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High-Resolution Reconstruction of Recent Vegetation Dynamics in a Mediterranean Microtidal Wetland: Implications for Site Sensitivity and Palaeoenvironmental Research

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ABSTRACT

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The analysis of recent sediment sequences from coastal wetlands provides an opportunity to examine the response of these sites to environmental change and events, many of which are independently documented. This also permits an evaluation of rates of response to be made that can help in assessing changes identified in longer-term (Holocene) coastal sediment sequences.

A short core from the Mulinello estuary, Augusta Bay, south east Sicily, was dated using ^{210}Pb and ^{137}Cs. Samples were analysed for pollen and spore content, and the results are presented here as both percentage and influx data. Temporal resolution of the pollen data is typically 5–15 years for the first 50 years of the record (circa 1895–1945 AD) and 2–5 years for the last 50 years (1945–1995 AD). Two phases of salt marsh expansion in the Bay occurred, up to the 1940s and from the 1960s to the mid 1980s. In the mid 1940s, the salt marsh underwent a significant decline, marked by a sudden fall in influx and percentage data for Chenopodiaceae. This correlates with an inwashing of catchment-derived pollen, particularly of resistant Lactucae grains, indicating more regular fluvial inundation. Climate records show the occurrence of significantly higher precipitation at this time. Since the construction of a port access road in the 1980s a second decline in the local halophyte community occurred.

Pollen influx data enable a precise assessment of how quickly local colonisation of surfaces at the sampling site occurred. During both episodes of salt marsh colonisation, the transition from low-moderate to high Chenopodiaceae influx took less than 6 years. The data show that salt marsh communities can expand and decline very rapidly and that these variations can occur independently of significant changes in relative sea level.

ADDITIONAL INDEX WORDS: *Salt marsh, Sicily, pollen taphonomy, accumulation, estuary, Pb dating, relative sea level.*

INTRODUCTION

Palaeoenvironmental studies of coastal wetland sequences have been central to many reconstructions of Holocene relative sea level change and associated environmental conditions (*e.g.* DEVOY 1977, SHENNAN *et al.* 1996, BERNASCONI and STAPLEY 1994, ZONG and TOOLEY 1996, NELSON *et al.* 1996, SMITH *et al.* 1999). Two of the key problems faced in this research have been identifying how quickly environmental shifts occurred, and to what extent the palaeoecological record represents a local or regional signal of change. This paper seeks to assess the potential rapidity of change that can affect coastal wetlands by considering a short recent sediment sequence from the central Mediterranean that has been dated at very high temporal resolution. In addition, the multi-proxy approach used here can be applied in future investigations to help differentiate local from regional contemporary conditions, in particular vegetation characteristics.

COASTAL WETLANDS AS RECORDERS OF CHANGE

Sediment sequences from current and former coastal wetlands have provided important evidence both for the way in which these wetlands change over time and how they respond to external forcing, for example relative sea level change (*e.g.* DEVOY 1977, SMITH *et al.* 1983, RULL *et al.* 1999). Many investigations have focused upon the reconstruction of coastal wetland change over medium to long time scales (typically century to millennia). Such palaeoenvironmental reconstructions permit broad patterns of change to be identified at sites and across regions. They also permit the impact of high magnitude, low frequency events such as earthquakes and tsunamis to be evaluated (ATWATER 1987, DARIENZO and PE-

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TERSON 1990, NELSON *et al.* 1995, 1996, SHENNAN *et al.* 1996, LONG and SHENNAN 1998). Chronological precision in these studies is generally limited by the unavoidable errors associated with radiocarbon dating, rarely being better than ±50 ^{14}C years which can increase to several hundred calendar years once the ^{14}C date has been calibrated (SMITH *et al.* 1999). This permits long-term trends to be examined, but is often insufficient for detailed assessments of the rapidity of change from one system condition to another. Radiocarbon-based chronologies, although often very effective in helping to explain why a wetland developed in a particular way, rarely permit a precise evaluation to be made of how quickly a wetland will respond to, and recover from a particular environmental event. This is particularly important when considering episodes of rapid relative sea level rise, such as that which occurred during the Early Holocene (*e.g.* ZONG and TOOLEY 1996, Smith *et al.* 1999). Within sediment sequences recording such rises, thin organic beds interpreted as representing periods of vegetation colonisation are frequently present. Understanding how quickly these can develop is clearly of some importance if the nature of the sea level rise (*i.e.* continuous or punctuated) is to be assessed. It is also essential to determine the contemporary conditions under which these deposits accumulated to assess whether they resulted from a local or more widespread change. Fundamental to this is an understanding of the processes that can affect subfossil assemblages in these settings.

TAPHONOMY OF POLLEN ASSEMBLAGES FROM FLUVIO-ESTUARINE DEPOSITS

Investigations at a number of sites have shown that robust vegetation and broader environmental histories can be constructed from fluvial and estuarine deposits (*e.g.* DEVOY 1977, SMITH *et al.* 1983, CHMURA and EISMA 1995, DAVIS 1992, COLLINS *et al.* 1996, SMITH *et al.* 1999). Fine-grained mineral sediments of the type found in fluvio-estuarine systems can contain pollen assemblages with significant reworked components. To successfully use such deposits, it is necessary to initially only consider variations in the most frequent taxa that can then be used to define local pollen assemblage zones. Care therefore has to be taken in reconstructing contemporary vegetation from these assemblages as the ratio of local to far-travelled pollen can be expected to vary in different sediment types. Organic-rich salt marsh deposits, for example, may have very high relative frequencies of Chenopodiaceae from the immediate community of halophytes. In comparison, underlying mineral sediments may have a higher relative frequency of taxa from inland and more distant sources. Bisaccate pollen taxa such as *Pinus* and *Picea,* for example, may be significantly over-represented in assemblages affected by water currents (*e.g.* WORSLEY *et al.* 1995).

