Chapter 12
Prehistoric Paleoecology of Easter Island

Valentí Rull

1 Introduction

Paleoecological knowledge has largely been neglected in the study of Easter Island's prehistory, defined as the time interval between Polynesian settlement (800–1200 CE, common era) and European contact (1722 CE). The initial works of Flenley and coworkers, carried out approximately four decades ago (Flenley and King 1984; Flenley et al. 1991), were taken by many as the final word in Easter Island paleoecology. These pioneering works demonstrated that the island was deforested during the last millennium and that the original palm-dominated forests never recovered. Following an earlier, hitherto unverified, hypothesis of Mulloy (1974), forest clearing was linked by Flenley et al. (1991) to the human overexploitation of natural resources, which would have caused starvation, social conflicts, and wars, leading to the cultural collapse of the prehistoric Polynesian society living on the island (thereafter, the ancient Rapanui society). Bahn and Flenley (1992) considered the socioecological demise of Easter Island as a microcosmic model for the whole planet and warned about current global exploitation practices based on the premise of unlimited growth and human selfishness. The idea of a self-induced cultural collapse, also known as the ecocide theory (Diamond 2005), was considered the paradigm of Easter Island's prehistory and dominated the scene for decades, not only in the scientific arena but also in the press and other popular media. However, a number of issues, such as the deforestation chronology and its spatial patterns across the island as well as the potential influence of climate changes and synergistic climate-human effects on ecological change, remain unclear and require

V. Rull (✉)
Botanic Institute of Barcelona (IBB), Spanish National Research Council (CSIC), Barcelona, Spain
e-mail: vrull@csic.es

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further paleoecological research (Rull 2016a; Rull et al. 2013, 2016). In addition, some archaeological evidence suggests that the ancient Rapanui did not experience a prehistoric population demise but remained a healthy society until European contact (Hunt 2006, 2007; Mulrooney 2013; Mieth and Bork 2015, 2017; Stevenson et al. 2015). As a result, the ecocide paradigm was called into question, and the search for a more holistic view that includes the possible influence of climatic changes and/or synergistic climate-human effects was recommended (Rull 2018).

One constant in research on Easter Island, including the pioneering paleoecological works of Flenley and coworkers, has been the idea that the climate remained constant or that small climatic variations were not influential in prehistoric ecological and cultural developments (Flenley et al. 1991). For example, Bahn and Flenley (1992) dismissed a potential influence of climate on deforestation, claiming that it "seems odd that the forest should survive for at least 37,000 years, including the major climatic fluctuations of the last ice age and the postglacial climatic peak, only to succumb to drought after people arrived on the island." These authors therefore concluded that only humans were responsible for forest clearing. The idea of climatic constancy was also extended to other research disciplines (e.g., archaeology, anthropology, ethnography), which adopted it as one more paradigm, a paradigm still in force today.

Shortly after the pioneering paleoecological works of Flenley and his colleagues, some researchers suggested the possibility that climatic changes, especially droughts, were involved in the ecological and cultural collapse on the island (McCall 1993; Haberle and Chepstow-Lusty 2000; Orliac and Orliac 1998; Hunter-Anderson 1998; Nunn 2000; Nunn and Britton 2001). However, most of these proposals were based on climate change records from distant locations (e.g., Australasia, New Zealand, South America) or regional climatic patterns, and in situ evidence of climate shifts on Easter Island remained absent. According to most of these authors, interannual variability in regional climatic mechanisms such as the El Niño-Southern Oscillation (ENSO) could have affected Easter Island's climate during the prehistoric period. However, the possible influence of the ENSO on the island's climatic variability was not universally accepted and remained controversial (MacIntyre 2001; Genz and Hunt 2003; Stenseth and Voje 2009; Caviedes and Waylen 2011).

In the following decades, paleoecological studies intensified, and clear evidence of prehistoric climatic changes on Easter Island was obtained (Mann et al. 2008; Sáez et al. 2009; Cañellas-Boltà et al. 2013; Rull et al. 2015). It was also demonstrated that deforestation was not homogeneous over time and space but, rather, occurred at different times and at different rates across the island (Rull 2020a). In addition, although paleoecology has not provided direct evidence regarding a number of cultural matters on Easter Island, it has furnished empirical information that can aid in understanding processes such as initial discovery (Rull 2019) or the potential role of climate changes and synergistic climate-human effects on significant prehistoric cultural shifts (Rull 2016a, 2020b).

This chapter reviews the paleoecological study of Easter Island's prehistory, with an emphasis on the research developed during the last two decades, which has been particularly overlooked. The chapter begins with a brief section about the cultural chronology of Easter Island, which is needed to place paleoecological discussions in an appropriate temporal context. Then, the paleoecological sites that have been studied to date on the island are briefly described, with an emphasis on sedimentary freshwater bodies and the cores retrieved from them. This is followed by a succinct historical account of paleoecological studies, with an emphasis on the last decade, which has witnessed a significant resurgence of paleoecological work. The most relevant paleoecological findings are summarized and discussed with regard to four main thematic issues: settlement, climatic change, deforestation, and cultural change. Finally, some remarks related to possible future research and the need for interdisciplinary studies aimed at achieving a holistic view of Easter Island's prehistory are provided.

2 Prehistoric Chronology

Traditionally, the prehistory of the island has been subdivided into three main periods, but agreement on the names of these periods and the boundary dates between them has yet to be reached, which hinders the development of a generally accepted chronology (Lipo and Hunt 2016). The different chronological schemes are presented and discussed in more detail in Rull (2020a); here only the main features and disagreement points are summarized.

The arrival of the Polynesian settlers who developed the ancient Rapanui society on the island has been dated to between 800 CE and 1200 CE by different authors (Steadman et al. 1994; Martinsson-Wallin and Crockford 2002; Flenley and Bahn 2003; Hunt and Lipo 2006; Vargas et al. 2006; Kirch 2010; Wilmshurst et al. 2011). There is still no consensus and some authors do not recognize a presence before 1200 CE, which complicates a phased approach.

The settlement phase, also known as the Early Period or *Ahu Moroki*, would have extended until approximately 1200 CE and was likely a phase of adaptation of the Polynesian colonizers to their new environments, linked to cultural activities with a low ecological impact on the landscape (Mieth and Bork 2010). Heyerdahl (1952) contended that the first settlers were not Polynesians but Amerindians (or Native Americans), who arrived on the island by 400 CE but were further eradicated by the Polynesian settlers. However, this author did not provide convincing evidence, and his proposal was deeply questioned by Flenley and Bahn (2003), who defended the notion that Easter Island was colonized only once, from East Polynesia. Recent genomic studies have suggested that the Amerindian influence on ancient Rapanui society can be dated back to pre-Columbian times (1280–1495 CE), although it is not clear whether Native Americans arrived on Easter Island by their own or were brought there by Polynesians after traveling to America (Thorsby 2007, 2016). Repeated pre-Columbian voyages of Polynesian navigators to America between 700 CE and 1350 CE have been supported by consistent evidence from a wide range of disciplines (Jones et al. 2011; Roullier et al. 2013).

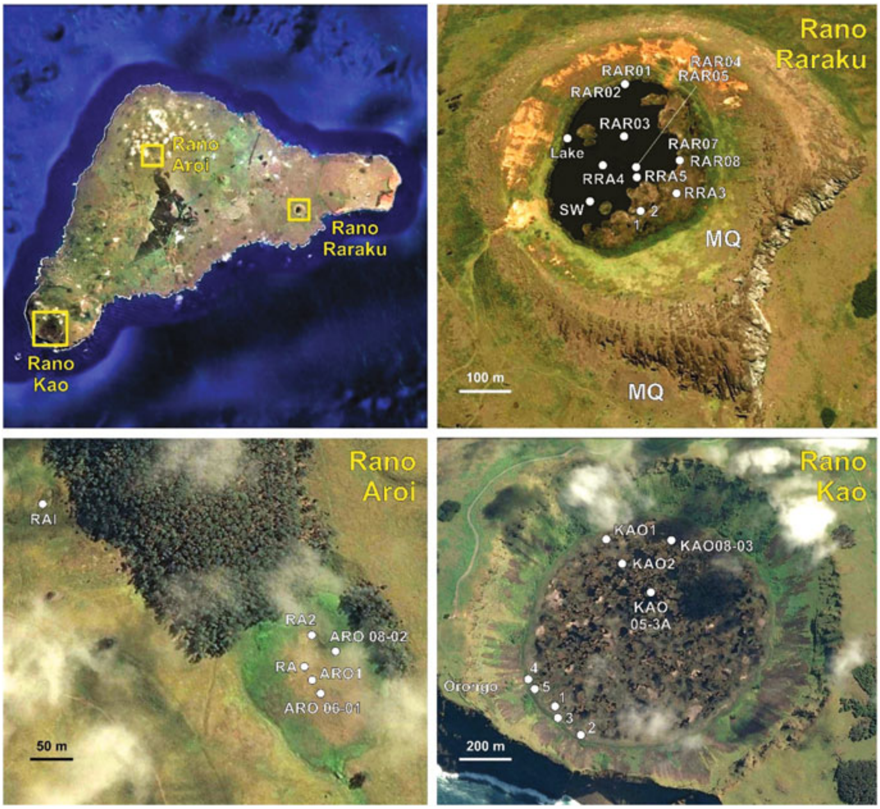

Fig. 12.1 Google Earth images of the paleoecological sites of Easter Island indicating all cores retrieved to date with published results, which constitute the basis for the EIRA radiocarbon database discussed in the text. *MQ, moai* quarry, slopes where most *moai* were carved. Modified from Rull (2016b)

The second period—Middle Period, *Ahu Moai*, or Expansion Phase, also known as Golden Age (Boersema 2015)—would have been the time of a flourishing ancient Rapanui society, characterized by a significant population increase, the development of the *moai* sculpture industry and cult, and the general deforestation of the island. During this phase, the cultural center of Rapanui society was the quarry where the megalithic sculptures, thought to represent clan chiefs (*ariki*), known as *moai*) were carved (Rano Raraku) (Fig. 12.1). The maximum authority of the island, the *Ariki Mau*, was always the chief of the *Miru* clan, considered to be a direct descendant of the first Polynesian settlers. This phase would have ended between 1500 CE and 1680 CE (Smith 1961; Kirch 1984; Flenley and Bahn 2003; Vargas et al. 2006; Nunn 2007; Boersema 2015).

