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Mid- and late-Holocene vegetation and fire history at Biviere di Gela, a coastal lake in southern Sicily, Italy

Roland Noti · Jacqueline F. N. van Leeuwen ·
Daniele Colombaroli · Elisa Vescovi · Salvatore Pasta ·
Tommaso La Mantia · Willy Tinner

Abstract The vegetation and fire history of few coastal sites has been investigated in the Mediterranean region so far. We present the first paleoecological reconstruction from coastal Sicily, the largest island in the Mediterranean Sea. We analysed pollen and charcoal in the sediments of Biviere di Gela, a lake (lagoon) on the south coast of Sicily. Our data suggest that the area became afforested after a marine transgression at ca. 7200 cal B.P. (5250 B.C.). Build-up of forest and shrublands took ca. 200–300 years, mainly with the deciduous trees *Quercus*, *Ostrya* and *Fraxinus*. *Juniperus* expanded ca. 6900 cal B.P. (4950 B.C.), but declined again 6600 cal B.P. (4650 B.C.). Afterwards, evergreen trees (*Q. ilex*-type and *Olea*) became dominant in the forest and *Pistacia* shrublands were established. Forest and shrubland reached a maximum ca. 7000–5000 cal B.P. (5050–3050 B.C.); subsequently forest declined in response to human impact, which was probably exacerbated by a general trend towards a more arid climate. During the Neolithic, fire was used to open the landscape, significantly reducing several arboreal taxa (*Q. ilex*, *Fraxinus*, *Juniperus*) and promoting herbs and shrubs (*Achillea*, Cichorioideae, Brassicaceae, *Ephedra*). Final forest disruption occurred around 2600 cal B.P. (650 B.C.) with the onset of the historically documented Greek colonization. We conclude that the open maquis and garrigue vegetation of today is primarily the consequence of intensive land-use over millennia. Under natural or near-natural conditions arboreal taxa such as *Q. ilex, Olea* and *Pistacia* would be far more important than they are today, even under the hot and rather dry coastal conditions of southern Sicily.

Keywords Charcoal analysis · Pollen analysis · Evergreen forest · Human impact · Mediterranean · *Quercus ilex* · *Olea europaea*

R. Noti · J. F. N. van Leeuwen · D. Colombaroli · E. Vescovi ·
W. Tinner (✉)
Institute of Plant Sciences and Oeschger Centre for Climate
Change Research, University of Bern, Altenbergrain 21,
3013 Bern, Switzerland
e-mail: willy.tinner@ips.unibe.ch

D. Colombaroli
Environmental Change Research Group, Department of
Geography, University of Oregon, Eugene, OR 97403-1251,
USA

E. Vescovi
C.N.R., Institute of Environmental Dynamics (I.D.P.A.),
Via Pasubio 5, 24044 Dalmine, Italy

S. Pasta
Via V. F. 19 no 60/A, 90126 Palermo, Italy

T. La Mantia
Department of Arboreal Cultures, University of Palermo,
Viale delle Scienze 11, 90128 Palermo, Italy

W. Tinner
Institute of Terrestrial Ecosystems, ETH Zurich,
Universitätstrasse 22, 8092 Zürich, Switzerland

Introduction

Only a few coastal sites from the Mediterranean area have been investigated so far (e.g. Reed et al. 2001; Pérez-Obiol and Sadori 2007; Caroli and Caldara 2007). Our new site on the southern coast is the first on Sicily, the largest island in the Mediterranean Sea. Sicily boasts several botanical highlights, for instance the endemic trees *Zelkova sicula* (Di Pasquale et al. 1992) and *Abies nebrodensis* (Pignatti 1982). These trees and the numerous endemic herbs must

have survived the ice ages locally, emphasizing the potential of Sicily as a refugial area for thermophilous European plants during glacial times.

Biviere di Gela studied here is the largest coastal lake or lagoon in Sicily and is located on the southern coast. So far, the upland sites Urgo di Pietra Giordano, Urgo di Pollicino (Bertolani Marchetti et al. 1984) and Lago di Pergusa (Sadori and Narcisi 2001) in central Sicily are the only other sites that have been intensely investigated by means of palynology. Therefore, considerable uncertainty exists about the Holocene vegetation history of Sicily. With the present study, we start to fill this gap by reconstructing the coastal vegetation and fire history of the past ca. 7,000 years by means of pollen and charcoal analysis. Considering that the study area has a long cultural history, as it is one of the most important city colonies founded by the Greeks in southern Italy around 2,700 years ago, we pay special attention to past human impact such as deforestation, agriculture and burning. Taking into account the general course of climate and vegetation history as well as anthropogenic activity, we briefly address the potential natural vegetation around our new coastal southern Mediterranean study site.

Study site

Biviere di Gela (37°01′N, 14°20′E, 2.5 × 0.6 km² in size, 7 m a.s.l., catchment 67.5 km²) is located on the eastern part of the southern Sicily coast, in the province of Caltanissetta (Fig. 1). The lake is about 8 km east of the city of Gela. Geologically, the "Piana di Gela" lies within the Caltanissetta Basin and originated by tectonic uplift and eustatic sea level changes until emersion in the Pleistocene. The eroded Mio–Pliocene terrains (clay, re-sedimented Mesozoic limestone and evaporitic deposits) were then covered by alluvional deposits during the Quaternary. Initially water exchange with the sea persisted; thus the lake remained a lagoon. During the Quaternary, this link was broken and the lake reached equilibrium with groundwater and sea level. Today, the lake is separated from the sea (ca. 1.3 km away) by a wide system of fossil sand dunes (the Macconi). The mapped size of the lake is 1.2 km², but a decrease in the lake size has been observed since the 1950s to <1 km². The perimeter is quite winding with numerous bends. The lake has an inlet (Valle Torta-Monacelle torrent), but no natural outlet. Water volume (2.5–5.0 million m³) varies according to precipitation/evaporation as well as human exploitation (Collura 1996). Nowadays, agricultural activity strongly affects the water quality and drastically accelerates the erosion of the beach dunes. However, human activities around the site have a millennial history. Gela was used as landing place by the Phoenicians. The city of Gela (Gelas, 8 km west of the lake) was founded in 688 B.C. by Dorian settlers from Rhodes and Crete, according to the ancient Greek historian Thucydides (History of the Peloponnesian War). It was the first Greek city on the southern coast of Sicily, whence great parts of the island were hellenized, for instance through the foundation of the important cities of Agrigento (Akragas) and Selinunte (Selinus) (Bernabò Brea 1958; Panvini 1996). In 282 B.C. Gela was destroyed and in A.D. 1233 it was rebuilt by Frederick II (King of Sicily from 1198 onwards, Holy Roman Emperor A.D. 1220–1250) as Terranova di Sicilia, until it was renamed as Gela in A.D. 1928.

The climate of Gela is Mediterranean, with a mean annual temperature of 18.5°C and a rainfall of 409 mm. The driest month is July (2.5 mm), the rainiest December (66.6 mm; Scelsi and Spampinato 1998).

Present vegetation

Many endangered endemic plants (e.g. *Muscari gussonei*, endemic to southeastern Sicily) underline the ecological relevance of this area (RAMSAR 1998). The submerged vegetation of the lake is characterised by *Potamogeton pectinatus, P. crispus, Myriophyllum verticillatum* and *Ceratophyllum submersum*, whereas the thelmatic vegetation comprises various communities with the dominant species *Schoenoplectus litoralis, S. tabernaemontani, Bolboschoenus maritimus, Phragmites australis, Carex otrubae, Cyperus laevigatus, Cyperus alopecuroides, Typha latifolia, T. angustifolia* and *Juncus acutus* (Brullo and Sciandrello 2006). The shore border vegetation is mainly formed by communities of *Tamarix africana, T. arborea* and *T. gallica* that, especially in the northern part of the lake, form dense layers. This extremely rich wetland vegetation hosts some rarities, such as *Tamarix arborea*, which is very rare in Sicily, and the only Europe-wide occurrence of tropical *Cyperus alopecuroides* (Brullo and Sciandrello 2006). There are uncultivated and garrigue zones adjacent to the lake and relics of Mediterranean scrubland, with *Ceratonia siliqua*, wild *Olea europaea* var. *sylvestris, Pistacia lentiscus, Chamaerops humilis, Cistus* spp.*, Rosmarinus officinalis* and *Corydothymus capitatus* (Fig. 1). Some acacias have been introduced south-east of the lake. The most common crops in the surroundings are wine grapes, olives and vegetables in greenhouses (RAMSAR 1998).

