



Settlement and anthropization of the Azores Islands

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Handling Editor: Jack Williams

The landscape of the Azores Islands (Figure 1) is one of the most deeply transformed among oceanic islands, as most of their pre-anthropogenic forests have been replaced by other vegetation types introduced from elsewhere (Dias, 2007). This has been considered a large-scale unintentional ecological and biogeographical experiment on the assembly of island biotas and ecosystems (Rull, 2021). These transformations are known to have been caused by the Portuguese colonizers who occupied the archipelago in the mid-15th century (Dias, 2007), but whether they were the first settlers and the main anthropization agents is currently under debate. The discussion is focussed on two main points: the earliest human settlement and the first large-scale landscape transformation (anthropization) across the archipelago.

Raposeiro et al. (2021) contended that the Azorean archipelago was settled by the early Middle Ages (700–850CE), much earlier than the Portuguese occupation in the 15th century. According to these authors, the earlier colonizers would have been the Norse, and their discovery would have been facilitated by anomalous north-easterly winds and warmer temperatures. These conclusions were based on multiproxy analyses from lake sediments, which Raposeiro et al. (2021) interpreted as a widespread and irreversible transformation of terrestrial and aquatic ecosystems. Extensive deforestation by logging and fire for cereal cultivation, as recorded by pollen and charcoal analyses, and livestock grazing, as documented by the presence of spores from fungi living in the dung of herbivores and faecal lipids characteristic of these animals, would have been the main disturbances. These authors proposed that the Azores landscape was already deeply and extensively modified when the Portuguese colonized the archipelago.

Elias et al. (2022) disagreed with this view, arguing that the evidence provided by Raposeiro et al. (2021) is insufficient to deny the written historical records documenting a 'pristine' landscape with

dense native forests before the Portuguese arrival. The critique by Elias et al. (2022) was based on a number of methodological and interpretation points, including dating issues and alternative explanations for the occurrence of pollen from anthropogenic plants, faecal lipids and the natural (volcanic) or anthropogenic origin of fires, as recorded by sedimentary charcoal. These authors did not deny human presence before Portuguese contact, but they doubted that these earlier settlers deeply transformed the Azorean landscape in the way proposed by Raposeiro et al. (2021). Finally, Elias et al. (2022) considered the proposal of the Norse settlement an undemonstrated but 'intriguing possibility'. Raposeiro et al. (2022) replied to these comments and reaffirmed their former conclusions. However, these authors admitted that a number of questions remain open and need further work. They also seemed to relax their former conclusions about the settlement timing and the origin of early settlers. Indeed, they concluded that their multisite and multiproxy analyses '...strongly suggest that people had already occupied the Azores Archipelago and altered the "pristine" landscape before the official arrival of the Portuguese', with no mention to a potential Medieval settlement by Norse cultures.

In this paper, I briefly discuss these contrasting views based on my own palaeoecological experience in the archipelago, where I have collaborated with Raposeiro, Elias and their co-workers in the past (Rull, Connor, et al., 2017; Rull, Lara, et al., 2017) but have not participated in the recent papers discussed here. The raw material for this discussion is the evidence furnished by Raposeiro et al. (2021), as Elias et al. (2022) did not provide new data. First, it should be highlighted that the evidence provided by Raposeiro et al. (2021) covers, for the first time, the whole archipelago and uses a wide arrangement of proxies useful for integrative climatic, ecological and anthropogenic reconstructions. This should be able to provide a first approach

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FIGURE 1 Map of the Azores Islands indicating the sites with palaeoecological records discussed in the text (yellow dots). 1, Caldeirão; 2, Alagoinha; 3, Rasa; 4, Fundá; 5, Caveiro; 6, Peixinho; 7, Pico; 8, Ginjal; and 9, Azul. Coring localities after Connor et al. (2012, 2013); Rull, Lara, et al. (2017) and Raposeiro et al. (2021).

to a holistic view of the Azorean archipelago (Figure 1). This said, some aspects of the Raposeiro et al. (2021) reconstruction not raised by Elias et al. (2022) will be analysed here in more detail, with the only aim of contributing to identifying potential issues to be addressed by future studies, as suggested by Raposeiro et al. (2022).