The third phase (Late Period, *Huri Moai*, or Decadent Phase) is thought to have been characterized by the end of the former Rapanui splendor, as manifested in a demographic decline, a deforested island, and a general exhaustion of natural resources, leading to starvation, social conflicts, and wars. Social conflicts among clans would have led to the toppling and breakage of the *moai* and the destruction of the stone altars (*ahu*) where they were erected and emplaced for worship. This would have led to a profound social, religious, and political shift from the ancestor worship (also known as *Moai* Cult) to the Birdman Cult, in which the *Ariki Mau* was no longer a permanent authority selected according to dynastic rules (Robinson and Stevenson 2017). Under the new cult, the maximum authority of the island, the Birdman (*Tangata Manu*), was reselected each year after an athletic competition aimed at obtaining the first egg of the migratory sooty tern (*Onychoprion fuscatus*), considered a symbol of fertility, which nested in the adjacent Motu Nui islet each Austral spring. The Birdman Cult was centered on the ceremonial village of Orongo, situated on the SW crest of Rano Kao (Fig. 12.1), which replaced Rano Raraku as the cultural center of Rapanui society. The end of the third period and of the island's prehistory was marked by the arrival of the first European explorers, in 1722 CE, but the ancient Rapanui culture continued, as reflected in the archaeological record.

This classical three-stage chronology has largely been influenced by the ecocide paradigm, as manifested in the purported occurrence of a profound social crisis and a demographic crash due to the depletion of natural resources, which characterized the transition between the second and third periods. The situation would have been different under a scenario of resilience of the ancient Rapanui society to island deforestation. The widespread use of protected stone structures for cultivation (*manavai*) and the use of novel methods to minimize evaporation and temperature fluctuations (lithic mulching) would have allowed the continuity of the Rapanui population with no significant declines (Stevenson et al. 1999, 2015; Wozniak 1999, 2001, 2017; Mulrooney 2013; Mieth and Bork 2015, 2017; Jarman et al. 2017). Regarding the shift from the ancestor worship to the Birdman Cult, some authors have suggested that this was a postcontact characteristic (Robinson and Stevenson 2017). In addition, some historians suggest that *moai* toppling might have occurred after European contact, as a result of the exacerbation of rivalry among the Rapanui clans competing for the position of Birdman (Fischer 2005). Historical records also show that the true cultural collapse of Rapanui society and culture occurred long after initial European contact and actually took the form of a genocide (Peiser 2005; Hunt 2006, 2007). Indeed, slavery practices and the introduction of epidemic diseases hitherto unknown by the Rapanui (syphilis, smallpox, tuberculosis) led to a population collapse that reduced the population of 3000–4000 people reported by the first European visitors to barely 110 individuals in 1877 (Pinart 1878). In addition, by 1868, the whole population of the island—approximately 800 people by that time—had been Christianized and therefore acculturated.

In summary, a robust chronology of prehistoric human developments on Easter Island remains to be defined. According to Lipo and Hunt (2016), the most precise information available concerns the timing of Polynesian settlement—which these authors place at 1220–1260 CE (Hunt and Lipo 2006)—and the arrival of Europeans, in 1722. The interval between these two dates can only be defined as "the past," with little more precision than that (Lipo and Hunt 2016). Based on the above discussion, a tentative chronology might be represented by a continuum defined by the following processes, with loose and sometimes overlapping boundaries: deforestation (800–1200 CE to 1450–1650 CE), *Moai* Cult or ancestral worship (1200 CE to 1600–1650 CE), Birdman Cult (1600–1850 CE), moai toppling (1770s–1830s CE), and the genocide (1860s–1870s CE).

3 Paleoecological Archives

Easter Island includes only three freshwater bodies with sediments suitable for paleoecological research: Rano Aroi, Rano Kao, and Rano Raraku (Fig. 12.1). Other archives that may contain paleoecological evidence include soils and archaeological sites, which are widespread across the island. In marine environments, corals are potential paleoecological archives that have been poorly exploited to date and deserve further consideration.

3.1 Sedimentary Basins

Rano Aroi is a swamp/mire of 150 m in diameter located at a 430 m elevation near the Terevaka summit (Fig. 12.1). Its water level is controlled by groundwater inputs subject to the influence of seasonal variations in precipitation and human extraction through the construction of an artificial outlet in the 1960s (Herrera and Custodio 2008). The aquatic vegetation is dominated by *Scirpus californicus*, *Polygonum acuminatum*, and ferns of the genera *Asplenium*, *Vittaria*, and *Cyclosorus*, whereas the surrounding area is covered by grasslands and a small *Eucalyptus* forest planted during the 1960s (Zizka 1991). The mire infilling is predominantly peat and is at least 16 m deep in the center, which may correspond to an age of approximately 70,000 yr BP (extrapolated age) (Margalef et al. 2013, 2014).

Rano Kao contains the largest lake of the island, with a diameter of 1250 m, located at a 110 m elevation. This lake is very peculiar, as its surface is a mosaic of water and aquatic vegetation taking the form of floating mats up to 3–4 m deep overlying the water column, which is approximately 10 m deep near the center. This configuration determines the existence of two different paleoecological archives: the superficial floating peaty mat and the more clastic bottom lake sediments accumulated below the water column. The floating mats are dominated by the characteristic semiaquatic species of the island, *Scirpus californicus* and *Polygonum acuminatum*, together with another sedge, *Pycreus polystachyos* (Zizka 1991). The oldest ages recorded so far in the floating mat correspond to the last millennium (Gossen 2007; Horrocks et al. 2013). A significant number of archaeological sites have been found within and around the Kao crater, including the ancient village of Orongo, formed by stone houses, which is one of the more important and well-preserved archaeological complexes of the island (Robinson and Stevenson 2017). The maximum depth of the lake sediments recorded thus far is approximately 21 m (but it is supposed to be deeper, as hard rock has not been reached), and the maximum age is 34,000 cal yr BP (Gossen 2007, 2011; Horrocks et al. 2013).

Rano Raraku contains a small and shallow lake of 300 m in diameter and 2–3 m in depth, located at an 80 m elevation. Hydrologically, the lake is closed, with no surface outlet, and is used by humans as a freshwater source for consumption. The main water inputs are rainfall and catchment runoff (Herrera and Custodio 2008). The water level is influenced by periodic water extraction, and the maximum depth recorded in modern times is approximately 3 m (Sáez et al. 2009); however, in some years, the lake may be totally dry. The aquatic vegetation is dominated by *Scirpus californicus*, which forms a more or less continuous floating belt (partly rooted in lake sediments) along the east margin of the lake, where the input of terrigenous materials from the catchment is greater and more continuous. Rano Raraku is one of the most emblematic sites of the island, as it was the quarry where the *moai* were carved. Many of these stone statues, some of which are unfinished, remain on the east side of the crater, where most of the *moai* were carved. The sedimentary infilling is at least 14 m deep in the center of the lake, which corresponds to an age of 34,000 cal yr BP (Sáez et al. 2009).

Cores from the Aroi, Kao, and Raraku sediments have been retrieved from different parts of these craters using a variety of coring equipment and extrusion techniques. Figure 12.1 shows the location of all cores obtained to date and Table 12.1 displays the main features of each core and the main paleoclimatic and paleoecological proxies studied. The EIRA (Easter Island Radiocarbon Ages) database, which includes all radiocarbon dates obtained in these sediments (Rull 2016b), is publicly available at the NOAA Paleo Data website (www.ncdc.noaa.gov/paleo-search/study/19805).

3.2 Other Archives

In addition to lake and swamp sediments, other paleoecological archives have been investigated on Easter Island, although less intensively. A coral paleoclimatic record covering only the second half of the twentieth century is available, although the authors of the study providing these data estimate that Easter Island's corals have the potential to span at least 250 years and possibly 400 years (Mucciarone and Dunbar 2003). The study of soil profiles and selected materials from some archaeological sites has also provided paleoecological information, mainly on the nature of the ancient forests and deforestation timing. In several of these archives, Mann et al. (2003) and Mieth and Bork (2005, 2010, 2015, 2017) found evidence of slash and burn activity, agroforestry, forest clearing and regeneration, soil erosion, and other ecological processes. In other dryland soils and archaeological sites, Horrocks and Wozniak (2008) and Horrocks et al. (2016) found evidence of forest clearing and the cultivation of Polynesian crops. At some archaeological sites, Orliac (2000) and

Table 12.1 Characteristics of radiocarbon-dated peat and lake sediment cores obtained in Easter Island, according to the original references. The main proxies studied in each core are also indicated. ND No Data. Publication lag refers to the years elapsed between coring and the first detailed publication of the original results