Recent ecological studies consider the potential natural vegetation to be maquis or forest in the area, where today crops are cultivated (Pasta et al. 2000). These authors assume that some of the currently most common remnant forest and scrubland patches represent the late-successional woody communities. The plant communities are mainly characterized by edapho-climatic requirements (see references in Table 1). Important trees are *Quercus suber, Q. ilex,*

Fig. 1 Maps showing the geographical position of the study site Biviere di Gela. **a** Location of Biviere di Gela (Sicily) in comparison with other important paleoecological sites. **b** Local vegetation around Biviere di Gela
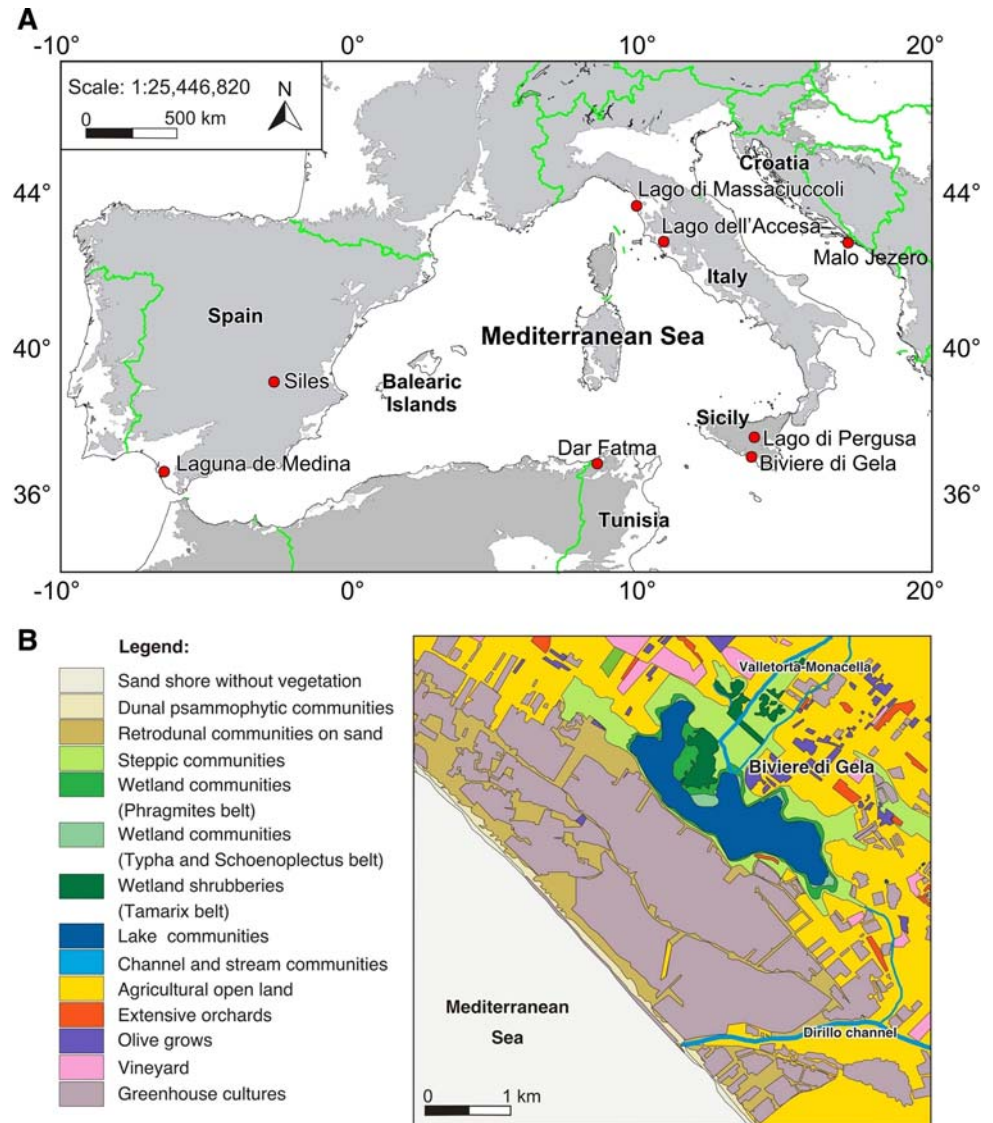
Q. coccifera s.l. *(including Q. calliprinos), Q. virgiliana, Q. pubescens, Erica arborea, Cistus* spp., *Arbutus unedo, Myrtus communis, Olea europaea* var. *sylvestris, Pistacia lentiscus, P. terebinthus, Euphorbia dendroides, Ostrya carpinifolia, Fraxinus ornus* and *Juniperus oxycedrus* subsp. *macrocarpa*. This vegetation composition is typical for the evergreen broadleaved thermo-Mediterranean belt which, in the southern Mediterranean lowlands (e.g. Sicily, Northern Africa), grows below the mixed evergreen-deciduous meso-Mediterranean belt (Lang 1994).

Methods

Coring

In 2003, two parallel cores (BV2 and BV3) were taken with a modified Streif–Livingstone piston corer (Merkt and Streif 1970) from the deepest point of the lake in the eastern part of the basin. Core BV2 covers a depth from 0 to 862 cm, core BV3 40–1042 cm. Sediments were described (Table 2) and stored in a dark cold room before sub-sampling. The cores were correlated on the basis of pronounced lithostratigraphic markers with an error range of ca. ±1 cm. The cores were sub-sampled for paleobotanical analysis as follows: BV2 0–80 cm, BV3 80–974 cm, the deeper sediments containing almost no pollen.

Chronology

Accelerator mass spectrometry (AMS) radiocarbon dates were measured on terrestrial plant macrofossils at the Poznań Radiocarbon Laboratory (Poznań, Poland) (Table 3). The radiocarbon dates were calibrated to calendar years before present (cal B.P.; years before A.D. 1950) using the program CALIB 5.0.1 (Stuiver et al. 2005). The depth–age

Table 1 Vegetation associations and environmental site information

Association	Description	Precipitation (annual mean, mm)	Substrate	Geographical situation	Important species
Stipo bromoidis–Quercetum suberis Barbagallo (1983)	Thermophilous woodland	500–600	Sandy/acid	250–500 m a.s.l; hilly surroundings of Gela	*Quercus suber, Q. ilex, Erica arborea, Cistus* spp., *Arbutus unedo, Myrtus communis*
Oleo sylvestris–Quercetum virgilianae Brullo (1984)	Thermophilous woodland	300–700	Sandy, calcareous, volcanic	Hyblean Plateau; 200–600 m a.s.l	*Q. virgiliana, Olea europaea*
Fraxino orni–Quercetum ilicis Horvatic (1958)	Between evergreen sclerophyllous maquis and temperate deciduous forest	800–900	Clay, calcareous	North-facing slopes of the Hyblean Plateau	*Pistacia terebinthus, Ostrya carpinifolia, Quercus ilex, Fraxinus ornus*
Pistacio lentisci–Quercetum ilicis Brullo and Marcenò (1985)	Evergreen mediterranean thermophilous maquis	–	Base-rich	Humid parts of Hyblean Plateau 100–600 m a.s.l	*Q. ilex, Pistacia lentiscus, Euphorbia dendroides, Chamaerops humilis*
Thymo capitati–Pinetum halepensis De Marco and Caneva (1984)	Pioneer thermophilous woodland	–	Base-rich soils	100–300 m a.s.l., catchment area of the rivers Ippari and Tellaro	*Pinus halepensis, Quercus ilex, Juniperus turbinata*
Myrto communis–Pistacietum lentisci Rivas-Martínez (1975)	Thermo-xerophilous maquis	<400–450	Sandy/marly	From the cliffs and dunes facing the seashore up to coastal hills (50–200 m a.s.l.)	*Myrtus communis, Olea europaea* var. *sylvestris, Pistacia lentiscus*
Calicotomo infestae–Rhoetum tripartitae Bartolo et al. (1982)	Thermo-xerophilous maquis	<400–450	Rocky or sandy seashores	Hyblean coasts between Marina di Ragusa and Pozzallo	*Calicotome infesta, Rhus* spp., *Pistacia, Phillyrea, Chamaerops humilis*
Ephedro fragilis–Juniperetum macrocarpae Bartolo et al. (1982)	Pioneer psammophilous maquis	–	Sand dunes	SE Sicilian coasts: Vendicari, between Scoglitti and Donnalucata	*Juniperus oxycedrus* ssp. *macrocarpa*
Junipero turbinatae–Quercetum calliprini Bartolo et al. (1982)	Pioneer thermo-xerophilous maquis	–	Nutrient-poor coastal dune	0–200 m a.s.l. Caltagirone, Scoglitti and along Ippari river	*Juniperus turbinata, Quercus calliprinos*

model was developed with a weighted mixed-effect regression model within the framework of generalised additive modelling (GAM, Heegaard et al. 2005; Fig. 2). This procedure allows estimation of 95% confidence intervals based on dating error, calibration error and the age–depth regression. We forced the depth–age model to pass through the 95% confidence interval of the youngest date (231–229 cm depth, A.D. 1644–1951), since it must be correct for biostratigraphical reasons (historically recorded plantations of *Eucalyptus* in the 19th century and the related expansion of *Eucalyptus* pollen above 176 cm depth).

