Review of Palaeobotany and Palynology 152 (2008) 113–128

Contents lists available at ScienceDirect

Review of Palaeobotany and Palynology

journal homepage: www.elsevier.com/locate/revpalbo

Holocene vegetation and climate records from Lake Sibaya, KwaZulu-Natal (South Africa)

Frank H. Neumann [a,b,*], J. Curt Stager [c], Louis Scott [a], Hendrik J.T. Venter [a], Constanze Weyhenmeyer [d]

[a] Department of Plant Sciences, Faculty of Natural and Agricultural Sciences, University of the Free State, PO Box 339, Bloemfontein 9300, South Africa
[b] Institute for Paleontology, University of Bonn, Nussallee 8, 53115 Bonn, Germany
[c] Natural Sciences, Paul Smith's College, Paul Smiths, NY 12970, USA
[d] Department of Earth Sciences, 204 Heroy Geology Laboratory, Syracuse University, Syracuse, NY 13244-1070, USA

ARTICLE INFO

Article history:
Received 29 September 2007
Received in revised form 9 April 2008
Accepted 10 April 2008
Available online 22 April 2008

Keywords:
palynology
vegetation history
Holocene
South Africa

ABSTRACT

The palynology of two overlapping Holocene cores from Lake Sibaya in KwaZulu-Natal elucidates the relationship between climate, vegetation and human impact in the region. By means of twenty-one AMS ^{14}C dates, loss on ignition, and palynological results we established a composite profile. Pollen assemblages include elements of swamp forest (e.g. *Rauvolfia*, *Macaranga*), dune forest (e.g. *Mimusops*), mangrove vegetation (*Bruguiera*), palmveld (e.g. *Phoenix*) and bushveld (e.g. *Spirostachys*, *Sclerocarya*). Poaceae, aquatics and Cyperaceae are abundant, and fynbos elements like Ericaceae and Restionaceae are rare. Based on comparisons between palynological and archaeological/historical data, the radiocarbon dates seem to show an age error of 50–550 yr, which is probably due to a hardwater reservoir effect. Applying the mean of this error range to our age model suggests that the oldest sediments represent ~6750–7100 cal yr BP, that a >5000 yr hiatus occurs ca. 253 cm depth, and that the upper 253 cm of the composite profile covers the period between ~1300–1500 cal yr BP (~450–650 AD, Early Iron Age), and 2004 AD. The Middle Holocene is characterized by high tree pollen values (especially *Phoenix*) suggesting warm humid conditions. The Early Iron Age is characterized by high *Podocarpus* percentages that indicate moist but possibly cooler climatic conditions. The upper part of the pollen sequence is characterized by the decrease of *Podocarpus*, *Isoglossa* and *Celtis* and a rise in *Spirostachys*. Increasing values of cereal pollen and algae might reflect human activity. *Zea mays* appears ~150–300 cal yr BP in the pollen sequence according to the radiocarbon chronology and both archaeological and historical evidence. The curve of *Pinus* pollen rises to 50–70% at the top of the diagram, reflecting the spread of pine plantations since the 1920's, and Poaceae values decrease. *Stoebe* and the introduction of neophytes like *Ambrosia* and *Casuarina* suggest recent human disturbance.

1. Introduction

High-resolution, continuous records of Holocene climatic history are sparse in the Southern Hemisphere in comparison to the Northern Hemisphere and the tropics (Maley and Brenac, 1998; Mayewski et al., 2004; Salzmann and Hoelzmann, 2005). The shortage of southern African records reflects a scarcity of continuous lake and peat deposits (Scott and Lee-Thorp, 2004), and most palynological studies in the sub-humid parts of the region have dealt with isolated springs and swamps (Coetzee, 1967; Scott, 1982; Meadows and Sugden, 1991; Scott et al., 1996, Meadows and Baxter, 2001, Turner and Plater, 2004). Existing pollen records from coastal lakes are discontinuous and are subject to past marine incursions; such sites include Groenvlei in the southern Cape (Martin, 1968), Verlorenvlei on the west coast (Meadows et al., 1996; Baxter and Meadows, 1999), and Lake Teza on the east coast (Scott and Steenkamp, 1996; Scott, 2002). A Holocene pollen record from the Mdlanzi swamp in KwaZulu-Natal covers 1500 yr based on a single AMS date, but no major change in the composition of the surrounding woodland, represented by generally low tree pollen concentrations, is reported (Turner and Plater 2004). A 9.80 m long core from the Mfabeni peatland at the eastern shore of Lake St. Lucia in KwaZulu-Natal yields a >45,000 yr pollen record but the Holocene sequence has a weak chronology based upon a single AMS date (Finch, 2005). To the north in the Chibuene area of southern coastal Mozambique, two pollen diagrams are available (Ekblom, 2004).

In this paper, we present fine-interval, late Holocene pollen records from coastal Lake Sibaya (also called Sibayi), the largest natural water body in South Africa (surface area: 65 km^2). Our work supplements earlier studies of late Quaternary sedimentological development of the

* Corresponding author. Department of Plant Sciences, Faculty of Natural and Agricultural Sciences, University of the Free State, PO Box 339, Bloemfontein 9300, South Africa. Fax: +27 51 4445945.
E-mail address: fneumann@uni-bonn.de (F.H. Neumann).

0034-6667/$ – see front matter
doi:10.1016/j.revpalbo.2008.04.006

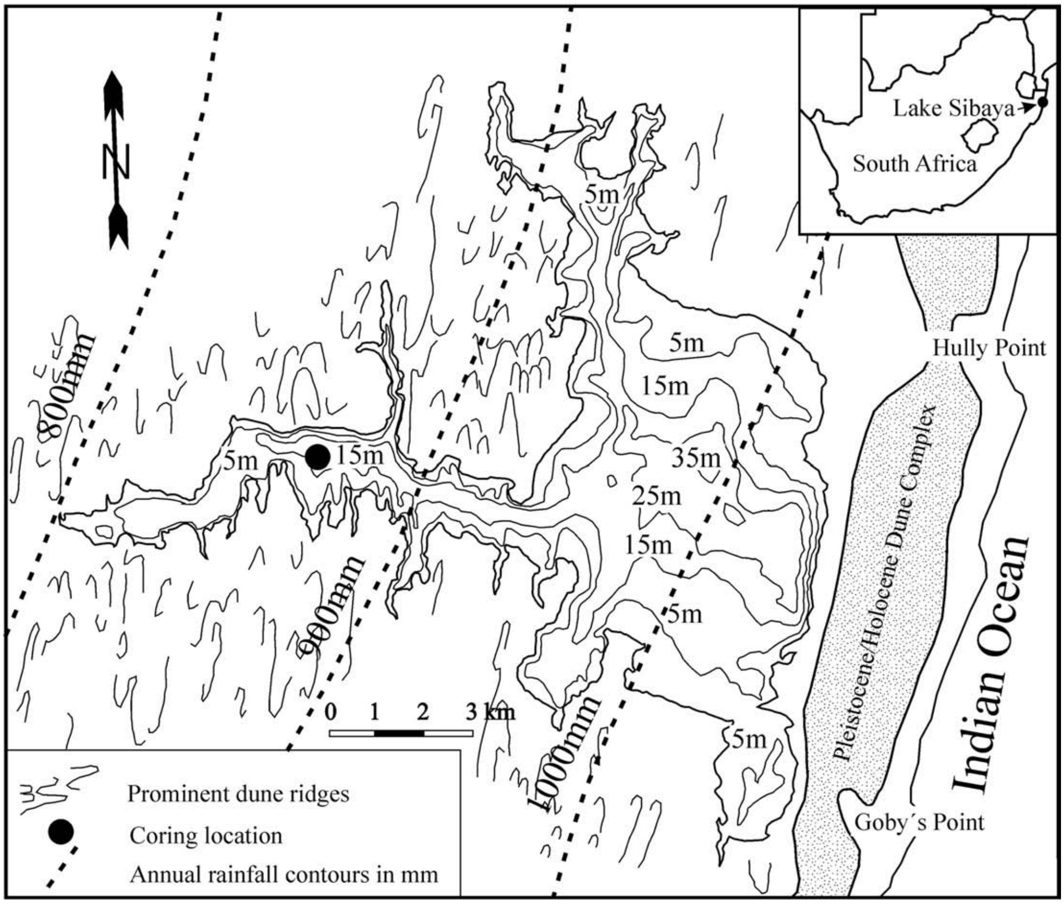

Fig. 1. Morphology of Lake Sibaya (after Wright et al., 2000), coring location. Annual rainfall in mm shown by dashed lines (after Maud, 1980).

lake basin (Miller, 2001) and *Podocarpus* pollen and charcoal profiles from deposits in the vicinity (Scott and Steenkamp, 1996; Mazus, 2000).

During the last 2000 yr Iron Age herders migrated from central Africa southwards along the savanna biome to the eastern and southeastern coasts of South Africa. Climate apparently influenced the pattern of settlement (Vogel, 1995) but it is also likely that those herders influenced the landscape. Detailed reconstructions of natural and human-induced changes in the environment, especially for the last 2000 yr, have not yet been available for this region and our study aims to address this problem. Specifically, the two central aims of this paper are:

1. The establishment of stratigraphic relationships and chronological frameworks for the Lake Sibaya cores.
2. The reconstruction of vegetation history in the Sibaya region during the last 2000 yr.

We also make preliminary comments on Middle Holocene pollen data from the oldest part of the longest core.

2. Regional setting

2.1. Morphology, geology, hydrology, climate

Lake Sibaya is located in Maputaland, on the Makhathini Flats of northern KwaZulu-Natal, while the surface of the coastal lake is ca. 20 m above sea level, the bottom extends to 20 m below sea level (Hill, 1979; Miller, 2001). The lake's catchment covers ca. 540 km^2. Mesozoic volcanics and sediments underlie marine and beach deposits (Hobday, 1979; Miller, 2001). During the Pleistocene, aeolian and shallow-marine sands and clays were deposited in a barrier-lagoon complex related to the last interglacial highstand (Hobday and Orme, 1974; Miller, 2001). In the late Pleistocene, sea level dropped, thus draining proto-Sibaya (Miller, 2001; Botha et al., 2003). Sediments of the Holocene Sibayi formation are largely comprised of marine lagoonal sediments developed in the absence of the coastal dune barrier during the Last Glacial Maximum's marine low stand (Wright et al., 2000; Miller, 2001). Between dunes, freshwater diatomite accumulated during the Early to Middle Holocene (Miller, 2001) as sea level rose to near its present elevation. The coastal dune barrier closed, and lagoonal sediments were deposited between 8800 and 5000 yr BP. Around 5000 yr BP large, broad dunes up to 2 km wide and 134 m high isolated the lake from the sea, and freshwater conditions have prevailed continuously thereafter (Wright et al., 2000; Miller, 2001).

The Sibaya region has a humid subtropical climate (Allanson, 1979b). The Intertropical Convergence Zone (ITCZ) and monsoonal flow from the warm Agulhas current of the western Indian Ocean bring rains to the region during austral summers, but winters are comparatively dry. Average annual rainfall at Sibaya is 900 mm. A steep precipitation gradient exists, with the eastern part of the basin wetter than sites farther inland (Fig. 1; Miller, 2001). Dominant surface wind directions are NE and SW.

2.2. Vegetation

Vegetation in northern KwaZulu-Natal, belonging to the Savanna and Indian Coastal Belt Biome (Fig. 2), is dominated by forest, thicket, and grassland communities (Eeley et al., 1999; Mucina and Rutherford, 2006). All plant names are checked and corrected according to Germishuizen and Meyer (2003).