Core	Water depth (m)	Core length (m)	Year	Coring device	Main proxies studied	References
Rano Aroi (27° 05' 37.37" N – 109° 22' 26.50"; 433 m elevation)						
ARO1	0.00	~11.50	1977	Russian	Lithostratigraphy, elemental analysis, pollen and spores, charcoal	Flenley (1979), Flenley and King (1984), Flenley et al. (1991)
ARO 06–01	0.00	13.90	2006	UWITEC	Facies description, mineralogy, elemental analysis, stable isotops, plant and animal macrofossils,pollen and spores	Margalef et al. (2014), Margalef et al. (2013, 2014)
ARO 08–02	0.00	4.00	2008	Russian	Facies description, mineralogy, elemental analysis, stable isotops, plant and animal macrofossils, pollen and spores	Margalef (2014), Margalef et al. (2013, 2014), Rull et al. (2015)
RA2	0.00	8.00	1997	Livingstone	Lithostratigraphy, diffuse spectral reflectance, pollen and spores	Peteet et al. (2003)
RA	0.00	4.00	2009	Russian	Lithostratigraphy, magnetic susceptibility, plant and animal macrofossils, charcoal, pollen and spores, biosilicates, phytoliths, starch	Horrocks et al. (2015)
RAI[a]	0.00	2.11	2009	Russian	Lithostratigraphy, magnetic susceptibility, plant and animal macrofossils, charcoal, pollen and spores, biosilicates, starch	Horrocks et al. (2015)
Rano Kao (27° 11′ 12.57" N – 109° 26′ 06.75"; 107 m elevation)						
KAO1	0.00	~11.00	1977	Russian	Lithostratigraphy, elemental analysis, pollen and spores, charcoal	Flenley (1979), Flenley and King (1984), Flenley et al. (1991)
1	ND	20.00	2009	Russian + Livingstone	Lithostratigraphy, magnetic susceptibility, plant and animal macrofossils, charcoal, pollen and spores, starch	Horrocks et al. (2013)

3	ND	~5.00	2009	Russian + Livingstone	Lithostratigraphy, phytoliths, pollen and spores, starch	Horrocks et al. (2012b)
2	ND	~6.00	2009	Russian + Livingstone	Lithostratigraphy, phytoliths, pollen and spores, starch	Horrocks et al. (2012b)
4	ND	~12.00	2009	Russian + Livingstone	Lithostratigraphy, phytoliths, pollen and spores, starch	Horrocks et al. (2012b)
5	ND	~7.00	2009	Russian + Livingstone	Lithostratigraphy, phytoliths, pollen and spores, starch	Horrocks et al. (2012b)
KAO2	10.50	20.85	1983	Russian	Lithostratigraphy, elemental analysis, pollen and spores, charcoal	Butler and Flenley (2001), Butler and Flenley (2010), Butler et al. (2004), Flenley (1996)
KAO3 (KAO05-3A)	10.50	21.50	2005	Russian + Livingstone	Magnetic susceptibility, oxygen isotopes, pollen and spores	Gossen (2007, 2011)
KAO08-03	ND	2.20	2008	Russian	Lithostratigraphy, pollen and spores, charcoal, non-pollen palynomorphs (NPP)	Rull et al. (2018), Seco et al. (2019)
Rano Raraku (27° 07′ 19.79” – 109° 17′ 20.66”; 80 m elevation)						
RRA3	0.00	~12.00	1977	Russian	Lithostratigraphy, elemental analysis, pollen and spores, charcoal	Flenley (1979), Flenley and King (1984), Flenley et al. (1991)
RRA4	2.80	~17.20	1983	Russian	Lithostratigraphy, mineralogy, elemental analysis	Flenley et al. (1991)
RRA5	ND	13.40	2005	Livingstone	Pollen and spores	Azizi and Flenley (2008)
SW	2.00	~3.40	1990	Piston	Magnetic properties, plant and animal microfossils (pollen, cladocera, ostracoda, diatoms), pigments	Dumont et al. (1998)
1	6.00	~1.00	1998	Gravity	Lithostratigraphy, magnetic susceptibility, organic matter, charcoal, pollen and spores	Mann et al. (2003, 2008)
2	6.00	~1.00	1998	Gravity	Organic matter	Mann et al. (2003, 2008)
RAR01	ND	~5.70	2006	UWITEC	Magnetic susceptibility, facies description, elemental analysis, mineralogy	Sáez et al. (2009)

(continued)

Table 12.1 (continued)

Core	Water depth (m)	Core length (m)	Year	Coring device	Main proxies studied	References
RAR02	ND	~6.80	2006	UWITEC	Magnetic susceptibility, facies description, elemental analysis, mineralogy	Sáez et al. (2009)
RAR03	ND	~13.80	2006	UWITEC	Magnetic susceptibility, facies description, elemental analysis, mineralogy, plant and animal macrofossils, pollen and spores	Sáez et al. (2009), Cañellas-Bolta (2014), Cañellas-Boltà et al. (2012, 2014, 2016)
RAR04	ND	~6.00	2006	UWITEC	Magnetic susceptibility, facies description, elemental analysis, mineralogy	Sáez et al. (2009)
RAR05	ND	~13.20	2006	UWITEC	Magnetic susceptibility, facies description, elemental analysis, mineralogy	Sáez et al. (2009)
RAR07	ND	~12.80	2006	UWITEC	Magnetic susceptibility, facies description, elemental analysis, mineralogy, plant and animal macrofossils, pollen and spores	Sáez et al. (2009), Cañellas-Bolta (2014), Cañellas-Boltà et al. (2012, 2014, 2016)
RAR08	ND	~12.60	2006	UWITEC	Magnetic susceptibility, facies description, elemental analysis, mineralogy	Sáez et al. (2009), Cañellas-Bolta (2014), Cañellas-Boltà et al. (2013)
Lake	2.60	2.25	2009	Livingstone	Lithostratigraphy, plant macrofossils, pollen and spores, phytoliths, starch	Horrocks et al. (2012a)

[a]Rano Aroi Iti (see Fig. 12.1)

Orliac and Orliac (1998) identified woody plant taxa from charcoal fragments. The usual proxies utilized in the study of soils and archaeological sites have been soil stratigraphy, with an emphasis on carbon layers, charred wood/endocarp and palm root casts, charred wood, pollen, phytoliths, and starch remains.

4 Historical Development of Paleoecological Studies

Paleoecological studies on Easter Island have their origin in some undated cores retrieved in the mid-twentieth century by Thor Heyerdahl, which were analyzed for pollen by Olof Selling, but the results remained unpublished. The only information available is a personal communication from Selling to Heyerdahl, suggesting that the island was probably forested at some time in the past (Heyerdahl and Ferdon 1961). These forests must have disappeared before European contact, as the first Europeans to arrive found a treeless island (Fischer 2005). The idea of a forested island had previously been proposed, albeit without empirical evidence, in the late eighteenth century by La Pérouse (1797), who also speculated that the ancient Rapanui would have cut down all the trees, making the island inhabitable. Mulloy (1974, 1979) related the initial palynological evidence to his own findings identifying palm root molds associated with carbonized wood in ancient soils, which were interpreted as remnants of former palm forests. In a paper written in 1976 but not published until two decades later, Mulloy (1997) emphasized the need for repeating and extending the paleobotanical studies initiated by Selling to test the hypothesis of a formerly forested island. From this point onward, the sediments of the suitable sites (Rano Aroi, Rano Kao, and Rano Raraku) began to be systematically cored and dated. However, the historical development of these studies was a discontinuous process due to the occurrence of a hiatus of approximately 10 years (1993–2004) characterized by a significant reduction in paleoecological research activity, which separated the more active pioneer (1977–1992) and revival (2005–present) phases (Fig. 12.2). A detailed account of the analyses performed, the interpretation of the obtained results, and the conclusions that were drawn is available from Rull (2020a); here, only a summary will be provided.

4.1 The Pioneer Phase

The first systematic paleoecological studies based on dated sediments were performed by a single research team led by the palynologist John Flenley. All the work developed during this phase was based on the analysis of pollen and other proxies from cores obtained between 1977 and 1983 in Rano Aroi, Rano Kao, and Rano Raraku and was published between 1979 and 1992 (Flenley 1979; Dransfield et al. 1984; Flenley and King 1984; Flenley et al. 1991; Bahn and Flenley 1992). The synthesis of all these works constituted the first general paleoenvironmental and

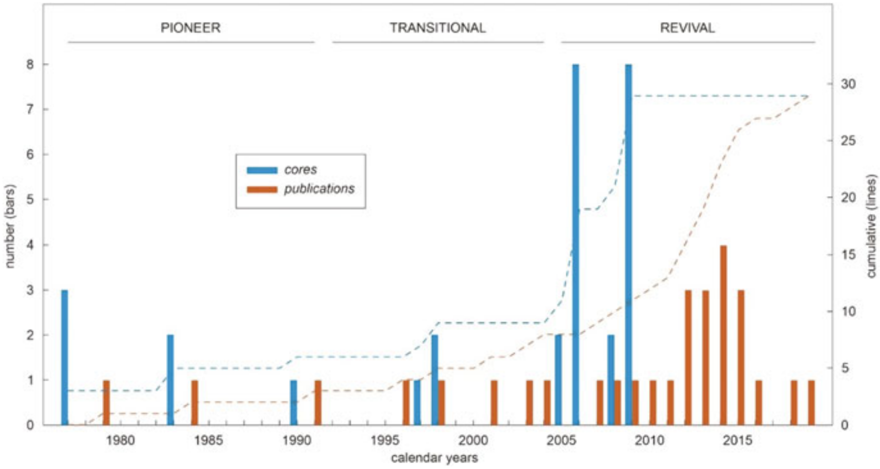

Fig. 12.2 Number of cores retrieved on Easter Island for paleoecological study and publications derived from these cores during the last four decades (1977–2019). Only publications with original data (Table 3.1) for the cores are considered, and reviews are excluded. Bars represent the actual number of cores and papers (left scale), and dotted lines are the cumulative trends (right scale)

paleoecological reconstruction for Easter Island, which was summarized by Flenley et al. (1991) in a graphical synthesis (Fig. 12.3). The same authors synthesized their findings into five main conclusions (Flenley et al. 1991):

1. Easter Island was formerly forested, and the main trees included an unknown palm, *Sophora toromiro*, and *Triumfetta semitriloba*.
2. The uppermost altitudinal limit of this forest probably consisted of a shrub belt dominated by *Coprosma* and an unknown Compositae-Tubuliflorae species. This upper boundary was located near the elevation of Rano Aroi (430 m) but oscillated in response to climatic changes.
3. The climate of Easter Island fluctuated between 38,000 and 26,000 ^{14}C yr BP. Between 26,000 and 12,000 ^{14}C yr BP, the climate was probably cooler and drier than in the present. The magnitude of this cooling would have been 2 °C or less compared to present average temperatures. A precipitation (or moisture balance) increase occurred beginning at 10,000 ^{14}C yr BP. The uppermost forest limit increased in elevation at this time, which suggested a coeval rise in temperature.
4. Anthropogenic forest clearance took place between 1200 and 800 ^{14}C yr BP (ca. 900 and 1260 CE), and the total demise of the forest occurred at 500 ^{14}C yr BP (ca. 1450 CE), which is compatible with the hypothesis that the decline of the megalithic culture was associated with deforestation.
5. The hypothesis that Easter Island is poor in woody species due to its isolation is not supported by these results, which are more compatible with the view that human activities were responsible for the present-day floristic depauperation.