The abundance of a few types of locally produced pollen in some organic deposits can lead to less frequent taxa not being encountered in routine counting, even if their influx to the site is unchanged. Consequently, relative frequency variations in all taxa, and particularly so-called rare types must be considered with the possibility that they are, at least in part, artefacts of the methodology. A further problem in many intertidal settings results when hydroperiods vary. This could happen in response to relative sea level changes or channel migration, incision or aggradation, or when there is a direct human impact on the site. Potential consequences of these factors can include the expansion, or contraction of wetland areas. If this happens, fully terrestrial pollen sources become further from, or closer to the sampling site over time. This can lead to changes in their relative frequency without there being a regional change in vegetation community (*cf.* WALLER and MARLOW 1994). One way of assessing the reliability of a pollen assemblage is to consider its state of preservation (*cf.* CUSHING 1967). This can help to identify if there has been differential preservation and if there is a significant reworked component. Problems potentially exist, however, if there are variations in sediment accumulation rate and, by inference, surface stability. If there are, then the time available for syn-and post-depositional grain degradation locally at the site will vary, as will the intensity of the degradational processes. This may mask any preservation signature that could be used as a proxy for reworking. An additional method of assessing a sequence of pollen assemblages is to consider absolute frequency changes in individual taxa from sediments of different ages (PENNINGTON and BONNY 1970, DAVIS 1992). Useful inferences can be made of vegetation changes using estimates of variations in concentrations. Problems in interpretation arise, however, where variations in sediment composition or in sediment accretion rate occur (see for example comments in LOWE and WALKER 1997). This is especially the case if the variations occur at a higher frequency than the chronological control points. A simple rise in concentration does not necessarily mean that pollen deposition was occurring at a greater rate-it might simply reflect slower sediment accumulation.

More useful consideration of vegetation changes over time can be made if sediment ages are known. Where this is the case, pollen and spore influx variations over time (*i.e.* the rate at which pollen and spores accumulate within the accreting sediment sequence) can be estimated. If vegetation patterns and community composition around a site remain static, grain concentrations will vary in direct relation to sediment accumulation rates — the higher the rate, the lower the concentration. In many situations, however, variations in accumulation will be associated with variations in vegetation. This is particularly important as a slowing of deposition may allow colonisation and exploitation of a surface by plants to proceed, leading, after a lag, to greatly increased supply of locally produced pollen. In salt marsh settings, the opposite may occur. Vegetation colonisation of a mud surface may enhance net sediment accumulation rates in comparison with adjacent, unvegetated mud flat where recently deposited material may be easily removed (*e.g.* ALLEN and PYE, 1992). Pollen and spore concentrations, however, may remain stable, or even increase, as there may be additional inputs from the new local vegetation community. In microtidal wetlands for example, this potentially will be reflected by a higher influx of pollen from halophytes such as Chenopodiaceae. Clearly there must be an upper threshold beyond which further increases in sediment accumulation have a detrimental

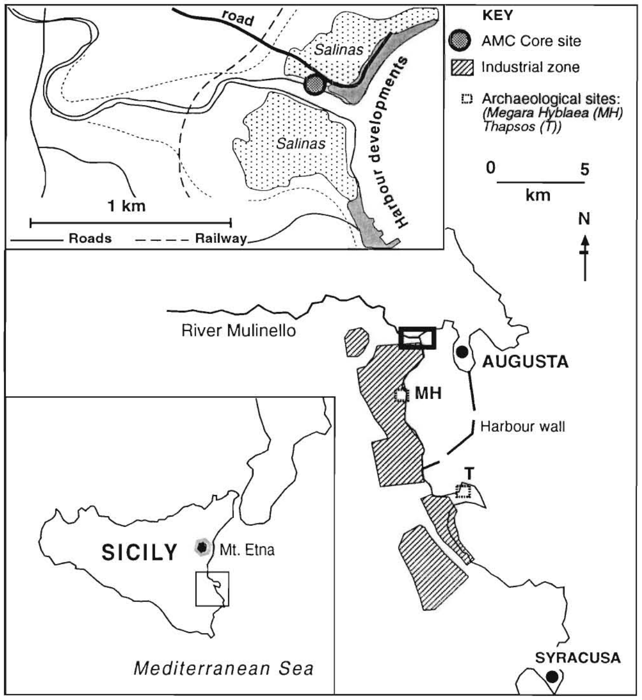

Figure 1. Augusta Bay, showing the course of the Mulinello river and the industrial zone. Inset top right - The Mulinello estuary, Augusta Bay, showing core locations and the port access road. Inset bottom right - South east Sicily, showing the locations of Augusta Bay and the two precipitation data sites: CA = Catania, PA = Piazza Armerina. Modified from CUNDY *et al.* 1998.

effect upon the supply of pollen from local halophytic vegetation. This could result from the burial and/or physical destruction of the plants, or a decrease in flooding frequency induced by the vertical accretion of the marsh surface. Influx (or accumulation) rates have been calculated from a number of sites. Radiocarbon dates can be used but these tend to be imprecise, resulting in influx rates with large potential errors. The most suitable sites are those where annually laminated sediments are present (*e.g.* PEGLAR 1993). Such sites are relatively rare and most sediment sequences are affected by less regular deposition and by bioturbation. This is particularly the case for fluvial-estuarine sites where flow can vary significantly over time.