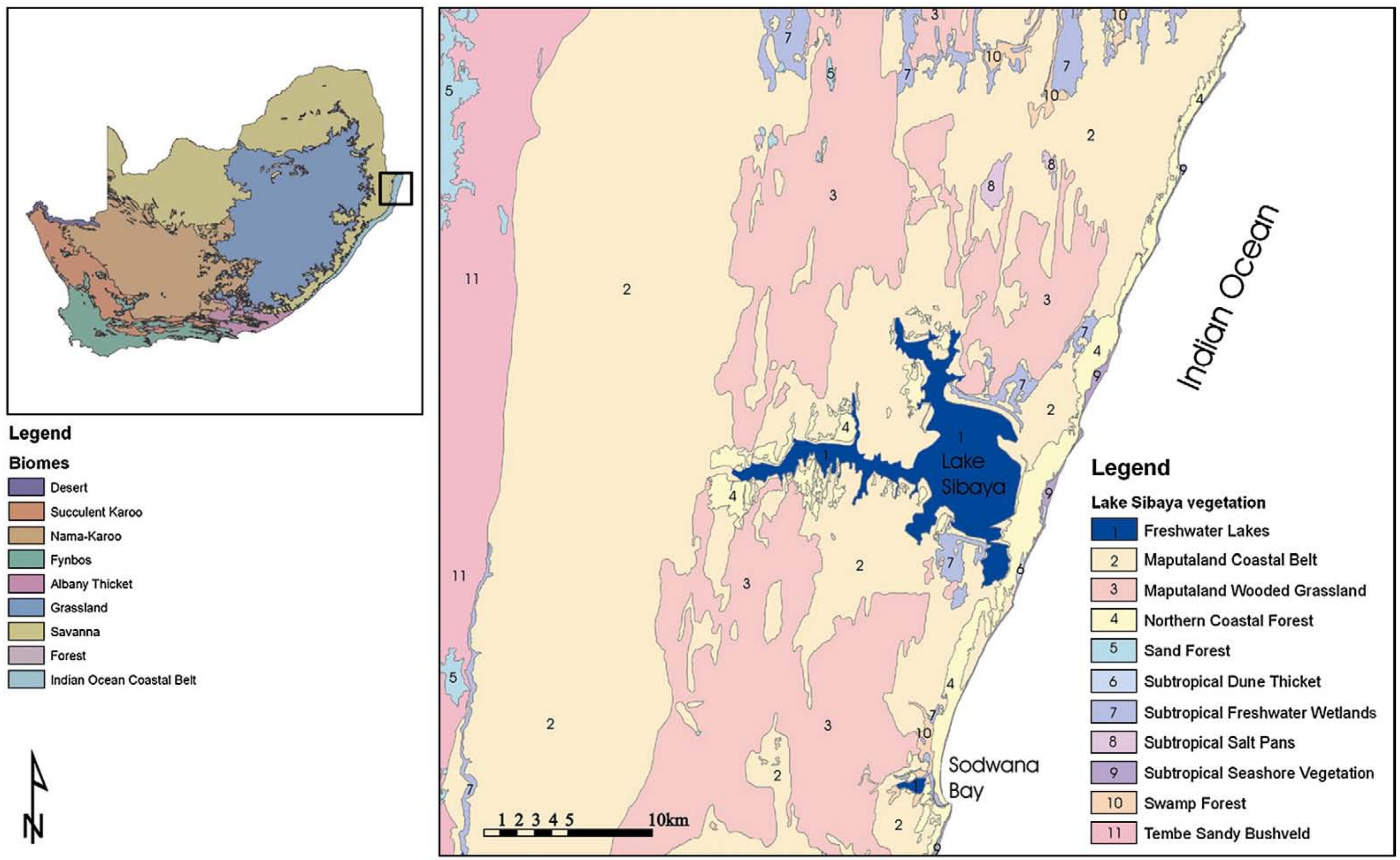

Fig. 2. Left: Biomes of South Africa (Mucina and Rutherford, 2006), black box shows study area. Right: Vegetation around Lake Sibya (after Mucina and Rutherford, 2006).

Afromontane forest patches rich in *Podocarpus* exist on the escarpment (Cooper, 1985; Pooley, 2003); but *P. falcatus* also grows in coastal swamp forests. The Indian Ocean belt is dominated by dune and coastal forests with *Alchornea hirtella, Englerophytum natalense, Olea woodiana, O. capensis, Ilex mitis, Gymnosporia [= Maytenus] nemorosa, Acalypha glabrata, Cleistanthus schlechteri, Euclea natalensis, Brachylaena discolor, Manilkara discolor, Morus mesozygia, Eugenia capensis, Mimusops caffra, Antidesma venosum, Deinbollia oblongifolia, Dodonaea angustifolia, Apodytes dimidiata, Allophyllus natalensis, Chaetachme aristata, Trema orientalis*, and *Celtis africana* (Venter, 1972; Breen, 1979; Weisser, 1980; Weisser and Drews, 1980, MacDevette, 1992; Pooley, 2003). Dune and coastal shrubland include *Passerina rigida* and *Rhus* spp. (MacDevette, 1992). The dune forest at the eastern shore of Lake Sibaya (Fig. 2) has a high diversity despite sandy soils, salt spray, and frequent storms, which result in a low growing scrub with a uniform canopy (Venter, 1972, 1976; Breen, 1979; MacDevette, 1989). *Acacia karroo* is common along the shores of the lake (Allanson, 1979b). Prominent climbers are *Rhoicissus tomentosa*, *Capparis tomentosa*, *Grewia caffra* and *Rhus natalensis*. *Isoglossa woodii*, a large woody and shade tolerant acanthaceous herb, builds the floor stratum of forests (Venter, 1972; 1976; MacDevette, 1992). Salt tolerant *Scaevola plumieri*, *Canavallia rosea* and *Ipomoea pes caprae* occupy the sandy beaches as part of the subtropical seashore vegetation (Fig. 2) (Mucina and Rutherford, 2006). *Strelitzia nicolai* is dominant above the beach (Venter, 1976; Breen, 1979).

Swamp forest exists where the water table is high (Pooley, 2003). Ferns are common, trees like *Macaranga capensis*, *Rauvolfia caffra*, *Syzygium cordatum*, *Cassipourea gummiflua* and *Voacanga thouarsii* grow close to the shore. The Mosi swamp, 20 km to the north of the lake (Fig. 2), contains well-developed swamp forest and *Podocarpus falcatus*. Mangrove communities (Fig. 2) include *Bruguiria gymnorrhiza*, *Avicennia marina* and the fern *Acrostichium aureum* (Pooley, 2003).

Savanna vegetation (bushveld) occurs to the west of Lake Sibaya. Typical elements include Poaceae, *Combretum* spp., *Sclerocarya birrea*, *Euphorbia ingens*, *Aloe* spp., *Acacia karoo* and *Spirostachys africana* (Moll, 1980; Pooley, 2003). Towards the coast "palmveld" (with *Hyphaene coriacea*, *Phoenix reclinata*) is found in a tussock grassland associated with *Strychnos madagascariensis* and *Spirostachys africana* (e.g. Maputaland wooded grassland, Fig. 2) (Palgrave, 1977; Moll, 1980; Pooley, 2003). Along the coast behind the dunes, "palmveld" grades into mesophytic open grassland (Moll, 1980).

Since the lake is very clear, aquatic macrophytes are found as deep as 9 m (Howard-Williams, 1979; 1980). Submerged aquatics include *Myriophyllum spicatum* and *Potamogeton* spp. In 1964–1973, when the lake level was low, *Phragmites mauritianus* and *Scirpus littoralis* were dominant on exposed shores and *Typha latifolia*, *Cyperus papyrus* and *Echinochloa pyramidalis* were widespread in sheltered areas.

During high stands (e.g. 1974–1977) dominant emergents of the previous low stand were sparse or absent, whereas *Cyperus natalensis* grew at the edges of the lake. Abundance of macrophytes declined but *Myriophyllum* and *Potamogeton* grew densely in shallow waters. *Nymphaea capensis* is common in the western arm (coring location), where aquatics are generally more abundant (Howard-Williams, 1979). *Closterium* spp. and diatoms (e.g. *Synedra acus*, *Aulacoseira granulata*) dominate the planktonic algal community today. Diatoms from the cores described in this paper are currently being investigated as indicators of water depth and salinity (C. Stager, in prep.). Other prominent phytoplankton elements are *Botryococcus braunii* and *Scenedesmus* sp. (Allanson, 1979b).

3. Materials and methods

3.1. Coring, sedimentology, organic content, palynological methods

3.1.1. Coring, sedimentology

Two cores were collected in 2003/2004 from near the center of the western arm of the lake (Fig. 1). One ca. 90 cm long core was obtained in 2003 with a hand-held, gravity-driven piston corer using a modified

Table 1

AMS (accelerator mass spectrometry) dates of the profile of Lake Sibaya, core segments **SWM, S-B1.** Levels with note "overlap" represent overlap between cores SWM and Sibaya-B (These AMS dates are not in Figs. 5–7 due to problematic correlation). The 1σ-range gives 68.3% probability and the 2σ range 95.4%. Composite depth is based on correlation (LOI, pollen indicators). Calibration data set: shcal 04.14c; McCormac et al. (2004). Calibrations calculated by Calib 5.0.2 for Southern Hemisphere (Copyright 1986–2005 M Stuiver and PJ Reimer*used in conjunction with Stuiver and Reimer, 1993). NA = not available. Seg. = Core segment. All AMS dates measured on bulk sediment. No age correction was used on the AMS dates in Tables 1–3

Segment	Segment depth (cm)	Composite depth (cm)	^{14}C (uncal.)	$^{13}C/^{12}C$	% area enclosed	Cal AD/BC Southern Hemisphere	Cal yr BP	Relative area/probability distribution
SWM	29–30	29.5	>Modern	−25	NA	NA	NA	NA
	50–51	50.5	Modern	−25	NA	NA	NA	NA
	60–61	60.5	320±50	−23.3	68.3 (1σ)	Cal AD 1506–1588	Cal BP 362–444	0.689
						1617–1651	299–333	0.311
					95.4 (2σ)	Cal AD 1464–1672	278–486	0.946
						1744–1756	194–206	0.015
						1762–1770	180–188	0.01
						1780–1796	154–170	0.029
	70–71	70.5	320±30	−23.1	68.3 (1σ)	Cal AD 1511–1549	401–439	0.486
						1560–1572	378–390	0.12
						1622–1647	303–328	0.394
					95.4 (2σ)	Cal AD 1501–1595	355–449	0.646
						1612–1660	290–338	0.354
	80–81	Overlap	370±40	−22.7	68.3 (1σ)	Cal AD 1498–1524	426–452	0.237
		Overlap				1535–1601	349–415	0.592
		Overlap				1607–1626	324–343	0.171
		Overlap			95.4 (2σ)	Cal AD 1464–1637	313–486	1
	90–91	Overlap	420±30	−21.9	68.3 (1σ)	Cal AD 1455–1501	449–495	0.775
		Overlap				1595–1612	338–355	0.225
		Overlap			95.4 (2σ)	Cal AD 1447–1513	437–503	0.636
		Overlap				1545–1623	327–405	0.364
S-B1	5–5.5	Overlap	515±35	−25	68.3 (1σ)	Cal AD 1421–1449	501–529	1
		Overlap			95.4 (2σ)	Cal AD 1402–1460	490–548	1
	25–25.5	92.25	440±35	−25	68.3 (1σ)	Cal AD 1447–1498	452–503	0.908
						1600–1608	342–350	0.092
					95.4 (2σ)	Cal AD 1435–1512	438–515	0.742
						1547–1563	387–403	0.023
						1569–1622	328–381	0.235

Kullenberg design (core SWM; 27° 20.65′S, 32° 36.73′E, water depth ca. 14.5 m). The sediment was extruded vertically in 1 cm increments shortly after collection, and subsamples were stored in WhirlPak™ bags under refrigeration. A longer core was collected in 2004 from ca. 16 m water depth, ca. 50 m away from core SWM and midway between shorelines. SCUBA divers drove most of a 4 m length of aluminum pipe into the sediment by hand (core Sibaya-B) without the aid of a piston. An undetermined section of the core top was sawn off in the field and discarded; ca. 65–70 cm of core material was lost in this manner. The remaining, denser section (192 cm long) was cut into 6 segments and capped for transport to Paul Smith's College, New York. Sediment loss in this sectioning process was minimal. Loss on ignition (LOI) of sediments was determined, and the core sediments were described visually.

3.1.2. Palynological methods

Samples for pollen analysis were treated with 10% HCl and 10% KOH, acetolysed (standard method after Faegri and Iversen, 1989), and concentrated by heavy liquid mineral separation using $ZnCl_2$ in the pollen lab in the Department of Plant Sciences, University of the Free State. No HF treatment was done in order to preserve biogene opal structures (e.g. phytoliths) for future study. Known numbers of *Lycopodium* spores were added for calculating pollen concentrations. Slides were mounted in glycerine-jelly. Pollen, algae, fungi, charcoal (>120 μm) and spores were identified at 1250× using the pollen reference collection at the Department of Plant Sciences, Bloemfontein, and references (Van Zinderen Bakker, 1953–1970; Bonnefille and Riollet, 1980; Scott, 1982; Coetzee and Praglowski, 1984; Moore et al., 1999). About 500 terrestrial pollen grains were counted per sample.

3.2. Dating

3.2.1. Radiocarbon

Bulk organic sediments in 24 samples from cores SWM and Sibaya-B were dated by accelerator mass spectrometry (AMS) at Lawrence Livermore National Laboratories and the University of Arizona (Tables 1–3). No obvious terrestrial organic fractions were present in abundances sufficient to permit radiocarbon dating. Calendar year ages were calculated using the Southern Hemisphere correction with CALIB 5.0.2 (Reference for calibration datasets: McCormac et al., 2004). In this paper, exotic pollen types are used to assess possible errors in the AMS ^{14}C dating.

4. Results and discussion

4.1. Correlation of core SWM and Sibaya-B

Stratigraphic alignment of cores Sibaya-B and SWM was accomplished by matching major peaks in the records of palynomorphs and percent LOI (weight loss on ignition at 550 °C). The results of the pollen analysis that are used to support the core-matching will be presented in Sections 4.4 and 4.5 in greater detail.