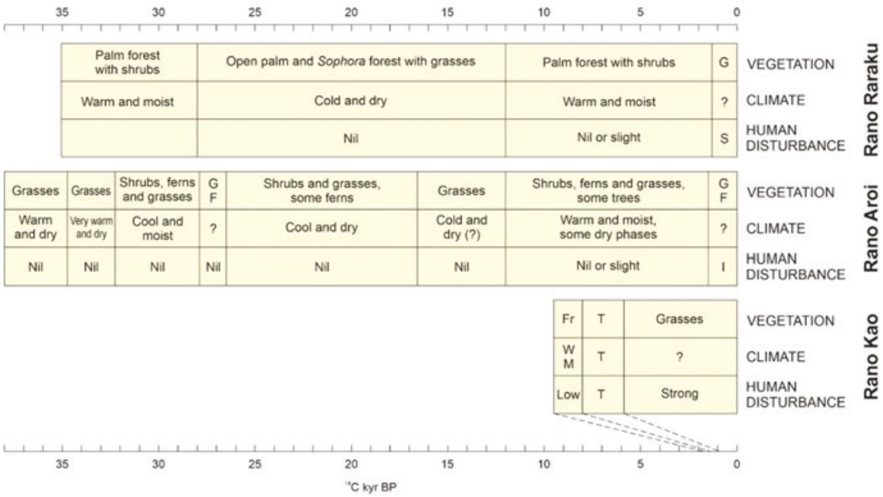

Fig. 12.3 Summary of the general conclusions of Flenley et al. (1991) regarding vegetation, climate, and human disturbance at the three coring sites studied. *G* Grasses, *F* Ferns, *Fr* Forest, *I* Increasing, *M* Moist, *S* Slight, *T* Transition, *W* Warm. Redrawn and modified from Flenley et al. (1991)

The pioneering paleoecological work developed by Flenley and his coworkers on Easter Island seemed to strongly support the ecocide hypothesis explicitly proposed some decades before by Mulloy (1974). Regarding a potential role for climatic change in this ecological and cultural demise on the island, Bahn and Flenley (1992) considered it implausible that forests that had survived major climatic fluctuations such as the last ice age and postglacial warming perished because of the occurrence of a drought just after island colonization by humans. For these authors, such a coincidence was difficult to believe. A year later, Bahn and Flenley (1992) published the first sociecological synthesis for the island, based on the chronology of the Rano Kao palynological record and the archaeological, ethnographical, anthropological, and historical evidence available at that time. These authors suggested that in addition to its religious motivations, the *moai* sculpture industry was a strongly competitive activity among clans aimed at producing the largest and most spectacular monuments. The *moai* workers were dedicated exclusively to this task and should have been maintained by other sectors of society dedicated to food production. As *moai* activity increased, food producers had to support ever-increasing numbers of nonfood producers, which led to deforestation and vegetation depletion by burning and cutting, leaching and soil erosion, increasing evaporation, and, ultimately, decreasing crop yields. This would have also caused the drying up of springs and streams. At the same time, the disappearance of large timber for canoe building eventually led to the abandonment of deep-sea fishing and prevented the islanders from navigating to other islands.

In agreement with Mulloy (1974), these authors considered the communal compulsion of the ancient Rapanui to produce giant statues and platforms “insane,” to the point that basic subsistence activities such as farming and fishing were neglected. Bahn and Flenley (1992) considered Easter Island to be a microcosm model for the whole planet, as both are isolated systems and have limited resources. Therefore, Easter Island may be viewed as a real experiment regarding the consequences of the overexploitation of natural resources, from which we can extract important lessons for the future of the Earth. However, Bahn and Flenley (1992) identified some obstacles to achieving this goal. One is the selfishness inherent to human nature, which prioritizes our own short-term goals rather than general social interests, and the other is the current attachment to unlimited growth, which ignores the preservation of natural resources for future generations.

4.2 The Transitional Phase

After the consolidation of the collapse theory by pioneering studies, paleoecological research on Easter Island experienced a hiatus of approximately a decade, which is referred to as the transitional phase here. This phase was characterized by sporadic, nonsystematic coring and the publication of only a few papers, which did not introduce significant modifications to the collapse paradigm. During this phase, paleoecological chronology research took a step backward, as most coring campaigns produced chronologically inconsistent sequences with frequent sedimentary gaps and age inversions, which prevented the development of reliable age-depth models. This was the case for Rano Kao (Flenley 1998), Rano Aroi (Peteet et al. 2003), and Rano Raraku (Dumont et al. 1998).

The occurrence of age inversions within radiocarbon dating depth sequences was attributed to the contamination of younger sediments with older carbon from different sources. After a detailed analysis of radiocarbon dates in a newly obtained sedimentary sequence from Rano Kao, Butler et al. (2004) concluded that it was not possible to draw conclusions about the ecological history of the island due to significant chronological inconsistencies. These authors recommended the development of additional coring activities and new chronologies after the careful selection of the materials to be dated. A new core with similar dating problems was obtained in Rano Raraku by Dumont et al. (1998). After the analysis of planktonic organisms from the most recent sediments, these authors suggested that Amerindians from the Inca Empire would have arrived on Easter Island by 1300–1450 CE and may have contributed to cultural collapse by halting the tradition of *moai* carving.

The most informative paleoecological reconstruction carried out during the transitional phase was performed by Mann et al. (2003), combining island-wide edaphic studies and a new sedimentary sequence from Rano Raraku. An island-wide analysis of buried primeval soils—i.e., those that supported former forests—revealed that general deforestation likely occurred between 1200 and 1650 CE,

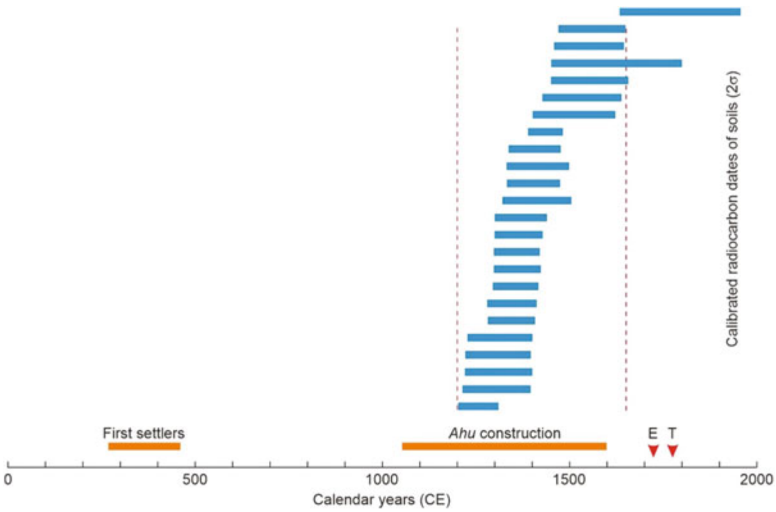

Fig. 12.4 Calibrated radiocarbon ages of charcoal from soils overlying the primeval forest soils (blue bars) and the main prehistorical events (orange bars and red arrows). E European contact, T *moai* toppling. Redrawn and simplified from Mann et al. (2003)

coinciding with the phase of megalithic statue construction (Fig. 12.4). This was supported by the study of a new core obtained in Rano Raraku, where evidence for major forest burning and soil erosion was recorded from 1070 to 1280 CE. Mann et al. (2003) noted that this occurred long after the initial human settlement of the island and suggested that the island might have been occupied, perhaps transiently, by Polynesian hunter-gatherers thriving on its rocky shores. Permanent settlement, dryland farming, and population growth might have been initiated by 1200 CE, leading to the ecological transformation of the island.

Orliac (2000) and Orliac and Orliac (1998) analyzed charred pieces of wood from some archaeological sites and identified a number of woody taxa from the fourteenth to seventeenth centuries. A number of these taxa are no longer present on the island, and it was speculated that they might have been components of the ancient forests, or trees/shrubs cultivated temporarily by the prehistoric Rapanui, or driftwood used for fire. Cummings (1998) performed the first phytolith and starch analyses on Easter Island and realized that the preservation of these proxies at archaeological sites was good enough to provide information on deforestation and Rapanui cultivation practices.

4.3 The Revival Phase

The revival phase can be subdivided into two well-differentiated parts. The first part extended between 2005 and 2010 and was characterized by a significant increase in coring activities and the reanalysis of previously obtained cores. The second part (2012–present) was marked by the publication of the analyses performed on the cores obtained between 2005 and 2009.

