occurrence of sweet potato remains throughout Polynesia in archaeological sites of similar ages has suggested that cultivation and consumption of this plant was common and widespread long before European contact. On Easter Island, carbonized fragments of sweet potato were found on archaeological sites dating back some centuries before European contact [36, 37]. It has been considered that the sweet potato was the main food source during the flourishment of the ancient Rapanui society, occurred between about 1200 and 1500 CE [4, 38]. How could the sweet potato be present on Easter Island before the Europeans arrived in America? Hypothetically, four main possibilities exist, which are called here: the long-distance-dispersal hypothesis, the back-and-forth hypothesis, the Heyerdahl hypothesis and the newcomer's hypothesis, which are presented at following.

4.1. Long-distance dispersal hypothesis

According to the long-distance-dispersal hypothesis, the sweet potato could have reached Easter Island by non-human means [3], including birds, wind or rafting. An analysis of the so called dispersal syndromes, based on seed morphology, concluded that birds would have been the dispersal agents of 75% of the Easter Island's original flora and the remaining 25% would have been dispersed by water drift; none of the species was considered to be anemochore (dispersed by wind) [39-40]. According to Zizka [11] the sweet potato was anthropocore (human dispersal) and, therefore, the long-distance dispersal was considered unlikely [21]. In addition, dispersal modeling suggested that the probability of long-distance seed dispersal from America and further successful establishment in Polynesia was very low [41].

4.2. Back-and-forth hypothesis

The back-and-forth hypothesis was based on the possibility that Easter Polynesians travelled to South America in pre-Columbian times and came back with the sweet potato, thus facilitating its spread over Polynesia [42]. Based on archaeological, ethnobotanical and liguistic data, it was suggested that the *kumara* variety of the sweet-potato could have dispersed from the Peru/Ecuador coasts to the Marquesas-Tuamotu-Society region (1000-100 CE) and then rapidly transferred to Hawaii, Easter Island and New Zealand (1150-1250 CE) [43-45]. Remarkably, the Amerindian name (*kumara*) has been preserved in Easter Island and New Zealand and their derivatives (*koumara, kumala, kumal, kuma'a*, *'uumara*, *kuuara*, *'uala*, *umala* and others similar) occur across the entire Pacific, from the Micronesian Mariana Islands (Fig. 1) to Easter Island [43]. Historical reports demonstrate that other sweet potato varieties (*camote*, *batata*) were transported to the West Pacific by European traders, after the Europe-America contact.

Currently, the back-and-forth option is the more accepted hypothesis by archaeologists and ethnobotanists working on this subject. This hypothesis implies that Polynesians arrived in America prior to Europeans, a view that is under discussion [46, 47]. Jones et al. [46] compiled the material, linguistic, biological, mythological, nautical, chronological and physical anthropological evidence in support of the pre-Columbian presence of Polynesians in America and suggested that such contact could have occurred repeatedly between approximately 700 and 135 CE by three main regions: southern Chile, Ecuador/Peru and California (Fig. 1). According to these authors, Polynesians did not alter the general cultural development of Amerindians but introduced new technologies and domesticates that affected the subsistence practices of local populations.

4.3. Heyerdahl hypothesis

The Heyerdahl hypothesis is based on the already mentioned possibility of Amerindians discovering Easter Island long before the Polynesian arrival and carrying the sweet potato with them. As it has been discussed above, this possibility was declared officially dead by the defenders of the unique Polynesian discovery and colonization but recent evidence has been put it back on the table.

4.4. Newcomer's hypothesis

In theory, it is also possible that Amerindians arrived to Easter Island after its Polynesian colonization, an option that has not been considered in the classical literature but deserves further examination in light of recent evidence. This option has two hypothetical possibilities, one is that Amerindians arrived by their own and the other is that they were transported to Easter Island by Polynesians in their return from America. The first possibility is similar to the Heyerdahl hypothesis but with different timing, whereas the second option implicitly includes the back-and-forth hypothesis.

