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ORIGINAL ARTICLE

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Human impact during the Bronze Age on the vegetation at Lago Lucone (northern Italy)

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Abstract Lake-sediment records were used to reconstruct human impact on the landscape around Lago Lucone (45°33′N, 10°29′E, 249 m a.s.l.), a former lake in the western amphitheatre system of the Lago di Garda. Presence of prehistoric human populations is attested by pile-dwelling settlements from the Early-Middle Bronze Age, with one settlement at a distance of only 100 m from the coring site. Pollen, plant-macrofossil and microscopic charcoal analyses were applied to a 250 cm sediment core with four dates providing the time control. A mixed oak forest that was important during the Early-Middle Holocene was cleared and replaced by open vegetation during the Bronze Age (∼2000–1100 B.C.) when open lands were estimated to have covered more than 60% of the total relevant pollen-source area. During a phase of high human impact, independent climatic proxies suggest warm and dry climatic conditions. Later, ca. 1100 B.C., palaeobotanical evidence indicates a sharp decrease in human pressure in the Lago Lucone area. The comparison with other sedimentary palaeocultural records shows that the period 1300–1100 B.C. was characterised by general declines of agricultural activities both south and north of the Alps. These declines have been previously attributed to a change towards wetter and colder climatic conditions in and around the Alps. However, the decline in human impact around Lago Lucone cannot be exclusively attributed to climatic variation. Therefore other forcing factors independent of climatic changes, such as cultural crises or changes in spatial organisation of the habitats, cannot be ruled out under the present state of knowledge.

Keywords Pollen analysis · Plant macrofossil analysis · Bronze Age · Human impact · Climatic changes · Northern Italy

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Introduction

Several archaeological findings show the presence of Neolithic settlements in the amphitheatre moraine system of the Lago di Garda, northern Italy. During the Early and Middle Bronze Age (ca. 2200–1300 B.C.), the number of settlements increased, as attested by the spread of pile dwellings near lakes or former lakes present in the moraine system of the Garda area and by settlements at high altitudes (Cremaschi 1991–1992). Compared with the Neolithic, human management of the landscape became more intense, with more extensive cultivation and animal husbandry, accompanied by a development towards more complex societies (Castelletti et al. 2001). After this rich settlement phase a general decrease in evidence from settlements is found in the Garda area starting at the transition between the Middle and Late Bronze Age (ca. 1300 B.C.).

In spite of the greater number of Bronze-Age dwellings in north-eastern Italy, only few palynological studies have been carried out in prehistoric pile-dwelling areas. On-site records and records from very close to settlements were studied in the Lago di Garda area (Lago di Ledro, Dalla Fior 1940; Lago di Castellaro, Bertoldi 1968; Fiavè mire, Dalla Fior 1932) and in the Po Plain (Terramara di Santa Rosa di Poviglio, Ravazzi et al. 2004; Tabina di Magreta, Bertolani Marchetti et al. 1989).

However in northern Italy and the adjacent Ticino region several palynological records not placed in an archaeological context (off-site records) provide accurate chronological positions for particular events (Schneider and Tobolski 1985; Wick 1996b; Tinner et al. 1999; Gobet et al.

2000, 2003; Finsinger 2001). Although in all settings human impact is visible, different extents of deforestation are observed in different records.

In order to understand the degree to which land was used by prehistoric populations, it is important to assess how changes in land use are registered in pollen records. Therefore comparisons should be attempted among the available palynological records inside prehistoric settlements, in their vicinity and remote from them. Lago Lucone was selected because Early to Middle Bronze Age settlements occurred near the lakeshores (Guerreschi 1980–1981; Bocchio 1985–1988). This site is therefore suitable to test the extent to which the landscape changed and how this change was registered in pollen and plant-macrofossil records. Moreover, because the coring location is close to the settlement, the signal from human impact in the palaeoecological record is enhanced. The archaeological record of Lago Lucone, parallel to the settlement phase in the Garda area, also shows the disappearance of the pile dwelling at the end of the Middle Bronze Age. However, a few artefacts from the Late and Final Bronze Age were found at Lago di Lucone (Guerreschi 1980–1981).

In this study we establish whether the decrease in land-use intensity as suggested by archaeological evidence from the transition Middle to Late Bronze Age is reflected in the palaeobotanical records of Lago Lucone. In addition, the comparison of our records with independent climatic proxies enables us to discuss potential correspondence between human occupation phases and variations in climate.

Study area (geographical, vegetation, climatic and archaeological setting)

Lago Lucone (45°33′N, 10°29′E, 249 m a.s.l.) is located in the western part of the amphitheatre system of Lago di Garda (Polpenazze-Brescia) and is nowadays a marshy area with *Alnus glutinosa* stands (Fig. 1). The lake was drained in A.D. 1459 in order to increase the cultivation area (Stegagno 1907). The basin receives its water from the major inlet, which flows from springs at the foothills of the Monte Soffiano (363 m a.s.l.). The outlet, Rio Seriola, is artificial and flows into the Rio Borgognini, which in turn enters the Lago di Garda (50 m a.s.l.). Before reclamation, the natural outlet passed between Monte San Pietro and Monte Basia, respectively 295 and 302 m a.s.l. (Stegagno 1907). Moraines of the Riss Stadial and other Quaternary sediments surround the former lake (Venzo 1957). Near the northern side of the basin, Tertiary carbonate rocks are present.

A mixed oak forest (*Quercus robur*, *Q. pubescens* and *Ostrya carpinifolia*) covers the moraines, and *Quercus cerris* and *Castanea sativa* grow on acidic soils. The mild climatic regime accounts for the presence of Mediterranean plants like *Cupressus sempervirens*, *Olea europaea*, and *Laurus nobilis* in the forest (Marchesoni 1958).

The study area is situated in the transitional climatic zones Cfa and Cfb of Köppen (Pinna 1977). The nearby climatic station of Saló (Fig. 1) shows the present day annual precipitation to be 1,000 mm, with maxima in spring and autumn. The annual, July and January mean temperatures are 13, 24 and 2°C respectively (Ufficio idrografico e mareografico di Parma-Bacino del Po 1962–1991).

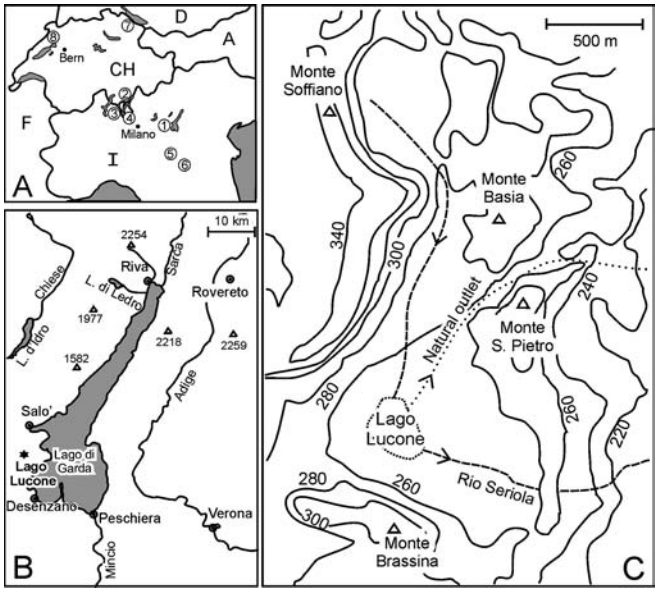


Fig. 1 Map of the study region. **A** sites mentioned in the text: **1** former Lago Lucone (this study); **2** Lago di Origlio and Lago di Muzzano (Tinner et al. 1999; Gobet et al. 2000); **3** Lago di Ganna (Schneider and Tobolski 1985); **4** Lago di Annone and Lago di Segrino (Wick 1996b; Gobet et al. 2000); **5** Terramara Santa Rosa di Poviglio (Ravazzi et al. 2004); **6** Tabina di Magreta (Bertolani Marchetti et al. 1989); **7** Nussbaumersee (Ammann 1977); **8** Twann (Haas and Hadorn 1998). **B** location of the Lago di Garda area. **C** location of the former Lago Lucone