4.3.1 Coring Intensification and Reanalysis

During the first part of the revival phase, a total of 20 cores were retrieved, almost half (9) of which were from Rano Raraku, while seven were from Rano Kao, and four were obtained in Rano Aroi (Table 12.1). Some preliminary results from these cores (Azizi and Flenley 2008; Gossen 2007; Sáez et al. 2009) along with some reanalyses of older cores (Mann et al. 2008; Butler and Flenley 2010) were published during the same time interval. All of these papers were related to Rano Raraku and Rano Kao (Fig. 12.1). Using the Rano Raraku core of Mann et al. (2003), the same authors identified a sedimentary gap of more than 3000 years—4090–4410 cal yr BP to 660–770 cal yr BP (1180–1290 CE)—that was attributed to a climatic drought or a series of droughts, causing lake to dry up (Mann et al. 2008). This drought was attributed to a latitudinal shift in the subtropical storm track, which controls the intensity and frequency of cyclonic storms on Easter Island. This was the first local, independent evidence of prehistoric climate change on Easter Island. Pollen analysis of the same core documented abrupt forest clearing by 1200 CE, in accord with previous edaphic studies by the same authors (Mann et al. 2003) (Fig. 12.4). The deforestation of the Raraku catchment was not linked to the drought mentioned above, as the decline of palms and a coeval charcoal increase, interpreted as evidence of anthropogenic forest burning, occurred after the sedimentary gap.

The occurrence of an extensive depositional gap across Rano Raraku sediments was confirmed by a further systematic study based on a N-S transect of new cores retrieved in 2006 (Table 12.1), combined with those from older studies (Sáez et al. 2009). This hiatus extended between approximately 5888–4200 cal yr BP and 550–850 cal yr BP (1100–1450 CE) and was related to the mid-Holocene aridity crisis documented elsewhere in the circum-Pacific area. According to Sáez et al. (2009), this extended drought would have been caused by an insolation minimum, leading to the weakening of the summer monsoon, or in agreement with Mann et al. (2008), the southern shift of storm tracks forced by El Niño-like dominant conditions in the South Pacific.

In 2005, the first core with a chronologically coherent age-depth model, obtained using *Scirpus californicus* (totora) seeds as dating material, was retrieved in Rano Kao (Gossen 2007, 2011). Preliminary sedimentological analyses of this core suggested a sudden increase in soil erosion, possibly linked to deforestation, by 650–720 CE. Further pollen analyses were carried out to confirm this fact, but to the knowledge of the author, this work remains unpublished. Butler and Flenley (2010) resumed the analysis of their problematic Rano Kao core using totora seeds as dating material and obtained a more consistent age-depth model. Pollen analysis revealed the occurrence of two main deforestation events associated with conspicuous charcoal increases. The first event (50–100 CE) occurred long before the hitherto accepted Polynesian settlement of the island, and the origin of the fires involved was considered to be problematic. The second event (1350–1800 CE) was chronologically consistent with human deforestation by fire. For Butler and Flenley (2010), the most interesting feature of this core was the possibility that human disturbance began approximately 100 CE and continued thereafter, possibly varying in intensity but never ceasing. However, according to these authors, this interpretation would contradict most archaeological reconstructions, and more research was needed for a sound assessment.

Soil investigations have also provided relevant information on Easter Island's prehistory during the first part of the revival phase. Using the density and distribution of palm root casts in primeval soils across the island, Mieth and Bork (2010) estimated that approximately 16 million palm trees had once grown on the island, covering approximately 70% of its surface. The same authors later extended their estimate to 20 million palms, covering 80% of the island (Mieth and Bork 2015, 2017). The radiocarbon dating of soil charcoal at different points on the island yielded dates of 1200 CE and 1500 CE for the beginning and the end, respectively, of intensive slash and burn practices across the island. The lack of evidence for extensive and intensive palm fruit eating by rats led these authors to conclude that the island-wide forest clearing was exclusively human-caused. As in the case of Butler and Flenley (2010), robust evidence of forest regeneration (i.e., the occurrence of two generations of root casts) after fire was found in soil profiles (Mieth and Bork 2010).

4.3.2 Publication Resurgence

During the second part of the revival phase, the renewed coring efforts of the 2005–2009 period began to bear fruit in the form of papers reconstructing the main paleoecological trends of the last millennia, mainly through pollen analysis but also based on a variety of physicochemical proxies that provided independent evidence for climatic and environmental change. This phase has been subdivided into two main categories according to the aims of the corresponding paleoecological studies. The first category encompasses studies based on biological analyses (pollen, phytoliths, starch, diatoms, arthropods) of cores from the three craters and an island-wide soil survey focused mainly on the reconstruction of prehistoric cropping activity. The second category includes multiproxy (physical, chemical, and biological) studies on continuous, mostly gap-free, cores from the same waterbodies, aimed at reconstructing the spatiotemporal deforestation patterns and their potential climatic and/or anthropogenic drivers.

Horrocks et al. (2012b) studied several cores retrieved along the SW margin of Rano Kao, just below the ceremonial village of Orongo (Fig. 12.1), the center of the Birdman Cult. The obtained results suggested terracing for gardening and dwelling within the crater. The radiocarbon dating of the four cores retrieved (albeit using totora fruit/seeds) again showed frequent age inversions, which prevented the development of a reliable chronology. The obtained results were consistent

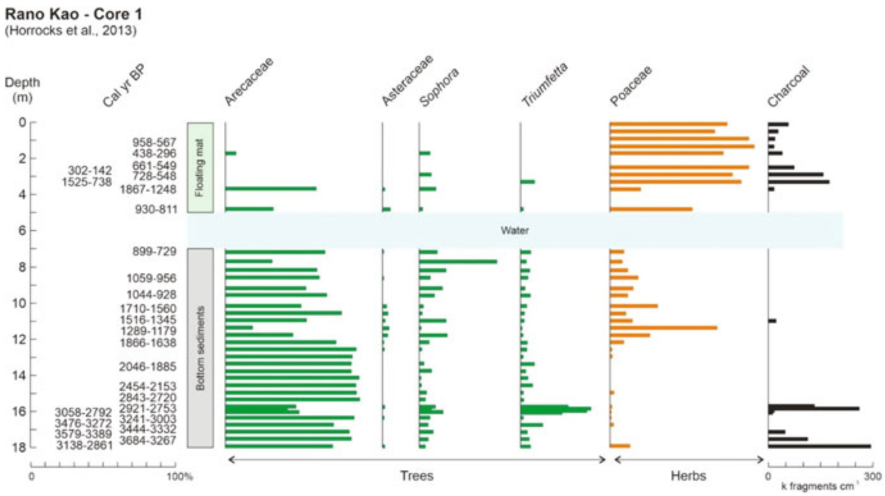

Fig. 12.5 Pollen percentage diagram for the Late Holocene from Rano Kao core 1 (Fig. 12.1, Table 12.1). Only dates obtained from totora seeds/fruits are indicated. Redrawn and simplified from Horrocks et al. (2013)

with a mixed-crop production system including common Polynesian cultigens such as paper mulberry (*Broussonetia papyrifera*), taro (*Colocasia esculenta*), yam (*Dioscorea alata*), sweet potato (*Ipomoea batatas*), bottle gourd (*Lagenaria siceraria*), and banana (*Musa* sp.). This study demonstrated that the SW margin of Lake Kao was an actively cultivated area during and after its deforestation, likely favored by the continuous availability of water and protection from the dominant winds. One of the obtained cores showed a chronologically consistent sequence between approximately 3500 and 1000 cal yr BP (1550 BCE and 950 CE). Microfossil analysis of this interval revealed the occurrence of three events of forest clearing by burning and cultivation (notably banana) between 1730 and 930 BCE, 1110 and 800 BCE, and 660 and 770 CE (Fig. 12.5). The authors considered the third of these events to be chronologically consistent with Polynesian settlement, but the other two events occurred long before that time, and the authors discussed the possibility of contamination by older carbon from different sources.

In Rano Raraku, Horrocks et al. (2012a) found evidence of forest clearing and the appearance of cultivated plants such as taro and sweet potato by 1320–1440 CE. These authors concluded that the Raraku catchment and its surroundings were used not only as a *moai* quarry but also as an extensive multicropping site and suggested that the crater was intensively gardened and terraced, possibly during the peak of the *moai*-quarrying period. Horrocks et al. (2015) also obtained cores from Rano Aroi, and although the age-depth model was poorly constrained between approximately 12,000 and 1000 cal yr BP (950 CE), the results for the last millennium were chronologically coherent and suitable for paleoecological study. Anthropogenic deforestation by burning occurred between approximately

1150–1300 CE and 1520–1770 CE, and the first signs of human occupation and agricultural activity (banana, paper mulberry) were recorded between 1670 and 1740 CE, which was later than in the lower sites (Kao, Raraku). The absence of sweet potato is noteworthy. Another relevant finding was the consistent presence of *Sisyrinchium*, an invasive American weed, since at least 410–630 CE.

The study of prehistoric agricultural activities using microfossils was completed with an extensive survey of dryland soils across the island, carried out by Horrocks et al. (2016). Only one of the soil profiles studied was dated, but the general stratigraphic similarity suggested to the authors that all of the profiles corresponded to times after Polynesian settlement. Microfossil analyses similar to those developed in lake cores allowed the identification of the same cultivated plants recorded in lake terraces, showing no cultivation specialization between lake shores and dryland soils. The most widespread species were paper mulberry, taro, and sweet potato.

The second category of paleoecological studies were focused on the multi-proxy analysis of continuous and chronologically coherent (i.e., free from large sedimentary gaps and age inversions) records of the last millennia, which were able to provide independent paleoclimatic and paleoecological reconstructions, thus avoiding circularity. Three cores encompassing continuous records of this type were obtained in Rano Raraku, Rano Aroi, and Rano Kao (Fig. 12.6).