5. New evidence

Most evidence discussed above was provided by archaeological, ethnological, ethnobotanical, historical and paleoecological research. During the last decade, the spectacular development of molecular phylogenetic and phylogeographic tools has increased the body of evidence to test the hypotheses about the colonization of Easter Island. These analyses have been applied to humans, thus providing direct evidence on the origin of settlers, and also to some plants and animals intimately linked to human life, as indirect evidence for human migrations. Other analyses carried out recently include physical anthropological techniques such as craniometry and paleodietary analysis. Finally, new paleoecological records have also provided evidence on plants associated to human activities, as indicators of potential human migrations.

5.1. Sweet potato phylogeography

Molecular DNA phylogenies have provided evidence for sweet potato dispersal across the Pacific Ocean. The first attempts yielded incomplete results, mainly due to insufficient geographical sampling but a recent study that included the Neotropics and the entire Pacific Ocean was more informative. In this study, Roullier et al. [48] genetically differentiated the *kumara* lineage and demonstrated that this was the sweet potato variety that spread over the whole Pacific, from the South American coasts of Peru/Ecuador. The spreading of the *kumara* lineage occurred before the introduction of the *camote* and *batata* lineages, that is, during pre-Columbian times but the study did not provide a specific chronology [48]. The authors of this study suggested that Polynesian sailors were the most likely agents of transport and diffusion of the *kumara* lineage from South America to Oceania, thus supporting the back-and-forth hypothesis.

A more recent molecular phylogenetic study of the genus *Ipomoea* [49] found that *Ipomoea littoralis*, a Pacific species absent from America, diverged from its sister species, the American *I. lactifera*, more than one million years ago, long before the human colonization of the Pacific. The authors suggested that *I. littoralis* reached the Pacific by long-distance dispersal of their seeds. The same occurred with *I. tuboides*, which is endemic to Hawaii but belongs to a clade dominated by Mexican species. All these species are closely related to the sweet potato (*I. batatas*) and have similar seeds, fruits and dispersal biology. Therefore, the authors of the study suggested that long-distance dispersal cannot be dismissed as a potential means of sweet potato to reach the Pacific islands in pre-Columbian times [49].

In support to the long-distance-dispersal hypothesis of *I. batatas*, the same study analyzed a specimen of sweet potato collected on the Society Islands (Fig. 1) by Captain Cook's expedition, in 1769 CE. The dated phylogeny of this specimen showed that it diverged from its closest relative during pre-human times, between about 110,000 to 140,000 years ago. Again, this was interpreted in terms of long-distance dispersal, a mechanism that was considered common in the genus *Ipomoea* [49]. These conclusions rely on phylogenetic dating, one of the more controversial steps of molecular phylogenetic analyses, which is in constant development. Given previous experiences, it would not be surprising that further studies find different divergence ages.

5.2. Physical anthropology

The demonstration that sweet potato was an important food source for Rapanuis in pre-Columbian times came from the finding of starch grains of *Ipomoea batatas* in the dental calculus of Rapanui skeletons dated to 1330 CE [50]. However, this did not resolve the enigma of whether the sweet potato was carried to Easter Island by Amerindians or by Polynesians in eventual back-and-forth travels. Genome-wide molecular analysis of a sample of 27 native Rapanuis without known foreign ancestry revealed a predominantly Polynesian origin (76% of the genome), with an early contribution from Native Americans (8%), dated to 1280 CE, and a later European contribution (16%), occurred from 1850 CE [51].

This suggested the presence of Amerindians on Easter Island shortly after Polynesian settlement and long before the Europe-America contact (newcomer's hypothesis) but, once more, it was not possible to know whether these Amerindians arrived by their own or were transported by Polynesians in their eventual return from South America (back-and forth hypothesis) [52]. Considering the navigation skills of these two cultures, the back-and forth hypothesis, seems more plausible. As it has been noted above, Polynesians were sophisticated sailors who colonized the entire pacific from West to East. One more step reaching South America would have not been surprising. Amerindians, on the contrary, used to navigate near the continental coasts and the longer trip known was to the Galapagos Islands, situated ca. 1000 km offshore [3].

