Aquatic Botany 89 (2008) 80–92

Contents lists available at ScienceDirect

Aquatic Botany

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

Review

Long-term retrospection on mangrove development using transdisciplinary approaches: A review

F. Dahdouh-Guebas[a,b,*], Nico Koedam[b]

[a] Biocomplexity Research Focus (Complexité et Dynamique des Systèmes Tropicaux), Département de Biologie des Organismes, Université Libre de Bruxelles – ULB, Campus du Solbosch, CP 169, Avenue Franklin D. Roosevelt 50, B-1050 Bruxelles, Belgium

[b] Biocomplexity Research Focus c/o Laboratory of Plant Biology and Nature Management, Mangrove Management Group, Vrije Universiteit Brussel – VUB, Pleinlaan 2, B-1050 Brussels, Belgium

ARTICLE INFO

Article history:
Received 25 May 2007
Received in revised form 6 March 2008
Accepted 13 March 2008
Available online 29 March 2008

Keywords:
Archaeology
Archive
Coral
Dendrochronology
Ecosystem reconstruction
Ethnoscience
Fieldwork
Historical ecology
Hydration
Interdisciplinarity
Interview
Isotope
Landscape photography
Lichenometry
Mangrove
Paleontology
Prediction
Radiocarbon
Religion
Remote sensing
Retrospection
Transdisciplinarity

ABSTRACT

Large ecosystem processes often take place beyond the observation time of a researcher. Yet, through retrospective research scientists can approach and understand ecosystem changes. This contributes to the fundamental understanding of both human-induced and natural dynamics in ecosystems worldwide. This also holds for fast changing coastal areas with mangrove ecosystems, which are important for biodiversity, for coastal protection, and for the daily livelihood of millions of people in tropical coastal developing countries. In addition, retrospective research generates a basis for predictions that can be used early on to protect an ecosystem. In attempting to protect ecosystems from adverse human-induced change and destruction, and to manage them for sustainability, scientists are only beginning to investigate and understand natural ecosystem dynamics. It is important and advisable to gather, combine and analyse all possible data that allow a researcher to look back in time. This paper reviews the available retrospective methods, and highlights the transdisciplinary way (i.e. combination between basic and applied sciences on one hand, and social and human sciences on the other) in which retrospective research on a scale between months and centuries can be carried out, but it also includes methods on larger scales that may be marginally relevant. The paper particularly emphasizes the lack of transdisciplinary (not interdisciplinary) integration between sciences in retrospective research on mangrove forests in the past.

Contents

---

* Corresponding author at: Biocomplexity Research Focus c/o Département de Biologie des Organismes, Université Libre de Bruxelles - ULB, CP 169, Av. F.D. Roosevelt, B-1050 Bruxelles, Belgium. Tel.: +32 2 650 21 37/629 34 22; fax: +32 2 650 21 25/629 34 13.
E-mail address: fdahdouh@ulb.ac.be (F. Dahdouh-Guebas).

0304-3770/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.aquabot.2008.03.012