Pollen and charcoal analysis

Standard techniques, including sieving through 0.5 mm mesh and decanting, treatment with HCl, KOH and HF,

followed by acetolysis (Moore et al. 1991), were used to prepare sediment sub-samples of 1 cm^3 volume (100 samples, with a temporal resolution of 74.6 ± 61.6 years, mean ± standard deviation). *Lycopodium* tablets were added to the sub-samples for estimation of pollen concentrations (Stockmarr 1971). A sum of ca. 400 (mean = 422, standard deviation = 144) pollen grains (excluding aquatic plants and spores) was counted at a standard magnification of ×400. Pollen grains were identified using pollen keys and atlases (Punt et al. 1976–2003; Moore et al. 1991; Reille 1992–1998; Beug 2004) and the reference collection at the Institute of Plant Sciences of the University of Bern, Switzerland. *Quercus* pollen was subdivided according to Beug (2004) into three morphological groups: (1) *Quercus suber*-type, which also includes *Q. cerris*; (2) *Quercus pubescens*-type, including the deciduous oaks except *Q. cerris*; and (3) *Quercus ilex*-type,

Table 2 The sediments of Biviere di Gela

Depth (cm)	Sediment
0–202	Silt with some organic to silty gyttja
202–247	(Silty) gyttja
247–254	Sandy gyttja
254–266	(Silty) gyttja
266–291	Sandy gyttja
291–310	(Silty) gyttja
310–318	Sandy gyttja
314	Tephra
318–321	Gyttja
321–330	Sandy gyttja
330–352	Sand with some silty gyttja
352–361	Silty gyttja
361–428	Sand with some silty gyttja
428–500	Silty gyttja
500–522	Sand, gravel
522–527	Gyttja
527–537	Sand, gravel
537–545	Gyttja
545–561	Sandy gravel
561–562	Gyttja
562–596	Sand with some gyttja
596–612	Sandy gyttja
612–645	Sandy gravel
645–660	Sandy gyttja
660–694	Gyttja
694–700	Silty gyttja
700–727	Gyttja
727–744	Sand with some gyttja
744–761	Silty gyttja
761–791	Sand, gravel
791–802	Gyttja
802–819	Sand, gravel
819–845	Gyttja
845–860	Sandy gyttja
860–864	Gyttja
864–874	Sandy gyttja
874–900	Silty gyttja
900–974	Gyttja
974–999	Fragments of shells, gyttja
999–1,043	Bluish clay, rich in lime

including the evergreen oaks except *Q. suber*. *Q. ilex* is the most widespread evergreen oak in Sicily, though *Q. coccifera* s.l. (including *Q. calliprinos*) also occurs (Pasta et al. 2000; La Mantia and Gianguzzi 2003). Oleaceae pollen is separated into *Fraxinus oxycarpa*-type, *Fraxinus ornus*, *Phillyrea*, *Ligustrum* and *Olea*. *Fraxinus oxycarpa*-type also includes *F. angustifolia* and *F. excelsior*, the latter

being however rare or even absent in southern or insular Italy (Ilardi and Raimondo 1999). *Juniperus* pollen includes *J. oxycedrus*, *J. communis* subsp. *hemisphaerica* and *J. turbinata*. *J. communis* subsp. *communis* is not present on the central Mediterranean islands (Brullo et al. 2001). The pollen diagrams were constructed using TILIA 2.0.b.4 and TgView 2.0.2 (Grimm 1992–2005). Local pollen-assemblage zones (LPAZ) were determined numerically with optimal-sum-of-square partitioning (Birks and Gordon 1985) using the program ZONE 1.2. Statistically significant pollen zones were determined by using the broken-stick model (Bennett 1996). One numerically determined, but statistically not significant zone limit was retained, because it was judged ecologically meaningful.

Microscopic charcoal particles >10 μm were counted on the pollen slides following Tinner and Hu (2003) and Finsinger and Tinner (2005). Concentrations (particles cm^{-3}) and influx (particles cm^{-2} per year) were estimated using the same approach as for pollen. Particle area concentration and influx were estimated by using the Origlio regression equation presented in Tinner et al. (1998) and Tinner and Hu (2003).

Numerical analysis

DCA was used to estimate the gradient length of the underlying latent variables (Hill and Gauch 1980). Because this was more than two standard deviations, DCA was used to extract the major underlying gradients. Rarefaction analysis with a sum of 142 was used to estimate pollen diversity, considered to be a proxy for past biodiversity (Birks and Line 1992; Odgaard 1999). Correlation coefficients between charcoal influx and pollen percentages of some important species were calculated for the period 6600–4000 cal B.P. and tested for significance ($\alpha = 5\%$, two-sided) with Student's *t* test (Table 4). We selected this period, because it includes the transition from (natural) forested to (increasingly human influenced) shrubby maquis environments. This approach follows Tinner et al. (2005, 2006).

Results

Chronology and lithology

The results of radiocarbon dating are presented in Table 3 and the depth–age model in Fig. 2. The youngest calibrated radiocarbon date (median) falls within the model envelope (confidence interval 2σ) of the depth–age model.

The sediments consist of clay from the core base (1,043 cm) to 999 cm, overlain by silty and sandy gyttja (202–999 cm) and detritus gyttja above 202 cm; for more

Table 3 Radiocarbon dates

Lab code	Core	Depth (cm)	Material	^{14}C-dates (B.P.)	Ages cal B.P. (2σ GAM)	Ages cal B.P. in diagram
Poz-14819	BV3	231–229	W	215 ± 30	261–1355	181
Poz-14771	BV3	399–396	Charred Caryophyllaceae S, PE, W, C	1935 ± 35	1294–2303	1945
Poz-14772	BV3	633–630	W	3265 ± 35	3191–4166	3492
Poz-14773	BV3	802–793	TW, C, S, PE	4380 ± 40	4822–5929	4943
Poz-14821	BV3	878–873	C, TW, PE, S, W	5740 ± 35	5756–6715	6538
Poz-14822	BV3	1,015–1,012	W	6970 ± 60	7067–8479	7803

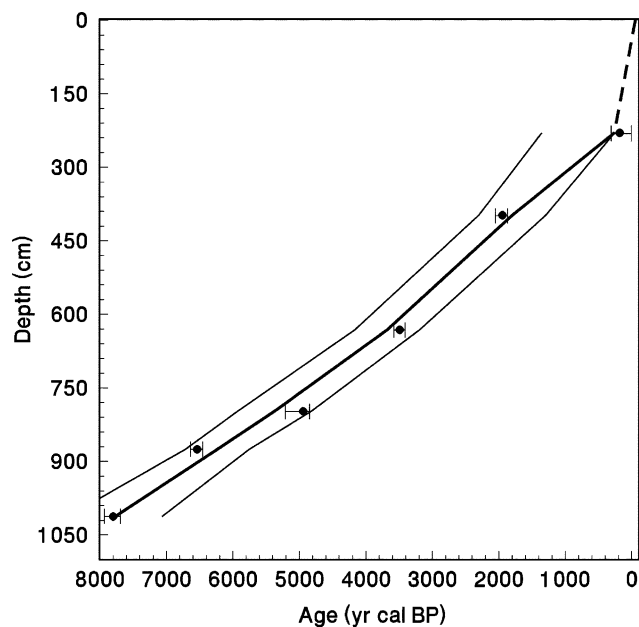*C* charcoal, *PE* periderm, *S* seed, *TW* twig wood, *W* wood

Fig. 2 Age–depth model of Biviere di Gela. It was developed with a weighted mixed-effect regression model within the framework of generalised additive modelling (GAM, Heegaard et al. 2005). We forced the depth–age model to pass through the 95% confidence interval of the youngest date, since it must be correct for biostratigraphical reasons

