Elba Deforested? – New Perspectives on the Ancient Bloomery Smelting Landscape of Elba Island (Tuscany, Italy)

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Ancient Iron Mining and Smelting on Elba Island

Elba Island hosts one of the largest iron ore deposits in Roman *Italia*.[1] Early evidence – however indirect – dates the onset of mining on the island to the 6th century BCE, when hematite from Elba was smelted in the furnaces at Populonia and Follonica-Rondelli on the Tuscan mainland.[2] Nearly all evidence of ancient mining activities on Elba got lost in the open pits of the modern mining period (1853 to 1981).

During the first centuries of mining on Elba, the raw ore was transported to the mainland; smelting on the island started most likely in the 3rd century BCE, as indicated by ceramic finds from different smelting sites.[3]

While iron production in Populonia continued until the 1st century CE,[4] it is commonly assumed that all smelting sites were abandoned in the mid-1st century BCE as indicated by the chronology of ceramic material.[5] Additionally, textual sources are interpreted as a description of the decline of production on Elba: Diodorus of Sicily (1st half of the 1st century BCE) describes mining and smelting of iron on Elba Island:

"For the island possesses a great amount of iron-rock ... those who are engaged in the working of the ore crush the rock and burn the lumps which have thus been broken in certain ingenious furnaces; and in these they smelt the lumps by means of a great fire."[6]

In contrast, Strabo (Augustan era), notes that iron was mined on Elba, but the raw ore was transported directly to the continent to be processed there.[7] Although Strabo gives no reasons why the ore could not be smelted on Elba, his observation is commonly interpreted as a description of deforestation and a lack of fuel resources – the 'deforestation narrative'.

Aims

In the following, we will contribute to the discussion on the end of iron smelting on Elba from a landscape archaeological point of view.

We discuss:

- the development of the so called 'deforestation' hypothesis;[8]
- published palynological data, own sedimentological cumulative probability functions of calibrated ^{14}C-dates to reconstruct the (mid- to) late Holocene landscape development on Elba;

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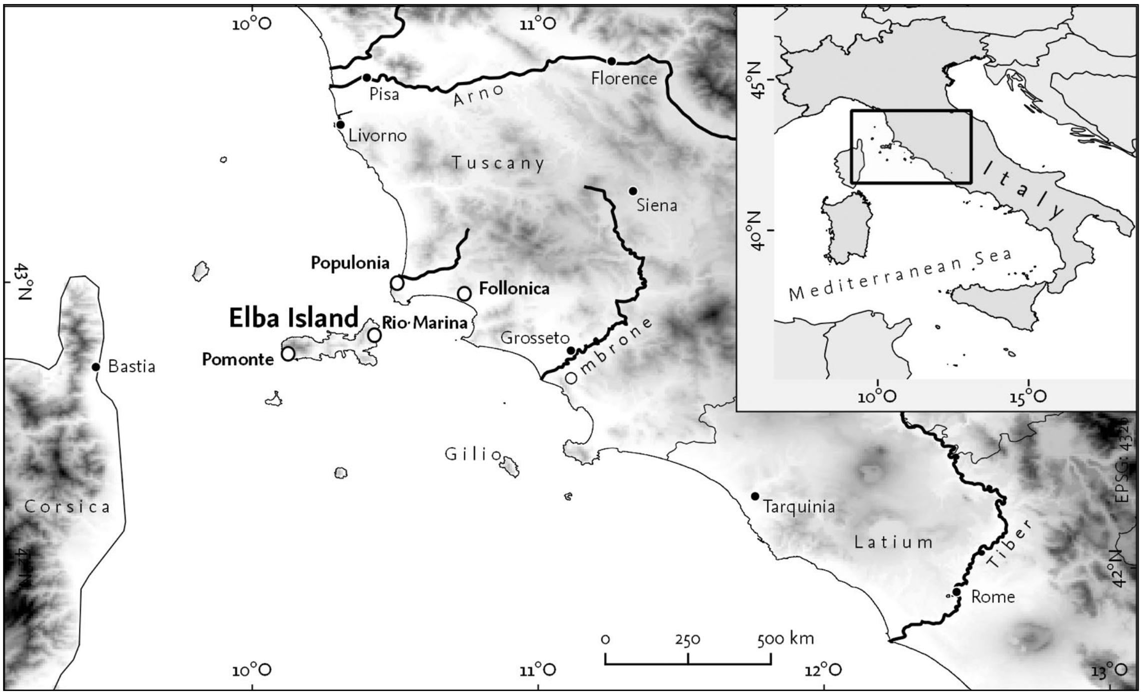

Fig. 1: Location of Elba in the Northern Tyrrhenian Sea.