A more recent study analyzed the DNA of five skeletons from an archaeological site of the Anakena beach dated to 1445-1624 CE (pre-European contact) to 1815-1945 CE (post-European contact) [53]. No American ancestry was found on any of them and the authors suggested that contemporary American ancestry found in previous studies [51, 52] was not present in the island prior to European contact and may be due to contacts in more recent history. However, the extrapolation of results obtained in five individuals from a single archaeological site to the entire island and the whole ancient Rapanui culture is unwarranted.

Perhaps the most convincing evidence of Polynesians travelling to South America (back-and-forth hypothesis) was the finding of chicken bones of Polynesian origin as old as ca. 1300-1400 CE on the Chilean coasts [54]. The genome of these bones was identical to chicken bones found at prehistoric archaeological sites from Tonga (Fig. 1), dated to 2000-1550 y BP. A further phylogenetic study of ancient and modern Polyneisan chickens did not find early South American ancestry and questioned chickens as providers of evidence for Polynesian-South America pre-Columbian contact [55]. This study demonstrates that the chickens analyzed have no American ancestry but they do not invalidate previous records of Polynesian chickens in South America [54].

Another evidence for the presence of Polynesians in America before the European contact was the craniometric analysis of pre-Columbian skeletons found on a 30-km offshore Chilean island, which suggested that they may be of Polynesian origin [56]. Two human skulls from Brazilian Botocudos indigenous were found to be of Polynesian origin with no detectable American components in their DNA [57]. The relatively recent age of these skulls prevented to unequivocally attribute its presence in South America to pre-Columbian voyaging from Polynesia but the authors of the study did not rule out this possibility.

5.3. Paleoecology

Recent paleoecological surveys have also provided new evidence useful to test the hypotheses about Easter Island discovery and settlement. One of the main advantages of paleoecology is that it provides evidence from pre-settlement times and is thus able to test hypotheses on discovery and occasional occupancy events [58]. In addition, paleoecological records may also inform on natural conditions prior to human discovery. On Easter Island, archaeological records begin with Polynesian settlement, between about 800-1200 CE onwards but paleoecological records preserved in the sediments of Rano Aroi, Rano Kao and Rano Raraku (Fig. 3) extend to the last ca. 40 kyr BP [59]. In this specific case, finding pollen of plants associated to human activities, notably the sweet potato, would be especially helpful. Charcoal records, as fire proxies, and/or forest clearing events could also be useful as indirect indicators but their anthropogenic character should be demonstrated by other independent evidence.

Although the sweet potato has been extensively cultivated on the Pacific during the last millennium, no fossil palynological evidence exists for this fact, as the pollen of

Ipomoea batatas is rare or absent in sediments from Pacific islands. This has prevented to reconstruct the dispersal history of this plant across the Pacific. The paucity of sweet potato pollen in sedimentary records is likely due to the strict entomophilous pollination, which involves low pollen production and poor wind dispersal, and the low preservation capacity due to the high susceptibility of this pollen to physico-chemical degradation [60]. The better preserved remains of sweet potato seem to be starch grains, which are found even on dryland soils, although identification is not always unquestionable due to the similarity with starch grains from others cultivated plants such as *Alocasia macrorrhiza* (elephant ear *taro*) and *Tacca leontopetaloides* (Polynesian arrowroot) [61, 62].