Table 4 Correlation coefficients between pollen and microscopic charcoal

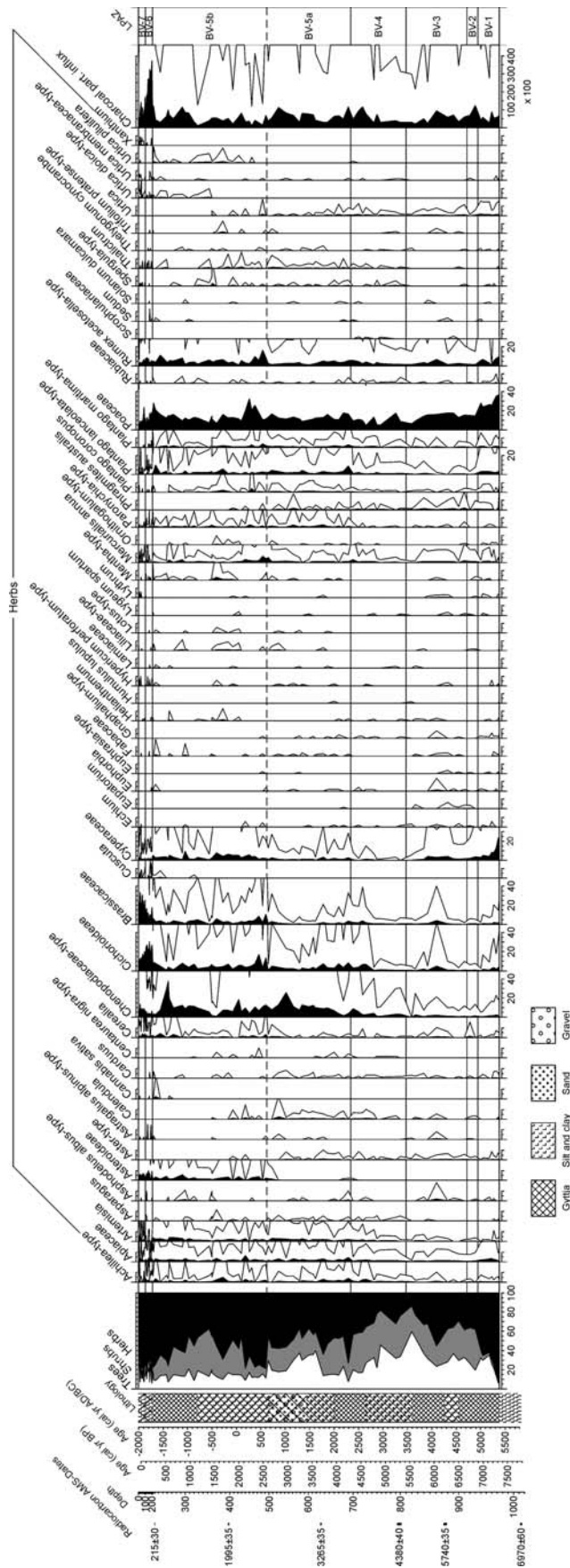| Taxon	Correlation coefficient
Sum of all trees	−0.49
Fraxinus oxycarpa-type	−0.52
Quercus ilex-type	−0.46
Ephedra fragilis-type	+0.44
Juniperus	−0.44
Achillea	+0.45
Cichorioideae	+0.65
Brassicaceae	+0.57

$\alpha = 5\%$, two-sided; level of significance: 0.43

(LPAZ BV-1–7) and two sub-zones (BV-5a, BV-5b; Figs. 3, 4, 5). 263 different pollen and spore types were identified in the Biviere di Gela sequence. Only the most important taxa are presented in the pollen diagrams.

LPAZ BV-1 (ca. 7300–6900 cal B.P.) is dominated by Poaceae pollen, which decreases in the upper part of the zone. *Plantago lanceolata*-type pollen remains rather constant at relatively high levels, and *Mercurialis annua* increases towards the middle of the zone as *Rumex acetosella*-type reaches a minimum. *Urtica dioica*-type pollen is constantly present, and Chenopodiaceae-type, Cichorioideae and Brassicaceae decrease towards the top. The sum of herb pollen decreases from about 90% to 50%, whereas tree pollen increases to almost 30%. *Quercus pubescens*-type pollen reaches a peak in the middle of the zone and *Quercus ilex*-type increases at the top of the zone. *Fraxinus oxycarpa*-type is, after the oaks, the most abundant tree pollen, reaching a peak in the middle of the zone. *Olea* pollen appears and remains constantly low. Shrub pollen increases together with tree pollen. *Juniperus, Pistacia, Erica arborea*-type*, Ephedra fragilis*-type*, Vitis* and *Corylus* are the most important shrub pollen types. Total pollen concentration is oscillating between 30,000 and 74,000 pollen grains/cm^3 sediment, influx 2,710–6,567 grains/cm^2 per year. Average estimated pollen diversity is 30.

detail see Table 2. The gravel and sand layers do not reflect erosional events; instead they are probably a consequence of salinity changes as evidenced by the crystalline structure of the grains. Numerous marine shell fragments between 974 and 999 cm indicate a substantial transgression of the sea. A tephra layer at 314 cm was dated ca. 1260 cal B.P. (by the depth–age model), but this age does not correspond to any other tephra horizons so far found in Sicily (e.g. Sadori and Narcisi 2001).

Pollen stratigraphy

The pollen percentage diagram is subdivided into seven statistically significant local pollen-assemblage zones

Fig. 3 Arboreal pollen percentage and charcoal diagram of Biviere di Gela. Only selected pollen types are shown. *Empty curves* show 10× exaggerations. Pollen analysts: R. Noti and J. F. N. van Leeuwen

◄ **Fig. 4** Non arboreal pollen percentage and charcoal diagram of Biviere di Gela. Only selected pollen types are shown. *Empty curves* show 10× exaggerations. Pollen analysts: R. Noti and J. F. N. van Leeuwen

LPAZ BV-2 (ca. 6900–6650 cal B.P.) is characterised by a huge peak of *Juniperus* pollen, resulting in a shrub pollen sum of 40%. Other pollen types such as *Quercus ilex*-type, *Olea, Q. suber*-type, *Corylus* and Poaceae decline or remain stable. Total pollen concentration is 108,000 grains/cm^3 for the first sample and 146,000 grains/cm^3 for the second, the influx is 9,633–13,000 grains/cm^2 per year. NAP is below 40%. Average estimated pollen diversity is 26.

LPAZ BV-3 (ca. 6650–5400 cal B.P.) is characterised by a marked increase in *Pistacia* pollen at the base of the zone, while *Juniperus* decreases and *Quercus ilex*-type reaches a marked peak towards the top. *Fraxinus oxycarpa*-type pollen remains constant at 3–5%, while *Taxus* appears and disappears again and *Ulmus* reaches a peak at the top together with *Olea.* Also *Tamarix* and *Erica arborea*-type pollen rises towards the top of the zone. Tree pollen (especially *Q. ilex*-type) reaches its mid and late-Holocene peak at about 60%, while trees + shrubs reach >80%. Pollen of herbs such as Cichorioideae, Brassicaceae and *Rumex acetosella*-type reaches a peak at about 6000 cal B.P. Total pollen concentration oscillates between 37,000 and 92,000 grains/cm^3, the influx is 2,993–24,821 grains/cm^2 per year. The uppermost sample is quite different, with 291,000 grain/cm^3. NAP is 15–55%. Average estimated pollen diversity is 26.

LPAZ BV-4 (ca. 5400–4300 cal B.P.) is dominated by *Pistacia* pollen, whereas *Quercus ilex*-type decreases rapidly and markedly in the middle of the zone, at ca. 4800 cal B.P. *Quercus suber*-type is already increasing at the end of zone BV-3 and reaches a peak towards the top of the present zone, while *Olea* and *Juniperus* pollen remains relatively constant at ca. 5%. *Tamarix* and *Ephedra fragilis*-type pollen increases, whereas *Erica arborea*-type reaches a maximum and decreases towards the top of the zone. Pollen of herbaceous taxa such as Chenopodiaceae-type, Cichorioideae, Brassicaceae, *Mercurialis annua* and *Rumex acetosella*-type increases towards the top of the zone. Total pollen concentration oscillates between 56,000 and 175,000 grains/cm^3, the influx is 5,743–13,109 grains/cm^2 per year. NAP is 25–45%. Average estimated pollen diversity is 28.

LPAZ BV-5 (ca. 4300–250 cal B.P.) is rather long and heterogeneous and is thus subdivided at ca. 2600 cal B.P. Sub-zone BV-5a is characterised by the dominance of *Pistacia* pollen, but with lower values than in zone BV-4, decreasing towards the top. *Quercus ilex*-type,