One approach which can help assess the issues of sediment accumulation rate changes and allow a more precise determination of pollen influx variations in coastal wetlands is the dating of young sediment sequences using short-lived radionuclides, particularly ^{210}Pb and ^{137}Cs (*e.g.* CUNDY and CROUDACE 1996). These do not rely on the presence of organic material and hence, high resolution and high precision dating of recent mineral sediments can be achieved. The use of such dating provides the opportunity to reconstruct the temporal dynamics of coastal wetlands for the last 100-150 years. This paper reports the application of this approach to a short intertidal sediment sequence from Augusta Bay, south east Sicily (Figure 1, 15°15′E 37°15′N).

STUDY AREA

Intertidal wetlands occur in a number of places along the south east coast of Sicily, an area that has experienced intensive post-Second World War industrial and port development. The mean tidal range here is small (0.3m neaps, HYDROGRAPHER OF THE NAVY 1996). Unlike the north eastern coast of Sicily, which is undergoing uplift (FIRTH *et al.* 1996, STEWART *et al.* 1997), the south east has experienced progressive subsidence in historic and late prehistoric times (BASILE *et al.* 1986). The region as a whole is seismically active. At least one documented episode of significant coastal flooding appears to have resulted from tsunami generated during the Straits of Messina earthquake in 1908 (PLATANIA 1909). The area of Augusta Bay itself, however, has experienced only limited seismic activity over the last one hundred and fifty years (MULARGIA *et al.* 1985).

This paper focuses upon the mouth of the Mulinello river, the main source of freshwater discharge into the northern part of Augusta Bay, where an area of salt marsh was cored in 1995 (Figure 1). Low energy conditions are created at the coast by rocky promontories to the north and south of the bay and the gently sloping offshore bathymetry. The Augusta area has experienced intensive human activity for several millennia (CHESTER *et al.* 1985). Commercial salt production, involving the construction and management of salinas, affected much of the present marsh in the 19th and early 20th centuries. The expansion of larger scale salt production in the west of Sicily led to the abandonment of the Augusta Bay salinas in the mid-20th century. Sediment sequences in the former salinas have been disturbed, though a number of intact areas remain between derelict salinas and near the Mulinello channel. Adjacent to the site is the port of Augusta, which has undergone major expansion since the 1950s (CHESTER *et al.* 1985). Large areas nearby have been developed for the petrochemical industry.

The salt marsh vegetation community at the site was dominated by *Sueda maritima* (L.) Dumort and *Atriplex portulacoides* (L.). Inland, maquis plant communities reflect the dry Mediterranean climate, though these have been largely replaced by agriculture with associated weed communities (particularly Lactucae). Immediately to the north of the coring site is the port access road that has been built across the salt marsh. Examination of air photographs taken in 1942 (Source: Royal Air Force) show that the position of the channel has changed little over the last half century. Furthermore, the coring site appears to have been between former salinas. As a result, the sediment record is believed to reflect 'normal' deposition, rather than the accelerated aggradation that might be expected in abandoned salinas.

METHODOLOGY AND RESULTS

Stratigraphy

A shallow (30 cm) core of cohesive sediment (principally organic-rich clays and silts) was collected from a point a few metres from the Mulinello channel in February 1995 for laboratory analysis. Further cores from the site revealed that a basal, waterlogged and poorly consolidated sand unit under-

Table 1. *Stratigraphy of the core taken from the Mulinello estuary, Augusta Bay, Sicily.*

Depth (cm)	Sub-unit	Characteristics
2.5–surface	D	Surficial organic-rich salt marsh deposit: plant detritus and roots, shells (*Hydrobia* sp. and *Bittium* sp.), plastic flotsam.
4.5–2.5	C	Brown/grey silt-clay with Fe-oxyhydroxide mottling, fine roots from surface.
14.0–4.5	B	Dark brown silt-clay with intercalated black organic laminae.
30.0–14.0	A	Dark brown/grey silt-clay with distinct Fe-oxyhydroxide mottling. Shell rich water-saturated sand at base.

lies this surficial unit. The shallow sampled core revealed four sub-units (Table 1).

Oven dried samples were ignited at 550°C for two hours to provide an estimate of organic carbon content (Figure 2). The results showed a general decline in percentage loss from top to base, with distinct peaks at the surface, 6-8 cm depth and at 13-14 cm depth. These thin organic horizons are similar in appearance and stratigraphic context to those frequently used to constrain water levels in relative sea level reconstructions (see *e.g.* SMITH *et al.* 1999).

Geochemical characteristics of contiguous 1 cm thick samples were determined using a Philips PW1400 sequential x-ray fluorescence spectrometer. CUNDY *et al.* (1998) provide a detailed account of these data. Significant variations in composition occur (*e.g.* Figure 2f) and CUNDY *et al.* (*op cit.*) have shown that these reflect changes in sediment provenance at the site over the last one hundred years.