On Easter Island, the first records of *Ipomoea batatas* pollen were dubious due to the bad preservation of the fragments found [63] but recent works confirmed the presence of sweet potato pollen in lake sediments. Horrocks et al. [64] found this pollen on the Rano Kao sediments (Fig. 3), slightly below a radiocarbon date of 377±30 ^{14}C yr BP (1460-1630 CE). Starch grains identified as cf. *Ipomoea* were found in deeper sediments of the same lake, but the occurrence of age inversions prevented to assign a specific date to them. The same authors reported the occurrence of *Ipomoea batatas* pollen in the sediments of Rano Raraku (Fig. 3), close to a sample dated to 587±30 ^{14}C yr BP (1320-1440 CE) [65]. Again, cf. *Ipomoea* starch was found on apparently older, but of uncertain age, sediments. These findings strongly suggest that sweet potato were cultivated on Easter Island about three or four centuries before the European contact, but they cannot decide between the back-and-forth or the newcomer's hypotheses. Using the argument of navigation skills, the first possibility would be favored.

Another plant of American origin linked to human activities whose pollen has been recently identified in prehistoric lake sediments from Easter Island is *Verbena litoralis* (locally called *puringa*), a ruderal species eventually used for medical purposes. Today, the plant is widespread across the island as a weed and is considered to have been introduced during the last centuries [11]. However, the pollen of this species (identified by comparison with present-day representatives collected around Rano Raraku) appeared in sediments dated to approximately 450 BCE and increased to become an important component of the pollen spectra from that date until the present [66]. The *Verbena* pollen appeared in an almost continuous and coherent -i.e., free of age inversions- Rano Raraku sedimentary sequence representing the last two millennia.

The first *Verbena* occurrence was found slightly below a radiocarbon date of 2120±30 yr BP (200 to 50 BCE) and the increase leading to present-like values occurred around another radiocarbon date of 1180±30 yr BP (790 to 990 CE), which includes the oldest dates proposed for the Polynesian settlement [3, 30]. The trends of the *Verbena* pollen paralleled those of grasses and charcoal and were opposite to the palm pollen trends, which suggested that forest clearance would have started approximately two millennia ago and accelerated by 800-1000 CE [66]. According to this, *Verbena litoralis* was already present when the Polynesians settled Easter Island and low-intensity deforestation, probably by fire, was already in progress. The incoming of Polynesians would have exacerbated forest clearing and the expansion of grasses and *Verbena*.

The possibility of early, pre-settlement, deforestation by fire was already suggested by Butler and Flenley [67]. Working in the Rano Kao sediments, these authors found a significant palm forest decline associated to a sharp charcoal increase, suggestive of forest clearing by fire, at about 1900-1850 cal yr BP. They discussed the possibility of this forest disturbance to have been due natural causes (climate, volcanism). However, the rarity of lighting in Pacific islands and the absence of volcanic ash in the Kao sediments led them to seriously considered the possibility of human intervention. Moreover, the charcoal never deceased to former values indicating continuous disturbance. Butler and Flenley concluded that: "…the most interesting feature of the diagram is the interpretation that human disturbance began around 1900 BP (c. AD 100), and continued thereafter, perhaps varying in intensity but never ceasing" [67].

These two palynological surveys on Rano Raraku and Rano Kao [66, 67] coincided in suggesting a millennial-scale forest disturbance by fire, possibly of anthropogenic origin, which may imply human presence on Easter Island since 450 BCE or 100 CE. The coincidence of *Verbena litoralis* pollen with charcoal trends in Raraku may suggest that Amerindians would have been among these early colonizers, which would support the Heyerdahl hypothesis, except for timing. The low fire incidence and gentle forest decline recorded in Raraku until 800-1000 CE may indicate low human pressure until the Polynesian arrival. The whole picture may be consistent with an Amerindian discovery of the island and a long period of occasional occupancy (either by Amerindians or Polynesians, or both) until the full Polynesian settlement. The absence of archaeological evidence prior to this settlement could be due to its paucity, due to occasional occupancy, and/or to the full Polynesian occupation of the island.

