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Review

Long-term retrospection on mangrove development using sediment cores and pollen analysis: A review

Joanna C. Ellison *

School of Geography and Environmental Studies, University of Tasmania, Locked Bag 1376, Launceston, Tasmania 7250, Australia

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Abstract

Mangroves are biogenic systems that accumulate sedimentary sequences, where cores can provide records of mangrove species variation in distribution with past climate change and sea-level change. Fossil evidence used for palaeoecological reconstruction is based on organic remains that preserve identifying features so that they can be identified to generic levels at least. This includes macrofossils such as fruit, flowers, wood or leaves, or microfossils particularly pollen. Anaerobic conditions in mangrove sediment allow the long-term preservation of these fossil records. Fossil pollen from core samples is concentrated for microscopic examination by use of standard chemical treatments, but refinements of these are necessary for the peculiarities of mangrove peat. Pollen diagrams are expressed in concentrations, or more usefully in mangrove environments as proportions relative to others, as this has been shown to demonstrate the depositional environment actually underneath the mangrove forest. Radiocarbon dating of sedimentary sequences is used to date palaeoecological successions shown by fossil sequences, or long-term sedimentation rates. Sediment accretion in the last 50–200 years can been analysed better using Cs^{137} and Pb^{210} analyses. From pollen and macrofossils mostly recovered from stratigraphic cores of sedimentary rock and more recent sediment, the evolution and dispersal of mangroves through geological time has been reconstructed. While reconstruction of actual temperatures in these earlier records is associative to the fossil types present, it is apparent that mangroves have always been tropical species, extending to higher latitudes only during global warm periods. Many sedimentary records show mangroves deeper than the present lower limit of mangrove growth at mean sea-level. These indicate sea-level rising over time, and mangroves keeping pace with rising sea-level. Stratigraphic dating shows accretion rates of 1 mm a^{-1} for low island locations, and up to 1.5 mm a^{-1} in high islands/continental margins. Sedimentary records can also show die-off of mangroves with more rapid sea-level rise and replacement by open water during rising sea-level, landward retreat of mangrove zones, or replacement of mangroves by freshwater forest with sedimentary infill. The causes of mangrove community changes identified in the palaeoecological record can only be inferred by comparison with ecological studies in the modern environment, the link between the two that may be possible through long-term mangrove monitoring being poorly established.

Keywords: Stratigraphy; Pollen analysis; Palaeoecology; Macrofossil; Sedimentation; Palynology

Contents

* Tel.: +61 3 6324 3834; fax: +61 3 6324 3839.
E-mail address: Joanna.Ellison@utas.edu.au.

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1. Introduction

Mangroves are an ecosystem dominated by a diverse yet small group of tropical tree species that have by parallel evolution developed special physiological and morphological adaptations to grow in inter-tidal conditions (Lugo and Snedaker, 1974; Chapman, 1976). Hence, while mangroves are by definition a biogenic community primarily of trees and associated fauna (Duke et al., 2007; Cannicci et al., 2008; Nagelkerken et al., 2008), they do, however, have strong sedimentological associations. This is because their dense vegetation favouring sheltered coastal situations tends to promote sedimentation (Furukawa and Wolanski, 1996; Furukawa et al., 1997; Kristensen et al., 2008). As a consequence mangrove development over geological time can be reconstructed from the fragmented sedimentary records of their own deposits. Being a wet environment, anaerobic conditions of mangrove sediment can allow the long-term preservation of these records.

This paper is a review of mangrove development from research using techniques involving coring of sediment and pollen analysis. There are a range of approaches to mangrove retrospection of which this is part (Dahdouh-Guebas and Koedam, 2008), and does not include biomarker and isotopic studies that can also be used for environmental reconstructions. In many ways there are different approaches, philosophies and objectives in stratigraphic research relative to ecological research. It tends to provide a far longer term perspective on mangrove development, and can also provide information on the adaptation or mortality of mangroves with past environmental changes.

2. Background to core based research

Coring sediment to reconstruct past environments is research guided by a number of assumptions that are different to those used in the ecological studies that dominate the mangrove literature. Walther's Law of Uniformitarianism states that "The various deposits of the same facies areas and similarly the sum of the rocks of different facies areas are formed beside each other in space, though in cross-section we see them lying on top of each other" (Middleton, 1973). The guidance that this gives to core based research is that one core is representative of a whole basin, which is why stratigraphic studies rarely use replication (numerous cores) unless they are looking for finer details of basin sedimentary evolution. The principle also guides that sedimentary units get older with depth, though there may be time disconformities corresponding with either periods lost to erosion, or periods of very low deposition.

Because of the increasing compaction and lithification of older sediments, the resolution of time and sequences of events that can be reconstructed from older sediments gets less. Like all land-based sedimentary sequences the length of record tends to become more fragmentary, unlike offshore sediment where a core can find a sequence of sediment deposits representing the whole Pleistocene or more (Shackleton and Opdyke, 1973). This is rarely possible for the changeable and erosive environment of coastal sediments. Deposits tend to get reworked and hence the fossil records are usually fragmented and have to be related from site to site. Deposits which are exposed tend to oxidise and lose their palaeo-records.

Fossil evidence of mangroves is either as macrofossils (fruit, flowers, wood or leaves) or microfossils. Microfossils include organic remains that preserve identifying features that they can be identified to generic levels at least. From coastal environments, these include a range of indicators such as dinoflagellates, foraminifera, diatoms and palynomorphs. The only specific indicators in this group of mangrove environments are mangrove pollen.

The occurrence of mangroves on shorelines means that fruits or pollen can be carried by tides or currents before entering a fossil forming situation. This points out a problem in use of isolated mangrove pollen grains or macrofossils such as disseminules to interpret from a fossil sample that this was a mangrove environment. Mangrove pollen particularly can extend far offshore from mangrove shorelines and end up in low concentrations in marine or coastal sediment.

2.1. Coring

A core is usually taken from a location in the swamp representative of the larger area, the author always places a transect through the centre of the swamp from landward to seaward, and cores systematically along this. This reduces the influence of usually local land based edge effects, and maximises the record of influence of non-local factors such as climate and sea-level. The corer used depends upon the research question, the amount of sample needed for the analysis planned, logistics such as access and sediment depth, and equipment availability. Hand operated piston corers such as Livingstones allow the recovery of an intact core tube able to be later analysed for micro-stratigraphy using techniques such as X-ray, and also allows later choice of levels from which to take pollen or radiocarbon dating samples. However, such piston corers are better suited for lake sediment and can be difficult to penetrate through estuarine sediment, and in roots and other macrovegetation remains cores can be subject to compaction. Mechanised corers such as vibrocorers work in a similar manner, and allow greater depth penetration and retrieval.

Sidewall samplers such as Davis, D section or Hiller corers like hand piston corers can be easily used to depths of 10–15 m. They have an auger action which allows easier penetration through mangrove roots, sand facies and wood. They also ensure no compaction through the sidewall sampling mechanism, so are better for research questions where elevation and depth are critical such as sea-level reconstruction. The disadvantage of these corers is that the sediment is scraped into the chamber so finer details of stratigraphy can be lost, and must then be sub-sampled from the chamber. The intact core is generally not able to be preserved for later description.

For microfossil research, it is best to core at low tide, and sample contamination is further prevented by dismantling and washing the corer each time used, and wiping tools such as spatulas used for sub-sampling. To avoid contamination from