- a model of the required and harvestable woodlot area on Elba; and
- the site pattern of ancient furnaces on Elba to evaluate if a 'forest management strategy' is visible.

In a synthesis we will integrate the evidence presented in a revisited chronological framework of ancient Elba and the wider economic development of the Roman iron industry between the 1st century BCE and 1st century CE.

Although the general discussion on ancient deforestation in the Mediterranean region is controversial and of wider interest, we do not give a comprehensive overview on the state of the art.[9] Further historic and more general views on iron and deforestation can be found in e.g. Lindsay;[10] Goucher;[11] and Iles.[12]

The 'Deforestation Narrative'

The 'deforestation narrative' dates at least to the 18th century. For example, in his travel narrative from 1775, R. Pococke refers to Strabo and states that "they [the Romans] could not melt the iron on the spot [Elba], but carried the ore immediately to the continent.", because there was not the "conveniency of wood for their foundry".[13] Also Täckholm cites Strabo: "We know from Strabo V 2.6 that ore was transported directly to the continent, without being melted. The reason is not indicated by Strabo, but might not have been any other than a lack of firewood."[14]

Fig. 2: View from the Volterraio castle over the Central Elban hills and plains and the Monte Capanne massif (August 2016).

Also, in recent literature on environmental and forest history, ancient Mediterranean deforestation, or ancient technology a lack of fuel on ancient Elba is discussed,[15] without citing evidence for deforestation.

The 'deforestation narrative' occurs contemporary to observations on fuelwood scarcity. E. Schweighardt mentions that in antiquity, iron was roasted on Elba, but further processed on the mainland. He records that "even now [in 1841], due to a lack of firewood, the ore is not processed on Elba, but on the mainland".[16] Landscape descriptions from the 18th and 19th century characterise Elba as an island with sparse tree cover; e.g., A. Thiébaut de Berneaud reports: "Wood for fuel is still more rare. The island affords nothing beyond a meager underwood […] In a word, forest-trees are wanted throughout the island. […] all the iron works in the island are destroyed; they have no wood […] they are obligate to transport the ore to Corsica, the coast of Genua, and the shores of Tuscany, in order to have it manufactured."[17]

Similar narratives were taken down by Swinburne in 1771 and Barker in 1815;[18] from Napoleon's short stay on Elba (1814), the anecdote is delivered that he send a vessel with raw ore to the U.S.A. because of a lack of fuel.[19] In a record from 1771, Giovannelli notes that although it is believed that the ancients degradated the island, it is the construction of agricultural terraces for wine production that eliminate most of forest on Elba.[20]

Landscape degradation on Elba is stated even today: "Most scholars believe that this shift [of iron production from Elba to Populonia] took place after the island had become totally deforested. Elba today is still heavily marked by erosion and barren hills."[21]

Common impression of the island is quite different (fig. 2, 3); Elba is marked as the "Grüne Insel Elba" (Die Zeit, 01.03.1968 and 26.02.2016) – the green island of Elba. Only

Fig. 3: View from the sea on the Ortano valley (September 2015).

some hills on northeastern Elba are today covered with grassland.[22] Since the 1960s – when tourism on Elba was in its early development and the local economy mainly relied on the primary sector – woodland cover increased and agriculture use in the plains and the adjacent slopes declined.