Radiometric dating

Total ^{210}Pb activity was determined in core samples by the proxy method of α-spectrometric determination of its granddaughter isotope ^{210}Po, following FLYNN (1968). The core was sampled from the surface at 1 cm resolution down to 27 cm. Age determinations (Figure 2) were derived using the ^{210}Pb constant rate of supply (CRS) model (APPLEBY and OLDFIELD 1978, 1992) and probable age expressed in calendar years AD. In addition, variations in ^{137}Cs activity with depth were measured (Figure 2). This provided a single discrete activity maximum, taken to correlate with the peak fallout from atmospheric nuclear bomb tests in 1963. The well-defined peak of ^{137}Cs activity in the core suggests it has not been re-mobilised by diagenetic processes due to competitive adsorption between organic materials and clay mineral lattice sites (DUMAT *et al.* 1997). Similarly, there is little evidence for bioturbation. A second peak frequently present in sequences from northern Europe, derived from the 1986 Chernobyl accident was absent, possibly reflecting prevailing wind flow directions at the time of the accident (CUNDY *et al.* 1998). A discrepancy of 10-12 years exists between the chronology indicated by ^{210}Pb and presumed 1963 peak in ^{137}Cs. A full discussion is given in CUNDY *et al.* (1998), but the slight difference in ages given by the two methods almost certainly reflects variations in sediment source and composition. These can be expected to have affected the flux of ^{210}Pb to the marsh

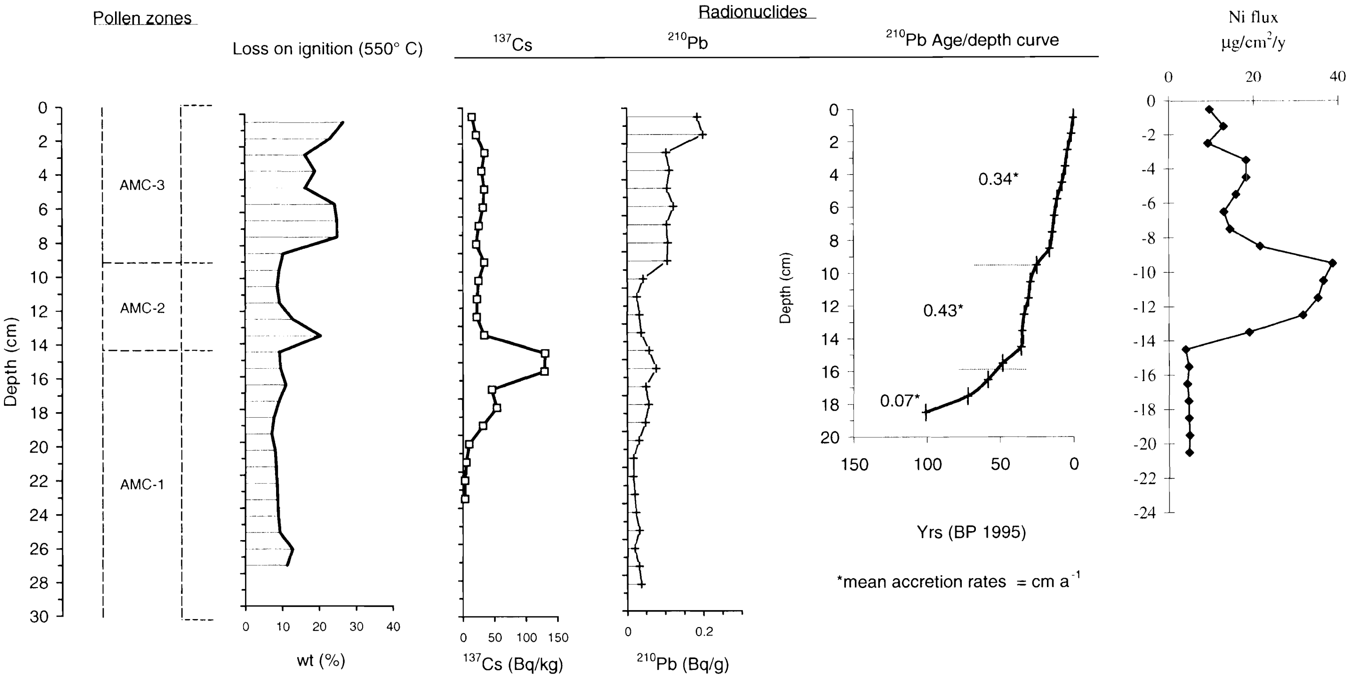

Figure 2. Stratigraphy of the Mulinello core. a) Local pollen assemblage zones. b) Loss on Ignition data shows an estimate of organic carbon. c) ^{137}Cs activity with depth: note peak in activity at 14 cm depth d) ^{210}Pb activity with depth. e) age depth curve based on ^{210}Pb chronology. f) Ni flux vs depth, acting as a proxy for catchment-derived sediment inputs (after CUNDY *et al.* 1998).