1. Introduction

Mangrove forests occur along tropical and subtropical coastlines and serve as breeding, spawning, hatching, and nursery grounds for many marine species (Baran, 1999; Barbier, 2000; Nagelkerken et al., 2008; Cannicci et al., 2008). Next to this habitat function, mangroves also provide wood and non-wood forest products and values to indigenous people (Bandaranayake, 1998; Ewel et al., 1998; Gilbert and Janssen, 1998; Rönnbäck, 1999; Bandaranayake, 2002; Moberg and Rönnbäck, 2003; Walters et al., 2008). They may act as a physical barrier to protect human settlements from the ocean (Badola and Hussain, 2005; Dahdouh-Guebas et al., 2005c; Danielsen et al., 2005; Dahdouh-Guebas and Koedam, 2006). It has been estimated that approximately 75% of tropical coasts world-wide were once fringed with mangroves (Chapman, 1976), but at present a world without mangroves is no longer an unrealistic prospect (Duke et al., 2007). Despite their values, mangroves are amongst the most threatened ecosystems world-wide, subject to over-exploitation, pollution, and conversion (Farnsworth and Ellison, 1997). In particular the large-scale conversion of mangrove forests to ponds for shrimp aquaculture is an underestimated problem (Naylor et al., 2000a,b; Dahdouh-Guebas et al., 2002b; Primavera, 2005). Not only direct or destructive anthropogenic effects such as clear felling, but also indirect impacts such as changes in hydrography have proved detrimental to mangroves (Dahdouh-Guebas et al., 2005b,c). In addition, climate change poses a threat to mangrove ecosystems (Gilman et al., 2008). This has stimulated many countries to pay attention to natural or induced mangrove recovery (Stevenson et al., 1999; Lewis et al., 2005; Bosire et al., 2008). In many locations, the above-mentioned threats have reduced the potential for economic recovery. For instance, economic recovery from the 26/12/2004 tsunami disaster is hampered because of the loss of traditional income sources related to coastal ecosystems rich in species and in ecological functions (Adger et al., 2005; Hughes et al., 2005). To reverse the eroding social-ecological resilience in mangrove areas under threat, it is important to reconstruct the past of the mangrove ecosystem, or better: the mangrove anthroposystem. This reconstruction is also the basis to understand its natural and anthropogenic dynamics (Berger et al., 2008), to forecast changes, and strive for early mitigation.

Few have attempted to forecast general impacts (Semeniuk, 1994; Clarke, 1995; Ellison and Farnsworth, 1996; Woodroffe, 1999), and even fewer to predict cryptic changes in more specific ecosystem characteristics such as vegetation structure and composition (Dahdouh-Guebas and Koedam, 2002; Dahdouh-Guebas et al., 2002a, 2005a). These studies have pointed out that there is a lack of description and understanding of past changes, and present functions and processes, let alone the ability to predict future scenarios in mangrove ecosystems. The need for long-term environmental monitoring, research and paleoecological reconstructions of past environments has been stressed (Parr et al., 2003). Historical ecology data have been adopted in the past in this perspective. Swetnam et al. (1999) state that 'historical ecology encompasses all of the data, techniques, and perspectives derived from paleoecology, land use history from archival and documentary research, and long-term ecological research from monitoring and experiments extending over decades. Also included are time series from instrument-based observations of the environment, such as weather records, stream gauges, and data from satellites'. However, the 'natural' and 'documentary archives' that contribute to historical ecology are with few exceptions from within natural sciences (Swetnam et al., 1999) overlooking highly valuable information derived from the social and human sciences (Cormier-Salem, 1999; Rist and Dahdouh-Guebas, 2006). This is corroborated by the significant lack of integration between disciplines from various science domains, particularly in historical research applied to mangrove forests. The term 'retrospective research' is used here to indicate all research approaches that look back in time to understand the present (historical ecology, historical biogeography, etc...).

The objective of this review paper is to highlight the potential of retrospective research on mangroves, and to recommend transdisciplinary approaches based on a subset of retrospective research methods to improve our understanding of past changes and spatio-temporal dynamics on a scale between months and centuries. In this light, transdisciplinarity equals interdisciplinarity that transcends the science fields (basic and applied science; social and human science; life science) in particular, and science in general (incorporating indigenous forms of knowledge) (Rist and Dahdouh-Guebas, 2006).

2. Retrospective data from the basic and applied sciences

2.1. Above-ground fieldwork observations

Measurements or visual observations in the field can be indicative for events in the recent past, such as tracks or broken branches for animal foraging, or concentrations of aromatic hydrocarbons for pollution (Burns et al., 1993; MacFarlane et al., 2003). Ecosystem morphology and physiognomy can provide a range of information on the past. The position and physiognomy of mangrove forests and coral reefs reflect changes on different time scales. Transient surface water levels (reflected in flood line marks on the vegetation) and shoreline position respond most rapidly to coastal environmental changes, and can be reflected in changes in colour, structure and mud coatings of stems and branches of plants, notches in channel banks, aggregated surfaces of wetlands, and more geomorphologic indicators (Morton, 2002). Distributional changes such as the natural expansion or regression of mangrove vegetation (including possible changes in species composition) and coral reefs are indicators of environmental changes occurring on the order of decades to millennia (Morton, 2002; Dahdouh-Guebas et al., 2004). Past exploitation practices can be deduced from the age structure and spatial distribution of trees (Dahdouh-Guebas et al., 2002a), the straightness of trees (Kairo et al., 2002), or the presence of tree stumps or dead trees (Dahdouh-Guebas et al., 2004). The difficulty with most of the above observations is that the time scale of reconstruction is very variable, and cannot always be quantified based on the observation alone (what is the time interval for a change to occur or to be observable?).