We therefore think that the 'deforestation' hypothesis is rooted in that kind of 'uniformitaristic' view on the ancient environment on Elba; an idea that is similar to Grove and Rackhams' ruined landscapes theory or Rackhams' pseudo-ecology.[23]

Palynological Evidence

A palynological study by Bertini et al. uses pollen records from coastal plains to reconstruct the vegetation history on Elba from ca. 6000 BP to present.[24] Their data indicate an alteration of wetter and dryer climatic phases on Elba and occasional changes from dominant wetland vegetation to terrestrial species. At least since 4000 BP deciduous oaks and *Ericacea* spec. dominate the pollen record. Bertini et al. link a drop of oak pollen and the synchronous increase in *Ericacea* pollen around 2150 BP to metallurgical activities on Elba. However, the data do not necessarily indicate a lack of fuel: First, *Ericacea* species (E. arborea) was used as main fuel for iron smelting on the continent;[25] also in sediment sequences from Elba, the (sparse) anthracological record is dominated by *Ericacea*-species, *Arbutus* spec.[26] Second, pollen were recovered from lagoonal sediments, which do not necessary represent the entire vegetation cover of the island; today the plains are often used for agriculture, whereas the distant slopes are often characterised by tree cover (fig. 3). Third, the alteration of oak and *Ericacea* is observed also for periods prior to the Iron Age.[27] Fourth, although the oak cover is reduced, the pollen record does not indicate large scale deforestation on Elba.

Sedimentological Evidence

Sedimentological data obtained from the Campo plain by Becker et al.[28] cover a period from ca. 8000 BP to the present. The most obvious environmental change recorded in the sediment archives occurred between 7000 BP and 6000 BP and is strongly linked to increased sedimentation and a change in the depositional environment during late transgressive and early high stand conditions (i.e., the transition from a rapidly rising sea level to more or less stable sea level). The change from a lagoonal/lacustrine environment to an alluvial plain and the deposition of relatively coarse gravel in the lower part of the plain dates to ca. 2300 BP. In addition, slope deposits (c 2200 BP) and high-magnitude flood layers (between 2200 BP and 1900 BP) point on accelerated morphodynamics during the period of Roman iron smelting. Additionally, charcoal deposition tends to increase in the late Holocene sediments from the Campo plain and is relatively high between ca. 2700 BP and 1400 BP. The taxonomic identification of 14 samples representing the interval between c 2200 BP and c 1900 BP reveals that the charcoal record is dominated by *Arbutus* spec., a typical *macchia* shrub used for fuel production on Elba.[29]

Meta-Analysis

Preliminary results of the meta-analysis of ^{14}C-ages obtained from sediment sequences from Elba Island[30] indicate phases of increase/decreased depositional activity on Elba: For a first analysis of the data, we used the ‘modelTest’ in the *rcarbon*-package[31] in R[32] to analyse the Cumulative Probability Function (CPF) of the available ^{14}C-dates. The approach follows the assumption that the probability density of calibrated radiocarbon dates in a time span is related to fluvial (depositional) activity. As the actual CPF might be biased by the shape of the calibration curve and by random coincidences of several ^{14}C-ages, we tested our CPF against a null model of randomly uniformly distributed samples over the study period; only phases where the CPF exceeds the 95%-envelope of the simulated CPF, we assume accelerated activity. The CPF for the late Holocene as depicted in fig. 4 clearly show several phases of depositional activity. During the Roman smelting period, the curves show a significantly accelerated activity, between ca. 2200 and 2000 BP. This phase is followed by a phase of significantly decreased activity around 1800 BP.[33]

Resource Model

We set up a resource model to estimate both wood consumption for smelting and the harvestable woodlot area. As most of the data necessary for the model are subject to