Fig. 5 Wetland, aquatic pollen and non pollen palynomorphs (NPP) ▶ diagram of Biviere di Gela. These pollen and spore types were excluded from pollen sum. *Empty curves* show 10× exaggerations. Pollen analysts: R. Noti and J. F. N. van Leeuwen
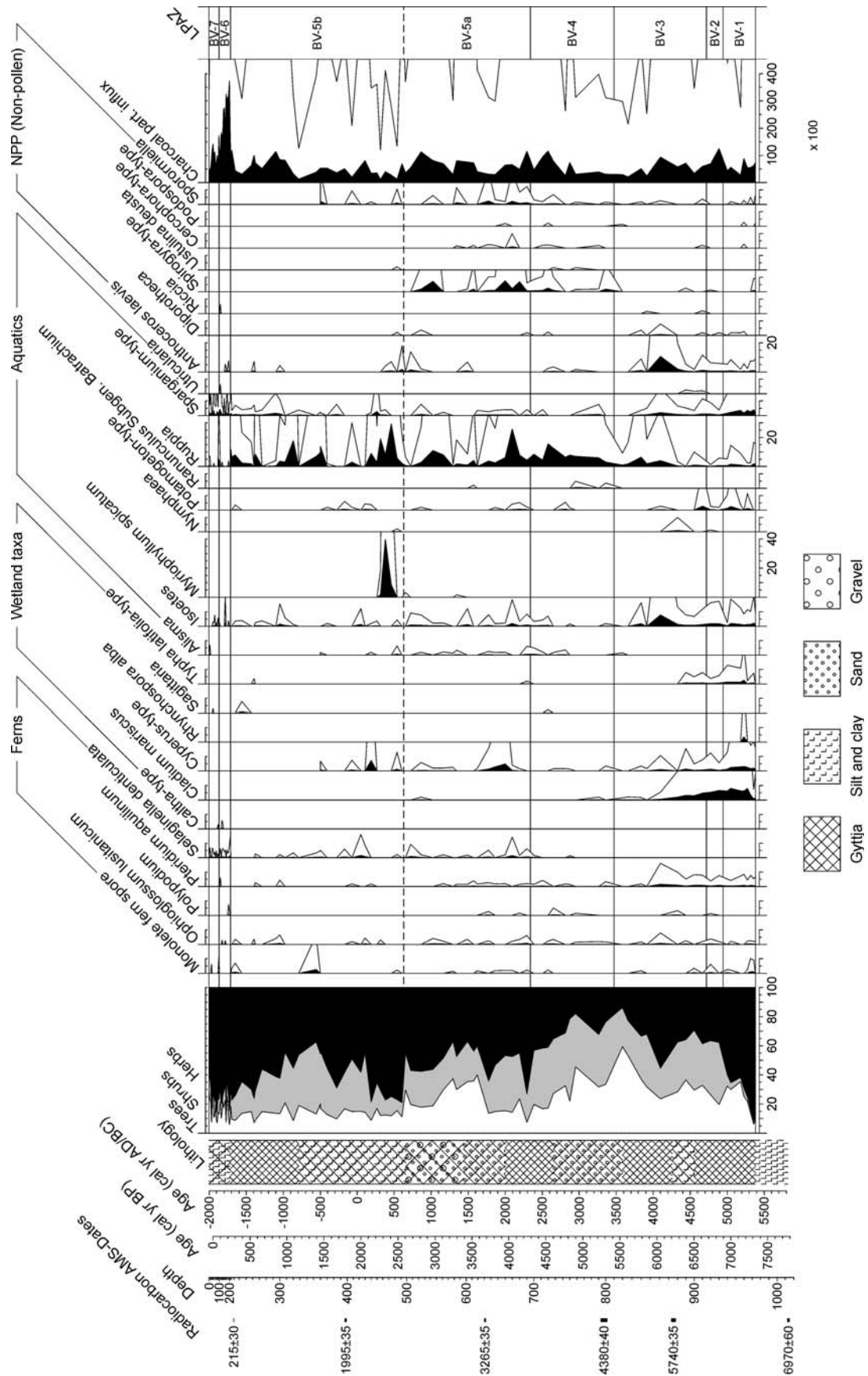
Q. suber-type and *Olea* pollen increases in the middle of the zone and decreases towards the top. Shrub pollen is decreasing, and tree pollen reaches >40% for the last time. Herb pollen increases towards the top, Chenopodiaceae-type reaches high values and *Chamaerops humilis* expands markedly never to disappear until the top of the core. Total pollen concentration oscillates between 24,000 and 157,300 grains/cm^3, the influx is 2,971–19,592 grains/cm^3 per year. NAP is 40–70%. Average estimated pollen diversity is 31.

The transition between subzones BV-5a and -5b (ca. 2600 cal B.P.) is characterised by a peak in *Quercus suber*-type pollen, its subsequent rather abrupt decrease, and a strong decrease in *Pistacia* pollen. In the middle of sub-zone BV-5b shrub pollen reaches high values, mostly due to a marked peak in *Pistacia*. Pollen of other shrubs such as *Juniperus*, *Salix, Phillyrea* and *Cistus* show a similar pattern and increase as well. The peak in *Pistacia* pollen is preceded and followed by peaks in *Chamaerops* pollen, which decreases towards the top. At the base of the zone, Poaceae pollen shows a peak and then declines to the level of the underlying zones, but increases again towards the top. *Plantago lanceolata*-type and Chenopodiaceae-type pollen reach their maximum at the top of the sub-zone. Total pollen concentration oscillates between 29,500 and 198,000 grains/cm^3, the influx is 3,225–28,996 grains/cm^2 per year. NAP is 50–85%. Average estimated pollen diversity is 31.

Zone BV-6 (ca. 250–50 cal B.P.) is characterised by a strong presence of *Olea* pollen, which reaches its maximum in the middle of the zone. *Cistus* pollen also plays an important role together with *Vitis* and *Ephedra fragilis*-type. *Eucalyptus* pollen is recorded for the first time. Herb pollen shows different patterns: Cichorioideae rises at the base and decreases towards the top, Brassicaceae increases over the entire zone, while Poaceae declines. Total pollen concentration oscillates between 10,200 and 41,500 grains/cm^3, the influx is 7,450–30,337 grains/cm^2 per year. NAP is 70–80%. Average estimated pollen diversity is 26.

Zone BV-7 (after ca. 50 cal B.P., i.e. A.D. 1900–2003) is characterised by a strong dominance of herb pollen. Brassicaceae, Chenopodiaceae-type and *Artemisia* pollen increases, while that of Poaceae and Cichorioideae declines. Arboreal pollen is strongly reduced at the base of the zone, but recovers towards the top with maximum values for *Olea* above 20% and *Juniperus* at about 10%. Total pollen concentration oscillates between 9,100 and 29,400 grains/cm^3, the influx is 6,681–21,479 grains/cm^3 per year. NAP is 55–90%. Average estimated pollen diversity is 26.

Rarefaction analysis was used to estimate pollen diversity (Birks and Line 1992; Odgaard 1999) and the results are plotted in Fig. 6. With exception of the past 500 years, the overall tendency shows that the pollen diversity decreases when arboreal pollen increases and vice versa.

Charcoal stratigraphy

Microscopic charcoal concentrations and influx are presented together with the pollen percentages (Figs. 3, 4, 5). The overall tendency is that charcoal influx is high when herb pollen percentages are high and those of tree pollen

Fig. 6 Main pollen diagram, sample scores of *DCA- axis 1* and *axis 2*, and estimated pollen richness (rarefaction analysis)
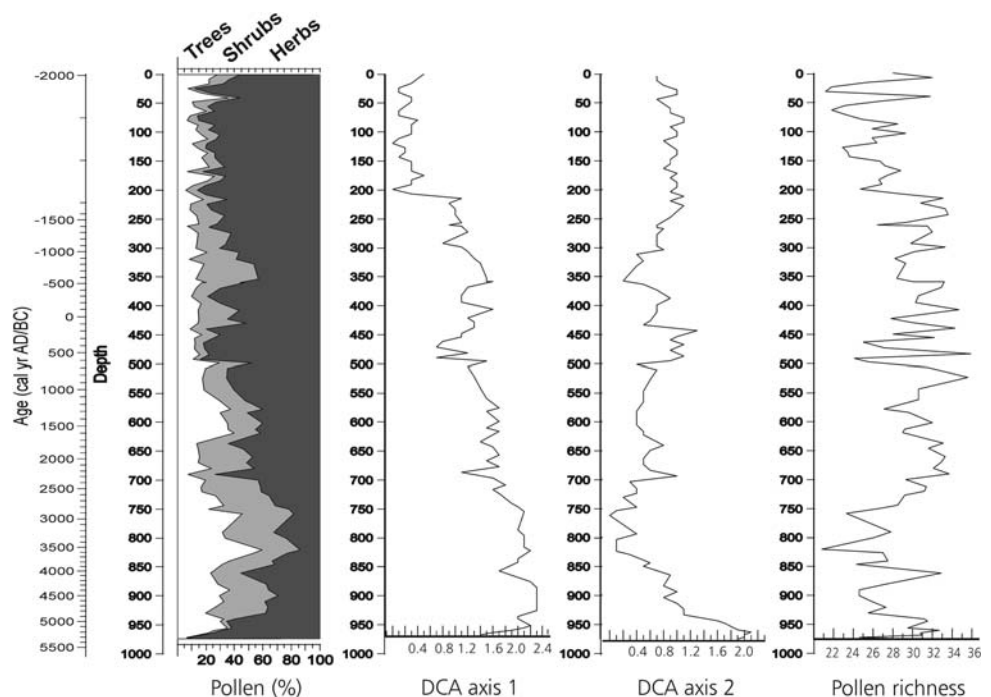
low. However, there is a remarkable charcoal peak in zone BV-2 (ca. 12,500, 4 mm^2/cm^2 per year, 6840 cal B.P.) together with a dominance of *Juniperus* pollen. High values are persistent until the marked increase of *Quercus ilex* pollen-type in zone BV-3 (ca. 2,150, 0.8 mm^2/cm^2 per year, 5613 cal B.P.). The next maximum (ca. 11,500, 4 mm^2/cm^2 per year, 4530 cal B.P.) appears where *Pistacia* pollen suddenly declines together with *Q. ilex*-type, and *Fraxinus oxycarpa*-type almost disappears (transition zone BV-4/5a, ca. 4530–4250 cal B.P.). Towards the top of sub-zone BV-5a (2810 cal B.P.), a charcoal peak (ca. 11,390, 4 mm^2/cm^2 per year) is again synchronous with a decrease in *Q. ilex*-type and *Q. suber*-type pollen, as well as in *Fraxinus oxycarpa*-type, although the signal is less clear for *Pistacia*. In sub-zone BV-5b, a decrease in *Pistacia* pollen and the increase of charcoal are again very well linked (min.: ca. 1,265, 0.4 mm^2/cm^2 per year, 1160 cal B.P.; max: ca. 12,000, 4 mm^2/cm^2 per year, 254 cal B.P.). In zone BV-6, the charcoal influx reaches its maximum (ca. 32,600, 10 mm^2/cm^2 per year, 177 cal B.P.), but this peak may be overestimated due to chronological uncertainty resulting in overestimation of sedimentation rates. In fact, in contrast to all previous charcoal influx peaks, this one has no accompanying concentration maximum. The same problem may affect the charcoal record in zone BV-7, where the influx has a minimum at the base (ca. 6,645, 2 mm^2/cm^2 per year, 46 cal B.P.), a maximum in the middle (ca. 14,180, 5 mm^2/cm^2 per year, 2 cal B.P.), and again a minimum towards the top (ca. 3,337, 1 mm^2/cm^2 per year, A.D. 2003).