Raposeiro et al. (2021) presented their results in a synthetic fashion and the detailed outputs of their analyses are unavailable, as they have not been published elsewhere or displayed in the supporting material. For example, in the case of landscape anthropization, a major point of the debate, pollen records are the critical evidence, but only summary diagrams are provided, which hinders detailed reconstructions of vegetation change and comparison with other similar records. Particularly significant is the lack of differentiation within forest categories, especially between native and introduced forests but also in other vegetation types. In one of the records (Lagõa Azul, São Miguel Island), this separation is possible (Figure 2) because the detailed pollen diagram was published some years ago (Rull, Lara, et al., 2017), but in others, this cannot be evaluated with the information provided. The same occurs in all other palaeoecological records, but detailed raw evidence remains unavailable for checking. Readers unaware of fundamental aspects such as these are unable to evaluate the reliability of interpretations, and this might be valid for other proxies. The solution is obvious: publish the detailed records for each proxy and their corresponding interpretations.

Another issue is the inaccuracy of some representations, including the cereal—*Cerealia*, not 'Cerealea', as repeatedly stated by Raposeiro et al. (2021)—pollen, one of the most important proxies for anthropogenic impact. Indeed, in the same Lagõa Azul record, rye (*Secale*) pollen is represented only in the 13th century in the form of scattered occurrences, but it truly occurred between the 13th and 19th centuries (Figure 2). Additionally, other cereal pollen, such as wheat (*Triticum*), are omitted by Raposeiro et al. (2021) but were actually present in a continuous and consistent fashion from the 13th century to the present. If correctly represented, cereal pollen trends would have strongly supported the interpretation of pre-Portuguese cultivation, which makes these omissions particularly significant. The lack of detailed diagrams in records from other localities prevents us from knowing whether these inconsistencies are more general, including other sites and proxies.

Of the five records utilized by Raposeiro et al. (2021), only two, from the Corvo and Pico islands, extend back to 600 CE, whereas one begins in 900–1000 CE (Corvo) and the other two, from São Miguel and Terceira, start in 1300–1400 CE (Figure 1). Therefore, whatever the evidence for human settlement, these records are insufficient to demonstrate that the whole archipelago was settled before 900 CE, as only two records from central and western islands are available before that date. Additionally, the only significant forest decline recorded before 900 CE corresponds to one of these records (Pico), whereas the other is too small to be interpreted in terms of forest