Table 2
Radiocarbon dates of the profile of Lake Sibaya, core segments S-B2–S-B5. Explanations and abbreviations see Table 1

Segment	Segment depth (cm)	Composite depth (cm)	^{14}C (uncal.)	$^{13}C/^{12}C$	% area enclosed	Cal AD/BC Southern Hemisphere	Cal yr BP	Relative area/probability distribution
S-B2	12–12.5	109.25	660±35	−25	68.3 (1σ)	Cal AD 1312–1359	591–638	0.764
						1380–1394	556–570	0.236
					95.4 (2σ)	Cal AD 1297–1400	550–653	1
	22.5–23	119.75	574±36	−24.4	68.3 (1σ)	Cal AD 1397–1431	519–553	1
					95.4 (2σ)	Cal AD 1323–1346	604–627	0.099
						1388–1445	505–562	0.901
	32–32.5	129.25	650±35	−25	68.3 (1σ)	Cal AD 1315–1357	593–635	0.733
						1381–1398	552–569	0.267
					95.4 (2σ)	Cal AD 1299–1404	546–651	1
S-B3	2.5–3.0	134.75	625±35	−25	68.3 (1σ)	Cal AD 1320–1350	600–630	0.585
						1386–1406	544–564	0.415
					95.4 (2σ)	Cal AD 1302–1364	586–648	0.569
						1376–1422	528–574	0.431
	22.5–23	154.75	716±36	−21.9	68.3 (1σ)	Cal AD 1287–1316	634–663	0.532
						1356–1381	569–594	0.468
					95.4 (2σ)	Cal AD 1276–1328	622–674	0.509
						1337–1391	559–613	0.491
	32–32.5	164.25	815±35	−25	68.3 (1σ)	Cal AD 1228–1275	675–722	1
					95.4 (2σ)	Cal AD 1208–1291	659–752	1
S-B4	9.5–10	177.75	825±30	−25	68.3 (1σ)	Cal AD 1228–1270	680–722	1
					95.4 (2σ)	Cal AD 1211–1283	667–739	1
	19.5–20	187.75	1192±37	−24.2	68.3 (1σ)	Cal AD 880–977	973–1070	1
					95.4 (2σ)	Cal AD 780–791	1159–1170	0.029
						806–987	963–1144	0.971
	39.5–40	207.75	1520±35	−25	68.3 (1σ)	Cal AD 573–636	1314–1377	1
					95.4 (2σ)	Cal AD 539–653	1297–1411	1
S-B5	9.5–10	219.75	1645±35	−25	68.3 (1σ)	Cal AD 426–467	1483–1524	0.424
						481–533	1417–1469	0.576
					95.4 (2σ)	Cal AD 396–559	1391–1554	1
	19.5–20	229.75	1807±38	−25.7	68.3 (1σ)	Cal AD 236–344	1606–1714	0.994
						374–375	1575–1576	0.006
					95.4 (2σ)	Cal AD 139–158	1792–1811	0.025
						166–196	1754–1784	0.043
						209–397	1553–1741	0.932
	29.5–30	239.75	1835±40	−25	68.3 (1σ)	Cal AD 145–151	1799–1805	0.025
						171–194	1756–1779	0.122
						210–264	1686–1740	0.436
						275–332	1618–1675	0.417
					95.4 (2σ)	Cal AD 130–356	1594–1822	0.977
						366–380	1570–1584	0.023

Table 3
Radiocarbon dates of the profile of Lake Sibaya, core segment S-B6. Explanations and abbreviations see Table 1

Segment	Segment depth (cm)	Composite depth (cm)	^{14}C (uncal.)	$^{13}C/^{12}C$	% area enclosed	Cal AD/BC Southern Hemisphere	Cal yrs BP	Relative area/probability distribution
S-B6	2	252	6370±35	−25	68.3 (1σ)	Cal BC 5324–5283	7232–7273	0.484
						5274–5224	7173–7223	0.516
					95.4 (2σ)	Cal BC 5461–5451	7400–7410	0.008
						5376–5212	7161–7325	0.992
	4–4.5	254.5	6420±35	−25	68.3 (1σ)	Cal BC 5463–5448	7397–7412	0.107
						5418–5412	7361–7367	0.029
						5378–5304	7253–7327	0.864
					95.4 (2σ)	Cal BC 5470–5295	7244–7419	0.94
						5262–5228	7177–7211	0.06
	8.5–9	258.75	6350±35	−25	68.3 (1σ)	Cal BC 5311–5282	7231–7260	0.381
						5274–5224	7173–7223	0.619
					95.4 (2σ)	Cal BC 5371–5207	7156–7320	0.989
						5161–5154	7103–7110	0.004
						5143–5139	7088–7092	0.002
						5091–5081	7030–7040	0.005
	10.5–11	260.75	6.431+−52	−23.1	68.3 (1σ)	Cal BC 5466–5439	7388–7415	0.198
						5425–5405	7354–7374	0.127
						5383–5308	7257–7332	0.674
					95.4 (2σ)	Cal BC 5474–5291	7240–7423	0.92
						5269–5225	7174–7218	0.08
	40–41 (sand)		>Modern	−25	NA	Modern contamination	NA	NA

LOI values are only used for correlation and their interpretation will be published later (C. Stager, unpublished data, Heiri et al., 2001).

Using this approach, we conclude that the top of Sibaya-B is coeval with the 67–68 cm level in SWM, as indicated by peaks in LOI and *Pediastrum*, and by similar, stable percentages in other important pollen taxa. The correlation in both cores (black dashed line in Fig. 4) is located immediately below a distinct peak of the *Pediastrum* values and within a zone of slightly increasing *Pinus* values. *Spirostachys* shows 12% in core SWM (depth 77.5 cm) and 13% in core Sibaya-B (depth 10.5 cm). The percentages of Poaceae are also similar (65% in core SWM, 66% in core Sibaya-B). The stratigraphic correlation of the cores due to palynological results supports the correlation due to LOI.

4.2. Lithology

The upper 253 cm of the 260 cm long composite profile (Fig. 4) consists of medium to dark brown gyttja. On the basis of finger testing we find that the sediments in the upper part of the profile are slightly silty clay with small but varying amounts of organic material. The dark brown to black peat at the bottom of the composite profile (253–260 cm) has a very high organic content. It is predominantly clayey but contains some sand grains.

4.3. Dating and sedimentation rate

Because plant material is not available from the cores; we used bulk sediments for radiocarbon dating (Tables 1–3). The use of bulk sediments in this manner has to be undertaken with caution because radiocarbon dates on lake sediments are often older than terrestrial organic material because of hardwater reservoir effects (MacDonald et al., 1991; Walker, 1991; Geyh et al., 1998; Stiller et al., 2001; Schwab et al., 2004; Neumann et al., 2007). Although the samples for AMS were treated with acids to remove carbonates, the remaining organic matter can still contain anomalously ancient carbon because most of it comes from the remains of algae that absorbed dissolved carbon from the water (see Heiri et al., 2001). One possible reason for a hardwater reservoir effect in the bulk sediments of Lake Sibaya is the geology of the surrounding bedrock and catchment area, which includes calcareous marine sediments (Miller 2001). Heating of selected ashed core sediments to 900 °C suggests that carbonate contents in the samples average 3–5% by weight (C. Stager, unpublished data). Lake water pH values range between 7.2 and 8.3 (Allanson, 1979a; Jury and Govender, in press; personal observation by C. Stager, 2004), though the effects of local calcareous deposits on lake chemistry might be ecologically significant, as they are apparently mixed with acidic peat-stained waters of local swamp forests (Allanson et al., 1990).

Table 4
Attributes of important cultivated neophytes (*Pinus*, *Casuarina*, *Zea mays*) relevant to their introduction and first extensive cultivation. *Eucalyptus* is not listed because it is not differentiated palynologically from other Myrtaceae. Literature in bold numbers: **1**: Poynton, 1977., **2**: Richardson, Higgins, 1998., **3**: Le Maitre, 1998., **4**: Pakenham, 1999, photos, **5**: Scott, Steenkamp, 1996., **6**: Bruton et al., 1980., **7**: Barbero et al., 1998, **8**: Lavery, Mead, 1998, **9**: Poynton, 1995, **10**: Kotze, 1929, **11**: Bruton et al., 1980, **11**: Palgrave, 1977., **12**: Miracle, 1965, **13**: McCann, 2005., **14**: Richardson, 1998., **15**: Saunders, 1930, **16**: Moran et al., 2000, **17**: Stirton, 1978, **18**: Huffman, 2006, **19**: Whitelaw (pers. communication)

	Pinus	*Casuarina*	*Zea mays*
First imported into South Africa/*area of distribution*	*P. pinaster*: End of 17th century, other *Pinus* species 1825–1855/*Cape region* **1**, **2**, **14**, **16**, **17**	Since 1830's *Cape region* **9**	Since ca. 1750/*Mozambique* Since 1655, mid of 17th century, since 17th century, since end of 18th century/*South Africa, eastern region incl. KwaZulu-Natal* **6**, **12**, **13**, **15**, **18**, **19**
Planted extensively in southern Africa/*area of distribution*	*P. pinaster*: widely planted by about 1780, First commercial *Pinus* plantings 1825–1830/*Cape region* **1**, **2**, **3**, **16**	Since 1920's/*Orange Free State, Natal* **9**	Fast distribution since end of 18th century/since beginning of 19th century replacement of sorghum as major crop/*eastern region incl. KwaZulu-Natal* **6**, **12**
Planted in KwaZulu-Natal/*area of distribution*	2nd half of 19th century, small *Pinus* plantations, ornamental pines/*Dundee, Ladysmith* 1920's: plantations/*Lake Teza* 1940's: plantations/*near* *Lake Sibaya* **4**, **5**, **6**	Since 1920's on dunes along the coasts *Natal and Zululand*, since 1940's for dune stabilisation/*Maputaland, also reported at Lake Sibaya* **6**, **9**, 10,	See above! *Natal, Zululand* **6**, **12**, **13**, **15**, **18**, **19**
Native range	Mediterranean Basin, America, Near East **1**, **7**, **8**	Australia, Far East **11**	Northern America **16**, and many others

Our calculation of the age error caused by hardwater reservoir effects is based on comparison between the pollen signals (esp. exotic pollen: *Pinus*, *Zea mays*) and archaeological/historical data (Table 4). This estimated age correction should be used with caution, however, because knowledge about the archaeology and history of the region is limited.

We did not date the top of core SWM, but we are reasonably certain that its mud–water interface was intact because an oxidized zone and emergent worm/insect tubes in growth position were observed at the core top. Therefore, we have assigned an age of 2004 AD to the top of SWM.

Pinus pollen grains became dominant in the uppermost 25 cm of SWM. Historical records indicate that the first pine plantations near Lake Sibaya appeared during the 1940's AD (Bruton et al., 1980). We assume that pollen production from those trees would have been strong by the late 1950's to early 1960's, and that the 25 cm level in SWM probably formed no later than ca. 1960 AD. Although we cannot exclude the possibility that the pine pollen came decades earlier from plantations farther away, the extraordinarily high amount of pollen indicates a local and extremely productive source.

Australian *Casuarina* pollen above the 30 cm level in SWM might reflect its introduction for dune stabilization stabilisation in the region since the 1940's AD (Bruton et al., 1980; Poynton, 1995). We therefore assign a tentative age of ca. 1950 AD to the 30 cm level.

The youngest “pre-modern” radiocarbon dates for the Lake Sibaya record (154–486 cal yr BP and 290–449 cal yr BP, Table 1) are situated at the horizon with a profile depth of 60–81 cm, which is characterised characterized by the onset of the strong increase of anthropogenic indicators (e.g. *Pinus*, *Ambrosia*). This level probably corresponds to the establishment of the first pine plantations in KwaZulu-Natal. Photographs from the end of the 19th century show pines in Ladysmith and plantations probably consisting of *Eucalyptus* and *Pinus* near Dundee in Natal (Pakenham 1999). After the foundation of the “Republic of Natalia” in 1839 (Williams, 1921), *Pinus* was seemingly present in the region. Around one decade later, pollen production by those pines should have been steadily increasing. The rise of *Pinus* pollen percentages at the bottom of SWM might also be related to the establishment of plantations during the late 1920's AD near Lake Teza (Scott and Steenkamp, 1996). Consequently, the 75 cm level might have been deposited between the middle of the 19th century and the 1920's, suggesting an age error for this horizon between 50 and 450 yr.

The radiocarbon age of the base of the SWM core is ca. 327–405 yr, which, after subtraction of estimated age offsets due to the hardwater reservoir effect, suggests that the sediments in SWM are too young to produce reliable ^{14}C dates, due to anthropogenic and natural disruptions of the radiocarbon cycle during the last 150–200 yr. The supramodern age for the 29.5 cm sample (probable true age: early 1950's AD) is likewise consistent with anthropogenic ^{14}C production due to nuclear testing after World War II.

The first pine pollen in the Lake Sibaya record appears at a depth of 105 cm. An AMS date from 109.25 cm depth gives an age of 550–653 yr BP (ca. 1297–1400 AD). Because pine pollen can be transported up to several thousand kilometres (Scamoni, 1949; Faegri and Iversen, 1989; Rousseau et al., 2006), it might have originated from the Cape region where the early history of pine trees is comparatively well investigated (Moran et al., 2000). However, the first recorded pollen grains of *Pinus* in the Lake Sibaya profile need not necessarily reflect the first plantings of pines at the Cape. Therefore age corrections based on the comparison between this pollen signal and the historical data must be considered tentative.