Ordination (DCA)

If aligned along the depth or age scale, the sample scores of DCA axis 1 closely follow total arboreal pollen percentages, while axis 2 more or less mirrors total herb pollen (Fig. 6), suggesting that these axes summarize a gradient from forested to open landscape in different ways (Fig. 4). The DCA species scores for axis 1 (Fig. 7a) show a gradient running from herb dominated samples (e.g. Brassicaceae, Cichorioideae, Cerealia-type) to tree and shrub dominated samples (e.g. *Quercus ilex*, *Q. pubescens*, *Pistacia*), while for axis 2, it spans from evergreen Mediterranean vegetation (e.g. *Q. ilex*, *Pistacia*) to deciduous sub-mediterranean vegetation (e.g. *Q. pubescens*, *Ostrya*, *Corylus*).

Sample scores aligned along axes 1 and 2 according to the stratigraphy (Fig. 7b), and the different pollen zones (rectangles), show the changes of vegetation through time. From zone BV-1 to BV-4, scores of axis 2 decrease to a minimum. From zone BV-5 to BV-6, scores on axis 1 decrease but on axis 2 gradually increase to more or less stable values in zone BV-7. This results in a clear trend through time, from top-right (BV-1) to bottom-right (BV-2, BV-3, BV-5a) and finally to the left.
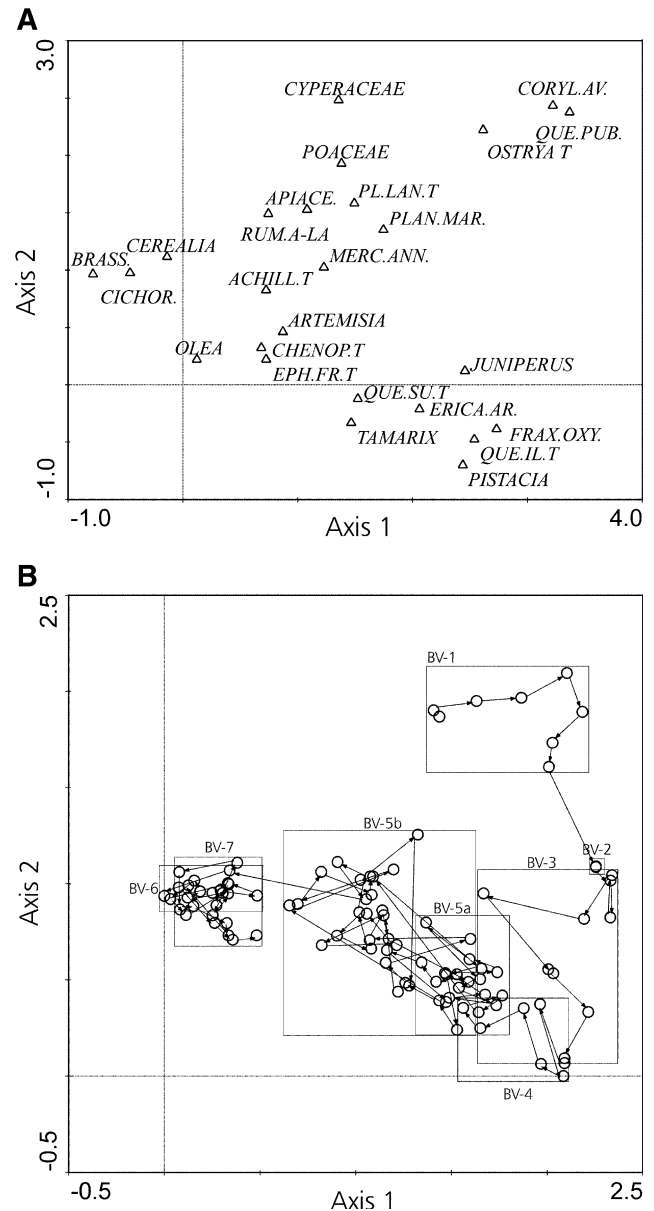
Fig. 7 Sample and species scores of DCA analysis. **a** *DCA- axes 1 and 2 of species scores*. **b** *DCA- axes 1 and 2 of sample scores*. *Rectangles* show LPAZ of Biviere di Gela according to optimal partitioning and b-stick analyses

Charcoal/pollen correlations

About 30 pollen types representing important plant taxa have been compared with microscopic charcoal influx for the period 6600-4000 cal B.P. to search for statistically significant correlations (Table 4). Tree pollen such as *Quercus ilex*-type and *Fraxinus oxycarpa*-type is significantly negatively correlated with charcoal, whereas herb pollen and *Ephedra fragilis*-type show significant positive correlation. In general, pollen of trees and shrubs (e.g. *Juniperus*) is negatively correlated with charcoal, and most herb pollen positively. This trend is also shown by taxa of

Table 5 Pre-historical and historical periods in coastal southern Sicily

Cultural Period	Age (cal A.D./B.C.)
Modern times	A.D. 1492–present
Middle ages	A.D. 568–1492
Migration period	A.D. 375–568
Roman period	212 B.C.–A.D. 375
Greek period	735–212 B.C.
Iron Age	900–735 B.C.
Late Bronze Age	1200–900 B.C.
Middle Bronze Age	1500–1200 B.C.
Early Bronze Age	2300–1500 B.C.
Late Neolithic/Copper Age	3500–2300 B.C.
Middle Neolithic	5000–3500 B.C.
Early Neolithic	6000–5000 B.C.
Mesolithic	9200–6000 B.C.
Palaeolithic	Before 9200 B.C.

Source: Leighton (1999)

which the correlation is not significantly correlated according to the statistical analyses (not shown).

Discussion

Climate as the primary trigger of weakly human-influenced vegetation before 5000 cal B.P. (3050 B.C.)

The marine transgression suggested by shells prior to ca. 7300 cal B.P. may correspond to the Versilian transgression that ended around 8000 cal B.P. (Federici 1993). Directly after the marine transgression treeless vegetation prevailed, which was rapidly replaced by deciduous forests and shrublands (zone BV-1, ca. 7300-6900 cal B.P.) of *Quercus pubescens*, *Ostrya* and *Fraxinus* lasting for ca. 200–300 years. Evergreen *Q. ilex* became dominant only after ca. 7000 cal B.P., probably accompanied by *Q. coccifera* s.l. on the driest sites (Pasta et al. 2000). *Olea* expanded rapidly around 7200 cal B.P. together with *Q. ilex*. Morphometric analyses of olive charcoals from archaeological sites in eastern Spain (Terral 1996) indicate that there olive was the earliest cultivated fruit, possibly dating back to ca. 8000–7000 cal B.P. (Early Neolithic). However, investigations (gas chromatographical analyses) of the Iron Age in Sicily indicated only the local use of animal fat and not of olives (Agozzino 2005), suggesting that in contrast to the Greek settlers (e.g. in Selinunte), the local Sicilian settlers ignored or did not cultivate them (Stika et al. 2008). Nevertheless, according to Sadori and Narcisi (2001), it is not clear whether the expansion of *Olea* (also dated 7200

cal B.P.) at Lago di Pergusa in central Sicily was due to the beginning of olive cultivation or to climate change. Our results (expansion of other forest trees together with *Olea*, especially *Quercus ilex*) clearly point to natural expansion, possibly in response to climatic change at Biviere di Gela.

At 7000 cal B.P., the climate shifted to moister conditions at several sites in southern Spain including Laguna de Medina, a lagoon located at a similar latitude to Biviere di Gela (Reed et al. 2001; Carrión 2002). Pollen-independent data indicate that in southern Spain humid conditions lasted until ca. 6000–5000 cal B.P., after which the climate became gradually drier (Reed et al. 2001; Carrión 2002). In agreement, our pollen data suggest that in the Gela area forests and shrublands reached maximum density during 7000–5000 cal B.P., after which arboreal vegetation gradually declined. However, it is also conceivable that the afforestation at Biviere di Gela at 7000 cal B.P. reflected only the recovery of local vegetation after the marine transgression rather than the regional trend.