In the Rano Raraku core, two smaller sedimentary gaps were detected, between approximately 500 CE and 1165 CE and between 1570 CE and 1720 CE, which were interpreted as a consequence of climatic droughts that resulted in the total drying out of the lake (Cañellas-Boltà et al. 2013). The first drought ended during the Medieval Climate Anomaly (MCA), and the second occurred during the Little Ice Age (LIA). The pollen record showed that deforestation did not occur in an abrupt manner but during three main pulses, with no signs of forest regeneration between them (Fig. 12.7). The first deforestation pulse (450 BCE) coincided with the first appearance of the Neotropical weed *Verbena litoralis* and the first increase in charcoal, which suggested an early Amerindian presence (likely

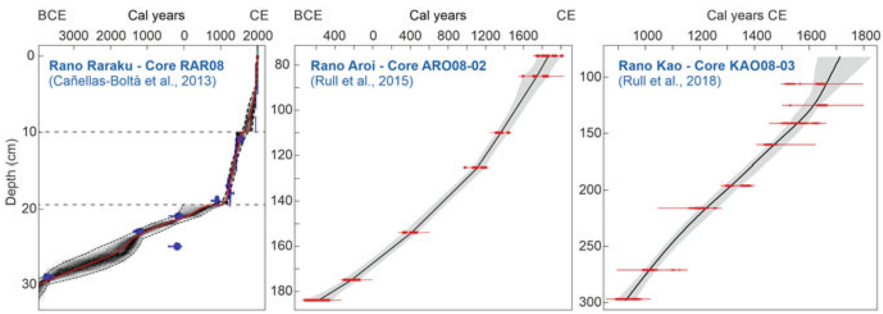

Fig. 12.6 Age-depth models of the continuous and chronologically coherent sedimentary records of the last millennia recovered in Rano Raraku, Rano Aroi, and Rano Kao. The dotted lines in the Raraku model at approximately 10 cm and 20 cm indicate minor sedimentary gaps (see text for explanation). Redrawn and modified from Rull (2020b)

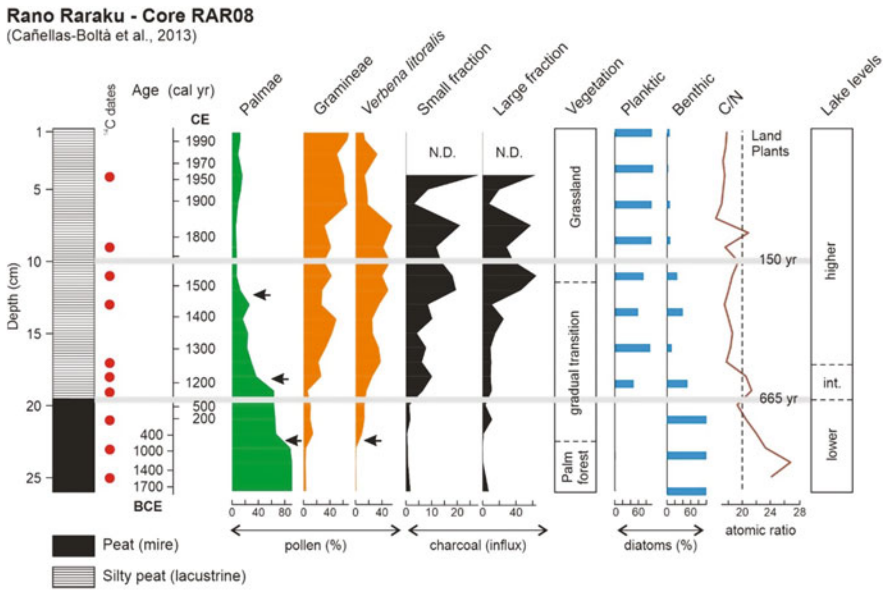

Fig. 12.7 Summary diagram of the last 3700 years as represented in core RAR08 from Rano Raraku (Fig. 12.1, Table 12.1). Sedimentary gaps are represented as gray bands, indicating the years lacking in each case. Black arrows indicate remarkable events discussed in the text. *N.D.* no data. Redrawn and modified from Cañellas-Boltà et al. (2013)

in small populations) on the island approximately one millennium and a half before Polynesian settlement (Cañellas-Boltà et al. 2013). This deforestation event occurred when the catchment was occupied by a mire, as indicated by lithology and diatom assemblages, suggesting the existence of climates that were dry but not as arid as during the MCA and LIA droughts. The second deforestation pulse (1200 CE) was the most intense and was coeval with an outstanding expansion of grass meadows and verbena populations, and an abrupt exacerbation of fires. These changes coincided with increasing lake levels, as recorded by diatoms, suggesting wetter climates after the MCA drought (Fig. 12.7). The acceleration of fire and forest clearing in such wetter climates suggested that humans were been the main driver responsible for these landscape changes. The third forest-clearing event (1475 CE) corresponded to the total deforestation of the Raraku catchment and the irreversible establishment of grass meadows, which was also associated with a significant increase in charcoal. Among the three forest declines, only the second could possibly be linked to climate change, as it occurred immediately after the MCA drought, which could have increased forest flammability, thus acting synergistically with anthropogenic burning (Cañellas-Boltà et al. 2013). After the LIA drought, the diatom assemblages suggested maximum lake levels and, hence, the wettest climates of the last 3700 years.

The Rano Aroi core recorded a long period of constant vegetation, consisting of open palm woodlands within a landscape dominated by grass meadows, between 750 BCE and 1250 CE (Rull et al. 2015). However, some minor variations in palm and grass density between 300 BCE and 50 CE and between 600 CE and 1100 CE coincided with significant reversals in geochemical records (C and N isotopes), indicating the occurrence of drier (but not arid) climates. The second dry phase coincided with the MCA drought reported at Rano Raraku (Cañellas-Boltà et al. 2013). After 1250 CE, a progressive densification of palm woodland to more closed forests took place, coinciding with the appearance of aquatic vegetation, indicating an increase in the water table that was likely due to a wetter climate, which would have favored forest growth. These dense forests were abruptly removed within a century (1520 CE to 1620 CE), coinciding with the first appearance of charcoal, which suggested anthropogenic burning (Rull et al. 2015). The geochemical proxies were consistent with a third dry phase similar to the first two between 1520 CE and 1700 CE, coinciding with the LIA drought documented at Rano Raraku (Cañellas-Boltà et al. 2013).

The Rano Kao record began at approximately 1000 CE, when the catchment was covered by open palm woodlands, which suggested that forests were already being disturbed (Seco et al. 2019). The further deforestation of Rano Kao was gradual but spiked with three pulses of acceleration at approximately 1070 CE, 1410 CE, and 1600 CE, followed by further regeneration trends except after the third pulse, which was irreversible. The first pulse occurred during the MCA drought, which suggested a potential influence of climate. The second pulse (1410 CE) coincided with a small charcoal peak and the first continuous appearance of coprophilous fungi, notably *Sporormiella*, suggesting the onset of continuous anthropogenic disturbance. Palms almost disappeared but slightly recovered until the third declining pulse (1600 CE), when charcoal and *Sporormiella* dramatically increased, roughly coinciding with the first phases of the LIA drought, which could have contributed to fire exacerbation. Seco et al. (2019) suggested that humans were present in the Rano Kao catchment from the beginning of the record but in dispersed or occasional populations. Human presence became more or less permanent by 1410 CE but remained sparse. The catchment was fully deforested and disturbed by larger human populations by 1600 CE. At the same time, the pollen of Apiaceae (likely *Apium*) species increased abruptly and remained constant until at least 1700 CE, which suggested the cultivation of these plants around the lake.

5 Contributions of Paleoecology to the Reconstruction of Easter Island's Prehistory

This section summarizes the usefulness of the paleoecological knowledge described above for a more holistic understanding of Easter Island's prehistory. The discussion is focused on the following aspects: (i) the possibility of the early discovery and/or settlement of the island before Polynesian colonization; (ii) the climatic changes that occurred during the last millennium that could have affected the island's ecology and society; (iii) the spatiotemporal deforestation patterns and their possible natural and anthropogenic drivers; and (iv) the possible influence of climatic droughts on prehistoric cultural aspects, with an emphasis on the shift from the ancestor worship to the Birdman Cult.

5.1 Discovery and Settlement

The first well-dated evidence of deforestation and meadow expansion associated with a fire event, which was suggestive of human disturbance, was found in Rano Kao sediments between 50 CE and 100 CE (Butler and Flenley 2010). The authors noted that this would be contrary to most archaeological reconstructions and discussed other possibilities for the origin of fire, such as spontaneous combustion, a combination of lightning and dry climates, and volcanic eruptions. However, Butler and Flenley (2010) noted that charcoal concentrations never returned to background levels after the 50–100 CE exacerbation, suggesting continuous rather than episodic disturbance. The conclusion was that this evidence should not be dismissed, but further studies would be needed for a sound interpretation in terms of human influence. This conclusion, however, has been maintained by the same authors several years after (Flenley and Butler 2018).

In Rano Kao, Horrocks et al. (2013) found a high concentration of charcoal fragments associated with banana phytoliths in sediments corresponding to 1730–910 BCE. According to these authors, this could be interpreted in terms of anthropogenic forest clearing by fire and associated agriculture, but the dates were confusing, as they were much older than the expected settlement of eastern Polynesia (Kirch 2010; Wilmshurst et al. 2011). Horrocks et al. (2013) did not dismiss the possible existence of dating problems due to contamination, but they maintained the robustness of their age-depth model.

In Rano Raraku, the coincidence of forest clearing with a charcoal increase and the first appearance of the Neotropical weed *Verbena litoralis* suggested that some Amerindian culture could have discovered Easter Island by 450 BCE (Cañellas-Boltà et al. 2013). The disturbance caused was minimal and was compatible with the presence of small scattered ephemeral or intermittent human populations, as previously suggested by Mann et al. (2003).