Pinus pinaster was introduced to the Cape region at the end of the 17th century, and other *Pinus* species followed until the 1850's AD (Poynton, 1977; Richardson and Higgins, 1998). A *P. pinaster–P. pinea* plantation was established at Genadendal in the Cape colony between 1825 and 1830, commercial plantings of other pine species followed around 1850 (Poynton, 1977; Stirton 1978; Richardson and Higgins, 1998; Le Maitre 1998; Moran et al., 2000, Table 4). So few *Pinus* pollen grains might have been transported to Sibaya from the Cape between the 18th century and the first half of the 19th century. Radiocarbon ages here therefore seem to be ca. 300–550 yr too old (see dates, Table 1).

The first appearance of maize pollen at a depth of 125 cm points to an age of ~500–650 cal yr BP (=1300–1450 AD) according to radiocarbon dates (Table 2, 2σ value). Early evidence of maize cultivation in KwaZulu-Natal lacks precise radiocarbon data (Hall and Maggs, 1979, Maggs, 1982), but the beginning of maize cultivation has been placed in the second half of the 18th century in KwaZulu-Natal and around 1750 in Mozambique (Miracle, 1965; Bruton et al., 1980; Hall and Vogel, 1980; Table 4). In contrast, new archaeological evidence indicates a date in the 17th century for maize cultivation (maize grind stones; Huffman 2006) which is in good agreement with Saunders (1930) who claims that maize reached South Africa as early as 1655 (see also McCann, 2005). The first maize pollen in the Wonderkrater record (Scott, 1982) appears ca. 554 cal yr BP, as calculated from the age model in Scott et al. (2003). Whitelaw (personal communication) suggests that maize was possibly cultivated in the Thukela Basin grasslands in the 17th century, probably introduced by people from northern KwaZulu-Natal who could have acquired the crop from Portuguese traders at Delagoa Bay. Seemingly, the eastern region including KwaZulu-Natal was a center of maize cultivation in South Africa during the 17th century. In conclusion the first maize pollen in the Lake Sibaya pollen record might be from the second half of the 17th or the 18th century (Miracle, 1965; Bruton et al., 1980). This conforms to a radiocarbon age error of ca. 200–500 yr.

We tentatively suggest an age correction range of 50 to 550 yr for the whole pollen record (see discussion above), and a 550 yr maximal shift for all AMS dates is shown in Fig. 4. For convenience, radiocarbon dates in the overlap area of cores SWM and Sibaya-B with 2σ values of 313–486 cal yr BP, 327–503 cal yr BP, and 490–548 cal yr BP (Table 1), are not shown in the composite profile (Figs. 3 and 4). The four oldest dates in the lowest 7 cm of the profile are very similar and suggest rapid sedimentation or, possibly, reworking and slight age reversals. A >5000 yr hiatus is indicated at ca. 253 cm depth.

The sedimentation rate is estimated to be around 3.5 mm/yr between the depth of 60.5 cm and 177.75 cm. A sudden decrease of the sedimentation rate to 0.6 mm/yr is shown below a depth of 177.75 cm (Fig. 4). The reasons for those changes in sedimentation rate might be linked to anthropogenic disturbances as discussed below.

4.4. Palynology

The zonation of the pollen diagram is based on visual observations of changes in assemblage composition and the relative abundance of individual species (Fig. 7).

4.4.1. Zone 6 — Phoenix –Isoglossa–Manilkara-Zone (251–258 cm)

Zone 6 is characterized by abundant forest elements like *Phoenix*, *Celtis*, *Manilkara*, *Chaetachme*, *Isoglossa* and *Mimusops*, and by relatively high percentages of Restionaceae. Pollen of Poaceae, other herbs, aquatics (except *Typha* and *Nymphaea*), swamp plants, fern spores and algae are sparse or absent. Zones 6 and 5 are separated by a hiatus of ~5000 yr.

4.4.2. Zone 5 — Podocarpus–Ilex–monolete-Zone (197.5–251 cm)

Zone 5 begins with high values of Poaceae increasing the herb values in comparison with Zone 6. Cyperaceae values are rising. In the course of the zone *Podocarpus* (15%), Moraceae, *Morella* [=Myrica] and *Ilex* reach an absolute maximum but decline towards the end of Zone 5. *Aloe*-type pollen is regularly detected. Asteraceae reveal a maximum at the beginning of Zone 5. In comparison to Zone 6, *Phoenix*, *Celtis*, *Manilkara*, *Cleistanthus*, *Chaetachme*, *Isoglossa* and *Mimusops* are less prominent. The curves of monolete fern spores and Haloragaceae pollen show a strong peak that characterizes Zone 5,

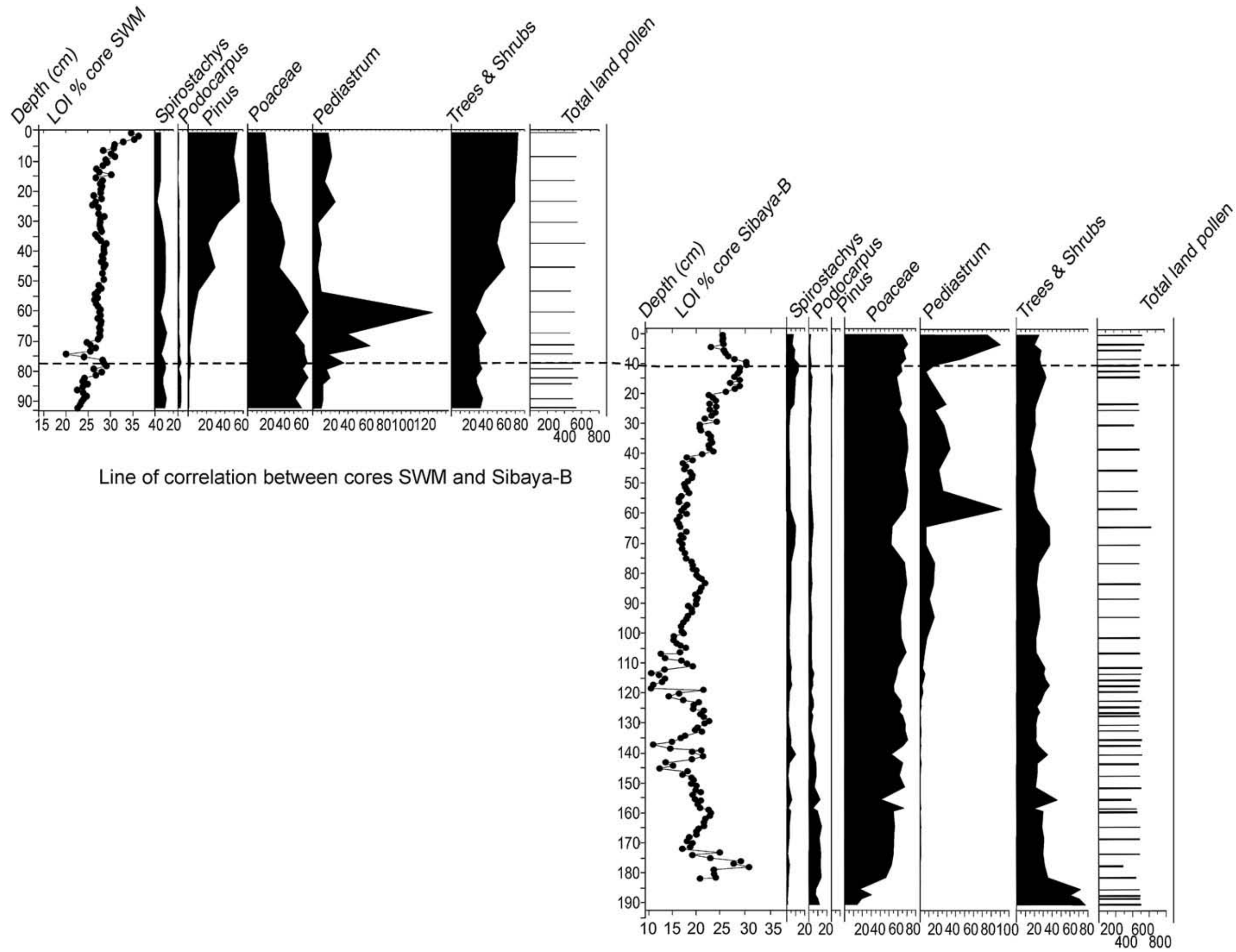

Fig. 3. Correlation of cores SWM and Sibaya-B based on matching %LOI (Loss of Ignition), and pollen percentages. Six main pollen curves are shown with the total land pollen sum (histogram, absolute numbers). The latter shows that we obtained a higher sample resolution in overlap area of cores SWM and Sibaya-B in order to improve correlation.

together with abundant *Nymphaea* and *Persicaria* [=*Polygonum*]. At the end of the zone the first large pollen grains of Poaceae (size >50 µm, excluding *Zea mays*) appear.

4.4.3. Zone 4 — Olea–Celtis-Zone (176.5–197.5 cm)

The transition to Zone 4 is marked by a sharp decrease of the monolete spores and of *Podocarpus* (<8%). Zone 4 is characterised characterized by a peak of *Olea*, *Manilkara* and *Celtis*. Values for *Bruguiera* are high in Zone 4.

4.4.4. Zone 3 — Phoenix–Hyphaene Zone (94–176.5 cm)

A peak of *Phoenix*, *Hyphaene*, and monolete spores characterizes the zone. Large Poaceae pollen (>50 µm) are recorded regularly. The first *Zea mays* pollen grains are detected. *Pinus* pollen appear in low numbers. Cyperaceae are common, other aquatics decrease. At the end of the zone *Dodonaea* and *Rhoicissus* become prominent.

4.4.5. Zone 2 — Spirostachys–Pinus-Zone (58–94 cm)

Poaceae pollen declines as *Pinus* pollen rapidly increases. Zone 2 is characterized by high values of *Spirostachys*, *Celtis*, *Stoebe* and a slight increase of *Manilkara* and *Rhus*. *Sclerocarya* is recorded regularly in Zone 2. The end of Zone 2 is marked by a sharp decrease of algae and Cyperaceae pollen.

4.4.6. Zone 1 — Neophyte Zone (0–58 cm)

Zone 1 shows the first neophyte pollen grains (*Ambrosia*, *Casuarina*, *Carya*) and the regular appearance of *Zea mays*. Ericaceae grains are also detected regularly, and *Pinus* grains reach a maximum. Other forest elements decrease. The presence of *Trema* and *Passerina* are continuous for the first time.

4.5. Vegetation history

Poaceae dominate the pollen diagram of Lake Sibaya (30–65%). The pollen results show elements of the swamp forest (e.g. *Rauvolfia*, *Macaranga*, *Voacanga*), mangrove communities (*Bruguiera*), dune and coastal forest (e.g. *Mimusops*, *Chaetachme*, *Isoglossa*), dune shrub (especially *Passerina*, *Anthospermum*), and bushveld (e.g., *Spirostachys*, *Hyphaene*, *Phoenix*, *Sclerocarya*).

Pollen of *Podocarpus* and *Ilex* probably stem from the mountains or from Kosi Bay (Mazus, 2000) although *Ilex mitis* grows on the dunes near Lake Sibaya. Fynbos elements (Ericaceae, Restionaceae) are rare and probably derived from long-distance transport. Other trees, which grow in diverse habitats, are *Celtis*, *Acalypha* (these genera might even include some herbs Scott, 1982), *Alchornea*, *Olea*, *Morella* [= *Myrica*], *Ilex*, *Manilkara*, *Rhus* and *Acacia*. Water plants and Cyperaceae are abundant in the study area.