It is intriguing that the expansion of evergreen forests might have been triggered by an increase of humidity under the very arid and hot conditions at Biviere di Gela, whereas towards the north, e.g. at Lago di Massaciuccoli, Lago dell'Accesa or Malo Jezero (Fig. 1), *Quercus ilex* was benefited by shifts towards drier climatic conditions (Jahns and van den Bogaard 1998; Drescher-Schneider et al. 2007; Colombaroli et al. 2008a). We explain this somewhat paradoxical behaviour of *Q. ilex* by the environmental dissimilarities at the sites. In fact, in coastal southern Sicily, the species is limited by drought and thus in competition with drought adapted maquis, whereas in the cooler and moister north it is in competition with taller, but less drought adapted deciduous trees (Colombaroli et al. 2008a).

The presence of maquis taxa like *Erica arborea*, *Ephedra fragilis* and *Phillyrea* as well as *Pistacia* shrubberies suggests that the forest was not very dense, even during the period of maximum density between 7000 and 5000 cal B.P. However, forests that had expanded around Biviere di Gela at 7300–7000 cal B.P. also contained rather mesophilous trees (e.g. *Quercus pubescens*, *Ostrya*, *Fraxinus oxycarpa*), which were probably growing on moister soils (e.g. north-facing slopes, along creeks). In upland Sicily, dense forests had expanded earlier during the early Holocene (Bertolani Marchetti et al. 1984; Sadori and Narcisi 2001). These differences between the Sicilian sites may be related to different environmental conditions between the cooler Sicilian uplands and the warmer coast.

Our pollen data suggest that, as at other sites in southern Europe (Colombaroli et al. 2008b), local Neolithic human activity (Table 5) had already started at the onset of the Biviere di Gela pollen record at 7000 cal B.P. (Cerealia-type, *Plantago lanceolata*-type, Chenopodiaceae-type, Cichorioideae, *Mercurialis annua* and Brassicaceae, together

with *Sporormiella* dung-fungal spores). However, the evidence is not entirely unambiguous, since plants producing these pollen types may also have been present in the natural Mediterranean vegetation of that time (Lang 1994). The dominance of *Juniperus* during ca. 6900–6600 cal B.P. (zone BV-2) suggests rather open heliophilous vegetation. The decline of e.g. *Quercus ilex*-type and *Fraxinus oxycarpa*-type associated with the expansion of *Juniperus* are not artefacts of percentage calculation, since they are also represented in the pollen concentrations and influx. Interestingly, fire activity inferred from microscopic charcoal increased and decreased together with *Juniperus*, indicating that fire contributed to the strong *Juniperus* expansion at 6900 cal B.P. A similar vegetational sequence with *Juniperus* expanding after the establishment of deciduous mixed-oak forests, but preceding the spread of evergreen oak forests has also been observed at the lagoon of Malo Jezero in southern Croatia (Fig. 1, Jahns and van den Bogaard 1998; Jahns 2002; Colombaroli et al. 2008a). At Biviere di Gela, the pollen data suggest that the dominance of *Juniperus* was followed by expansion of *Pistacia* shrublands at 6600 cal B.P. (zone BV-3). It is difficult to judge whether the *Pistacia* expansion was natural or anthropogenic. Today evergreen *Pistacia lentiscus* is abundant in maquis, where it occurs together with evergreen trees (e.g. *Quercus ilex* and *Olea europaea*). Habitats range from the dune and coastal environments to the uplands (see Table 1 for more details). On the one hand, the decrease of herbs suggests declining anthropogenic activity. On the other, transient and minor increases of Cerealia-type and *Plantago lanceolata* around 6600 cal B.P. may suggest modest agricultural activity. Anyway, agricultural activity increased around 6300–6200 cal B.P. (Cerealia-type, *Asphodelus albus*-type, Cichorioideae, Brassicaceae and *Rumex acetosella*). Around 6200–5500 cal B.P. *Quercus ilex*, *Fraxinus oxycarpa*, *Ulmus* and *Olea* became more important in the rather closed woods, where other trees or shrubs such as *Juniperus* and *Erica arborea* were also present. *Tamarix* was probably growing near the lake shore. Forested environments reached their maximum expansion (59% tree pollen) at 5540 cal B.P. when *Pistacia* shrublands declined.

Fire frequency was higher during the dominance of *Pistacia* and significantly decreased when *Q. ilex* (and possibly *Q. coccifera* s.l.) became the dominant trees. Recent studies from Italy and Croatia suggest that low fire incidence and high abundances of *Q. ilex* were closely linked over millennia in those regions (Colombaroli et al. 2007, 2008a, b; Vannière et al. 2008). However, given the presence of anthropogenic activity during the *Pistacia* phase at Biviere di Gela, it is likely that most fires were of anthropogenic origin.

In contrast to Biviere di Gela, pollen concentration data from Lago di Pergusa suggest that forests in upland central Sicily began to decline slowly around 6800 cal B.P. Forests there contracted to a minimum around 5700 cal B.P. (Sadori and Narcisi 2001), when around Biviere di Gela they were still expanding. The trend at Lago di Pergusa matches other Mediterranean records, e.g. from the Balearic islands, at Albufera d'Alcudia in Mallorca (Burjachs et al. 1994, Pérez-Obiol and Sadori 2007) and at Cala Galdana in Minorca (Yll et al. 1994), and also from continental Spain, at Navarrés near Valencia (Yll et al. 1997; Carrión and van Geel 1999) with shifts towards more xeric conditions between 6800 and 5700 cal B.P. The good match of the record from Biviere with pollen (e.g. Pantaléon-Cano et al. 2003) and paleoclimatic records of southern Spain (pointing to a humid phase during 7000–5000 cal B.P.; Reed et al. 2001; Carrión 2002) as well as the good match of the Lago di Pergusa record with records from central Spain and the Balearic islands might be explained by the high spatial variability of past precipitation patterns.

Effects of Neolithic and Copper Age land-use after 5000 cal B.P. (3050 B.C.)

Pistacia shrublands in the Biviere di Gela area persisted with unchanged high abundance until ca. 4300 cal B.P. (zone BV-4). Evergreen *Quercus ilex*-dominated forests had already started to decline around 5400 cal B.P., but this trend became pronounced only between 5000 and 4000 cal B.P., with a partial shift from evergreen forests to *Pistacia*-dominated shrublands. Other maquis shrubs such as *Tamarix*, *Erica arborea* and *Ephedra fragilis* remained stable or expanded. However, *Juniperus* declined together with *Q. ilex*, but this was in part compensated by the rise of *Q. suber*, an evergreen oak growing both in forest and in maquis. The rather large presence of *Fraxinus oxycarpa* and *Olea* as well as remnant *Q. ilex*, however, suggests that the woodlands were only partially displaced. A marked increase in agricultural and pastoral activity is suggested by an increase in, for example, Cichorioideae, Brassicaceae, *Rumex acetosella* and *Sporormiella*. We thus assume that this gradual but marked shift from woodland to maquis, which reached its culmination around 4300 cal B.P. with the expansion of the palm *Chamaerops humilis*, was the direct consequence of human activity. However, *Chamaerops humilis* was present prior to 4300 cal B.P. (single pollen grains found) probably in rather open habitats. Regional fire frequency increased substantially as forested environments with *Q. ilex*, *Olea* and *Fraxinus* declined (Fig. 3). Correlation analyses for the period 6600–4000 cal B.P. show that fire not only contributed to the disruption of forest, but also favoured the expansion of shrubs and herbs (e.g. *Achillea*, Cichorioideae, Brassicaceae and *Ephedra fragilis*; Table 4). It is noteworthy that the transition from forested to more open environments (boundary between

LPAZ BV-4 and BV-5) approximately corresponds to the transition between the Copper and Bronze Ages (4300 cal B.P., 2350 cal B.C.).

Climatic change probably exacerbated the effects of human impact between 5000 and 4000 cal B.P. Several studies show that climate in the Mediterranean region became drier ca. 5300–4800 cal B.P. (e.g. Magny and Haas 2004; Marchetto et al. 2008; Vannière et al. 2008). In agreement with this, a final reduction of forest biomass occurred somewhat after 4900 cal B.P. at Lago di Pergusa in upland Sicily, well correlated with a minor drop in tree pollen concentration at Lago di Vico in central Italy (Lazio) dated to around 4850 cal B.P. (Magri and Sadori 1999). Furthermore, an important change in vegetation occurred after ca. 5300 cal B.P. at Dar Fatma in the mountains of neighbouring Tunisia (Ben Tiba and Reille 1982). There, the sharp decline of *Quercus canariensis* was accompanied by an increase of both *Q. suber* and *Erica arborea*. This vegetational shift was interpreted as being triggered by a change towards more arid conditions. However, at Biviere di Gela, comparable drastic vegetational changes did not occur before 2600 cal B.P., when important forest elements such as evergreen oak became as marginal as they are today. Indeed forest vegetation (*Quercus ilex*, *Q. suber*, *Fraxinus oxycarpa* and *Olea*) partly recovered between 3700 and 2600 cal B.P. (zone BV-5a), when according to the pollen record, human impact slightly diminished.