2.2. Lichenometry

Based on the radial, slow and steady growth of most lichens, lichenometry is commonly used as a technique to date the exposure of certain natural or human features, such as bridges, gravestones, landslides or geological features (Bull and Brandon, 1998; Winchester and Chaujar, 2002). However, the assessment of lichens in forest gap dynamics (Benson and Coxson, 2002) also opens doors to lichenometry in a mangrove forest ecosystem context. Lichens do occur in mangroves (e.g. Ellison, 1997), but are not well studied, let alone used in lichenometry.

2.3. Dendrochronology

Dendrochronology is the science of measuring time-related features in the wood of woody plants. As woody plants grow, tree cambium produces xylem at the pith side of a root, stem or branch section, which may display variable characteristics depending on seasons or environmental conditions. Seasonal climates of the temperate type induce the formation of rings in the xylem of a tree. Dendrochronologic research can be purely based on the wood-anatomical characteristics of these tree rings that must be analysed visually or through image analysis (Cherubini et al., 2003), or it can be based on the analysis of isotopes extracted from the successive tree rings (February, 2000). However, both approaches are obscured in areas where the spatio-temporal climatic variability inhibits tree rings to form consistently such as under mediterranean or tropical climates (Cherubini et al., 2003). Nevertheless, for the mangrove trees rings have demonstrated to be useful for age determination (Menezes et al., 2003; Verheyden et al., 2004a), with potential for dendrochemistry (Verheyden et al., 2004b, 2005a) and for research on wood anatomy and hydraulic architecture (Schmitz et al., 2006). Growth layers of *Avicennia* are not annual which is, however, related to their peculiar growth via successive cambia (Schmitz et al., 2007a,b). Some other mangrove species do show growth rings in regions with a seasonal climate. In *Rhizophora mucronata* Lamk., annual growth rings were identified in Kenya (Verheyden et al., 2004a,b) and also *Heritiera fomes* Buch.-Ham and *Sonneratia apetala* Buch.-Ham from Bangladesh show a good potential for dendrochronological research (Chowdhury et al., in press).

Following the above approach, environmental and ecological aspects of a system can be deduced from the characteristics of the tree rings. Dendroecology may reveal changes in for instance fire incidence (Stephens et al., 2003), climatic conditions (Briffa et al., 1998; Verheyden et al., 2005b), total environments or ecosystems (February, 2000), sea-level rise (Yu et al., 2004) and even retrospective information on fish abundance hidden in the rings of riparian trees (Drake et al., 2002). Normally the natural archiving of information, which can be used in dendrochronology, stops when a tree dies, and it is therefore important to know how long ago a tree died. To solve this, methods have been proposed to estimate the time a dead tree has been on the ground (Gore et al., 1985; Johnson and Greene, 1991).

2.4. Landscape (repeat) photography

Landscape photography from a single location is often used to view the typical landscape features under different environmental conditions such as seasons in temperate regions, or inundation in fluvial or tidal forests (Stafford-Deitsch, 1996). Such comparative photographs have also been used to compare the 'before' and 'after' situations in case of catastrophes or successive stages in restoration studies (Lewis, 1982; Finn, 1996; Turner and Lewis, 1997; Stevenson et al., 1999). However, apart from documentary books for a wide audience (Vanhecke et al., 1981), few scientists used sequential photographs to actually research ecosystem or vegetation changes (e.g. Rogers et al., 1984; Butler and DeChano, 2001; Brook and Bowman, 2006; Moseley, 2006), or to corroborate other data (e.g. Wolanski and Gereta, 2001). Although the analysis of such sequential photographs is often limited to visual inspection, the inherent information to interpret ecosystem changes in a wide framework can be very valuable (Fig. 1). Landscape photography or repeat photography definitely qualifies as a cheap and accessible data source for the present and future, but for the past it evidently requires reference photographs.