6. Conclusions

According to the classical literature based on archaeological, ethnological and paleoecological evidence, Easter Island was discovered and settled just once by Polynesians, likely from the Marquesas or the Gambier Islands, specifically Mangareva. This is in agreement with the Rapanui oral tradition and would have occurred between 800 and 1200 CE, depending on the author. However, the finding of sweet potato (*Ipomoea batatas*) remains long before European contact (1722 CE), even before the Europe-America contact (1492 CE), challenged this classical view and opened new perspectives for the colonization of this remote island. This American plant was found to be extensively cultivated for human consumption in the Polynesian archipelagos before these dates and was considered to be crucial for the flourishment of the ancient Rapanui civilization. The arrival of this plant to Polynesia, including Easter Island, before the Europeans suggested four main hypotheses that affect the classical view of discovery and settlement of this island.

According to the long-distance dispersal hypothesis, the seeds of sweet potato could have arrived from America to Polynesia transported by wind, rafting or birds. Another possibility is that Polynesians discovered America before the Europeans and transported the sweet potato in their return (back-and-forth hypothesis). Easter Islanders could have travelled to America by themselves or the plants could have been introduced to the island by Polynesian settlers. Finally, Amerindians could have travelled to Easter Island by themselves carrying the sweet potato either before (Heyerdahl hypothesis) or after (newcomer's hypothesis) the Polynesian settlement. These hypotheses have been discussed in this review in light of the evidence provided during the last decade by molecular DNA phylogeography, physical anthropology (DNA and microfossil analysis) and new paleoecological findings.

The long-distance dispersal hypothesis found some support on DNA phylogeographies of sweet potato. The back-and-forth hypothesis was also supported by other philogeographic studies of this species and also by physical anthropology (dietary, DNA and craniometric analysis of modern and ancient Rapanuis), DNA analysis of domestic Polynesian animals (chickens) and paleoecological analysis involving the finding of *Ipomoea batatas* pollen in the island before 1495 CE. Some of these studies strongly supported the discovery of America by Polynesians before the Europe-America contact but failed to differentiate between the back-and-forth and the newcomer's hypotheses. Finally, the Heyerdahl hypothesis, which was officially dismissed for long time, was revived by the finding of pollen from another American species, *Verbena litoralis*, long before the purported Polynesian colonization. In summary, some hypotheses are more supported than others by the evidence collected during the last decade but there is no conclusive evidence to falsify none of them. Therefore, in terms of Easter Island's discovery and settlement, all possibilities remain open.

7. Final remarks

The discovery and settlement of Easter Island provides one more example of the application of a multiple-working-hypothesis framework combined with the strong inference method of hypothesis testing [8]. The classical view of a single discovery and settlement event by Polynesians could be considered the ruling theory (*sensu* Chamberlin [68]) that directed research until new observations put it into question. This fostered the incoming of new possible explanations to be tested with further studies. In this case, four main hypotheses were erected and tested using a diversity of methods, including newly developed analysis tools. In this way, the debate was enhanced from a simple dual controversy between the defenders and the opponents of the ruling theory, to become a truly multiple-hypotheses discussion.

In this framework, hypotheses are not necessarily excluding, as it occurs in the ruling-theory scheme, and hypotheses may be complementary. Using the strong inference method [69], based on Popperian logics [70], to dismiss any of these existing hypotheses, it should be falsified using empirical evidence. Contrary to the dual excluding approach, supporting a given hypothesis does not necessarily mean rejecting the others. In the case of the discovery and settlement of Easter Island, none of the existing hypotheses could have been falsified with the available evidence. In principle, the hypotheses erected to date seem not necessarily be totally excluding and it is possible that elements of most or all of them could be maintained for a sound explanation. It is also possible that new challenging evidence may appear that change the current state of the art, a common feature in scientific research.