Establishment of human influenced vegetation as a consequence of the foundation of ancient Greek towns

Pistacia and *Chamaerops humilis*-dominated maquis as well as the remnant evergreen forests declined abruptly at ca. 2600 cal B.P. (650 B.C.; onset of sub-zone BV-5b). This vegetational change falls in the historically documented Greek colonisation around Gela (Panvini 1996). It was accompanied by a strong increase of agricultural activity (e.g. increase of Cerealia, *Rumex acetosella*, Cichorioideae, Asteroideae, Brassicaceae and *Mercurialis annua*) and was preceded by the first indications of local *Castanea* trees (sweet chestnut) at 2650 cal B.P. (700 cal B.C.). Thus Greek colonists probably favoured sweet chestnut in southern Sicily. Intense human impact continued for about 400 years (e.g. high values of *Rumex acetosella* and Cichorioideae). *Fraxinus oxycarpa* almost completely disappeared and *Olea* became the dominant tree. It is therefore likely that the Greek colonists cultivated olives, as is also suggested by archaeobotanical studies from western Sicily (Stika et al. 2008). Non-cultivated landscape was probably garrigue and Mediterranean grassland, a result of intense slashing and browsing (Poaceae and *Juniperus* reaching almost 80%). According to ecologists

(e.g. Chiappini 1988; Reisigl et al. 1992; Pignatti 1997, 1998) the formation of garrigue and Mediteranean grasslands (or steppe) is closely related to heavy human impact such as repeated burning or clear-cutting. The excellent match of our new Biviere di Gela record with historical sources convincingly shows that the conversion of forests and shrublands into the very open cultural landscape of today at ca. 2600 cal B.P. was primarily the consequence of human land-use related to the Greek colonization. After the Greeks, the Romans ruled the area between ca. 200 B.C. and A.D. 400, but the town of Gela had been already destroyed in 282 B.C. and was not populated until the Middle Ages (Panvini 1996). The abandonment of the town is well reflected in our pollen record. After ca. 2200 cal B.P. (250 B.C.) *Fraxinus oxycarpa* partly re-established, *Olea* decreased and evergreen oak re-expanded slightly. Shrublands of *Pistacia*, *Chamaerops humilis* and *Juniperus* became much more wide-spread, probably on abandoned pasture. Another hint of land abandonment is the decrease in grasses, although other indicators of human impact decreased only slightly with exception of Chenopodiaceae. The latter, however, also represents halophytes, and therefore may be not related to human impact in coastal areas. At the very end of the Roman period, around A.D. 300–400, human impact apparently increased transiently (e.g. Chenopodiaceae and Brassicaceae).

In the early Middle Ages, the arboreal vegetation recovered slightly, as *Pistacia*, and also *Q. ilex* and other trees, became somewhat stronger, building up maquis and possibly small woods. This suggests a slight decline in human activity during the early medieval period. From around A.D. 1000, the rapid decline of *Pistacia*, the increase of crops and weeds (e.g. Cerealia, *Achillea*, *Artemisia*, *Mercurialis annua*, *Rumex acetosella* and Chenopodiaceae) and the marked increase of fire frequency suggest a further intensification in land-use. Garrigue re-expanded gradually forming the modern Mediterranean vegetation. Around A.D. 1750, human impact became extremely intense (transition zones BV-5b/6) and the sedimentation rate increased markedly, probably as a consequence of both erosional input and higher lake productivity (Fig. 2). According to our pollen record *Eucalyptus* appeared around A.D. 1800 (BV-6), which is in good agreement with its expansion in southern Europe after the discovery of Australia. Cultivated trees were *Olea*, *Castanea* and *Citrus*, and Cerealia cultivation remained important. Cichorioideae were dominant in open lands, for example in olive groves. Finally, only during the past few decades (transition to zone BV-7) *Olea* decreased and *Pinus* increased. *Tamarix* expanded around the lake, where it still grows. Amongst the herbs, Cichorioideae were loosing their dominant position but remained important, whereas Chenopodiaceae and Brassicaceae expanded markedly, probably on disturbed soils around the lake.

Summarizing the vegetational dynamics by DCA analysis: natural versus human influenced vegetation

The main patterns of vegetational change over the past 7,000 years at Biviere di Gela are summarised by DCA axes 1 and 2 of species and sample scores. DCA axis 1 of species scores probably reflects the gradient from forested to open environments as well as increasing human impact (Fig. 7a), given the relation between high scores of some important forest and shrubland plants such as *Quercus pubescens*-type, *Corylus*, *Ostrya*-type, *Fraxinus oxycarpa*-type, *Q. ilex*-type, *Pistacia* and *Juniperus* and low scores of pollen of crops or meadow plants such as Cerealia-type, Brassicaceae and Cichorioideae. DCA axis 2 species scores (Fig. 7a) seem to reflect a gradient from summer-drought adapted Mediterranean evergreen vegetation to rather mesophilous sub-Mediterranean deciduous vegetation (e.g. *Olea*, *Ephedra fragilis*-type, *Quercus suber*-type, *Tamarix*, *Erica arborea*-type, *Q. ilex*-type and *Pistacia* with low scores; *Ostrya*-type, *Q. pubescens*-type and *Corylus avellana* with high scores). Herb taxa follow this gradient with high scores for the rather moisture demanding Cyperaceae to the lowest scores for more steppic elements like *Artemisia* or Chenopodiaceae (Fig. 7a). Comparison of DCA axis 1 and 2 sample scores with the zonation (Fig. 7b) and alignment along the time axis (Fig. 6) shows that zone BV-1 is well separated from the other zones, reflecting the dominance of NAP in zone BV-1 (contrasting with the dominance of AP in later zones), while *Pistacia* pollen remains irrelevant. DCA axis 1 sample scores partly correspond to the AP curve (Fig. 6), the highest scores suggesting the highest forest and shrubland cover (e.g. BV-3 and -4). On axis 2 a decisive shift occurs between zone BV-1 and zone BV-2/4, but sample scores increase again in zones BV-5/7 (Fig. 7b). Axis 1 probably follows a land-use gradient, from more natural conditions (zones BV-1/4) to increasingly human influenced landscapes (zones BV-5/7). Axis 2 follows vegetation openness from closed (low scores) to open (high scores). Combining sample scores on DCA axis 1 and 2 (Fig. 7b), it is thus possible to separate natural open Mediterranean from human influenced open environments (zone BV-1 vs. BV-5/7).

Conclusions

During the past 7,000 years, the vegetation around the coastal lake Biviere di Gela (Southern Sicily, Italy) was of Mediterranean type adapted to relatively arid conditions. Our data suggest that forest and shrubland cover reached a maximum between 7000 and 5000 cal B.P., probably in response to moister (or less arid) conditions and low human impact. The mid- and late-Holocene aridification trend observed at many Mediterranean sites (e.g. Reed et al. 2001;

Sadori and Narcisi 2001; Carrión 2002; Marchetto et al. 2008) was not pronounced at our already rather open site, but probably exacerbated the effects of human impact on vegetation during the late-Holocene. Our data suggest that after 5000 cal B.P., humans had a much stronger impact on the landscape near the site than climate change. A major difference between the two existing Sicilian records (the other being Lago di Pergusa in the central highlands) is that deciduous trees and shrubs were never dominant at our coastal site. This probably reflects warmer conditions, absence of frost, and possibly also lower moisture availability at the coast.

On the basis of our palaeovegetational reconstruction, we briefly reconsider the potential natural vegetation of the area following the approach of Tinner et al. (1999). We assume that climate today is not considerably drier than during 6000–2600 cal B.P. From this it follows that potential natural vegetation today is similar to the vegetation reconstructed for that period, with its still minor human impact on vegetation. This time period encompasses the period 5300–5000 cal B.P. recognized as one of the driest in the Mediterranean area (Marchetto et al. 2008), and even under such dry climatic conditions evergreen oak could form coastal stands together with *Olea*, *Juniperus* and somewhat surprisingly, *Fraxinus oxycarpa,* the latter probably in the wetlands around the lake. *Pinus* and deciduous oak were of rather marginal importance, whereas shrublands (especially *Pistacia,* but also *Tamarix*, *Erica arborea*, *Ephedra*, *Cistus* and *Phillyrea*) as well as Mediterranean grasslands were frequent. This vegetational setting is best described by a mosaic of Mediterranean woodland, shrubland and grassland, and we assume that under natural or near-natural conditions these formations would be of similar abundance also today. These results are in good agreement with the ecological estimations provided by Maugeri and Leonardi (1974), Di Benedetto et al. (1984) and Federici and Mangialardi (1995), who also emphasized that woods that are rare today of *Quercus ilex*, *Q. suber*, *Olea, Fraxinus oxycarpa, Pistacia* and *Juniperus* played a much more prominent role under natural or quasi-natural conditions. However, to better assess this issue, additional paleoecological information from other sites in coastal Sicily is needed, which would allow more detailed and spatially precise estimates of past environmental dynamics.

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