The archaeological findings at the Lago Lucone are distributed in five different areas (Fig. 2; Baioni and Bocchio 2004). Neolithic artefacts (Vasi a Bocca Quadrata) have been found in area C (Fig. 2), while other investigated areas provided only Bronze Age findings. At Lucone, two pile dwellings were excavated in areas A and D, where lithic and bronze assemblages were correlated to the Early and Middle Bronze Age (Guerreschi 1980–1981; Bocchio 1985–1988). A more accurate dating is provided by the dendrochronological investigation carried out on 50 *Quercus* sp. posts which suggests that the settlement in zone D was restricted to the Early Bronze Age from 2166±10 to 1987±10 B.C. (Martinelli 1996). Plant macrofossil analysis on material found during the excavation in areas A and D highlighted cultivation of *Triticum* sp., *Panicum miliaceum*, and *Hordeum* sp. (Guerreschi 1980–1981; Bocchio

Table 1 Chronology of the Bronze Age in Garda area[a]

Age B.C	Periods of the Bronze Age
1150–800	Final
1300–1150	Late
1600–1300	Middle
2200–1600	Early

[a]Source de Marinis (1999)

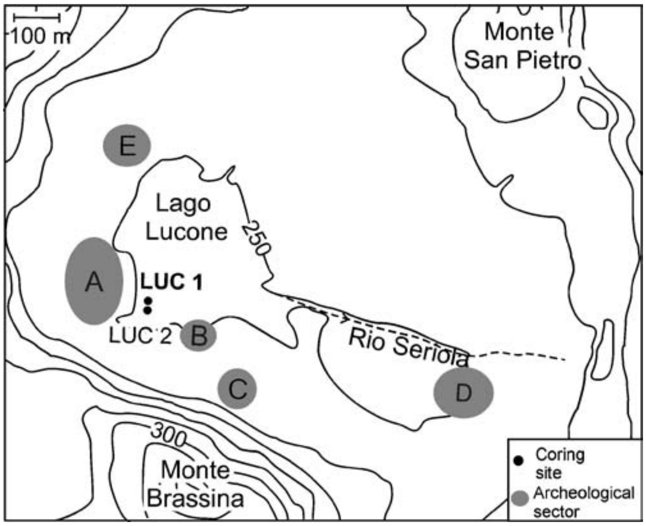


Fig. 2 Map showing archaeological sectors (*grey areas*) and coring sites (*black dots*). The archaeological sectors can be grouped as follows: **C**—Neolithic artefacts, **A** and **D**—Early-Middle Bronze Age settlements, **B** and **E**—Bronze Age findings

1985–1988). Table 1 shows the chronological scheme for north-eastern Italy during the Bronze Age (de Marinis 1999) used in this paper.

Materials and methods

Fieldwork

A Streif piston corer of 8 cm diameter (Merkt and Streif 1970) was used to take parallel cores 100 m from the dwelling area A (Fig. 2). The two cores (LUC-1 and LUC-2 of 7 and 4 m length, respectively) were described following Faegri and Iversen (1989) and using Munsell charts (1954) for the sediment colour. Since sedimentological features of the two cores were comparable, only core LUC-1 was analysed because of its greater length. In both cores the first 90 cm were not recovered because of ploughing disturbance.

Pollen and microscopic charcoal analysis

Samples for pollen analysis were taken between 90 and 250 cm with sampling at higher temporal resolution between 180 and 140 cm (~2300 to 250 B.C.); in total 33 samples were analysed. Pollen samples of 1 cm^3 were prepared by standard physical (500 µm sieving and decantation) and chemical (HCl, KOH, HF and acetolysis) methods. *Lycopodium* tablets were added for estimation of pollen concentration (Stockmarr 1971). Pollen grains and spores were counted at magnifications of ×400 and ×1000 and identified with keys (Punt et al. 1976–1996; Moore et al. 1991), pollen atlases (Reille 1992–1998) and the reference collection at the Institute of Plant Sciences in Bern. At least 400 pollen grains per sample, excluding aquatic plants and ferns, were counted. The results are presented as TILIA pollen percentage diagrams (Grimm 1993). Charcoal particles longer than 10 mm were identified in the pollen slides with a light microscope at ×250 magnification. Charcoal was identified as black, completely opaque, angular fragments and at least 200 objects were counted for each sample (Tinner and Hu 2003; Finsinger and Tinner 2005). Rarefaction analysis using the program RAREPOLL (Birks and Line 1992) was carried out using the raw count to estimate the palynological richness, the lowest pollen count (410 grains) was used as the reference sum.

Plant-macrofossil analysis and dating

For plant macrofossils, 110 contiguous sub samples were taken between 140 and 250 cm sediment depth. These were wet sieved (mesh widths of 200 and 100 µm) after measurement of their volume by water displacement. Macrofossils greater than 200 µm were analysed with a stereomicroscope at 10–40× magnification and identified using the seed reference collection of the Institute of Plant Sciences of the University of Bern and atlases (Katz et al. 1965; Schoch et al. 1988). Macrofossil concentrations are referred to a volume of 50 cm^3 sediment. Macroscopic remains of terrestrial plants were selected from four sediment levels and dated by accelerator mass spectrometry (AMS) at the Poznań Radiocarbon Laboratory. The resulting radiocarbon dates were converted to calendar year B.P. (cal B.P.) with the program CALIB rev 4.3 method A (Stuiver and Reimer 1993; Stuiver et al. 1998. Linear interpolation between the means of calibrated dates was used to estimate the depth-age relationship (Fig. 3).

Loss on ignition (LOI)

Samples of 1 cm^3 of wet sediment were taken between 90 and 250 cm depth and dried at 105°C for 12 h. Then the samples were heated for 4 h at 550°C and for 2 h at 950°C. The weight loss, which represents the content of organic matter and carbonate of the sediment (Heiri et al. 2001), was measured by weighting the samples before and after heating. The LOI of the sediment was calculated as the percentage dry-weight loss after ignition.

Characterisation of the open land

Pollen percentages of herbaceous indicator species were used to characterise the use of the non-forested area from the Copper Age until Modern Times. The categories here considered were field, fallow and ruderal communities, pastures, mowing, wet meadows, dry meadows and finally the occurrence of the species as an element of the natural communities of the Garda area. Herb pollen types were assigned to these categories of land use according to previous studies as follows: (i) the anthropogenic indicator-species approach of Behre (1981), (ii) the indicator values of

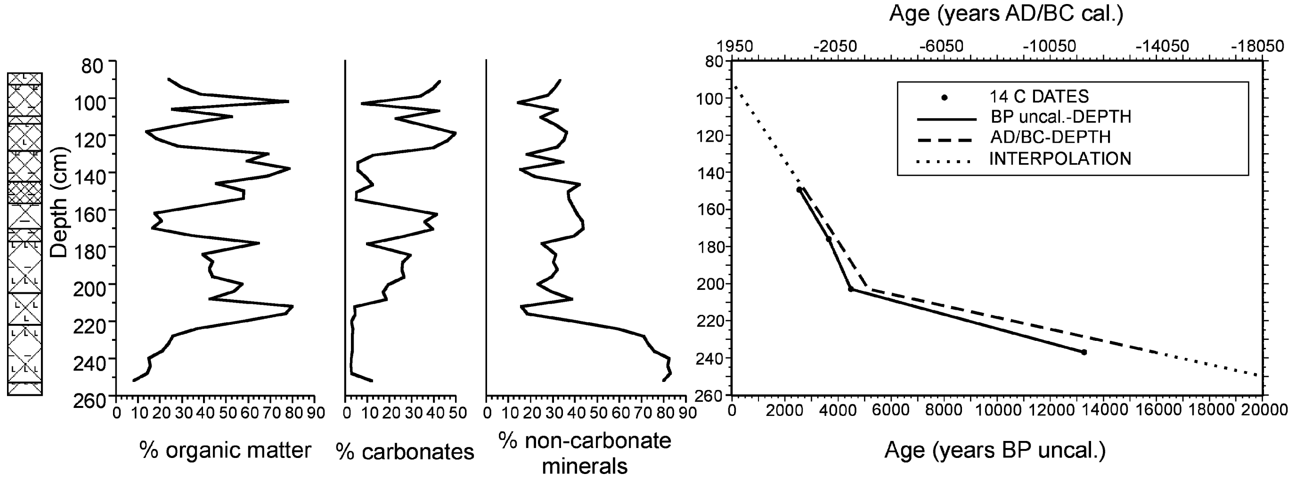


Fig. 3 Lithostratigraphy, loss-on-ignition curves and depth-age model for core LUC-1. For lithostratigraphic legend see Fig. 4