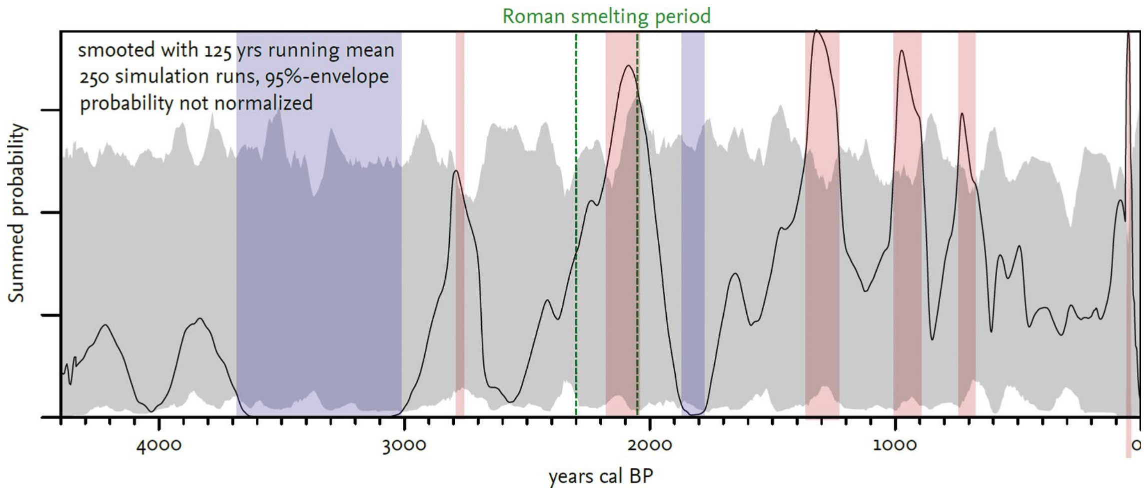

Fig. 4: Cumulative probability function of calibrated ^{14}C-ages from sediment sequences tested against a null model (95%-envelope, grey background); coloured bars indicate phases of significant high/low activity. Created using the *rcarbon* package in R.

uncertainties, we used a Monte-Carlo-simulation and propagated the uncertainty in the input parameter (i.e. a lack of detailed quantitative information on the conditions on ancient Elba and no specific information on the applied technologies, e.g. coppicing or clear-felling) to the model output by using randomly select values in the possible value range and repeated the calculation 1000 times; the result is therefore a probability function of consumption, production, and thus a possible scarcity of fuel wood. The model explicitly estimates potential deforestation by iron smelting; we are aware that also other economic activities and daily life have contributed to deforestation. The methodological approach is summarised as follows:[34] (i) We obtained information on the extend of iron production on Elba from the amount of ancient slag found on Elba; these data are available from statistics taken down by the re-smelting concessionaires in the first half of the 20th century,[35] reported extends of slag heaps, and published and own (field) data.[36] (ii) Based on the total amount of ancient slag form Elba we estimated the amount of charcoal to charge the furnace and the amount of wood to produce the charcoal using parameter obtained from experimental and ethnographic data. (iii) Using the present day vegetation cover and estimations of the ancient cover used in other calculations and forest yield tables as a baseline assumption, we were able to estimate wood availability and regrowth. (iv) As a time frame, we used a phase of intensive production in the 2nd century BCE, when most of the dating material was deposited on smelting sites.

We modeled a wood consumption ranging between 3,500 and 25,600 t a^{-1} in for the 2nd century BCE (at 95%-confidence); annual wood production on the island is estimated to be between 13,800–54,200 t a^{-1} (clear-felling) and 29,800–78,300 t a^{-1} (coppicing). The modeled total land area required to satisfy the wood consumption by smelting ranges