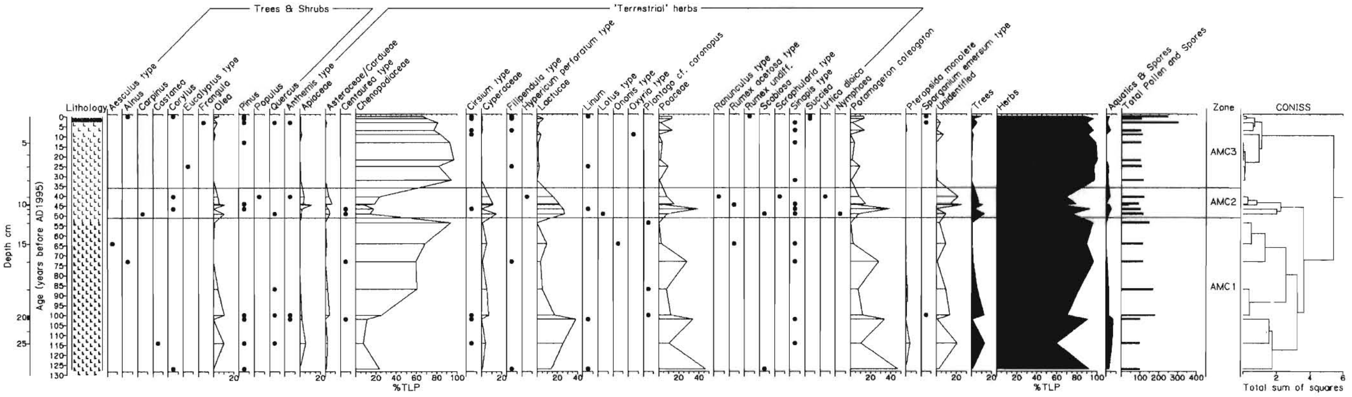

Figure 3. Relative pollen diagram for core AMC, Augusta Bay, showing local pollen assemblage zones. All percentages are based upon Total Land Pollen (TLP). Black circles indicate the presence of pollen taxa that occur at less than 4% of TLP.

surface, and may have slightly affected the ages given by the CRS model. Despite the discrepancy, the age-depth curve in Figure 2 clearly shows considerable variation in sediment accumulation rate, with increased sediment accumulation in the period 1945-1965.

Pollen analysis

Subsamples were prepared for pollen analysis following standard techniques (MOORE *et al.* 1991) with mineral material removed using repeated treatments of concentrated hydrofluoric acid where necessary (*cf.* WEST 1977). *Lycopodium* tablets were added to subsamples of known mass and volume to enable pollen and spore concentrations to be estimated:

$$P_c = (M_a/M_n)*(P_n/S_{vol})$$

where

P_c = pollen & spore concentration (grains per cm^3 of sample)

P_n = number of pollen and spore grains counted (not including exotics)

S_{vol} = sample volume (cm^3)

M_a = number of exotic marker grains added

M_n = number of exotic marker grains counted

From this an estimate of the rate of pollen influx to the accumulating sediment sequence is possible by considering sediment accumulation rates and pollen concentrations.

$$P_i = (T_{1cm}/P_c)$$

where

P_i = pollen and spore influx rate (grains per year to one cm^2 of sediment surface: grains cm^{-2} a^{-1})

T_{1cm} = Time taken for 1 cm depth of sediment to accumulate

Pollen and spore assemblages were examined at X 1000 magnification, using phase contrast where necessary. Identification follows MOORE *et al.* (1991), with reference to PUNT (1976, 1980, 1981) and type slides. Pollen nomenclature follows the recommendations of BENNETT *et al.* (1994). CUNDY *et al.* (1998) provide a preliminary account of relative (i.e. percentage) variations in pollen assemblages for the Augusta Bay core, with associated geochemical analyses. The minerogenic nature of the sediments, together with frequently poor preservation, made pollen analysis difficul~~t and tim~~e consuming. As a result, total counts of identifiable taxa are low, with a mean of 120 and a range of 242 (from the surface) to 27 (from 12 cm depth). In addition, a sample from 20 cm depth yielded only three deteriorated grains after exhaustive searching. The low counts mean that subtle variations in relative and absolute frequencies may be artefacts of the methods, rather than reflecting real changes in contemporary vegetation and pollen supply. Consequently, only major assemblage changes can be used to help reconstruct the site's history.

The chronological control provided by the ^{210}Pb and ^{137}Cs dating means that the sediment interval between pollen assemblages is typically 2-5 years for the last 40 years and 5-15 years for the first 50 years of the record. This degree of temporal resolution makes it possible to assess rates of change to a high level of precision.

VEGETATION HISTORY AT AUGUSTA

The pollen data were initially evaluated for major variations by visual inspection (Figures 3 and 4). As the counts were in some cases small, only significant variations (typically >10% change) in the most frequent taxa were initially considered when determining local pollen assemblage zones (LPAZs). Subsequent cluster analysis on the complete data set, using CONISS (included in the TILIA pollen data analysis and graphics software, Grimm 1991), identified the same zonation. The pollen percentage data suggest three zones that appear to relate to temporal variations in the dominance of particular vegetation communities across the whole site.

Zonation of the influx data is more problematic, largely because of the amplitude of absolute variations in influx rates, particularly for Chenopodiaceae. Indeed, rather than being primarily a reflection of the whole site, pollen influx appears to be influenced by very local conditions, in particular the depositional environment and local plant communities. The zones, or more accurately the zone boundaries, determined from the percentage data can still be picked out, identifying significant shifts in pollen assemblage composition.