pollen types for grazing, mowing and wetness of Birks (1990) on a 9-point scale (for our estimations only the pollen types with values of 7, 8, and 9 were used), (iii) the indicator values for mowing and grazing of Gaillard et al. (1992) on a 5-point scale (only pollen types with a score of 4 or 5 were used), (iv) the index for humidity (F) of Ellenberg et al. (1992) and (v) the ecological indications of Pignatti (1982). Several NAP-types were not considered as anthropogenic indicators because the pollen was derived from plant species that either occur in present-day natural communities (i.e. *Centaurea nigra* t.) or which are related to different land-use (i.e. *Artemisia*). Percentages of the indicator species were then grouped according to land-use category by summing pollen percentages (Table 5 and Fig. 6).

Estimation of the landscape openness within the relevant-source-area

The quantitative estimation of the landscape openness (e.g. percentage of open land, forested land, etc.) is possible once the “relevant source area” (RSA) of the study site is known (Broström et al. 1998; Gaillard et al. 1998; Sugita et al. 1999). The RSA of pollen is the area within which local differences in plant abundance are recorded as variance in pollen assemblages. It can be considered as the area beyond which the correlation between pollen loading and distance-weighted plant abundance does not improve (Sugita 1994).

Care should be taken when estimating the percentage of open land represented by non-arboreal pollen (NAP), for this procedure gives only a non-linear approximation (Sugita et al. 1999). Moreover, in order to estimate quantitatively the landscape openness from pollen data it is necessary to know the background pollen values and pollen production (Sugita et al. 1999). Then the vegetation composition of the RSA is obtained from a pollen assemblage by using the inverse forms of the Extended *R*-value model. The model described by Sugita et al. (1999) cannot be fully applied here because the background pollen, pollen production and fall speed of pollen in the study area were not estimated. Although the use of NAP percentage is tentative, because landscape openness and NAP percentages are not linearly related, we decided to use this value in order to have a first estimate of the percentage of open land.

Since at Lago Lucone the Bronze Age settlements were located on the 250 m contour, we inferred a palaeo-lake area of ∼18 ha and estimated the radius as about 1000 m (for small lakes 0.5–20 ha) for the RSA, following Broström et al. (1998). Subsequently, the landscape openness within the RSA was estimated following the model-based relationships between NAP percentages versus percentage cover of open land (Fig. 4b in Sugita et al. 1999; results in Table 4).

Results and interpretation

Lithostratigraphy and loss-on-ignition

At the base the sediment of the core LUC-1 consists of silty clay with increasing organic matter followed by a dark silty gyttja between 180 and 158 cm. Then a detritus gyttja 158–144 cm is overlain by an alternation of gyttja and clay gyttja up to 90 cm depth (Table 2 and Fig. 3). The sediment above 90 cm was not cored as ploughing had disturbed it. These results are borne out by the loss-on-ignition (LOI) analysis. From the bottom to 215 cm depth percentages of non-carbonate minerals are high in the sediment. This level is followed by a sharp change highlighted by a sharp increase in organic matter and carbonate (Fig. 3).

Depth-age model

The earliest date (Table 3) at a depth of 237 cm has a mean age of 15960 cal B.P. Since no significant change in the sediment composition is apparent below the last level dated a constant accumulation rate would lead to an age at the bottom of ca. 20000 cal B.P. (250 cm). The most recent date at 149 cm has a mean age of 2735 cal B.P. Changes in sedimentation rate cannot be excluded for the top section of the core. However, despite the few dates available, a

Table 2 Description of the Lago Lucone sediments (core LUC-1)

Depth (cm)	Description	Colour
66–77	(Clay) gyttja	10 YR 2/2
77–93	(Silty clay) gyttja	2.5 Y 4/2
93–111	(Silty clay) gyttja	10 YR 4/3
111–114	(Clay) gyttja	10 YR 2/2
114–130	(Silty clay) gyttja	10 YR 4/3
130–144	(Clay) gyttja	5 YR 2/2
144–158	Silty detritus gyttja	10 YR 2/2
158–171	Silty gyttja	5 Y 3/2
171–179	Silty clay gyttja	10 YR 2/2
179–207	Clay silty gyttja	5 Y 4/2
207–223	Clay gyttja	10 YR 2/2
223–253	Clay silty gyttja	5 YR 4/2
253–256	Silty clay gyttja	5 YR 5/1

tentative depth-age model was constructed assuming a constant sedimentation rate to the top of the sediment cored; for the 90 cm depth the estimated date was A.D. 1950.

As shown by the LOI results, non-carbonate minerals mainly form the deposits at the bottom of the core, whereas an increase of organic matter occurs at around 215 cm (ca. 7000 B.C.). It is likely that this sedimentary change was connected with the decrease of the accumulation rate visible in the depth-age model at ~205 cm. Later, in the time frame of our interest (i.e. from ~3000 B.C.), the sedimentation rate was fairly constant.

Vegetation history

Pollen and plant-macrofossil diagrams were subdivided into five and four zones respectively (Figs. 4 and 5). The visual zonation of the diagrams is based on changes in pollen percentages (LPAZ), and plant macrofossil concentrations (MZ).

LPAZ Luc-A and MZ Luc-A (250–225 cm), ca. 20000?–12100 cal B.P.

At the base of the zone, herb pollen types were dominant, particularly *Artemisia* and Poaceae. Among the arboreal pollen, *Pinus sylvestris* type (from 20% up to 60%), *Betula* and *Juniperus* are the most important. Charcoal concentration is extremely low (less than 15,000 fragments/cm^3). Macrofossil remains of *Betula* and *Larix* show that birch and larch were involved in the afforestation. We infer that open vegetation with pioneer herbs was dominant at the base of the zone and *Betula*, *Larix* and *Juniperus* were locally present. Probably the high percentage of pine pollen is in part due to long-distance transport as very few pine macrofossils were found. A similar vegetation type during the Late glacial has also been described for several sites in the southern Alps (Bertoldi 1968; Schneider and Tobolski 1985; Wick 1996a; Tinner et al. 1999).

LPAZ Luc-B and MZ Luc-B and -C (225–178 cm), ca. 12100–4000 cal B.P. (10150–2050 B.C.)

At the begning of this zone *Quercus* (deciduous), *Ulmus*, *Tilia*, *Fraxinus excelsior* t. and *Corylus* pollen values increase. Later the rise in *Alnus glutinosa* type (*Alnus glutinosa* and *A. incana*) was followed by an increase of *Fagus* and *Carpinus* pollen percentages, whereas percentage values of NAP decreased. Charcoal values were stable; only in one sample was a peak registered.

Palaeobotanical data suggest that at the beginning of this zone mixed oak forests were present on the hills near the lake, while alder occurred in wetter places. The local presence of this vegetation type is confirmed by macrofossil results such as *Quercus* (deciduous) and *Alnus glutinosa* remains. Our palaeovegetational records suggest that afterwards the mixed oak forests were partly replaced by *Fagus* and *Carpinus* (~2600 B.C.) The contemporaneous expansion of *Fagus* and *Carpinus* may be partly attributed to the low resolution of our pollen diagram. An impressive expansion in *Najas flexilis* seeds is recorded in the macrofossil diagram (~3150 B.C., MZ Luc-C). Today this annual and rather thermophilous aquatic plant lives in freshwater bodies up to three metres deep. The minimum germination temperature for successful growth lies around 19°C during the second half of June (Haas 1996). Although this species no longer occurs in northern Italy (Pignatti 1982), a few *Najas flexilis* seeds were previously found at Lago di Ganna (Schneider and Tobolski 1985) and dated to the Boreal chronozone (ca. 9,000–8,000 B.P., Mangerud et al. 1974). The occurrence of seeds in our record could be related to oligotrophic to slightly mesotrophic water conditions (Haas 1996).