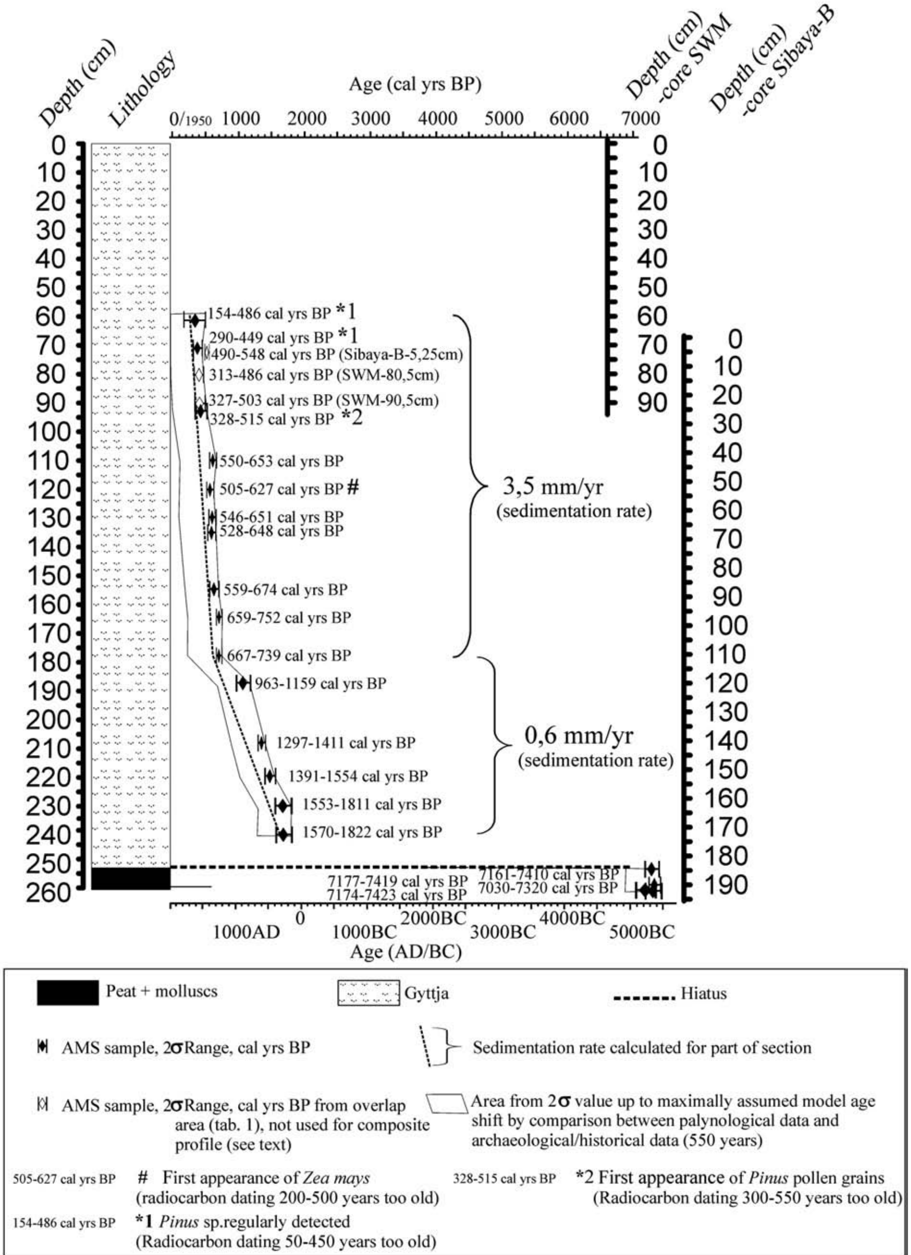

Fig. 4. Age-to-depth relation of the composite profile (left) after correlation of cores SWM and Sibaya-B (right), showing AMS ^{14}C dates (2σ range, black rhombs), sedimentation rate and lithology. Dating errors (shift of radiocarbon ages due to hardwater reservoir effect) are explained in text. Radiocarbon dates in overlap area of cores SWM and Sibaya-B are shown by white rhombs and will not be used in the composite pollen diagrams due to problematic correlation.

In the text and Figs. 5–7, the calibrated 2σ range of radiocarbon dates is used (Tables 1–3). For convenience, we have tentatively applied a 300 yr average shift (mean of highest and lowest pollen-derived errors) to all AMS dates discussed.

We propose the following explanations for changes in the pollen profiles

- *Human activity*: Settlement has affected the natural vegetation near Lake Sibaya through destruction of woodland and forests, cultivation of crops (e.g. *Sorghum*, *Zea mays*) and neophytic trees (*Pinus*, *Casuarina*) and protection or introduction of plants by settlers through agricultural and other activities, e.g. the protection of indigenous *Sclerocarya caffra* as a fruit tree (Pooley, 2003) and the unintentional introduction of weeds (e.g. *Ambrosia*, Moore et al., 1999).
- *Climatic change*: Temperatures and precipitation regimes have strong influences on vegetation, e.g. favouring forest trees like *Podocarpus* during moist periods. Lake level changes triggered by precipitation changes might also alter the communities of aquatic and swamp plants (Howard-Williams, 1979, 1980).
- *Facies change*: During the Middle Holocene a different water body configuration may have altered pollen trapping patterns.

Human impact increased markedly during the most recent phase of the lake's history, and it seems to overshadow climate and other factors as an agent of change in pollen composition. Ecological interactions between introduced and natural species might also influence the vegetation development at Lake Sibaya.

4.5.1. Middle Holocene (Zone 6)

Information about the Middle Holocene is rare in KwaZulu-Natal, consisting of unpublished and provisional work or underdeveloped chronologies (Scott and Steenkamp, 1996; Mazus, 2000; Finch, 2005).

F.H. Neumann et al. / Review of Palaeobotany and Palynology 152 (2008) 113–128

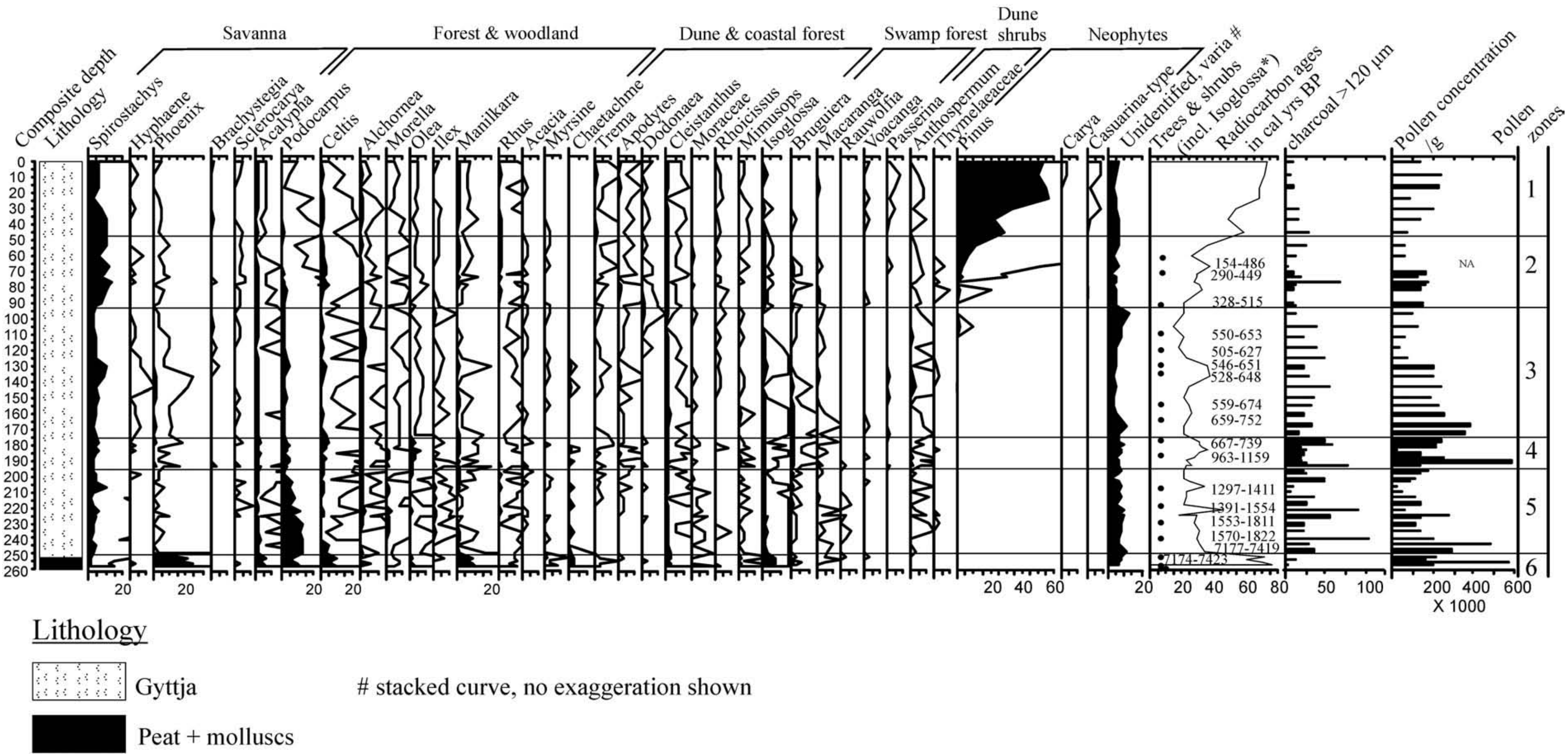

Fig. 5. Simplified composite pollen diagram of Lake Sibaya: trees and shrubs, charcoal, pollen concentration. Lithology (left), pollen zones (right). **Isoglossa*, a woody herb, was grouped under "dune & coastal forest" and included in the tree pollen since it is a prominent element of the forest undergrowth. # Curves are stacked, exaggeration not possible. NA = pollen concentration in sample not available. Radiocarbon dates calibrated (2σ range) and uncorrected.

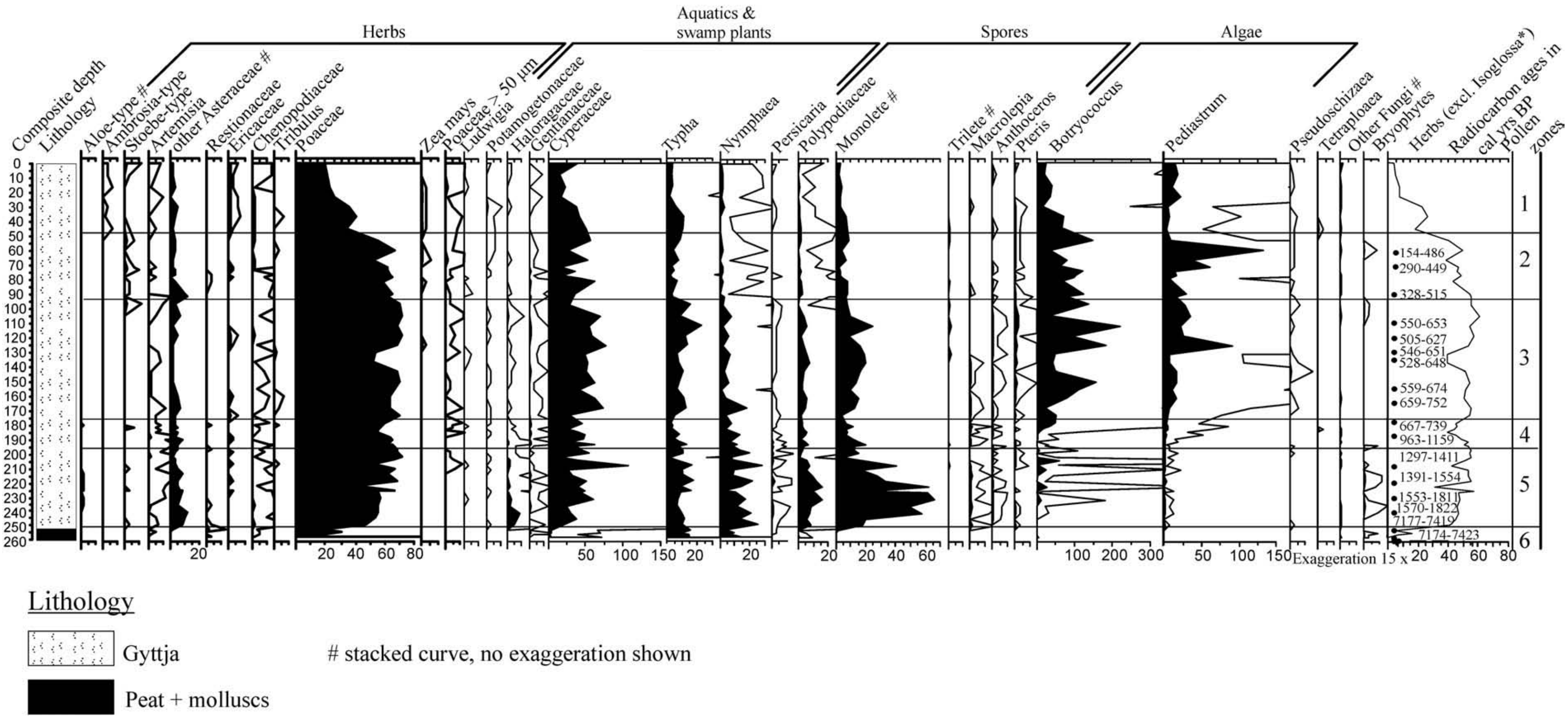

Fig. 6. Simplified composite pollen diagram of Lake Sibaya: herbs, aquatics and swamp plants, spores, algae, fungi, *Pseudoschizaea*, bryophytes; lithology (left), pollen zones (right). # Curves are stacked, exaggeration not possible. NA = pollen concentration in sample not available. Radiocarbon dates calibrated (2σ range) and uncorrected.