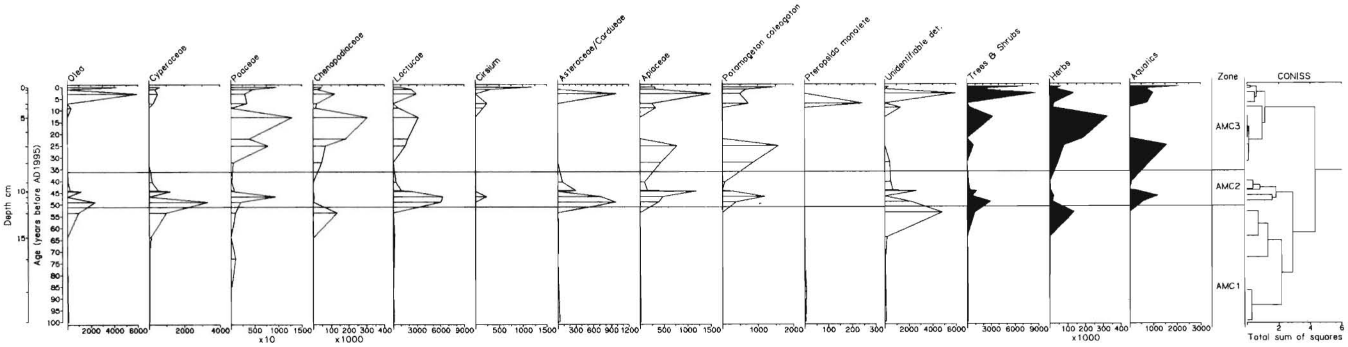

Figure 4. Pollen influx diagram (selected taxa) for the top 18 cm of core AMC, Augusta Bay (approximately the last 100 years). Note horizontal scales vary. Pollen zonation follows that used in figure 3.

The low diversity of pollen taxa largely reflects the dominance of a few types (Chenopodiaceae, Lactucae, and Poaceae) which, in relatively low counts, effectively reduce the likelihood of encountering other taxa during routine analysis.

LPAZ AMC-1. Pre-AD1900 to *circa* AD1945

The progressive increase in the relative frequency of Chenopodiaceae through this zone suggests gradual expansion of salt marsh at the site (Figure 3). Higher Lactucae frequencies near the base probably reflect supply from either ruderal communities on higher ground around the site, or possibly inputs from inland sources, though this latter hypothesis is not supported by geochemical data (CUNDY *et al.* 1998). The subsequent decline in Lactucae appears to be largely a relative decline due to higher Chenopodiaceae inputs. There may also have been a slight decline in ruderal vegetation communities around the salt marsh margins. This could be because of local relative sea level rise (a hypothesis for which there is no independent supporting evidence) or more probably is a result of changes in site management (*e.g.* variations in grazing intensity).

The peak in the influx rate of Chenopodiaceae in a single sample at 14 cm depth (= *ca.* AD1945) could reflect a 'freak' event such as the inclusion of an intact flower in the sediment from this depth. The relative frequency of Chenopodiaceae from this depth, though high, is broadly similar to those from samples immediately below it, and very similar to several samples in zone AMC-3. A likely explanation therefore is that this peak represents the colonisation of the mud surface immediately around the coring site with the additional pollen being supplied directly to the surface deposits either by fallout of the pollen, or by supply of intact flowering parts. It is also possible that the increase in macrophytes locally could have enhanced the production of local-pollen enriched faecal pellets (*cf.* CHMURA and EISMA 1995).

Although there is documentary evidence for the site being affected by tsunami waves generated during the AD1908 Straits of Messina earthquake (PLATANIA 1909), there is no pollen or sediment compositional evidence for these having an impact upon vegetation communities in the coastal wetland.

LPAZ AMC-2 *circa* AD1945- AD1964. 13.5-8.5 cm depth

The pollen assemblages from this zone are markedly different from those of LPAZ AMC-1. The most significant differences are the lower relative and influx values for Chenopodiaceae, while Lactucae, Apiaceae and Asteraceae/Cardueae are higher. In addition, there is a wider range of pollen taxa present, representing a wider range of plant communities. The fact that both percentage and influx values for Chenopodiaceae decline at the base of this zone suggests that there was not just a local decline in the vigour and extent of salt marsh vegetation. At the same depth in the core, sediment geochemistry changed significantly (CUNDY *et al.* 1998) indicating a sudden increase in the supply of catchment-derived particles to the site. The rise in Lactucae, Poaceae and Cyperaceae may indicate a simple replacement of salt marsh by damp, less saline wet and dry habitats. These could perhaps have colonised the slightly higher surface produced by rapid deposition. The increase in surface elevation, however, is small (about 4 cm at the core site) and such expansion is likely to have been very limited.

The transition from AMC-1 to AMC-2 occurs over a depth of at most 1 cm. There is no abrupt decline in the ^{137}Cs and ^{210}Pb profiles from the core at this depth (Figure 2) suggesting that it is unlikely that the abruptness of this transition is a result of a significant hiatus or erosive episode. The transition represents a time interval that could be less than one year and certainly less than nine years (the precision of the dating at that depth). This change reflects a significant shift in environmental conditions that, at the local scale at least, was 'catastrophic'. In a very short period, the salt marsh at the site appears to have experienced a major decline.