Table 3 AMS-radiocarbon dates from Lago Lucone (LUC-1)[a]

Lab-number	Depth (cm)	Material dated	Years ^{14}C B.P	δ^{13}C (‰)	Age cal B.P. (2σ)	Mean calibrated date
Poz-3201	149–150	Periderm and *Quercus* sp. bud scale	2545±35	−28.4	2750–2490	2735 cal B.P., 785 B.C.
Poz-3111	176	periderm and *Quercus* sp. base of acorn	3650±35	−23.6	4090–3865	3950 cal B.P., 2000 B.C.
Poz-3203	202–204	*Quercus sp.* bud scale, *Alnus glutinosa* seed	4485±35	−27.4	5300–4975	5145 cal B.P., 3195 B.C.
Poz-3202	237	Terrestrial seed	13,280 ± 70	−26.7	16440–14970	15,960 cal B.P., 14010 B.C.

[a]Calibration was carried out with CALIB rev 4.3 using the IntCal98 database (Stuiver et al. 1998)

Table 4 Estimation of the percentage of open land in the RSA (1000 m radius area around the lake). Deforestation index is based on the estimated percentage of open land: 1.0–30%; 2.30–60%; 3.60–80%, 4.80–100%

Depth (cm) of the pollen sample	Calibrated years based on the depth-age model	Percentage of open land in the RSA	Deforestation Index (1–4)	Culture	LPAZ
90	1950 A.D.	30-70	2.5	Modern Times	Luc-E
100	1490 A.D.	35-60	2	Middle Ages	Luc-E
110	1030 A.D.	70-80	3	Middle Ages	Luc-E
120	570 A.D.	40-70	2.5	Middle Ages	Luc-E
130	110 A.D.	30-70	2.5	Roman period	Luc-E
138	260 B.C.	15-45	1.5	Iron Age	Luc-D
140	350 B.C.	10-50	1.5	Iron Age	Luc-D
143	490 B.C.	10-50	1.5	Iron Age	Luc-D
146	620 B.C.	10-55	1.5	Iron Age	Luc-D
148	710 B.C.	15-45	1.5	Iron Age	Luc-D
150	800 B.C.	10-50	1.5	Final Bronze Age	Luc-D
153	950 B.C.	15-45	1.5	Final Bronze Age	Luc-D
156	1080 B.C.	10-55	1.5	Final Bronze Age	Luc-C
158	1180 B.C.	40-80	2.5	Late Bronze Age	Luc-C
159	1220 B.C.	40-80	2.5	Late Bronze Age	Luc-C
159	1270 B.C.	60-80	3	Late Bronze Age	Luc-C
160	1310 B.C.	60-80	3	Middle Bronze Age	Luc-C
162	1360 B.C.	35-60	2	Middle Bronze Age	Luc-C
164	1450 B.C.	30-70	2.5	Middle Bronze Age	Luc-C
166	1540 B.C.	40-80	2.5	Middle Bronze Age	Luc-C
170	1720 B.C.	35-60	2	Early Bronze Age	Luc-C
173	1860 B.C.	40-80	2.5	Early Bronze Age	Luc-C
176	2000 B.C.	40-70	2.5	Early Bronze Age	Luc-C
178	2090 B.C.	0-20	1	Early Bronze Age	Luc-C
180	2180 B.C.	0-20	1	Early Bronze Age	Luc-B
183	2300 B.C.	0-20	1	Copper Age	Luc-B
190	2600 B.C.	0-20	1	Copper Age	Luc-B
200	3060 B.C.	0-20	1	Copper Age	Luc-B

Table 5 Selection of non-arboreal pollen types used as anthropogenic indicators. The catagory of land used was assigned to the pollen types following Behre (1981), Birks (1990), Gaillard et al. (1992), Ellenberg et al. (1992) and Pignatti (1982). Number of + indicates the number of authors. Pollen types in bold were chosen as indicators of a land use catogory (grey fill).

POLLEN TYPE	LAND USE CATEGORIES AND ECOLOGY							
	Field	Fallow land ruderal communities	Pastures	Mowing	Grazing and wet meadows	Wet meadow	Dry meadow	Natural communities in Garda area
Apiaceae				+		+		+
Artemisia		+	+			+		rare
Cannabis sativa	**+**							absent
Centaurea nigra t.			+					+
Centranthus		**+**						absent
Cerealia	**++**							rare
Chenopodiaceae		**++**						rare
Cirsium		+			+			+
Cyperaceae					+			+
Filipendula				+		++	+	+
Fritillaria t.			+			+	+	rare
Helianthemum/Cistus			+	+			+	rare
Humulus lupus						+		+
***Linum austriacum* t.**							**++**	+
***Mentha* t.**		+				**++**		+
Orlaya grandiflora		**+**						absent
***Plantago lanceolata* t.**		+	**++**	+				rare
Plantago media			+				++	+
Poaceae		+	+			+		+
***Polygonum bistorta* t.**			**+**					rare
Potentilla t.			+			+	+	+
***Ranunculus acris* t.**					**++**			+
Rhinanthus			**++**	+				rare
Rubiaceae		+	++					+
Rumex acetosa* t. / *R. acetosella		+	**+++**			+		rare
Rumex alpinus		+				+		+
Sanguisorba minor							**++**	+
Scabiosa		+					**++**	+
Secale	**++**							absent
Thalictrum						+	+	+
***Trifolium repens* t.**		**++**	+					rare
Urtica		**++**		+				rare