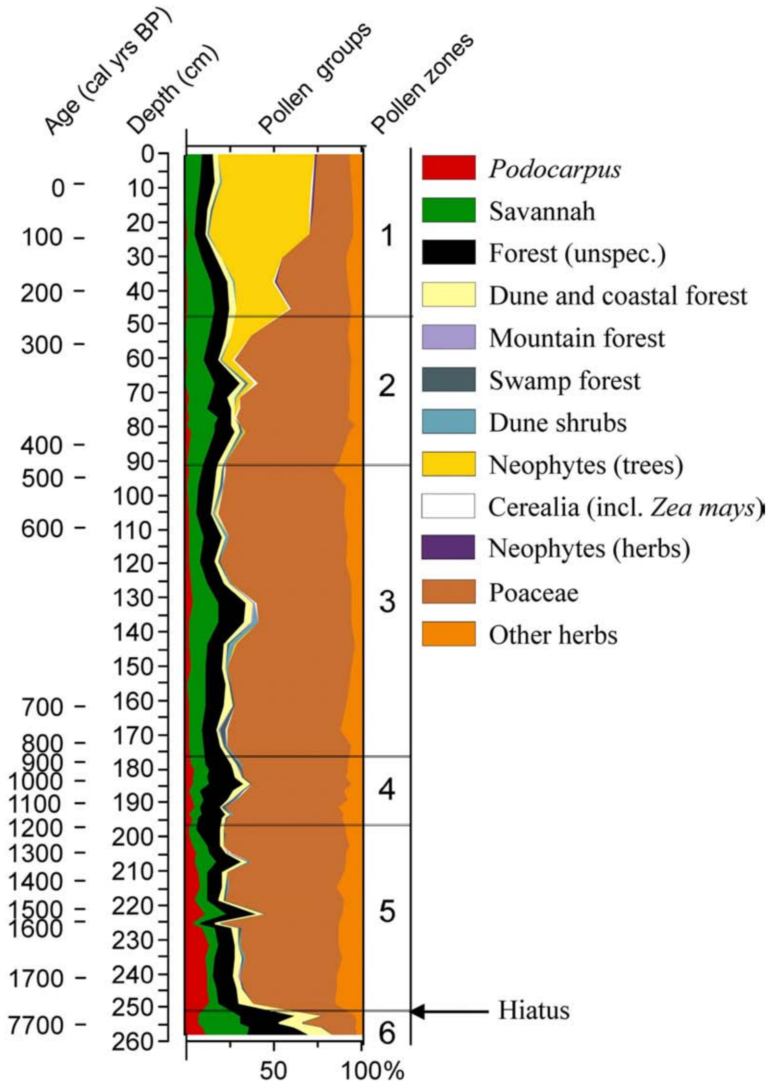

Fig. 7. Summarised pollen percentage diagram of the Lake Sibaya sequence with pollen zones (right), all curves are stacked. Radiocarbon ages (cal yr BP) are given, age error ranges (50–550 yr) are not shown.

The Middle Holocene at Lake Sibaya is represented by only four pollen samples in our cores but it provides insight into the longer term vegetation dynamics in the region.

Four AMS ^{14}C dates suggest a corrected age of ~6750–7100 cal yr BP (Figs. 5 and 6, Table 3). The composition of the vegetation is different from the plant communities in the late Holocene (Fig. 6). Percentages of forest elements are the highest of the pollen record (>60%), and the pollen of Poaceae and other herbs is relatively scarce. *Phoenix*, probably *P. reclinata*, the only indigenous *Phoenix* species in Southern Africa (Palgrave, 1977), is dominant (>20%). This wild date palm grows along streams, in open grassland and in forests at low altitudes and is common near Lake Sibaya today (Pooley, 2003). *Hyphaene* (*H. coriacea*, widespread in open sandy environments but normally not found along river banks; Pooley, 2003), is sparse in Zone 6. *Podocarpus* reaches 10% (Fig. 6). *Manilkara*, *Celtis*, *Chaetachme* and *Isoglossa* (~8%) reach their highest percentages of the record. *Acalypha*, *Mimusops*, *Cleistanthus* and *Myrsine* are abundant whereas *Spirostachys* values are low. Green algae and pollen of aquatics, with the exception of *Nymphaea*, are rare or missing, and Cyperaceae reach their lowest values. Values of *Typha* are comparably high in Zone 6 (Fig. 6).

Eeley et al. (1999) have modeled the forest distribution in KwaZulu-Natal under the palaeoclimatic scenario of the Middle Holocene altithermal. They infer an expansion of Afromontane forests that extended through the midlands of KwaZulu-Natal, all along the coast where there was a high potential for forest. The high percentages of trees represented in our record, especially *Phoenix* which grows near open water, support this and indicate warm moist conditions then. *Podocarpus*, an Afromontane element, is not very abundant. Nonetheless, the significance of the Lake Sibaya record for the climate history of the Middle Holocene is limited because only a short sequence belonging to this time slice is preserved.

The rarity of aquatics, algae and swamp plants indicated by our data (Fig. 6) is consistent with the suggestion by Miller (2001) that, prior to ~5030 BP, the area was still a marine lagoon with conditions unfavourable for most freshwater plants. *Typha*, well-represented in Zone 6, can grow in brackish as well as in fresh water (Howard-Williams, 1980), and small amounts of *Nymphaea* might have grown in freshwater pools along streams near the lagoon. Salt tolerant *Phoenix reclinata* might have grown near the lagoon. Restionaceae grains are more prominent than in all other pollen zones, and bryophytes are indicative of local moisture. Pollen-trapping patterns may also have differed significantly due to a changing shoreline configuration.

4.5.2. Iron Age until modern times (Zones 5–1)

Four AMS dates are available for Zone 5 (~1000–1500 cal yr BP = ~450–950 AD, Fig. 4, Table 2). The late Holocene in the Lake Sibaya record probably begins during the Early Iron Age (300–800 AD) (Bruton et al., 1980; Maggs, 1984) at around 450–650 AD (Figs. 4–6, Table 2), and the pollen data suggest that vegetation during this phase differed from that of the Middle Holocene. Poaceae values (~60%) indicate an extensive grassy ground cover associated with savanna. *Anthospermum*, common in grasslands (Scott, 1982) and an element of the dune shrubs, appears regularly (Fig. 5). *Phoenix* pollen are <2%, and percentages of *Isoglossa*, *Manilkara*, *Chaetachme* and *Acalypha* are low. Pollen percentages of *Spirostachys*, a bushveld tree, are higher than in Zone 6.

Podocarpus reaches a peak (>15%, Figs. 5 and 7) which probably indicates local stands of these trees (Coetzee, 1967). Our data suggest that they were much more abundant near Sibaya than nowadays, and probably grew near swamps or at the coast. *Ilex* (probably *I. mitis*), often sharing the same habitats with *Podocarpus* (Pooley, 2003), reaches its highest values in Zone 5. *Morella* [=*Myrica*] spp. occupies a wide range of moist forest habitats, e.g., swamp forest and forest margins (Pooley, 2003) and is also abundant. Swamp forest elements like *Macaranga* and *Rauvolfia* appear regularly. Moraceae, probably *Morus mesozygia*, a large tree of the coastal forests (Pooley, 2003), reaches its highest values in the pollen record. *Podocarpus*, which can cope with low temperatures, and the other forest and swamp forest elements may represent a humid climate during this period (Pooley, 2003).

Charcoal shows isolated but high peaks in Zone 5. Fire, frequent in humid savanna with abundant fuel, is a natural phenomenon in Southern Africa but not in forests where leaf moisture is high (Bond, 1996). Human induced fires cannot be excluded for that time period.

An important feature of the first half of Zone 5 is the abundance of aquatics and swamp plants representing moist conditions. Ferns (undifferentiated monoletes, *Macrolepia*, *Anthoceros*, Polypodiaceae) and Haloragaceae (probably mostly *Myriophyllum spicatum*; see Howard-Williams, 1979) show a strong peak while *Nymphaea* and *Persicaria* [= *Polygonum*] have high values (Fig. 6). Howard-Williams (1979) calculates correlation coefficients between relative biomass and environmental variables, concluding that *M. spicatum* and *Nymphaea* are among those aquatics which are least able to tolerate low lake levels. Consequently their high values in Zone 5 might represent a lake high stand. During this time a freshwater lake is thought to have been established after the closing of the lagoon by the dune cordon ~5000 BP (Miller, 2001).

In the second half of the pollen zone *Podocarpus* declines together with prominent swamp forest elements (*Macaranga*, *Rauvolfia*), *Ilex*, *Isoglossa* and *Manilkara* signifying a gradual decrease of the forest elements (Fig. 6). In contrast, the rising values of Poaceae show a spread of the grasslands perhaps due to human activities (Fig. 6). Other trees (e.g. *Apodytes*, *Trema*) are more common at the end of Zone 5 (Fig. 5).

The identification of cereal pollen in Africa (sorghum and millet) is problematic. Size ranges of Poaceae pollen show overlaps and many wild species overlap with cultivated species (Bonnefille and Riollet, 1980; Scott, 1982). Some cultivated species have a pollen grain size between 41 and 49 μm (Scott, 1982) but some authors suggest that only grains larger than 60 μm should be accepted (Hamilton, 1972). We consider only Poaceae pollen grains >50 μm as probable cereals since sizes of smaller cereal pollen grains overlap with those of wild Poaceae (Bonnefille and Riollet, 1980).

Shortly after the beginning of the decline of *Podocarpus* ~1250–1500 cal yr BP or ~450–700 AD (Fig. 5, compare Table 2) we find the first isolated pollen grains of Poaceae >50 μm, which might include a high number of cultivated cereals. Early Iron Age farmers practised shifting cultivation in the area of the coastal dunes ~950 cal yr BP (~1000 AD) (Hall, 1980; MacDevette, 1989) but earlier human activity in the Lake Sibaya region is possible. Evidence exists for Early Iron Age herding in the region between ca. 350 AD and ca. 650 AD at Enkwazini near Lake Sibaya (Bousman, 1998, radiocarbon data calibrated by the authors of this study with Calib 5.0.2). Those settlers might have cleared forests to get space for settlements and pastures and collected wood as fuel. Consequently we might attribute the decrease of the *Podocarpus* forests to human disturbances.

Mazus (2000) mentions the retreat of *Podocarpus* pollen in lake and swamp deposits northward to the Kosi bay area after 1300 cal yr BP (650 AD). Several aquatics, e.g. Haloragaceae and *Nymphaea*, decline in the upper part of Zone 5 and possibly mark a drop in lake level. Algae (*Botryococcus*, *Pediastrum*) that are nearly absent during the Middle Holocene in the Lake Sibaya pollen record, appear in low numbers. *Botryococcus* is more prominent at the top of Zone 5 and might represent limited cultural eutrophication due to human disturbances by e.g., grazing and settlement near the shores of the lake (Greeson, 1982; Prat and Daroca, 1983; Truter, 1987; Haas, 1991; Roos, 1991). Animal dung is a source for phosphorus (mainly PO_4^{3-}) and nitrogen (NO_3^-, NO_2^-, $NH4^+$) which can increase algal productivity (Raymont, 1980; Vollenweider, 1981; Davies and Day, 1998).

The AMS dates of Zone 4 (~350–850 cal yr BP or ~1100–1600 AD) suggest that this level belongs to the Late Iron Age (Maggs, 1984). The zone is characterized by short-term peaks of *Olea* and *Celtis*, which often grow together in the coastal forest and generally show similar fluctuations in the Lake Sibaya record. *Bruguiera*, *Phoenix* and *Macaranga*, occupying wetter habitats, show slightly higher values.

This part of the Lake Sibaya profile may signal moister conditions regionally. Ferns, *Typha*, *Nymphaea* and Haloragaceae decrease during Zone 4. Climatic effects on this part of the pollen diagram are probably overshadowed by anthropogenic disturbances of the vegetation, as evidenced by the appearance of Poaceae >50 μm and, perhaps, the spread of the eutrophic algae. Human influence might also be indicated by the increase of *Trema*, a pioneer tree often growing on disturbed soils (Pooley, 2003).

Sedimentation rates increase from 0.6 mm/yr to 3.5 mm/yr, possibly as a result of enhanced erosion due to human activities (Fig. 4). As with Lake Teza (Scott, 2002) no peak of charcoal is detected in Zone 4 with increasing human impact in the pollen record. Cattle might have removed much of the flammable grass, minimizing burning during dry seasons (Bond, 1996).

Zone 3 is represented by six AMS ^{14}C dates which point to ages between ~250 and ~450 cal yr BP i.e., ~1500–1700 AD (Fig. 7, Tables 1 and 2). This section of the pollen record shows the vegetation development until the arrival of the first European settlers in South Africa. Modern Bantu who practised iron-working, animal husbandry and agriculture, entered the region around Mkuzi Game Reserve ~500 cal yr BP i.e., ~1450 AD (Bruton et al., 1980). Indicators for human impact are strong in the first half of Zone 3, and values of the algae (especially *Botryococcus*) are high, perhaps suggesting eutrophication. *Pseudoschizaea*, generally considered to be of algal origin but questioned by Scott (1992), is also prominent (Fig. 6). Pollen grains of large Poaceae (>50 μm) are regularly detected in this Zone. Elements of the savanna, e.g. *Phoenix*, *Hyphaene* or *Spirostachys* are common. *Podocarpus* is low (<5%), other forest elements, e.g., *Celtis*, *Olea* and *Manilkara* have minor importance in the first half of Zone 3 in comparison with Zone 4. To what extent the clearing of trees for firewood and for grazing contributed to the decrease of forest trees (especially *Podocarpus*), is uncertain (Bruton et al., 1980). However, charcoal values are not especially high in Zone 3.