The change in pollen assemblage characteristics, linked to geochemical evidence suggests that the salt marsh was subject to increased flooding by water derived from inland. Available climatic data (Figure 5) do show some major precipitation events in south east Sicily, particularly in December 1944, January 1946 and October 1951. These data, however, come from stations some distance from the Mulinello catchment. Consequently, it is not yet possible to say conclusively if one or more of these recorded events were responsible, or

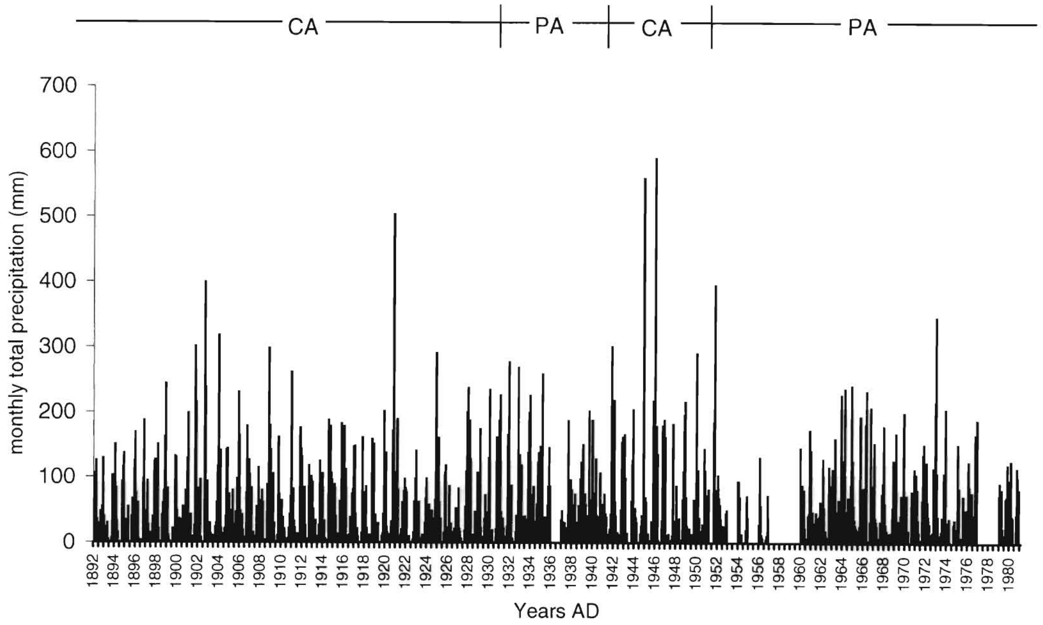

Figure 5. Precipitation data for south east Sicily for AD1892-1981. Note this is a compilation from two measuring stations. CA = Catania, PA = Piazza Armerina. There are gaps in the data for 1936, 1953, 1955, 1957, 1958, 1959, 1977 and 1978. Sources: SIMPSON *et al.* 1927, 1934, U.S. DEPARTMENT OF COMMERCE 1959, Argenti 1998.

if a separate event affected the catchment but was not experienced at the recording stations. Migration of the Mulinello channel could perhaps have had a similar effect. Given that its present position is similar to that in 1945 however, this seems less probable.

Influx rates for Lactucae, the dominant pollen type for AMC-2, decline noticeably through the zone. Through the same depth, some trace elements derived from inland sources (*e.g.* Ni; Figure 2) experienced an increase in flux (CUNDY *et al.* 1998). An explanation for this is problematic. It may reflect an initial inwashing of pollen-bearing topsoil, including some from channel margin sites, reflected by the Apiaceae and Cyperaceae, followed by subsequent supply of pollen deficient material. This could represent a greater contribution of sediment resulting from erosion of deeper, less pedogenically altered soil horizons, or sediment derived directly from volcanic rocks further inland.

LPAZ AMC-3 *circa* AD1964- AD1995. 8.5-0.0 cm depth

The transition from AMC-2 to AMC-3 marks the final major change in vegetation at the site. This uppermost zone is characterised by high relative frequencies of Chenopodiaceae, reflecting reestablishment of a salt marsh plant community, and its persistence until the time of coring in AD1995. The transition occurs over a depth of 1 cm (the sampling resolution in this part of the core). ^{210}Pb dating suggests this represents an interval of between two and seven years. Pollen influx data suggests subdivision of this zone into two. The earlier episode is characterised by high inputs of Chenopodiaceae and moderate inputs of Lactucae and Poaceae. The transition from this earlier episode to the final part of the pollen record is marked by a decline in the influx of the main taxa, followed by their recovery. This oscillation suggests a short-lived decline in local vegetation, lasting less than five years and beginning in the mid 1980s. Such a decline may reflect the construction of the port access road across the site that must inevitably have caused significant local disturbance. The recovery of Lactucae and Poaceae towards the frequencies found near the top of AMC-3 and the increased influx from a variety of other herb taxa (*e.g.* Cirsium) are almost certainly due to colonisation of the disturbed ground at the margins of this road. In comparison, while Chenopodiaceae influx does rise, it does not approach the levels encountered at the base of the zone, probably because its spatial extent has been restricted by road construction.

DISCUSSION

Pollen taphonomy in microtidal, estuarine wetlands

Selective preservation resulting, for example, from mechanical stresses, bacterial attack and oxidation potentially affects the characteristics of any pollen assemblage. Less resistant pollen taxa may, as a result be significantly underrepresented in counts of identifiable grains. Conversely, resistant taxa may be significantly over-represented. Lactucae in particular are typically robust and may persist when most of the original pollen assemblage has disappeared. This may potentially lead to problems in producing a realistic reconstruction of contemporary vegetation, particularly when relative data are relied upon (COLLINS 1994).

Relative pollen data can also give potentially misleading information where successional change in a wetland occurs.