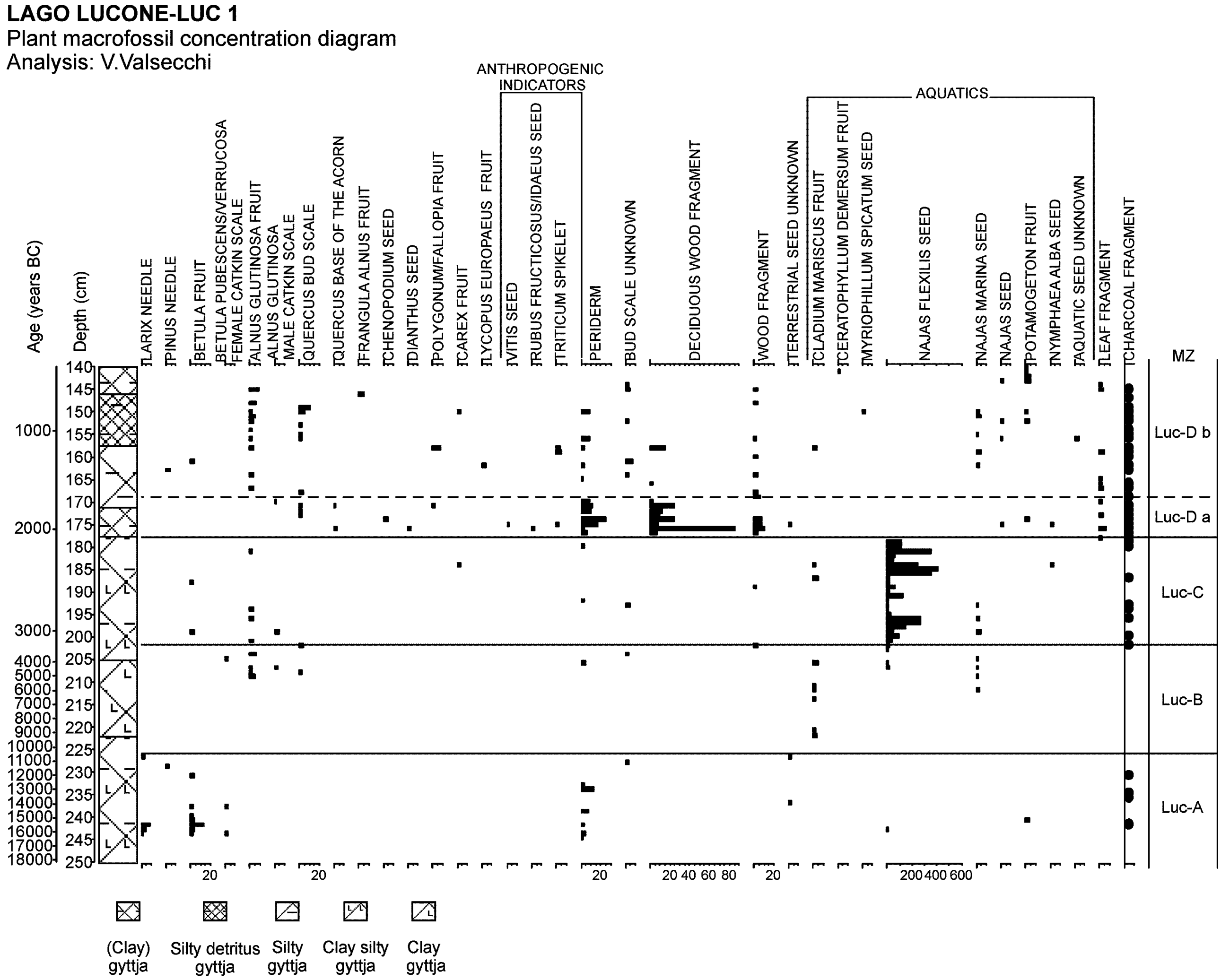


Fig. 4 Plant-macrofossil concentration diagram for Lago Lucone. Values refer to a sediment volume of 50 cm^3

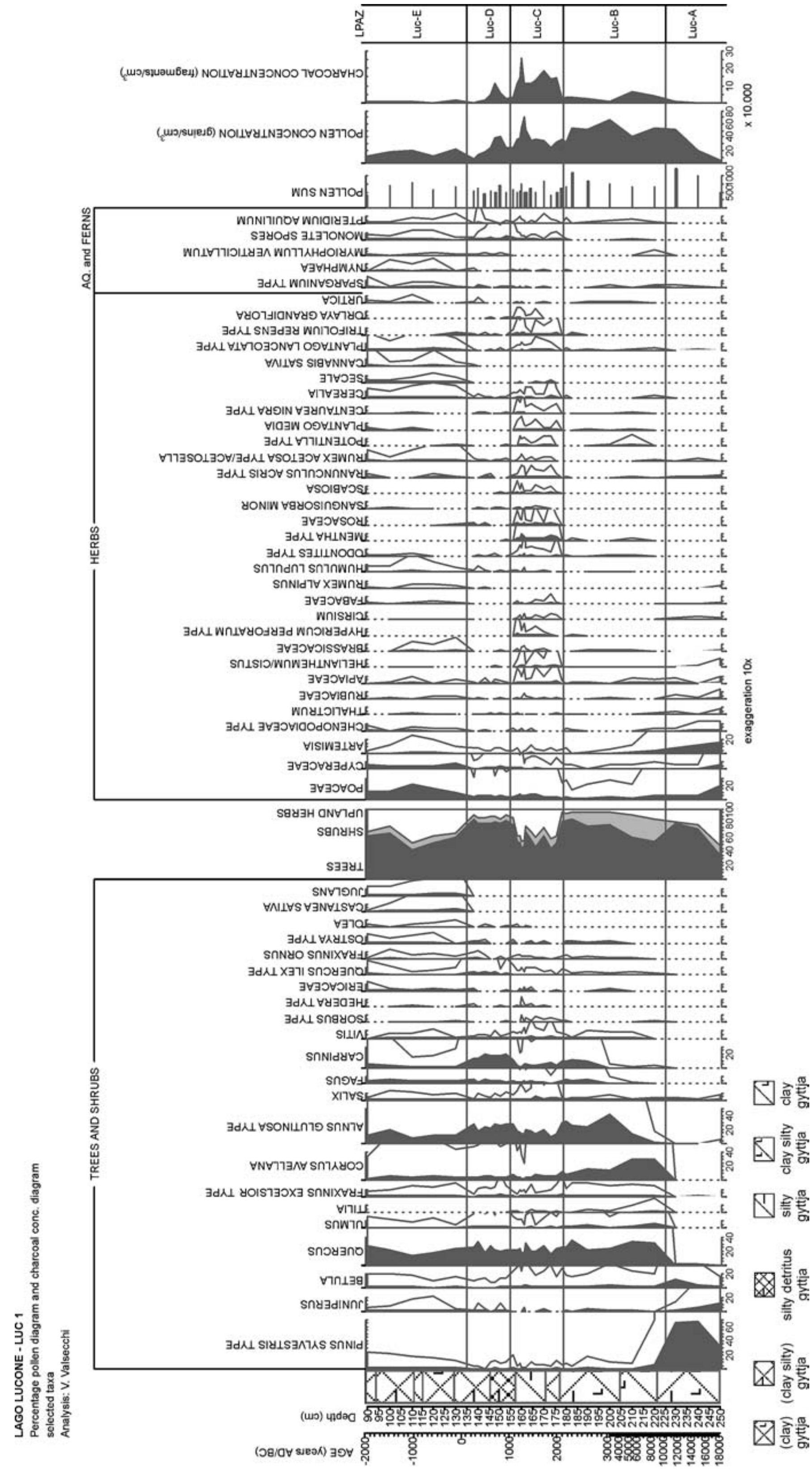
LPAZ Luc-C and MZ Luc-D (178–157 cm), ca. 4000–3100 cal B.P. (2050–1150 B.C.)

The beginning of this zone is characterised by high values of NAP (up to 45%). The main taxa involved are *Mentha* t., *Centaurea nigra* t., *Ranunculus acris* t. and *Potentilla* t., as well as several pollen types indicative of human activities (Cerealia, *Urtica*, *Orlaya grandiflora, Rumex acetosa* t./*acetosella*, *Trifolium repens* t. and scattered *Secale*). An increase of *Pteridium aquilinum* spores is also visible; this species is often connected to fire events (Tinner et al. 1999). A more intense occurrence of fire is also indicated by a five-fold increase in the microscopic charcoal concentration (Fig. 5). In the plant-macrofossil record, wood and charcoal fragments reach high quantities (zone MZ Luc-Da 178–169 cm) and *Triticum* spikelet bases as well as *Vitis* and *Rubus* seeds were found. We infer that a reduced oak forest was still present on the surrounding hills, while alder grew near the lake shore. Forest reduction was probably caused by human activity as also suggested by the presence of several anthropogenic indicators and the enormous increase in microscopic and macroscopic charcoal concentration. These latter were probably related to local fire events. Moreover, the disappearance of *Najas flexilis* in the sediment of Lago Lucone at the beginning of this zone (~2000 cal B.P.) could be related to eutrophication that occurred as a consequence of human settlement.

LPAZ Luc-D and MZ Luc-D (157–135 cm), ca. 1150 – ca. 350 B.C.

This zone is characterised by a decrease in upland herb pollen values (up to 10%). At the beginning of this zone, pollen percentages of *Carpinus*, *Alnus glutinosa* t., *Ulmus*, *Fraxinus excelsior* t. and *Corylus* increase, whereas microscopic charcoal concentration values are lower than in the previous zone. Only one peak was detected which was followed by a maximum in *Pteridium aquilinum*. Afforestation was mainly by *Carpinus*, however the macrofossil record suggests that *Alnus glutinosa* expanded locally around the lake.