At a profile depth of 135 cm, a peak of *Spirostachys* (>10%) occurs together with peaks of *Phoenix* and *Hyphaene* as *Bruguieria* and *Macaranga* are decreasing, perhaps showing a lessened influence of the mangrove vegetation and swamp forest. During the same period Poaceae with large pollen grains (>50 μm) are absent. This might point to a lower degree of human impact and a short-term recovery of the savanna vegetation. Two radiocarbon dates point to an age ~250–350 cal yr BP or ~1600–1700 AD. This period might fall within the Little Ice Age, which extended from ~150–650 cal yr BP (~1300–1800 AD) and which has been associated with famines in eastern South Africa (Huffman, 1996; Tyson et al., 2001). A clear signal for a cooler environment during the Little Ice Age, as suggested by the stalagmite-based record from Makapansgat in northeastern South Africa (Holmgren et al., 1999), is missing in the Sibaya record, but the peak of *Spirostachys* and other savanna elements and the decrease of human impact might be connected to this event.

The first appearance of *Zea mays* pollen in the record might indicate maize cultivation during the 17th or 18th century. Bruton et al. (1980) report that in the early 1800s, maize replaced sorghum as a major crop in Maputaland. Poaceae (>50 μm, including cerealia) regularly appear in the upper part of Zone 3, and we conclude that a stronger human impact and a retreat of forest occurred although dune elements as *Dodonaea* and *Rhoicissus* were increasing. Dunes may have spread during this time due to grazing and farming leading to the mobilization of sandy substrates (personal communication B. Chase, 2007). Huffman (1996) discusses the increase of settlement size at the end of the 18th century. Hall (1976) suggests that higher rainfall occurred during the same time in the Karkloof area on the basis of a single tree ring record. The introduction of maize during this wet period is apparently another reason for population growth (Bruton et al., 1980). A few *Pinus* pollen grains from the top of Zone 3 might have blown in between the 18th century and the first half of the 19th century.

In Zone 2 *Pinus* pollen increases, probably indicating pine plantations in the region during the 19th and the first half of the 20th century. *Spirostachys* values are high whereas other forest elements (*Podocarpus*, *Acalypha*, *Bruguieria*, *Isoglossa*) decline, perhaps because of woodland clearings and *Pinus* propagation. High pollen production of pine trees overshadows the pollen of other plants. *Trema*, indicating disturbed soils (Pooley, 2003), appears more often. *Mimusops* and *Manilkara*, elements of the dunes, become prominent since the upper part of Zone 2. For the first time pollen grains of *Sclerocarya* are regularly detected. Its survival may be due to its value as an indigenous fruit tree that is often left standing when woodland is cleared for crop production (Pooley, 2003).

Poaceae pollen decreases, probably as a result of local disturbance of grass cover and increased pine plantations. *Stoebe*-type pollen, more prominent in Zones 1 and 2, might be due to anthropogenic disturbances. Although it is a typical Cape genus with pollen similar to that of *Elytropappus*, *Stoebe* is widespread and often an intruder in much of South Africa after disturbances through overgrazing (Adamson, 1938; Acocks, 1975). Chenopodiaceae are abundant in Zones 1 and 2, and are typical of dry regions but also occur in saline habitats in wetter areas or areas affected by anthropogenic disturbances (Coetzee, 1967).

In Zone 1 neophytes appear including *Ambrosia*, a North American weed, and *Casuarina* (Bruton et al., 1980). Pine pollen in the upper 30 cm of the Lake Sibaya record have percentages >55%, probably reflecting massive pine plantations near Lake Sibaya (Bruton et al., 1980). A single hickory (*Carya* sp.) pollen grain might be derived from exotic ornamental or food trees. The presence of Ericaceae, usually associated with winter-rain and cool conditions under natural conditions, is difficult to explain in the modern sediments from coastal KwaZulu-Natal. Although the family's pollen is not well-dispersed (Van Zinderen Bakker, 1970; Hamilton, 1972), its presence might be related to the regional appearance of exotic ornamentals such as *Azalea*, *Vaccinium* and *Rhododendron* planted near Lake Sibaya (H.J.T. Venter, personal observation). *Zea mays* pollen appears regularly in Zone 1. *Passerina*, a common pioneer in the dune shrubs (Pooley, 2003) and *Rhus* appear often. Human influence may perhaps increase shrubby *Rhus* spp. (e.g., *R. discolor*, *R. natalensis*, *R. nebulosa*, *R. pyroides*; H.J.T. Venter, personal observation). Although low charcoal values might mean a suppression of forest fires due to recent protection of the Greater St Lucia Wetland Park, evidence for human impact is strong in Zone 1.

5. Conclusion

Based on sedimentological and palynological studies we present a reconstruction of the late Holocene vegetation history at Lake Sibaya since the Early Iron Age and a short time slice within the Middle Holocene. This study includes a chronology based on 21 AMS radiocarbon dates of two overlapping cores that were correlated and then combined. The significance of the AMS dates is limited by an estimated age error of 50–550 yr due to hardwater reservoir effects in the lake. The age correction used here is based on a comparison of pollen results and archaeological/historical data and should be interpreted with caution.

The palynological sequence provides indicators of human disturbance of the natural vegetation (e.g. eutrophication and the decrease of some woody elements). Direct pollen indicators of agricultural activities include the introduction of crops (e.g., *Zea mays* at ~150–300 cal yr BP). Planting of exotic trees (*Pinus*, *Casuarina*) during the 20th century changed the local pollen spectra markedly.

High values of arboreal pollen during the Middle Holocene point to relatively humid and warm conditions. The beginning of the late Holocene ~1500–1300 cal yr BP (~450–650 AD) in the Lake Sibaya record is characterised by high *Podocarpus* percentages that also indicate a relatively moist environment but possibly different cooler climatic conditions.

Acknowledgements

We gratefully acknowledge financial support from the United States National Science Foundation (Earth Systems History grants ATM-9808972 and ATM-01117170), from Paul Smith's College and from the South African National Research Foundation (grants for F. Neumann and L. Scott). Any opinions, findings, and conclusions are those of the authors and the NRF does not accept any liability in regard thereto. The manuscript has benefitted from discussions with Brian Chase, Janusz Zwolinski, Johan Grobbelaar, Gavin Whitelaw, Thomas N. Huffman and numerous members of the SASQUA 2007 conference. We also thank Rodney Maud, Rio Leuci, Wade Kidwell, Tim Partridge, Johann du Preez, Charles Barker, Petrus Chakane and Steve Norton for logistical and technical support. Jason Fitzpatrick, Matthew Hazzard, and Jerome Madson helped to collect the cores and conducted preliminary microfossil analyses on the cores.

References

Acocks, J.H., 1975. Veld types of South Africa. Memoirs of the Botanical Survey of South Africa 40, Botanical Research Institute, Department of Agricultural Technical Services—South Africa. Pretoria.

Adamson, R.S., 1938. The Vegetation of South Africa. British Empire Vegetation Committee, London.

Allanson, B.R., 1979a. Lake Sibaya. Monographiae Biologicae, vol. 36. Dr W Junk bv Publishers, Boston.

Allanson, B.R., 1979b. The physico-chemical limnology of Lake Sibaya. In: Allanson, B.R. (Ed.), Lake Sibaya. Monographiae Biologicae, vol. 36. Dr W Junk bv Publishers, Boston, pp. 42–74.

Allanson, B.R., Hart, R.C., O'Keeffe, J.H., Robarts, R.D., 1990. Inland Waters of Southern Africa: an Ecological Perspective. Kluwer Academic Publishers, Dordrecht.

Barbero, M.R., Loisel, P., Quezel, D.M., Richardson, D.M., Romane, F., 1998. Pines of the Mediterranean Basin. In: Richardson, D.M. (Ed.), Ecology and Biogeography of *Pinus*. Cambridge University Press, Cambridge, pp. 153–170.

Baxter, A.J., Meadows, M.E., 1999. Evidence for Holocene sea level changes at Verlorenvlei, Western Cape, South Africa. Quaternary International 56, 65–79.

Bond, W., 1996. Fire. In: Cowling, R.M., Richardson, D.M., Pierce, S.M. (Eds.), The Vegetation of Southern Africa. Cambridge University Press, Cambridge, pp. 421–446.

Bonnefille, R., Riollet, G., 1980. Pollens des savanes d'Afrique Orientale. Editions du Centre National de la Recherche Scientifique, Paris.

Botha, G.A., Bristow, C.S., Porat, N., Duller, G., Armitage, S.J., Roberts, H.M., Clarke, B.M., Kota, M.W., Schoeman, P., 2003. Evidence for dune reactivation on the Maputaland coastal plain, South Africa. In: Bristow, C.S., Jol, H.M. (Eds.), Ground Penetrating Radar in Sediments. Geological Society, London, Special publications, vol. 211, pp. 29–46.

Bousman, C.B., 1998. The chronological evidence for the introduction of domestic stock into Southern Africa. African Archaeological Review 15 (2), 133–150.

Breen, C.M., 1979. The dune forest: its structure and maintenance. In: Allanson, B.R. (Ed.), Lake Sibaya. Monographiae Biologicae, vol 36. Dr W. Junk Publishers, Boston, pp. 21–33.

Bruton, M.N., Smith, M., Taylor, R.H., 1980. A brief history of human evolvement in Maputaland. In: Bruton, M.N., Cooper, K.H. (Eds.), Studies on the Ecology of Maputaland. Rhodes University and the Natal Branch of the Wildlife Society of Southern Africa, Durban, pp. 432–459.