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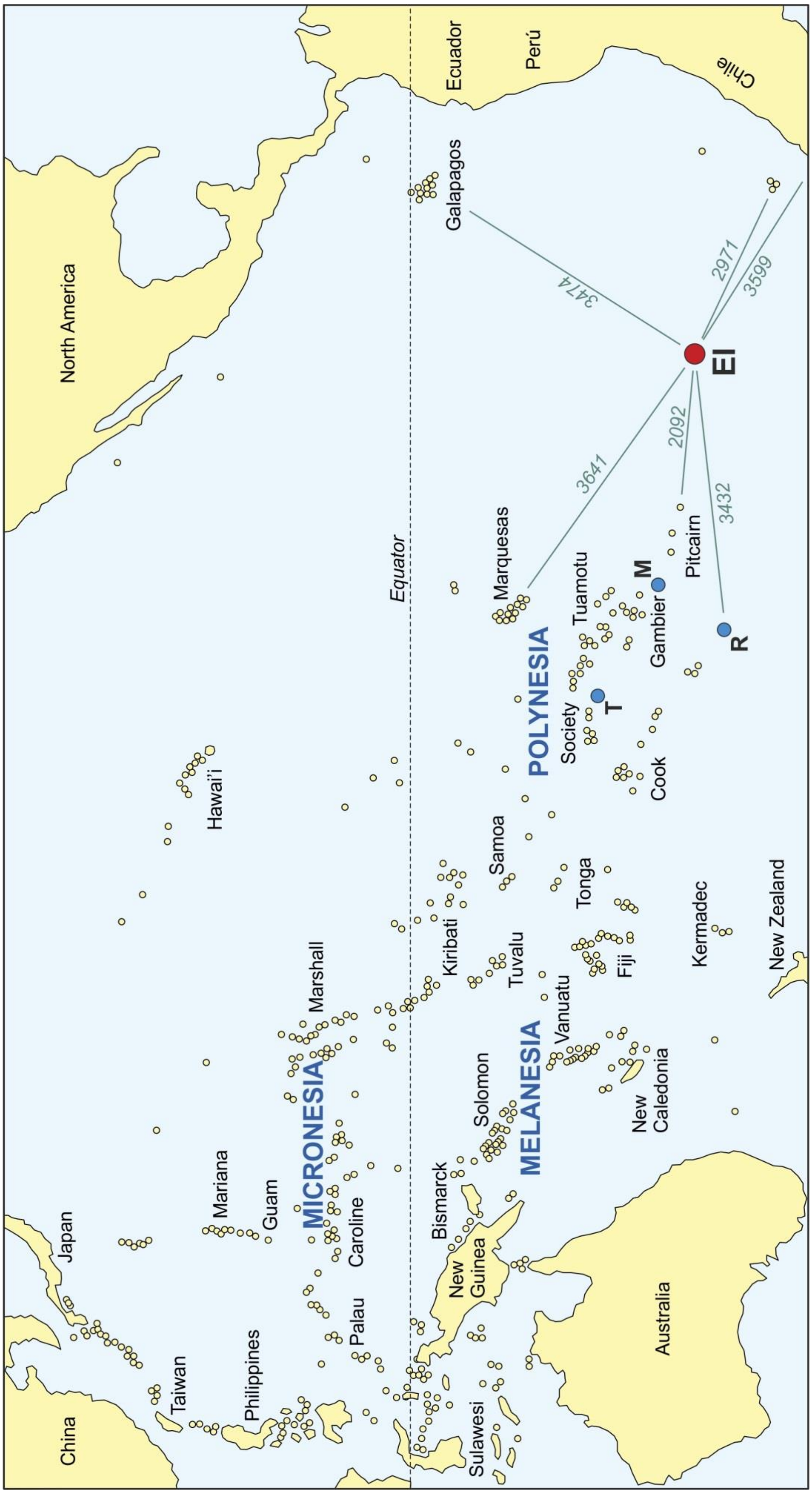
Figure captions