Fig. 5 Percentage pollen diagram of selected taxa for Lago Lucone



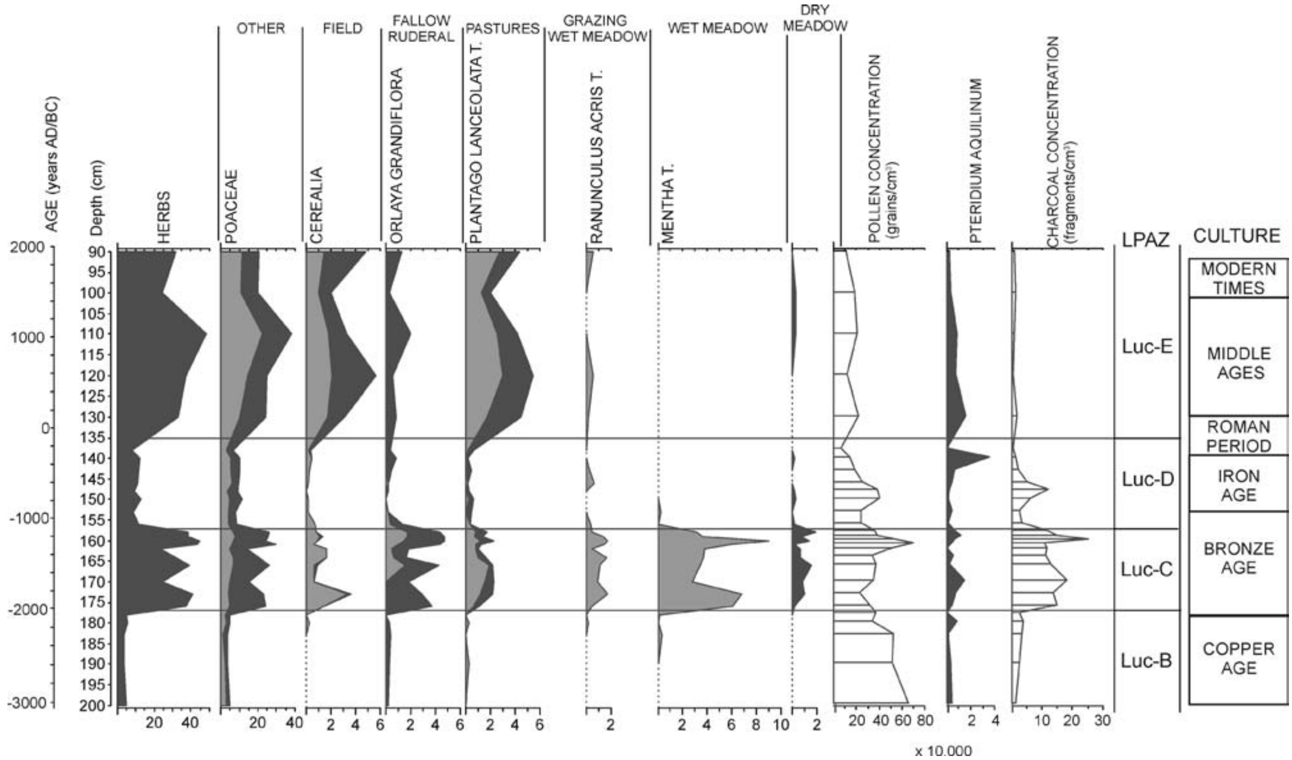


Fig. 6 Percentage pollen diagram of selected non-arboreal taxa. Pollen types are divided by the category of use and ecology. Black curves indicate the total pollen percentage of each category (e.g. field), grey curves show pollen percentages of the indicated pollen type (e.g. Cerealia)

LPAZ Luc-E (135–90 cm), ca. 350 B.C.-A.D. 1950?

In this zone *Castanea* and *Juglans* pollen appear together with *Cannabis sativa* and *Secale*. At the same time *Carpinus*, *Quercus* and *Alnus glutinosa* t. decrease. These changes reflect strong human impact, i.e. agricultural and silvicultural activities related to the Roman period.

An attempt to quantify the landscape openness

Different periods of intensified human impact were detected in our study and were assigned according to age to the Copper Age, Bronze Age, Roman period, Middle Ages or Modern Times (Table 4). During the Copper and Early Bronze Age (ca. 3000–2200 B.C.) the forest was rather dense with estimated open land of ∼0–20% of the RSA (∼1000 m around the palaeo-lake). Subsequently, around 2000 B.C., the landscape was opened as evidenced by a sudden increase in the estimated open land cover percentage (reaching 80% of the RSA). This reduction in the forest cover, which lasted until ∼1100 B.C., could be attributed to human forest clearances related to the establishment of the pile dwellings (Table 4). However, slightly lower values of open land cover percentages around 1700 and 1350 B.C. suggest that a reforestation of minor importance could have occurred. Then, during the Final Bronze and Iron Age the open land cover in the RSA was ca. 15–50% of the total area. Hence, a clear re-expansion phase of the forest is inferred, which ended during the Roman period and Middle Ages, when ca. 70–80% of the area was deforested.

Changes in the use of open land

In order to characterise the land use around the archaeological site at Lago di Lucone, NAP-types indicative of human impact were divided into different categories (Table 5).

During the Copper Age, NAP percentages were very low and among the herbs Poaceae pollen was dominant (Fig. 6). A change towards more intensive land use occurred during the Early Bronze Age (ca. 2000 B.C., LPAZ Luc-C), when the first unambiguous evidence of cultivation is recorded (Cerealia ca. 1.5%). Plants indicative of grazing (e.g. *Plantago lanceolata* t. and *Polygonum bistorta* t.), fallow land and ruderal communities (*Urtica*, Chenopodiaceae), as well as wet meadows (e.g. *Mentha* t.) were common or very common. This vegetational pattern suggests that starting from ca. 2000 B.C. the landscape was exposed to more intense human management than before. The influence of land-use is also indicated by the microscopic charcoal concentration record. Subsequently, during the Late-Final Bronze Age (ca. 1100 B.C.), a reforestation phase is evidenced by a lowering in the NAP percentages. Poaceae were dominant, whereas plants indicative of human impact (e.g. *Plantago lanceolata* t., Cerealia etc.) were less important but still present. A similar pattern is also characteristic of the Iron Age, whereas further intense impact on vegetation occurred during the Roman period (LPAZ Luc-E; Fig. 6). Evidence of grazing, ruderal communities, and cultivation of cereals and *Cannabis sativa* increased (Fig. 5). This tendency continued during the Middle Ages and Modern Times, when Poaceae as well as *Plantago lanceolata* t. reached their highest values.

Discussion

Human impact on vegetation during the Bronze Age

Pile-dwelling settlements in wet areas were characteristic of the Early-Middle Bronze Age in northern Italy (Cremaschi 1991–1992). During this period intensive agriculture is attested by several pieces of archaeological evidence (e.g. finding of ploughs and sickles; Perini 1982). Besides cultivation, animal husbandry was also important (Cremaschi 1991–1992).

At Lago Lucone, land-use changes by prehistoric populations are evidenced by the pollen, plant macrofossil and microscopic charcoal records (Figs. 4 and 5). A clearing phase in the area around the lake occurred between ~2000 and ~1100 B.C. (Table 4). However, small oscillations in the NAP pollen percentage can be seen and hypothetically these could be attributed to reforestation phases (~1700 and 1350 B.C.) due to temporary abandonment of the settlement. This explanation seems unlikely, since some of the important anthropogenic indicators did not decrease or disappear (e.g. *Plantago lanceolata* t., Cerealia). Synchronously with the clearing phase, pollen values of several anthropogenic indicators increased (e.g. Cerealia, *Orlaya grandiflora*, *Trifolium repens* type; Fig. 6). Moreover, a large increase of microscopic charcoal fragments occurred since ~2000 B.C. (Fig. 5). Palynological richness $E(T_n)$ values show a sharp increase (Fig. 7D), either due to a change towards a more varied landscape (increasing mosaic structure) or due to an increase in floristic richness (Birks and Line 1992). In the plant macrofossil record of Lago Lucone spikelet bases of *Triticum* were found (Fig. 4) as well as remains of edible wild plants (e.g. bases of *Quercus* acorns, *Rubus* and *Vitis* seeds). Morphological features of *Vitis* seeds which were found during archaeological excavations carried out in area A at Lago Lucone (Fig. 2) were attributed to wild *Vitis vinifera*; however an early phase of grape cultivation was not excluded (Di Vora and Castelletti 1995).