Coetzee, J.A., 1967. Pollen analytical studies in East and Southern Africa. Palaeoecology of Africa 3, 1–146.
Coetzee, J.A., Praglowski, J., 1984. Pollen evidence for the occurrence of Casuarina and Myrica in the Tertiary of South Africa. Grana 23, 23–41.
Cooper, K.H., 1985. The Conservation Status of Indigenuous Forests in Transvaal, Natal and O.F.S., South Africa. Wildlife Society of South Africa, Durban.
Davies, B., Day, J., 1998. Vanishing waters. Unversity of Cape Town Press, Cape Town.
Eeley, H.A.C., Lawes, M.J., Piper, S.E., 1999. The influence of climate change on the distribution of indigenous forest in KwaZulu-Natal, South Africa. Journal of Biogeography 26, 595–617.
Ekblom, A., 2004. Changing landscapes—an environmental history of Chibuene, Southern Mozambique. Studies in Global Archaeology, vol. 5. Department of Archaeology and Ancient History, Uppsala.
Faegri, K., Iversen, J., 1989. Textbook of Pollen Analysis. John Wiley & Sons, Chichester.
Finch, J.M., 2005. Late Quaternary palaeoenvironments of the Mfabeni peatland, northern KwaZulu-Natal. Master thesis, University of KwaZulu-Natal, Pietermaritzburg.
Germishuizen, G., Meyer, N.L., 2003. Plants of southern Africa, an annotated checklist. Strelitzia, vol. 14. National Botanical Institute, Pretoria.
Geyh, M.A., Schotterer, U., Grosjean, M., 1998. Temporal changes of the ^{14}C hardwater effect in lakes. Radiocarbon 40, 921–932.
Greeson, P.E., 1982. An annotated key to the identification of commonly occurring and dominant genera of algae observed in the phytoplankton of the United States. Geological Survey Water-Supply Paper.
Haas, N., 1991. Neorhabdocoela oocytes—palaeoecological indicators found in pollen preparations from Holocene freshwater lake sediments. Review of Palaeobotany and Palynology 91, 371–382.
Hall, M., 1976. Dendroclimatology, rainfall and human adaption in the Later Iron Age of Natal and Zululand. Annals of the Natal Museum 22 (3), 693–703.
Hall, M., 1980. Man's role in the development of threatened habitats. Working document vol. 5, HABCON; CSIR, Pretoria.
Hall, M., Maggs, T., 1979. Nqabeni: a later Iron Age site in Zululand. South African Archaeological Society Godwin Series 3, 159–176.
Hall, M.J., Vogel, J.C., 1980. Some recent radiocarbon dates from Southern Africa. Journal of African history 21, 431–455.
Hamilton, A.C., 1972. The interpretation of pollen diagrams from highland Uganda. Palaeoecology of Africa 7, 45–149.
Heiri, O., Lotter, A.F., Lemcke, G., 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. Journal of Palaeolimnology 25, 101–110.
Hill, B.J., 1979. Bathymetry, morphometry and hydrology of Lake Sibaya. In: Allanson, B. R. (Ed.), Lake Sibaya. Monographiae Biologicae, vol. 36. Dr W Junk Publishers, Boston, pp. 34–39.
Hobday, D.K., 1979. Geological evolution and geomorphology of the Zululand coastal plain. In: Allanson, B.R. (Ed.), Lake Sibaya. . Monographiae Biologicae, vol. 36. Dr W Junk Publishers, Boston, pp. 1–20.
Hobday, D.K., Orme, A.R., 1974. The Port Dunford Formation, a major Pleistocene barrier-lagoon complex along the Zululand coast. Transactions of the Geological Society of South Africa 77, 141–149.
Holmgren, K., Karlen, W., Lauritzen, S.E., Lee-Thorp, J.A., Partridge, T.C., Piketh, S., Repinski, P., Stevenson, C., Svanered, O., Tyson, P.D., 1999. A 3000-year high-resolution stalagmite based record of palaeoclimate for northeastern South Africa. The Holocene 9 (3), 295–309.
Howard-Williams, C., 1979. Distribution, biomass and role of aquatic macrophytes in Lake Sibaya. In: Allanson, B.R. (Ed.), Lake Sibaya. . Monographiae Biologicae, vol. 36. Dr W Junk Publishers, Boston, pp. 88–107.
Howard-Williams, C., 1980. Aquatic macrophytes of the coastal wetlands of Maputaland. In: Bruton, M.N., Cooper, K.H. (Eds.), Studies on the Ecology of Maputaland. Rhodes University and The natal Branch of the Wildlife Society of Southern Africa, Durban, pp. 42–51.
Huffman, T.N., 1996. Archaeological evidence for climatic change during the last 2000 years in Southern Africa. Quaternary International 33, 55–60.
Huffman, T.N., 2006. Maize Grindstones, Madikwe Pottery and Ochre Mining in Precolonial South Africa.
Jury, M.R., Govender, Y. (in press). A survey of tropical southeastern Africa in the context of coastal Zone management. Environmental Studies Department, University of Zululand. http://www.unesco.org/csi/act/maputaland/maputa1.htm).
Kotze, P.C., 1929. Tree Planting on the Natal Coast Belt and in Zululand. The Government Printer, Pretoria.
Lavery, P.B., Mead, D.J., 1998. Pinus radiata: a narrow endemic from North America takes on the world. In: Richardson, D.M. (Ed.), Ecology and Biogeography of *Pinus*. Cambridge University Press, Cambridge, pp. 432–449.
Le Maitre, D.C., 1998. Pines in cultivation. In: Richardson, D.M. (Ed.), Ecology and biogeography of *Pinus*. Cambridge University Press, Cambridge, pp. 407–431.
MacDevette, D.R., 1989. The vegetation and conservation of the Zululand coastal dunes. In: Gordon, I.G. (Ed.), Natal Indigenous Forests. Natal Park Board, Pietermaritzburg.
MacDevette, D.R., 1992. The woody vegetation of the Zululand coastal dunes. South African Forestry Handbook. Southern African Institute of Forestry, Pretoria.
MacDonald, G.M., Beukens, R.P., Kieser, W.E., 1991. Radiocarbon dating of limnic sediments: a comparative analysis and discussion. Ecology 72 (3), 1150–1155.
Maggs, T., 1982. Mgoduyanuka: terminal Iron Age settlement in the Natal grasslands. Annals of the Natal Museum 25 (1), 83–113.
Maggs, T., 1984. The Iron Age south of the Zambezi. In: Klein, R.G. (Ed.), Southern African Prehistory and Palaeoenvironments. A.A.Balkema, Rotterdam.
Maley, J., Brenac, P., 1998. Vegetation dynamics, palaeoenvironments, and climatic changes in the forests of western Cameroon during the last 28,000 years B.P. Review of Palaeobotany and Palynology 99, 157–187.
Martin, A.R.H., 1968. Pollen analysis of Groenvlei lake sediments, Knysna (South Africa). Review Palaeobotany and Palynology 7, 107–144.
Maud, R.R., 1980. The climate and geology of Maputaland. In: Bruton, M.N., Cooper, H.H. (Eds.), Studies on the Ecology of Maputaland. Rhodes University and the Natal Branch of the Wildlife Society of Southern Africa, Durban, pp. 1–7.
Mayewski, P.A., Rohling, E.E., Stager, J.C., Karlen, W., Maasch, K.A., Meeker, L.D., Meyerson, E.A., Gasse, F., van Krefeld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R.R., Steig, E., 2004. Holocene climate variability. Quaternary research 62, 243–255.
Mazus, H., 2000. Clues on the history of Podocarpus forest in Maputaland, South Africa, during the Quaternary, based on pollen analysis. African Geoscience Review 7, 75–82.
McCann, J.C., 2005. Maize and Grace: Africas Encounter with a New World Crop 1500–2000. Harvard University Press, Cambridge.
McCormac, F.G., Hogg, A.G., Blackwell, P.G., Buck, C.E., Higham, T.F.G., Reimer, P.J., 2004. SHCal04 Southern Hemisphere Calibration 0 – 11.0 cal kyr BP. Radiocarbon 46, 1087–1092.
Meadows, M.E., Baxter, A.J., 2001. Holocene vegetation history and palaeoenvironments at Klaarfontein Springs, Western Cape, South Africa. The Holocene 11 (6), 699–706.
Meadows, M.E., Sugden, J.M., 1991. A vegetation history of the last 14000 years on the Cederberg, south-western Cape Province. South African Journal of Science 87, 34–43.
Meadows, M.E., Baxter, A.J., Parkington, J., 1996. Late Holocene environments at Verlorenvlei, Western Cape Province, South Africa. Quaternary International 33, 81–95.
Miller, W.R., 2001. The Bathymetry, sedimentology and seismic stratigraphy of Lake Sibaya-Northern KwaZulu-Natal. Bulletin, vol. 131. Council for Geoscience South Africa, Pretoria.
Miracle, M.P., 1965. The introduction and spread of maize in Africa. The Journal of African History 6 (1), 39–55.
Moll, E.J., 1980. Terrestrial plant ecology. In: Bruton, M.N., Cooper, H.H. (Eds.), Studies on the Ecology of Maputaland. Rhodes University and The natal Branch of the Wildlife Society of Southern Africa, Durban, pp. 52–68.
Moore, P.D., Webb, J.A., Collinson, M.E., 1999. Pollen Analysis, 2nd edition. Blackwell Science, Oxford.
Moran, V.C., Hoffmann, J.H., Donnell, D., Van Wilgen, B.W., Zimmermann, H.G., 2000. Biological control of alien, invasive pine trees (*Pinus* species) in South Africa. Proceedings of the Xth International Symposium on Biological Control of Weeds, 4–14 July 1999, Montana State University, Bozeman, Montana, USA, pp. 941–953.
Mucina, L., Rutherford, M.C., 2006. The vegetation of South Africa, Lesotho and Swaziland. Strelitzia, vol. 19. South African National Biodiversity Institute, Pretoria.
Neumann, F., Schölzel, C., Litt, T., Hense, A., Stein, M., 2007. Holocene vegetation and climate history of the northern Golan heights (Near East). Vegetation History and Archaeobotany 16, 329–346.
Pakenham, T., 1999. The Boer War. Jonathan Ball Publishers, Johannesburg.
Palgrave, K.C., 1977. Trees of Southern Africa. C Struik (Pty) Limited, Cape Town.
Pooley, E., 2003. The Complete Field Guide to Trees of Natal, Zululand & Transkei. Natal Flora Publication Trust, Durban.
Poynton, R.J., 1977. Tree Planting in Southern Africa: The Pines, vol. 1. Department of Forestry, Pretoria.
Poynton, R.J., 1995. Casuarina. Report to the Southern African regional commission for the conservation and utilization of the soil (SARCCUS) on tree planting in Southern Africa, vol. 3. Forestry Branch, South Africa. Other Genera.
Prat, N., Daroca, V., 1983. Eutrophication processes in Spanish reservoirs as revealed by biological records in profundal sediments. Hydrobiologica 103, 53–158.
Raymont, J.E.G., 1980. Plankton and productivity in the oceans. 2nd edition, Vol. Phytoplankton, Pergamon Press, Oxford, 1.
Richardson, D.M., 1998. Forestry Trees as Invasive Aliens. Conservation Biology 12 (1), 18–26.
Richardson, D.M., Higgins, S.I., 1998. Pines as invaders in the Southern Hemisphere. In: Richardson, D.M. (Ed.), Ecology and Biogeography of *Pinus*. Cambridge University Press, Cambridge, pp. 450–473.
Roos, J.C., 1991. Primary productivity of the Vaal River phytoplankton. Phd thesis, University of the Orange Free State, Bloemfontein.
Rousseau, D.-D., Schevin, P., Duzer, D., Cambon, G., Ferrier, J., Jolly, D., Poulsen, U., 2006. New evidence of long distance pollen transport to southern Greenland in late spring. Review of Paleobotany and Palynology 141 (3–4), 277–286.
Salzmann, U., Hoelzmann, P., 2005. The Dahomey Gap: an abrupt climatically induced rain forest fragmentation in West Africa during the late Holocene. The Holocene 15 (2), 190–199.
Saunders, A.R., 1930. Maize in South Africa. South African Central News Agency, Johannesburg.
Scamoni, A., 1949. Beobachtungen über den Pollenflug der Kiefer und Fichte. Forstwissenschaftliches Centralblatt 68, 12, 735–751.
Schwab, M., Neumann, F., Litt, T., Stein, M., Negendank, J.F.W., 2004. Holocene palaeoecology of the Golan Heights (Near East): investigation of lacustrine sediments from Birkat Ram crater lake. Quaternary Science Reviews 23 (16/17), 1723–1731.
Scott, L., 1982. Late Quaternary fossil pollen grains from the Transvaal, South Africa. Review of Palaeobotany and Palynology 36, 241–278.
Scott, L., 1992. Environmental implications and origin of microcopic *Pseudoschizaea* Thiergart and Frantz ex R. Potonie emend. In sediments. Journal of Biogeography 19, 349–354.
Scott, L., 2002. Microscopic charcoal in sediments: Quaternary fire history of the grassland and savanna regions in South Africa. Journal of Quaternary Science 17 (1), 77–86 2002.
Scott, L., Lee-Thorp, J.A., 2004. Holocene climatic trends and rhythms in Southern Africa. In: Battarbee, R.W., Gasse, F., Stickley, C.E. (Eds.), Past Climate Variability Through Europe and Africa. Springer, Dordrecht, pp. 69–78.

Scott, L., Steenkamp, M., 1996. Environmental history and recent human disturbance at coastal Lake Teza, Kwazulu/Natal. South African Journal of Science 92, 348–350.
Scott, L., Steenkamp, M., Beaumont, P.B., 1996. Palaeoenvironmental conditions in South Africa at the Pleistocene–Holocene transition. Quaternary Science Reviews 14, 937–947.
Scott, L., Holmgren, K., Talma, A.S., Woodborne, S., Vogel, J.C., 2003. Age interpretation of the Wonderkrater spring sediments and vegetation change in the Savanna biome, Limpopo Province, South Africa. South African Journal of Science 99, 484–488.
Stiller, M., Kaufman, A., Carmi, I., Mintz, G., 2001. Calibration of lacustrine sediment ages using the relationship between ^{14}C levels in lake waters and in the atmosphere: the case of lake Kinnere. Radiocarbon 43, 821–830.
Stirton, C.H., 1978. Plant invaders—beautiful, but dangerous. The Department of Nature and Environmental Conservation of the Cape Provincial Administration, Cape Town.
Stuiver, M., Reimer, P.J., 1993. Extended ^{14}C data base and revised CALIB 3.0 14C age calibration program. Radiocarbon 35, 215–230.
Truter, E., 1987. An Aid to the Identification of the Dominant and Commonly Occurring Genera of Algae Observed in some South African Impoundments. Department of Water Affairs Hydrological Research Institute, Pretoria.
Turner, S., Plater, A., 2004. Palynological evidence for the origin and development of late Holocene wetland sediments: Mdlanzi swamp, Kwa-Zulu-Natal, South Africa. South African Journal of Science 100, 220–229.
Tyson, P.D., Odada, E.O., Partridge, T.C., 2001. Late Quaternary environmental change in southern Africa. START Regional Syntheses. South African Journal of Science 97 (March/April 2001), 139–150.
Van Zinderen BakkerSr. Sr., E.M. (Ed.), 1953–1970. South African Pollen Grains and Spores. Part I–III. A.A. Balkema, Amsterdam.
Van Zinderen Bakker Sr., E.M., 1970. Observations on the distribution of Ericaceae in Africa. Colloquium Geographicum 12 Ferd Dümmlers Verlag, Bonn.
Venter, H.J.T., 1972. Die plantekologie van Richardsbaai, Natal. Phd, Universiteit van Pretoria.
Venter, H.J.T., 1976. An ecological study of the dune forest at Mapelana, Cape St. Lucia, Zululand. Journal of South African Botany 42 (2), 211–230.
Vogel, J.C., 1995. The temporal distribution of radiocarbon dates for the Iron Age in southern Africa. South African Archaeological bulletin 50, 106–109.
Vollenweider, R.A., 1981. Eutrophication—a global problem. Water Quality Bulletin 6, 59–89.
Walker, M., 1991. Quaternary Dating Methods. John Wiley & Sons, Ltd., Chichester, England.
Weisser, P.J., 1980. The dune forest of Maputaland. In: Bruton, M.N., Cooper, H.H. (Eds.), Studies on the Ecology of Maputaland. Rhodes University and The Natal Branch of the Wildlife Society of Southern Africa, Durban, pp. 78–90.
Weisser, P.J., Drews, B.K., 1980. List of vascular plants of the forested dunes of Maputaland. In: Bruton, M.N., Cooper, H.H. (Eds.), Studies on the Ecology of Maputaland. Rhodes University and the Natal Branch of the Wildlife Society of Southern Africa, Durban, pp. 91–101.
Williams, R., 1921. The Cape to Cairo railway. Journal of the African Societies 20 (35), 1–20.
Wright, C.I., Miller, W.R., Cooper, J.A.G., 2000. The late Cenozoic evolution of coastal water bodies in Northern KwaZulu-Natal, South Africa. Marine Geology 167, 207–229.