In Rano Aroi, Horrocks et al. (2015) reported the presence of *Sisyrinchium*, another American invader taxon, since at least 410–630 CE. These authors were very cautious and stated that "... we report this evidence and note that there is no clear reason to dismiss it, nor there is a clear case to accept it. Specifically, we are unaware of any Rapa Nui archaeological excavations or other evidence that provide conclusive support for prehistoric Amerindian presence." However, the case of *Sisyrinchium* is compatible with that of *Verbena* regarding the possible early Amerindian presence on Easter Island.

The absence of archaeological evidence for these early discoveries could be explained by the phenomenon of “evidence clearing” (Rull 2020a), according to which erosion, rising sea levels, and/or further colonizers may destroy or hide the meager terrestrial evidence left by scarce and scattered populations (Stevenson et al. 2000; Flenley and Bahn 2011). Paleoecological evidence contained in lake/swamp sediments, however, is less susceptible to clearing and can provide evidence that is absent in the archaeological record, as has been documented on other oceanic islands (e.g., Rull et al. 2017). The paleoecological findings summarized above could represent the first steps toward obtaining robust evidence of human presence on Easter Island before Polynesian settlement and cannot be neglected, as they are based on robust age-depth models and reliable taxonomic identification. However, the situation can be improved by the incorporation of direct evidence of human presence obtained using biomarkers such as DNA and specific fecal lipids, among others (e.g., Bull et al. 2002; D’Anjou et al. 2012; Hofreiter et al. 2012; Rawlence et al. 2014; Parducci et al. 2017). The field of biomarker analysis in lake sediments is currently in full swing, and it is hoped that future paleoecological studies on Easter Island can take advantage of this.

5.2 Climatic Changes

Paleoecological research on Easter Island has also provided local paleoclimatic information using biotic and abiotic proxies. To date, only changes in the moisture balance have been recorded, notably, the occurrence of two centennial-scale droughts separated by a phase of wet climates (Fig. 12.8). The MCA drought was recorded in Rano Raraku between 500 and 1170 CE, when the lake dried out and remained in that condition for more than six centuries (Cañellas-Boltà et al. 2013). The same event was recorded in Rano Aroi between 600 and 1100 CE (Rull et al. 2015), but in this case, the moisture reduction was less intense, likely due to the higher humidity of the highlands compared to the lowlands (Puleston et al. 2017). This MCA drought was coeval with the Classic Maya Collapse (ca. 900 CE) in Central America, which was attributed to a series of prolonged droughts that led to the ultimate demise of this civilization (Haug et al. 2003). An ensuing moisture increase was recorded between approximately 1100–1170 and 1520–1570 CE in both Rano Raraku and Rano Aroi (Cañellas-Boltà et al. 2013; Rull et al. 2015). The LIA drought occurred between 1570 and 1720 CE, when Lake Raraku dried out again (Fig. 12.8). In Rano Aroi, this drought was more difficult to detect due to the masking effects of human disturbance from 1520 CE onward. The LIA drought coincided with the so-called seventeenth century crisis in tropical Asia, characterized by droughts, famines, and large-scale economic and political disruption (Grove and Adamson 2018). Before the intense MCA and LIA droughts, the climates were drier than at present (but not arid) in both Raraku and Aroi (Cañellas-Boltà et al. 2013; Rull et al. 2015). After the LIA drought, Lake Raraku reached its present-day levels, which suggested the return of wetter climates. These

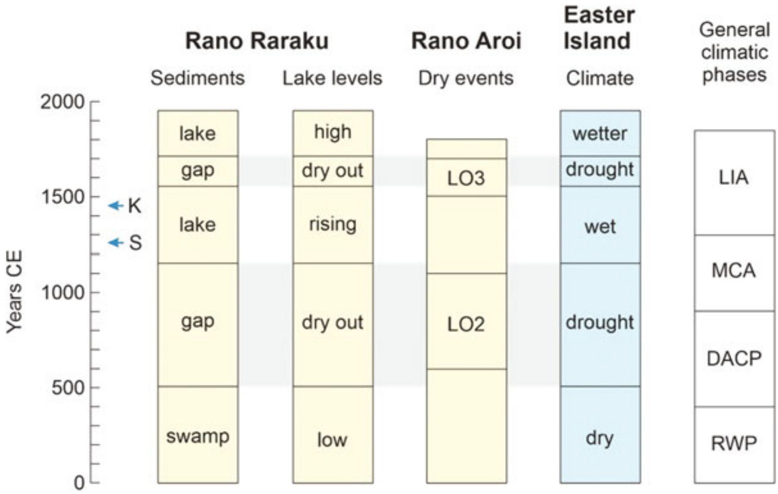

Fig. 12.8 Reconstructed climatic trends of the last two millennia at Rano Raraku and Rano Aroi. Raw data from Cañellas-Boltà et al. (2013) and Rull et al. (2015). Droughts are highlighted with a gray band. Blue arrows indicate regional volcanic eruptions that occurred during Easter Island's prehistory (K—Kuwae eruption, S—Samalas eruption) (Margalef et al. 2018). *DACP* Dark Ages Cold Period, *LIA* Little Ice Age, *MCA* Medieval Climate Anomaly, *RWP* Roman Warm Period

climatic trends have recently been supported by additional geochemical records from Rano Aroi (Roman et al. 2021).

The potential climatic mechanism causing the MCA and LIA droughts can be summarized as a southern shift of the humid subtropical storm track and the emplacement of the dry South Pacific Anticyclone over Easter Island, likely forced by ENSO fluctuations (Mann et al. 2008; Sáez et al. 2009). A potential role for volcanic eruptions occurring in the Pacific Islands has also been discussed, but it is still too soon for a definite answer (Margalef et al. 2018). The most remarkable eruptions of the last millennia corresponded to the Samalas (1257 CE) and Kuwae volcanoes (1453 CE)—located on Lombock Island, near Bali, and the Melanesian Vanuatu Archipelago, respectively—both of which occurred during the Easter Island humid phase between the MCA and LIA droughts (Fig. 12.8). There is still much work to do to achieve a sound understanding of the recent paleoclimatology of Easter Island, especially in terms of resolution and spatial patterns. At present, the Rano Kao core utilized above to reconstruct deforestation trends (Seco et al. 2019) is being studied for high-resolution paleoclimatic reconstruction using the isotopic composition of plant leaf waxes as a precipitation proxy. Other organic biomarkers are available (Eglington and Eglington 2008; Castañeda and Schouten 2011; Maloney et al. 2019; Sear et al. 2020) and should be tested on Easter Island for a more complete paleoclimatic reconstruction.

5.3 *Spatiotemporal Deforestation Patterns*

Paleoecological records have shown that the deforestation of Easter Island was heterogeneous in time and space, as forest clearing occurred at different times and different rates across the island (Fig. 12.9). The first deforestation event of the last millennium occurred in Rano Kao by 1050 CE, during the MCA drought, and was probably caused by synergistic climate-human effects (Seco et al. 2019). At that time, the Rano Raraku forests and the Rano Aroi open woodlands were still untouched. The next forest clearing event occurred in Rano Raraku at approximately 1200 CE, immediately after the MCA drought, under moderate but sustained fire pressure (Cañellas-Boltà et al. (2013). The occurrence of wetter climates that are more favorable for forest growth (Fig. 12.8) suggests that this deforestation pulse was of anthropogenic origin. Forest retreat was continuous although fires did not increase significantly, which suggests the existence of positive feedback amplifying

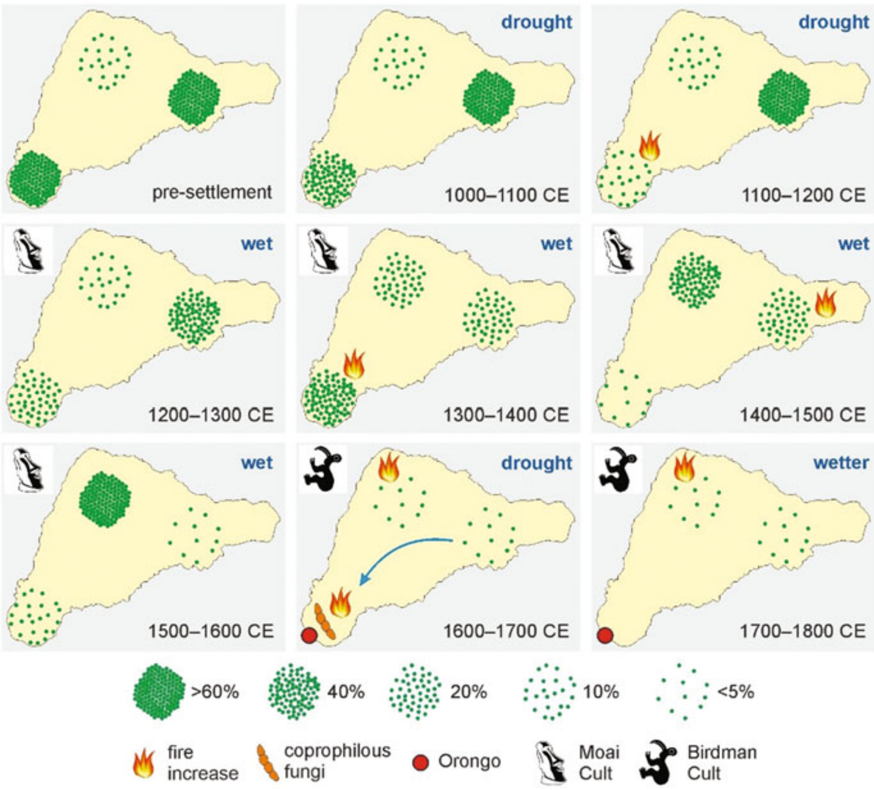

Fig. 12.9 Spatiotemporal deforestation patterns of the Rano Aroi, Rano Kao, and Rano Raraku areas and their potential drivers after Polynesian settlement. Forest cover was estimated from the palm pollen percentage. The blue arrow indicates the relocation of the cultural core of Rapanui society from Rano Raraku to Rano Kao. Redrawn and modified from Rull (2020a)

forest responses to a sustained fire incidence. At the same time, the Rano Kao forests were recovering, likely due to favorable climates and the absence of human pressure (Seco et al. 2019). This forest regeneration was interrupted by another deforestation event (1350 CE), likely anthropogenic in nature (Seco et al. 2019).