Our records suggest a continuous presence of human activity for a long period (e.g. ~900 years) at Lago Lucone. The persistence of the settlement is attested by the almost constant occurrence of pile dwellings during the Early and Middle Bronze Age (~2000–1300 B.C.; Fig. 7) and by lithic and bronze assemblages (Guerreschi 1980–1981; Bocchio 1985–1988). However, a slightly longer duration (~200 years) of human influences at Lago Lucone is inferred from the palaeobotanical records and could be explained by a delay in afforestation, by the presence of settlements in areas not suitable for the conservation of any archaeological remains (e.g. on the surrounding hills) or by the exploitation of the area by groups coming from nearby settlements.

To conclude, the Lago Lucone record documents a strong influence of Bronze Age societies on the environment. The mixed oak forest was largely destroyed and the cleared areas used for cultivation and pastures, while the timber was probably employed in the building of settlements and manufacture of implements. Drastic changes in landscape vegetation during the Bronze Age were detected not only at our site but also in the Po Plain and in the northern and central Apennines (Oldfield et al. 2003), in Central Italy (Lago di Mezzano–Sadori et al. 2004) and north of the Alps (Gobet et al. 2003; Tinner et al. 2003).

Comparison between sites with respect to inferred human impact on vegetation

In order to compare the degree of human impact on vegetation, ten sites were chosen in which the Early-Middle Bronze Age (ca. 2200–1300 B.C.) had been studied by means of pollen analysis (Fig. 1A). These sites were classified as on-site or off-site records (Table 6). Five of the sites are located in areas where evidence of settlements is absent or remote from the site. We refer to these as off-site records—Lago di Origlio (Tinner et al. 1999), Lago di Muzzano (Gobet et al. 2000), Lago di Ganna (Schneider and Tobolski 1985), Lago di Annone (Wick 1996b), and Lago di Segrino (Gobet et al. 2000). The Terramara Santa Rosa di Poviglio (Ravazzi et al. 2004) and Tabina di Magreta (Bertolani Marchetti et al. 1989) records are considered as on-site records because the samples were from within archaeological excavations. These two records are located in the so called "Terramare", which are dry-pile settlements surrounded by ditches and ramparts and were present in the Po Plain during the Middle and Late Bronze Age (Bernabo' Brea et al. 1997). Due to its closeness to the Bronze Age settlement (~100 m), Lago Lucone is also considered as an on-site record. Nevertheless, the Lago Lucone core is a lake sediment record within which archaeological layers were not detected. For a broader comparison we considered also two on-site records located in the forelands of the northern Alps: Twann (Ammann 1977) and Nussbaumersee (Haas and Hadorn 1998).

Off-site pollen records indicate the dominance of mixed oak forests in the lowlands of northern Italy during the Early-Middle Bronze Age (Schneider and Tobolski 1985; Wick 1996b; Tinner et al. 1999; Gobet et al. 2000). Among the ten sites huge differences in herb percentages exist; from 10–20% in off-site records, but with much higher values at Lago Lucone, Terramara di Poviglio and Tabina di Magreta. Surprisingly, low NAP percentages were documented in the Twann record. Among the herbs, Poaceae are dominant in off-site but not in all on-site records. At Lago Lucone and at Nussbaumersee anthropogenic indicators were more frequent. Cerealia pollen was present in almost all diagrams, but the highest values (ca. 5%) were registered at the Terramara di Poviglio. Beside Cerealia

Table 6 Non-arboreal pollen percentages from 2000 to 1300 B.C. (i.e. Early-Middle Bronze Age) for off-site records (Schneider and Tobolski 1985; Wick 1996b; Tinner et al. 1999; Gobet et al. 2000), and on-site records (Ammann 1977; Bertolani Marchetti et al. 1989; Haas and Hadorn 1998; Ravazzi et al. 2004)[a]

Pollen type	Off-site records					On-site records				
	Origlio	Muzzano	Ganna	Annone	Segrino	Lucone	Poviglio	Tabina di Magreta	Nussbaumersee 20%	Twann
HERBS	15%	20%	15%	10%	20%	34%	75%	70%		5%
Poaceae	7%	11%	8%	6%	8%	6%	40%	25%	5%	1%
Cerealia	0.5%	rare	<1%	1%	<1%	2%	5%	absent	<1%	2%
Orlaya grandiflora	unclear	unclear	unclear	rare	unclear	1%	rare	unclear	unclear	unclear
Plantago lanceolata t	1.5%	1%	<1%	1%	<1%	1%	rare	unclear	2%	<1%
Ranunculus acris t	rare	absent	unclear	rare	rare	1%	rare	unclear	absent	unclear
Rumex acetosa t./ *acetosella*	1%	2%	absent	1%	2%	<1%	rare	unclear	<1%	rare
Trifolium repens t	rare	rare	rare	rare	absent	2%	absent	absent	rare	absent
Urtica	rare	rare	<1%	rare	rare	0.5%	absent	absent	<1%	absent

[a]Absent: pollen type not present during the time frame considered; Rare: pollen percentage curve not continuous; Unclear: pollen identification to genus or family level

pollen, common anthropogenic indicators at all sites were *Plantago lanceolata* t., *Rumex acetosa* t./*acetosella* and to a minor degree *Urtica*.

The presence of settlements is unequivocally registered in pollen records and stronger signals are obtained from on-site records. Occurrence of Cerealia pollen in almost all diagrams indicates that cultivation was widespread. However higher values documented at Poviglio can be explained by the closeness of the cereal fields or of the threshing floor. On the other hand, in reconstructing the regional vegetation dynamics, on-site records should be accompanied by off-site records, since intense human activity signals induced by the settlements could decisively mask the imprint of regional vegetation.