1. General map of the Pacific Ocean with indication of the main archipelagos including those mentioned in the text. Easter Island (EI) is displayed as a red dot and some significant islands in the context of this paper are highlighted as blue dots (M – Mangareva, R – Rapa Iti, T – Tahiti). The distance between Easter Island and some relevant islands is expressed in km [3].
2. Google Earth view of Easter Island indicating the main features mentioned in the text.
3. The thre permanent waterbodies of Easter Island. Photos: V. Rull.
4. Ahu Tongariki, near Rano Raraku, he largest moai agrupation and ceremonial center of Easter Island. The largest of these 15 moais attains ca. 9 m high and 90 tons of weight. Photo: N. Cañellas.
5. Peopling of the Pacific from East Asia, according to Kirch [31]. The green arrow is the approximate trajectory of the Kon-Tiki experition [28].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Gambier
Pitcairn
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POLYNESIA
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Cook
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Samoa
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Kermadec
New Zealand
Kiribati
Tuvalu
Fiji
Marshall
Vanuatu
MELANESIA
New Caledonia
Solomon
MICRONESIA
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Caroline
Bismarck
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Palau
Australia
Taiwan
Philippines
China
Sulawesi

Figure 1

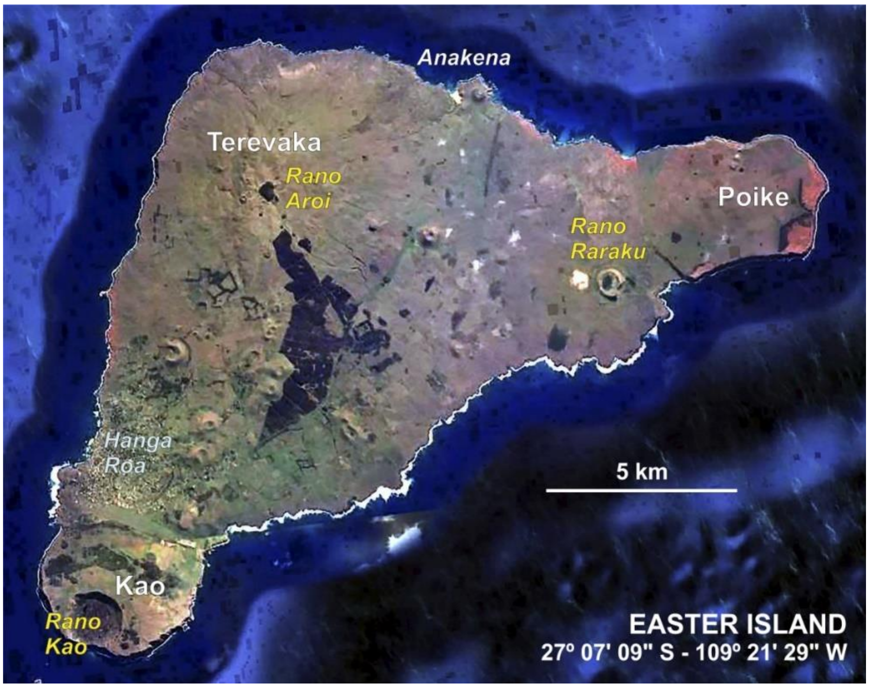

Figure 2

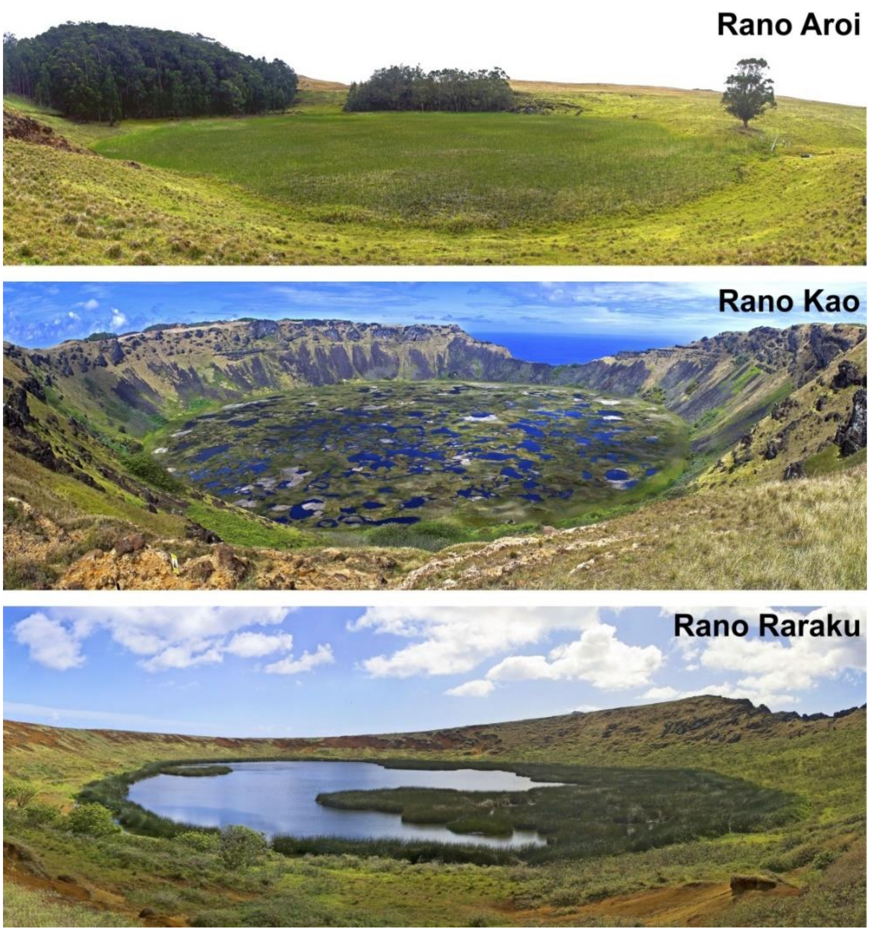

Figure 3

Figure 4

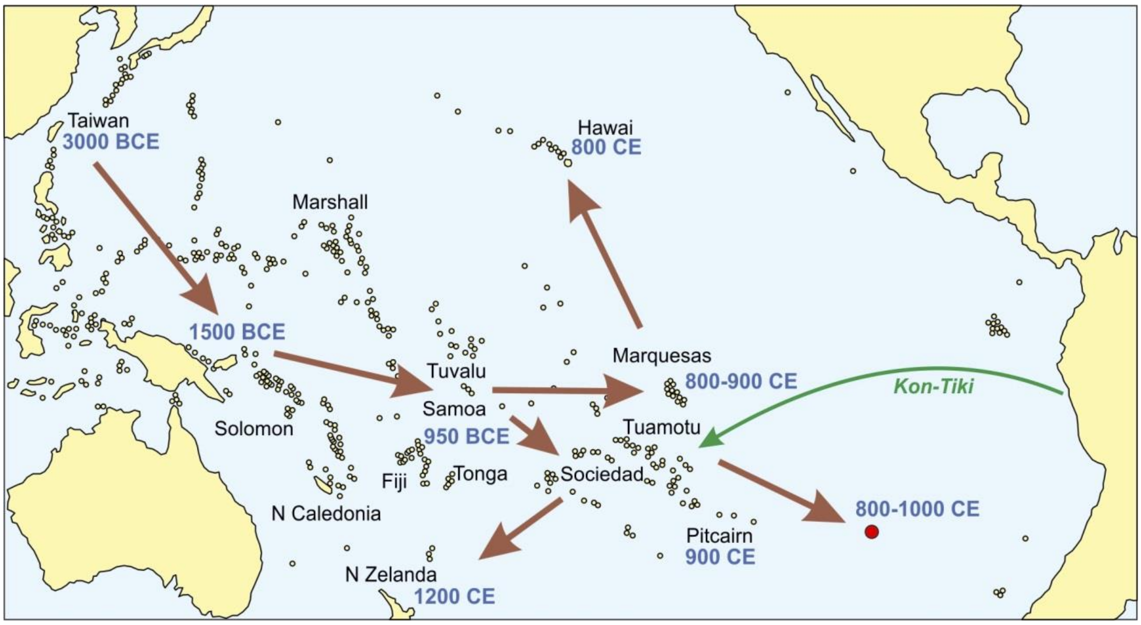

Figure 5