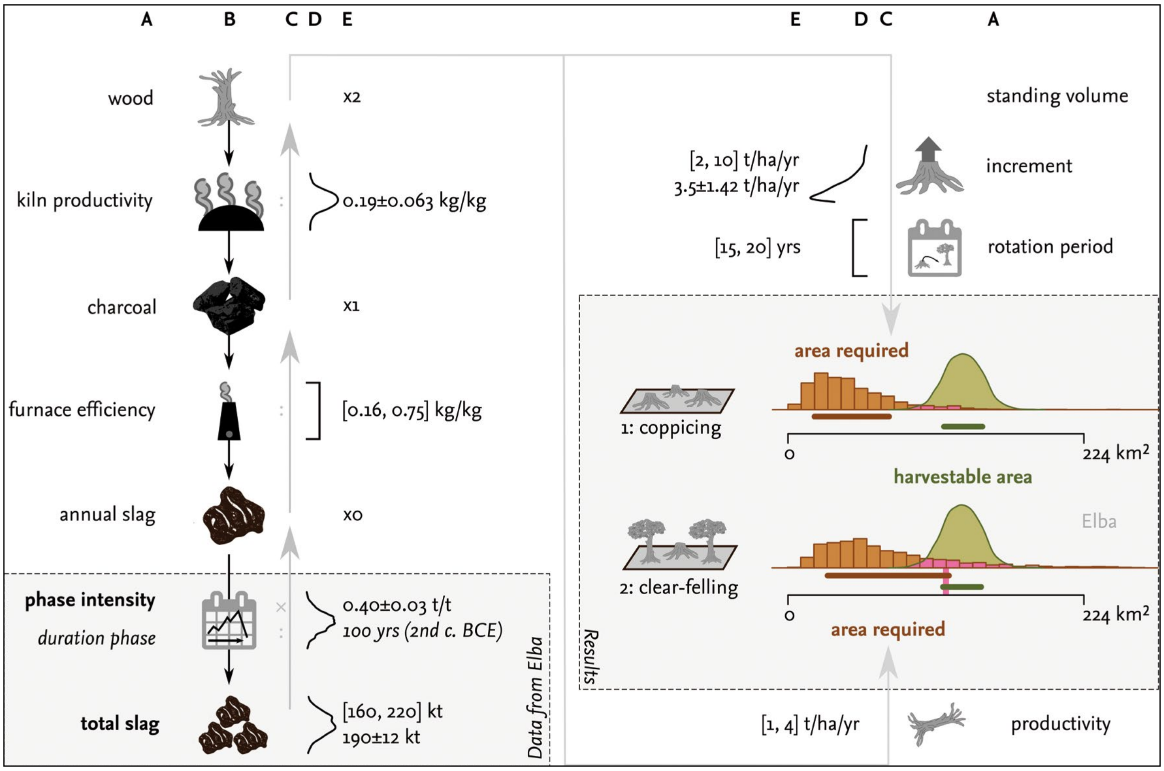

Fig. 5: Model of the required woodlot area (brown) on Elba for iron smelting in the 2nd c. BCE and the harbestable area (green). For details see Becker et al. submitted; columns: A = parameter, B = production steps, C = reconstruction steps, D = parameter probability, E = values ([range], median ± median absolute deviation).

between 7 and 89 km^2 (coppicing) or between 20 and 262 km^2 (clear-felling); the total harvestable area was potentially >138 km^2. Therefore, in 5.0% (coppicing) or 19.9% (clear-felling) of our simulation runs, the entire area of the island had to be under forestry to supply fuel for the furnaces, thus it is (very) unlikely that Elba had to be deforested to charge all the furnace.

Site Pattern

The ancient iron mines on Elba Island are characterised by (i) proximity to the coast, (ii) a disruption of the ancient structure by modern mining, (iii) (mainly) hematite deposits in shallow depth, and (iv) a location exclusively in eastern Elba. In contrast, the latter, ancient smelting sites are not only located in eastern Elba – in the vicinity of the mines – but spread over the entire Island. The most remote site at Pomonte is located in 42 km distance by sea to the Rio mines – the industrial quarter of Populonia is located about 13 km from the Rio mines. The furnaces are situated very close to the (ancient) shoreline, often at sandy pocket beaches which are suitable for landing – even today – and embayments that offer anchorages with some degree of protection. Especially in western Elba, a wider valley is located in the hinterland of the sites, where wood resources are easily accessible.[37] In the late 2nd – early 1st century BCE, most of the sites on Elba were active. We interpret the site pattern as a clear evidence for strategy to efficiently use the wood resources on the island.[38] The transport of ore to the location of charcoal is much more efficient than the transport of charcoal or even wood, as one can carry more amount of ore than charcoal at the same volume. The transport by land is hindered by (steep) hills and mountains (fig. 6).[39]

Synthesis and Conclusions

We used different approaches and data sets to discuss the hypothesis that Elba Island was deforested during the ancient period of iron smelting (4th/3rd century BCE to 1st century CE). The following points are our main conclusions:

- The 'deforestation' hypothesis cited in the relevant literature lacks a fundamental basis; the main evidence presented is an observation of Strabo, who only notes that iron is not smelted on Elba in the Augustan era – Strabo does not give any reasons for the observation. The hypothesis rather developed on the background of the 18th–20th century-landscape of Elba, which is marked by reduced forest cover and a scarcity of wood.[40]
- Palynological studies do not necessarily indicate a lack of fuel on Elba in the 1st century BCE. The percentage of e.g. oak pollen decreases during the ancient smelting period, but the percentage of other fuel wood species (*Ericacea*) increases.
- Sedimentological evidences obtained from the Campo plain in Central Elba shows that morphodynamics (potentially as a result of clearing and subsequent soil erosion) increased during the Roman Middle Republic to early Imperial period. Additionally, more charcoal was deposited in the sediments since then.
- Cumulative probability functions obtained from calibrated ^{14}C-dates support the interpretation of the detailed sedimentological analysis and shows several significant phases of deposition, one is related to the ancient smelting period in Elba Island; a phase of decreased deposition follows the Roman smelting period.
- Regardless of assumed silvicultural system and a possible phase of high production, our Monte-Carlo-based model of resource consumption and production clearly suggests that it is (very) unlikely that the demand of wood for iron smelting exceeded the regrowth of the woodland cover on Elba.
- The pattern of smelting sites on Elba Island is strongly related to the access of forest resources – an interpretation that Corretti describes with "the fullest exploitation of wood resources".[41] Smelting sites are located in considerable

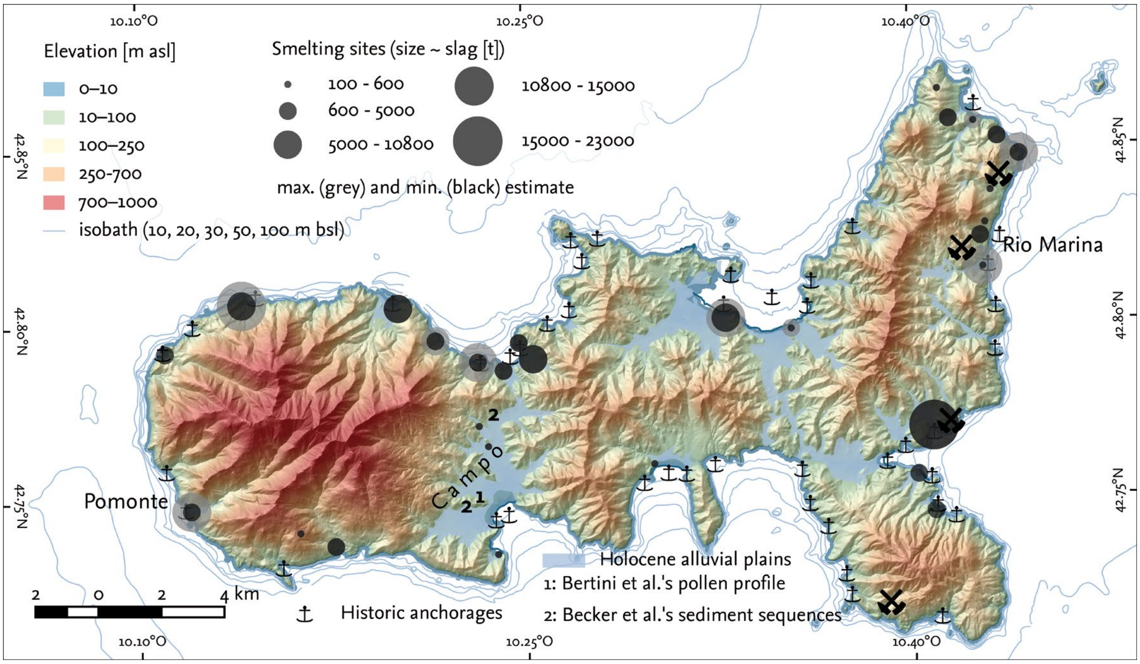

Fig. 6: Distribution of ancient smelting sites on Elba.

distance from mines in areas (where wood is available), in the direct vicinity of sandy beaches (where ships can easily land), and at the end of wider valleys (where forests are well accessible).