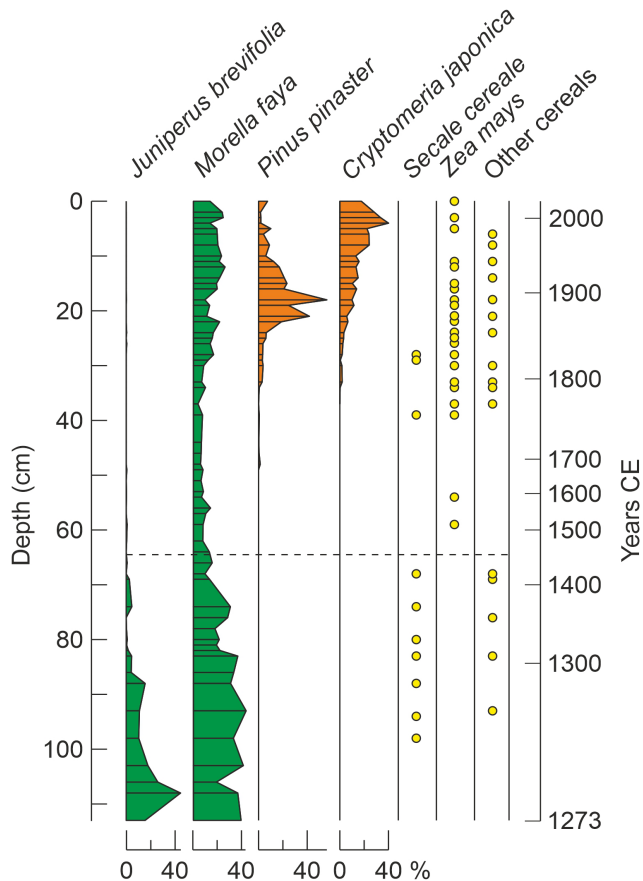


FIGURE 2 Selected elements of the pollen diagram from Lagõa Azul (São Miguel Island). The dominant taxa of native forests are in green, and the introduced tree taxa are in orange. Yellow dots are the occurrences of cereal pollen. The dashed line represents the official date of the Portuguese occupation. Simplified from Rull, Lara, et al. (2017).

clearing (Corvo). In summary, the evidence for general landscape anthropization before the arrival of the Portuguese is insufficient. The most significant deforestation events took place between 1200 and 1400 CE, as recorded in the other three sequences from Flores, Pico and São Miguel.

The only pre-900 CE deforestation documented in Pico coincided with the first consistent evidence for fire (charcoal and polycyclic aromatic carbon), along with a tephra layer and a local peak of faecal lipids attributed by Raposeiro et al. (2021) to the presence of livestock, as wild herbivores were absent prior to human settlement. Both coprophilous fungi, a grazing proxy, and coprostanol, a faecal lipid present in herbivores, humans and other omnivores, were absent until the 11th–12th centuries. Under these conditions, it is not possible to attribute the documented fires to either volcanic activity or human influence. Therefore, the only potential evidence of human impact before these dates remains debatable. Again, widespread evidence for human presence is more consistent across all islands analysed between 1200 and 1400 CE. Therefore, these dates emerge as the best candidates for

human impact in the archipelago, although the intensity of landscape modification was not comparable to that occurring after Portuguese occupation (Rull, Lara, et al., 2017).

Finally, the palaeoclimatic simulations utilized by Raposeiro et al. (2021) to infer the origin and the navigation routes of the purported early settlers between 700 CE and 850 CE do not correspond to this time period but to a later phase (850–900 CE), with no overlap with the period of interest. Therefore, inferences about Norse people coming from northern Europe as the early colonists are unwarranted (Rull, 2023). Even in the case that the palaeoclimatic reconstruction utilized coincided with the time interval of interest, this would not constitute a proof for the Norse arrival to the Azores at those times, but just a hypothesis to be demonstrated with future studies, where archaeological and anthropological evidence—which is absent in the Raposeiro et al. (2021) study—must be essential.

In summary, according to the data provided by Raposeiro et al. (2021), the first consistent evidence of widespread anthropogenic impact on the Azorean landscape seems to occur in the 13th–14th centuries, roughly a century before Portuguese contact, as formerly proposed by Rull, Lara, et al. (2017). This does not deny the ‘intriguing possibility’ (Elias et al., 2022) of more ancient settlements, but additional evidence is needed to support this proposal. This evidence should be sought in new records containing pre-1200 CE sediments, especially in the islands of Flores, Terceira and São Miguel (Figure 1). Pioneering palaeoecological works by Connor et al. (2012, 2013) documenting widespread anthropogenic impact only after the Portuguese arrival were fundamental for unravelling the ecological history of the Azores Islands, but new and consistent evidence on former human occupations is emerging that cannot be disregarded. The work by Raposeiro et al. (2021) is very useful in that, contrary to the opinion of Elias et al. (2022), it provides strong and widespread support for pre-Portuguese human colonization of the Azores archipelago and the ensuing landscape impact (Rull, 2023). However, whether this human occupation took place in early Medieval times by Norse people, facilitated by favourable climatic conditions, remains undemonstrated.

ACKNOWLEDGEMENTS

The author is grateful to Rui Elias and an anonymous reviewer for constructive and helpful comments. No funding was received specifically for the development of this paper. No new data have been used in this paper. No permits have been required for the development of this work.

CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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How to cite this article: Rull, V. (2023). Settlement and anthropization of the Azores Islands. *Journal of Biogeography*, 00, 1–4. <https://doi.org/10.1111/jbi.14712>