Rano Aroi continued to be devoid of humans, and the significant forest expansion recorded between approximately 1300 and 1500 CE was likely due to the occurrence of wetter climates (Rull et al. 2015). The Rano Raraku forests disappeared after a final deforestation event by 1450 CE, coinciding with significant fire exacerbation, supporting anthropogenic causes (Cañellas-Boltà et al. 2013). At the same time, human pressure declined in Rano Kao, and its forests experienced a new regeneration trend, although this was less intense than the previous regeneration (Seco et al. 2019). At the same time, Rano Aroi was truly forested for the first time, and its forests became the densest and most extensive on the island. This forest densification could likely have been due to wetter climates and the absence of human activities in Rano Aroi. However, the situation changed by 1570 CE, when a sudden deforestation event completely removed these forests (Rull et al. 2015). This coincided with intense fire exacerbation, suggesting anthropogenic causes; however, the LIA drought would have acted synergistically by favoring forest flammability and preventing regeneration. The last deforestation event on the island irreversibly removed the Rano Kao forests by 1600 CE, coinciding with the highest human occupation of this crater (Seco et al. 2019).

Taken globally, the intensification of deforestation between approximately 1200 CE and the total disappearance of forests by approximately 1600 CE coincide with the phase of increased forest clearing formerly proposed by Mann et al. (2003) and Mieth and Bork (2015), after a phase of low-intensity ecological impact. However, the detailed reconstruction described here, based on continuous sedimentary records from the three basins suitable for paleoecological study, significantly increases the spatiotemporal resolution and provides much more detail about the patterns, processes, and possible causes of the different forest removal and regeneration events. Further efforts should emphasize the study of proxies for human presence such as coprophilous fungi and specific molecular biomarkers of human presence. The use of paleoclimatic biomarkers and an increase in the temporal resolution are also recommended.

5.4 Cultural Responses to Climatic Droughts

During the MCA and LIA droughts, Rano Raraku was totally dry, and freshwater availability was critical for human life. Polynesians arrived on the island during the MCA drought, when Lake Raraku was devoid of water, but its surroundings were still forested (Fig. 12.9). At that time, the only permanent freshwater sources were Lake Kao and the Aroi swamp. Not surprisingly, the Rano Kao forests were the first to be disturbed (Seco et al. 2019). The LIA drought and the second drying out of Rano Raraku occurred when Rano Raraku was already deforested (Cañellas-Boltà et al. 2013). The situation was more critical than that during the MCA drought, as the Rapanui population was more numerous, and Rano Raraku—the site of the *moai* quarry and a central point for the Rapanui culture by that time—was likely transformed into a badland devoid of freshwater and forests (Rull 2020a, b). Again, the only permanent freshwater bodies were Lake Kao and the Aroi swamp, which began to be fully exploited and were totally deforested by 1600 CE (Rull et al. 2015; Seco et al. 2019). Human pressure significantly intensified in Rano Kao, as manifested by the dramatic increase in paleoecological indicators of human presence and agricultural activity along the lakeshores immediately below the ceremonial village of Orongo (Horrocks et al. 2012b, 2013; Seco et al. 2019). This possibly favored the emergence of the Birdman Cult and the shift of the Rapanui cultural center from Rano Raraku to Rano Kao (Fig. 12.9).

The causes of the shift from the ancestor worship to the Birdman Cult remain controversial, but some potential explanations may be suggested from the above observations. One is the search for freshwater (Rull 2020c). Another is that the Rano Kao rocks were not suitable for *moai* carving. Indeed, the Kao crater is composed of hard basalt and was one of the quarries from which the tools to carve the softer Raraku tuff were obtained (Gioncada et al. 2010). Only 13 of the ca. 1000 known *moai* are made of basalt (Van Tilburg 1994). Robinson and Stevenson (2017) suggested that the shift from the *Moai* Cult to the Birdman Cult corresponded to a territorial restructuring in response to soil nutrient depletion in interior lands, probably due to deforestation and a long period of dryness, which is in agreement with the above paleoecological observations. It has also been proposed that the shift to the Birdman Cult corresponded to a change from a rigid, hierarchical, and dynasty-based society, which flourished during the phase of relatively stable wet climates, to a more dynamic sociopolitical organization, which represented a strategy that was better adapted to changing environmental conditions (Rull 2016a).

An additional freshwater source for the prehistoric Rapanui has been proposed, involving coastal seeps fed by the groundwater system (Brosnan et al. 2018). To obtain water from these seeps, the ancient Rapanui used to excavate pits parallel to the shoreline, known as *puna*, which are still preserved at several sites near prehistoric habitation sites. All waters found in these coastal seeps today are brackish, which led Brosnan et al. (2018) to suggest that the Rapanui drank brackish water. As rain is the only freshwater source for recharging the groundwater system, its supply should have been drastically reduced during the LIA drought, which suggests that the salinity of coastal seeps could have been higher than it is today. Therefore, it is unlikely that coastal seeps would have been major freshwater sources for circumventing the LIA freshwater crisis, which lasted for a century and a half, representing approximately six human generations (Rull 2021c).

5.5 Toward an Integrated View

The prehistory of Easter Island is a complex subject that cannot be properly understood using simplifications that favor either one or another deterministic theory. Rather, natural and anthropogenic drivers of ecological and cultural change, along with their potential feedback and synergy, should be considered to obtain a more objective explanation of the available evidence. Ideally, such a synthesis should be conducted by interdisciplinary teams including open-minded researchers from a range of disciplines. Each of these disciplines provides part of the same puzzle, and we should learn how to assemble these parts together instead of claiming to know the absolute truth using only our own particular, always incomplete, set of pieces. Here, the available paleoclimatic and paleoecological findings from the last millennia are placed in a cultural chronological framework following the archaeological, ethnographic, and historical knowledge summarized in Sect. 2 to pave the way for a more integrated view (Fig. 12.10). This should be considered as an attempt to show the potential contribution of paleoecology to an integrated view of Easter Island's prehistory. The new information and the varied approaches

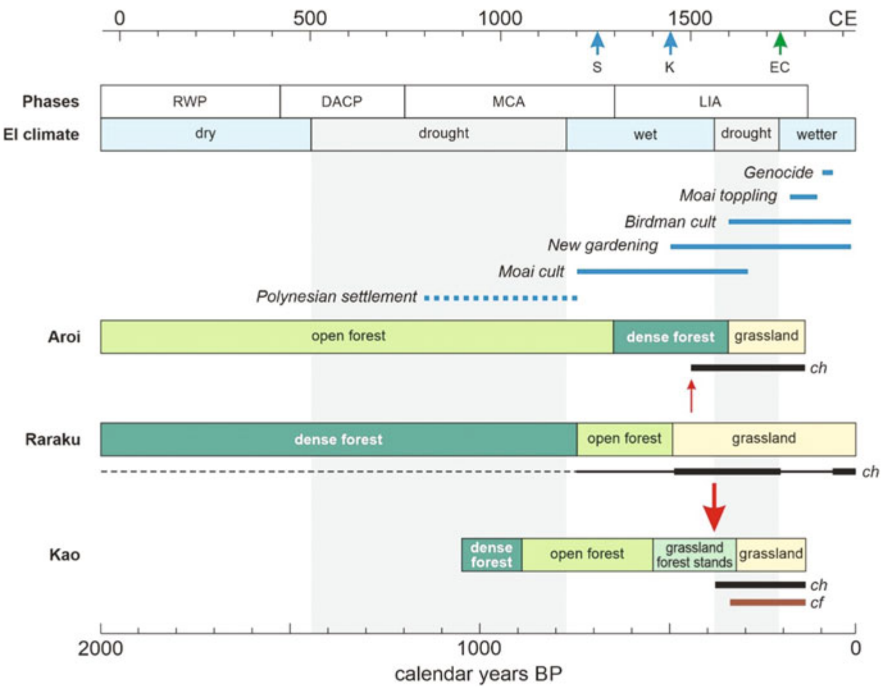

Fig. 12.10 Paleoclimatic and paleoecological scenarios of Easter Island during the last two millennia, indicating the main cultural features discussed in this paper. Drought phases are highlighted by gray bands. Blue lines represent the main cultural features, and the bars below indicate the vegetation shifts of each paleoecological site (Aroi, Raraku, Kao). Black bars represent charcoal (ch) occurrence, and the brown bar in Kao represents the presence of coprophilous fungi (cf), especially *Sporormiella*. Red arrows indicate possible geographical displacements of the Rapanui population. The green arrow indicates European contact (EC), and the blue arrows indicate the Samalas (S) and Kuwae (K) volcanic eruptions. *DACP* Dark Ages Cold Period, *LIA* Little Ice Age, *MCA* Medieval Climate Anomaly, *RWP* Roman Warm Period, *EI* Easter Island

and views arising from a wide range of disciplines compiled in this book will provide the basis for improving the preliminary synthesis presented here. The EHLFS (Environmental-Human-Landscape Feedbacks and Synergies) framework (Rull 2018), together with the multiple working hypotheses approach (Chamberlin 1965) and the strong inference method of hypothesis testing (Platt 1964), may provide a suitable methodological framework to accommodate multidisciplinary knowledge into a coherent holistic perspective. The first steps in the application of this methodology to the case of Easter Island have already been made (Rull 2018, 2020a), but there is still much room for improvement. Another possibility for addressing the problem could be the human ecodynamics (HE) approach (Fitzhugh et al. 2019), but this topic will be discussed in more depth in the final chapter of the book dedicated specifically to the integration multidisciplinary evidence on Easter Island.

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