Other historical events might have triggered the decline of smelting activities on Elba:

- The proposed end of iron smelting on Elba in the mid–1st century BCE coincides with the Roman occupation of further iron mining districts in Europe, especially in as one can carry more amount of ore than charcoal at the same volume *Gallia*, *Hispania Tarraconensis*, and *Noricum*.[42]
- A possibly contemporary *senatus consultum* mentioned by Pliny HN, 3.138 and 33.78 might be interpreted as evidence for a strategy to conserve the ore resources in Italia.[43]

Additionally,

- a reinterpretation of published evidence on the chronology of iron smelting on Elba and newly obtained dating material (e.g. ceramic fragments and calibrated ^{14}C-dates) shows that smelting on Elba continued in the 1st century CE, most likely on a smaller scale than in the preceding centuries.
- The interpretation of the site pattern as a forest management strategy – together with the fact that smithing and refining of iron blooms took not place on Elba[44] – might indicate that resource management was an integral part of the production cycle of iron in the Elba–Populonia industrial area.

In conclusion, we assume that it is reasonable that Elba was not (completely) deforested in the 1st century BCE, but smelting activities had a significant impact on the environment.

Notes

[1] Tanelli et al. 2001.
[2] Cf. Corretti – Benvenuti 2001, 141 f.; Corretti 2017, 452.
[3] Corretti et al. 2014, 183 f.
[4] Chiarantini et al. 2018, 12.
[5] Corretti 1988, 27; Corretti – Firmati 2011, 232.
[6] Diod. Sic. 5.13.1. Translation by Oldfather 1993, 131.
[7] Str. 5.2.6.
[8] We understand the term deforestation as a (even temporal) absence of sufficient three cover; for a discussion of the terminology in the archaeological context see i.a. Iles 2016 and Harris 2013.
[9] The interested reader is referred to the relevant literature: Hughes – Thirgood 1982; Meiggs 1982, 371–403; Hughes 1983; Wertime 1983; Williams 1989; Hughes 2011; Harris 2013.
[10] Lindsay 1975.
[11] Goucher 1981.
[12] Iles 2016.
[13] Pococke 1745, 180 f.
[14] Täckholm, 1937, 21; in German: "Wir wissen durch Strabon V 2.6, dass das Erz direkt aufs Festlande transportiert wurde, ohne noch geschmolzen zu sein. Der Grund dafür wird von Strabon nicht angegeben, doch kann es wohl kein anderer als Brennholzmangel gewesen sein"; translation: by the authors.
[15] Forbes 1964; Meiggs 1982; Williams 2010, 78; Harris 2013; Sands 2013, 22; Penna 2014, 151.
[16] Schweighardt 1841, 23.
[17] Thiébaut de Berneaud 1814, 23 f.
[18] Swinburne 1814, 429 f.; Barker 1815, 4.
[19] Campbell – Maclachlan 1869, 4.
[20] Giovannelli 1771, 112.
[21] Wiman 2013, 17.
[22] Foggi et al. 2006.
[23] Grove – Rackham 2003; Rackham et al. 1996; see also the German ‚Holznotdebatte' (debate on wood shortage) and problems related to the understanding of deforestation in the 18th c. in e.g. Radkau 1986 and Schenk 2006.
[24] Bertini et al. 2014.
[25] Sadori et al.2010.
[26] Becker et al. 2019.
[27] Bertini et al. 2014.
[28] Becker et al. 2019.
[29] Cf. Brambilla 2003.
[30] Unpublished data; D'Orefice – Graciotti 2014; Becker et al. 2019.
[31] Bevan – Crema 2018.
[32] R Core Team 2016.

[33] It should be noted that the CPF results are preliminary and some biases in the data need further assessment and discussion.
[34] Becker et al. 2020a, Becker et al. 2020b.
[35] Pistolesi 2013, passim.
[36] Cf. Zecchini 2001.
[37] Cf. Corretti 1988, 25 f.
[38] Cf. Corretti 2017, 455.
[39] In the Middle Ages, transport over land is more often practiced.
[40] Interestingly, Chiarantini et al. 2018, 12, even state that the forest resources might be already exhausted in the 6st c. BCE, as iron was only mined on Elba and smelted in Populonia—far prior the onset of smelting on Elba in late 4th/3rd c. BCE.
[41] Corretti 2017, 455.
[42] Cf. Camporeale 2013, 206.
[43] Corretti 2004, 282 f.; Cambi 2009, 226 f.; Contra Camporeale 2013, 207.
[44] Only very scanty founds of smithing slag were recorded, see Corretti 2016. Corretti 2017, 455 f.

Image Credits

All images by the authors. Elevation data from Regione Toscana, 2014.

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