This could produce an increase in pollen supply from a particular element of the local vegetation. The passing of a critical geomorphological and ecological threshold, such as accumulation to the elevation of mean high water can result in a sudden change. At Augusta, this may explain the sudden increase in Chenopodiaceae pollen at 14 cm depth (~AD1945). This may be expressed as a change of state where no macrophytes were present on the surface to establishment of a pioneer salt marsh community. The sudden increase in locally produced pollen may lead to an apparent relative decline in less local taxa, even if no such absolute change occurred.

By adopting the dual approach of considering pollen and influx data, it is possible to address these problems. The percentage and influx datasets from Augusta (Figures 3 and 4) demonstrate overall similarities, which suggests that the changes in assemblage composition are real, rather than simply an artefact of the methodology. Most notably, the percentage decrease in Chenopodiaceae in LPAZ AMC-2 clearly reflects an actual decline in halophytes. At the same time, the percentage increase in Lactucae is a result of more pollen of this type being supplied to the site, rather than of selective preservation.

Some differences do exist between the relative and influx datasets. The most significant occurs in LPAZ AMC-1, percentage frequencies for Chenopodiaceae show a progressive increase toward the top of the zone, while influx values remain steady until the very top. An explanation for this may be found if changes in the local depositional environment are considered. Throughout much of the time period represented by LPAZ AMC-1, the coring site was unvegetated and may have been an open mud flat or bar within the estuarine channel of the Mulinello, below high water level. As such it would have been regularly affected by tidal water currents moving inland from the seaward margins of the coastal wetland, and in the opposite direction by both tidal and river currents from the inland margin of the wetland. Pollen supply to the coring site would, therefore, have been from the whole site. The gradual percentage rise of Chenopodiaceae therefore indicates widespread expansion of salt marsh near the Mulinello channel. The final pollen sample from LPAZ AMC-1, with high relative and influx values, coincides with an increase in organic content. This suggests the surface was above the influence of most tides, permitting colonisation of the coring site itself by halophytes.

The differences between the percentage and influx data therefore permit the differentiation of meso-scale (whole site) vegetation changes from micro-scale (sampling locality) changes. In particular, influx data appear to be closely associated with local changes in sediment budget.

The Augusta results certainly show that abrupt change and recovery are identifiable using combined relative and influx pollen data, in combination with other evidence such as geochemistry. This provides essential information of wetland sensitivity to events of a variety of magnitudes.

Sensitivity of microtidal wetlands

The data presented here provide a useful insight into the sensitivity of Mediterranean microtidal wetlands to environmental change. After its collapse in the mid 1940s, possibly in response to increased freshwater flooding, the Augusta marsh recovered to a state where pollen influx of Chenopodiaceae had begun to approach early 1940s levels by approximately AD1960. Such abrupt change in the ecosystem has implications both for the interpretation of older sediment sequences and for conservation management at similar sites elsewhere. The data suggest that, even with no deliberate restoration scheme and with the absence of significant disturbing factors, such sites may regain their ecological status within a few years (*cf.* Allison 1996). This recovery, however, can be reversed by detrimental human activity, such as the construction of the port access road that reduced the spatial extent of the marsh.

Implications for longer timescale palaeoenvironmental reconstructions

The rapidity of vegetation change identified here has important implications for the interpretation of older sediment and palaeoecological records, in particular for reconstructions of relative sea level. The changes in the Augusta record occurred without major oscillations in sea level (there may be a background signal of subsidence but this cannot be proven from the Augusta results).

The timescale of the vegetation changes at Augusta (<100 years for the salt marsh to develop, suffer significant reduction and expand) is much less than the timespan represented by even a single precise radiocarbon date, particularly if it is calibrated. Indeed, some of the most abrupt changes identified here occurred over shorter time periods than the interval between successive pollen samples, generally being less than six years. An implication of this is that stratigraphic and palaeoecological transitions in older sediment sequences may represent virtually instantaneous events. Sudden stratigraphic changes from silt to peat and then silt, a common feature in sequences used for relative sea level sites in areas such as Scotland, may sometimes represent local fluctuations, such as distance to a tidal channel or sediment compaction, rather than relative sea-level change in response to eustatic variations or more local isostasy. This supports the view that sedimentology and relative pollen data, on their own, are not sufficient for assessing relative sea level records in coastal wetlands sediments and that other methodologies must also be applied. In recent years, diatoms, foraminifera and geochemistry have been successfully used (*e.g.* Long and Shennan 1998, Smith *et al.* 1999). To these should be added pollen influx data analysis where sufficiently robust chronologies can be determined.

CONCLUSION

The potential influence of moderate and low frequency events on microtidal wetlands is highlighted by the results from Augusta Bay. This insight into their sensitivity to external controls and events has important implications both for the interpretation of sedimentary records of past wetland environments and for the conservation management of such sites. Five key conclusions from this research are:

- Change within coastal wetlands can be rapid, both in terms of destruction of halophytic vegetation communities, and their recovery

- Combined analysis of pollen percentage and influx data provides a powerful tool for assessing and distinguishing the record of local and regional vegetation change in coastal wetland sediment sequences
- When linked to detailed geochemical analyses, pollen data can provide robust reconstructions of change at coastal wetland sites
- Oscillations between organic and inorganic wetland sediments, and between 'terrestrial' and halophytic pollen assemblages cannot be assumed to be a reflection of relative sea level change without support from other proxy evidence

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