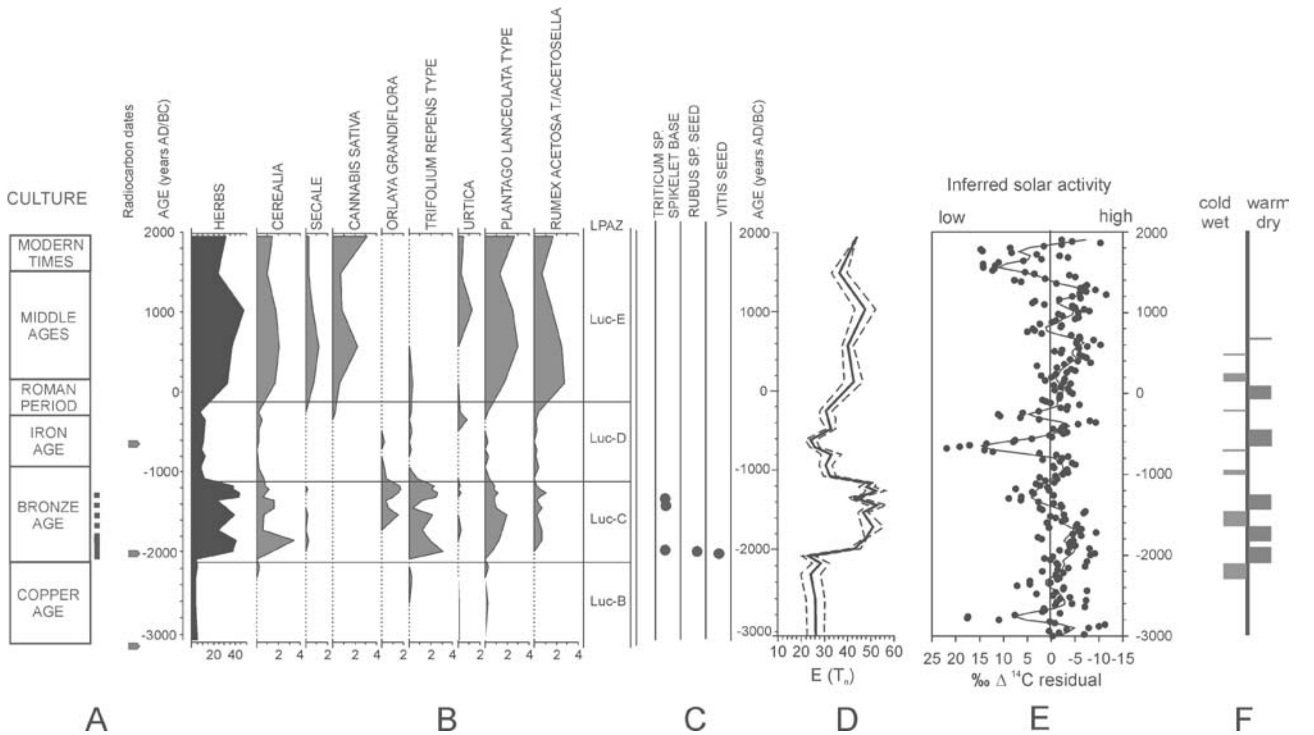


Fig. 7 Comparison between pollen and plant macrofossil data for Lago Lucone, atmospheric $\Delta^{14}C$ (proxy for solar activity) and climatic phases (cool/wet versus warm/dry). **A**: periods of settlement in sector A (Guerreschi 1980–1981); **B**: pollen percentage of selected anthropogenic indicators for Lago Lucone, radiocarbon dates are indicated by arrows; **C**: presence of anthropogenic plant macrofossils for Lago Lucone; **D**: estimated number of pollen taxa standardised to a common count size and plotted against sample age; **E**: atmospheric $\Delta^{14}C$ from tree rings (LOWESS-smoothed curves with span 5%; Stuiver and Reimer 1993); **F**: climate phases following Tinner et al. (2003) with an error of ±100 yr. Warm and dry climate phases are indicated as dark grey boxes while cool and wet climate phases are in light grey

Human population dynamics and climate changes – are there any causal connections?

During the Bronze Age, agriculture, fishing, and animal husbandry permitted increasing population growth and more complex societies. At that time, human populations were highly dependent on natural energy sources and local nutrient production; harvest yields depended mainly on climate (Messerli et al. 2000). Several studies indicate that climatic changes were able to cause the collapse of prehistoric societies in the Near East, in South America, and in Europe (Weiss et al. 1993; van Geel et al. 1996; deMenocal 2001). Furthermore, north and south of the Alps cereal-field cultivation expanded pulse-wise during warm and dry climatic periods (Tinner et al. 2003).

It has been suggested that the reduction of archaeological records in the Garda area commenced at the end of the Middle Bronze Age (ca. 1300 B.C.). Although a possible explanation for the scant archaeological record from that time may be the transfer to higher settlements that are not preserved, as suggested by Grosse-Klee and Maise (1997) for Switzerland, the assessment of this problem is hampered by the lack of archaeological evidence. In contrast to the archaeological evidence, our palaeobotanical record suggests the persistence of human influence beyond the Middle Bronze Age; Cerealia and *Plantago lanceolata* t. pollen were present continuously since ∼2200 B.C. and spikelet bases of *Triticum* sp. occurred at ∼1100 B.C. Despite this strong evidence of human influence, pile dwellings were not present on the lake shore at Lago Lucone according to our present archaeological knowledge.

Independent proxies for climatic and environmental changes might be considered for the discussion of potential links between climate and land-use intensities. We have chosen the following proxies: (i) climatic phases as summarised by Tinner et al. (2003) on the basis of Alpine dendroclimatic and Greenland oxygen isotope records and (ii) potential phases of solar-radiation changes as inferred from atmospheric Δ^{14}C record (Stuiver and Reimer 1993) (Fig. 7E and F).

A correspondence between short-term atmospheric ^{14}C variations (which is often used as a proxy for solar activity), Holocene glacier and tree-line fluctuations was observed in early studies (Denton and Karlen 1973). Later Magny (1993) detected a correspondence between atmospheric ^{14}C variations and lake-level changes. Short-term ^{14}C variations may result from variations in solar radiation which may induce climatic changes (van Geel et al. 1996; Beer et al. 1999; Björk et al. 2001; Bond et al. 2001; Blaauw et al. 2004). However, the relationship between climate and solar activity is not linear and is still a matter of discussion (Muscheler et al. 2004; Ponyavin 2004; Solanki et al. 2004). Moreover, without a comparison with other proxies for solar activity (e.g. ^{10}Be) it is difficult to judge whether ^{14}C variations were influenced by factors other than solar activity (Stuiver et al. 1991). In order to analyse the correspondence between phases of human impact and climatic change at Lago Lucone, the presence of anthropogenic indicators in the pollen and plant macrofossil records as well as the palynological richness $E(T_n)$ were compared to proxies of climatic change (Fig. 7). According to the dendrochronological and archaeological records, the settlement phase at Lago Lucone (area D) started around 2160 B.C. (Early Bronze Age) (Martinelli 1996). For this time our pollen and plant-macrofossil records show the beginning of a marked human impact (Table 4, Fig. 7). In the Alps the climate was warm and dry (Tinner et al. 2003), and high solar activity can be inferred from low ^{14}C values. Thus, according to the available palaeoclimatic and palaeoenvironmental records the Early-Bronze Age occupation phase occurred during a favourable climatic period.

Our palaeobotanical record suggests that human impact on vegetation decreased or disappeared around 1100 B.C. (Fig. 7B and C). At that time, the Lago Lucone lake-level was probably decreasing, as suggested by the transition from fine detritus to detritus gyttja. Similarly, a general lowering of lake levels was described for the Swiss Plateau from 1150 to 800 B.C. (Magny 2004). This lowering of lake levels apparently coincided with the end of the warm phase on the Swiss Plateau and in the southern Alps, which is set at ∼1250 B.C., whereas the beginning of the subsequent cold phase is set at ∼1000 B.C. (Fig. 7; Tinner et al. 2003). In this context it is intriguing that atmospheric^{14}C values would suggest a local minimum of solar activity around 1350 B.C. and a subsequent local increase between 1200 and 1000 B.C. Thus discrepancies exist between proxies for past solar radiation and Alpine palaeoclimatic series.

However, similar Bronze-Age settlement crises were also detected by off-site pollen records north and south of the Alps (Lago di Origlio, Muzzano, Soppensee and Lobsigensee) and in the Upper and Lower Engadin (Gobet et al. 2003; Tinner et al. 2003). Despite some connections with other palaeocultural series it is difficult to attribute changes in cultural activities at Lucone around 1100 B.C. exclusively to climatic change as was suggested for example for the periods 800–650 B.C. and 400–150 B.C. in Central Europe by Maise (1998). Cultural crises (e.g. wars), plagues or changes in spatial organisation as forcing factors for declining human impact in the area cannot be ruled out under the present state of knowledge. New, better-dated independent palaeoclimatic series from the region are urgently needed for better disentanglement of human and climatic forcing.

Conclusions

The Bronze Age in the Garda area was characterised by drastic changes in the vegetation, which were mainly caused by human impact. The mixed oak forest characteristic of the Early-Middle Holocene was cleared and replaced by open vegetation during the Bronze Age. Open lands were estimated to have been more than 60% of the total relevant pollen-source area between the Early and Middle Bronze Age (2200 and ∼1300 B.C.). The pollen data suggest that open lands were used as cultivation fields, pastures and fallow land. However, when using the indicator-species approach it must be kept in mind that pollen types indicative of human impact can partly refer to natural environments or to several land-uses. The comparison between on-site records and off-site records with regard to their ability to detect local human impact by means of pollen indicated that drastic changes in the landscape are better recorded at sites close to settlements, whereas in off-site records human impact on vegetation is documented at lower amplitudes. Intensification of agriculture resulted in more crops, probably allowing the development of more complex societies from 2200 to 1300 B.C. Warm and dry climates during this period probably permitted higher agricultural production. At Lago Lucone, human pressure started to decrease around 1100 B.C., when Alpine climatic records indicate the end of a warm and dry phase (~1250 B.C.). Hence it might be suggested that the settlement at Lago Lucone was abandoned in response to a less warm and less dry climate. However, this conclusion seems in contrast with the lower lake level inferred from the lithology change at Lago Lucone and with an increase of solar activity ~1200 B.C. inferred from atmospheric ^{14}C values. Such contradictions should be re-addressed by new local palaeoclimatic series.

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