Fig. 1. Repeat landscape photography of a selected mangrove stand in Gazi Bay (Kenya) from approximately the same place taken in 1993 (top) and in 2003 (bottom). Over a period of 10 years, the unaffected *Sonneratia alba* J. Smith stand on the background is thriving, but the cleared mangrove area on the foreground has failed to recover naturally from the over-exploitation, necessitating rehabilitation (cf. Bosire et al., 2008).

2.5. Air- and space-borne remote sensing

One of the most widely used methods to look into the recent past, and which will undoubtedly evolve into the single most important monitoring technology in the future, is remote sensing. There is a large difference between air- and space-borne remote sensing as far as their spatial, temporal and spectral characteristics are concerned (Green et al., 2000; Dahdouh-Guebas, 2002). Whereas satellite remote sensing is a relatively new technology that started with the Apollo program in 1963, the first black/white aerial photographs were taken in 1858 from a hot air balloon, and in 1906 from an airplane. It was during World War I that aerial photography missions on a large scale were launched. Hence, aerial photography constitutes the only available imagery for retrospective monitoring on a sequential scale of decades, starting long before the birth of space technology (Dahdouh-Guebas et al., 2000b). Aerial photography remains the only imagery with the highest spatial resolution, and is often preferred to satellite imagery (Ramsey and Laine, 1997; Mumby et al., 1999; Hyyppä et al., 2000; Manson et al., 2001; Thampanya et al., 2006). Of course, the choice of a particular sensor depends on the study purpose (cf. Blasco et al., 1998).

From as recently as 2001, images of very high spatial resolution and of good spectral resolution from space-borne sensors (Ikonos, Quickbird, OrbView) have made it possible to optimise the identification of differential assemblages, genera and species within and beyond mangrove ecosystems (Wang et al., 2004; Dahdouh-Guebas et al., 2005a; Kovacs et al., 2005). Before that, the application of satellite sensors in change detection was limited to large homogeneous land-cover or land-use classes. The research community should consider also the ‘physiognomic resolution’ of remote sensing methods or of any method. The ‘physiognomic resolution’ is referred to as the form that a method is able to identify within the variety of life forms, or as the ecological entity that a method is able to identify within an ecosystem (e.g. forest, individual). It implies that the identified level can be monitored to detect temporal changes in it. For instance, a method (e.g. a sensor) that is able to make physiognomic distinctions such as ‘grassland’, ‘forest’, ‘submerged vegetation’, even if fitted with further characterisations like ‘dense’ and ‘sparse’, would be considered having a ‘low physiognomic resolution’. So would a method that can only detect whether an ecosystem entity is mangrove forest or not, without further details. However, a method that succeeds in identifying the taxonomic level of *species* or even individuals would be considered having a very high physiognomic resolution. Studies that serve to pinpoint individual trees will require methods with a very high physiognomic resolution.

Next to spatial resolution of remote sensing sensors and physiognomic resolution, the very high temporal resolution of satellite remote sensing (as frequent as 3 days to revisit a particular place) is conducive for the detection of changes on small temporal intervals. The higher radiometric resolution is also an advantage. Unfortunately, the highly commercialised cost poses a restriction on its use by institutions in developing countries.

2.6. Isotope analyses

Isotope analysis may employ the use of ‘radiogenic isotopes’ or ‘stable isotopes’. Radiogenic isotopes are not stable and undergo radioactive decay that can be traced back in time by comparing the mass of the original element to that of the element newly formed during the decay process. Based on the time that is required for a certain mass of an original radiogenic isotope to spontaneously decay to half of its mass (=the isotope’s half-life), it may have a specific medical or environmental application on a time scale between seconds and billions of years (Firestone and Shirley, 1996). Radiocarbon (^{14}C) for instance, has a half-life of 5700 years and is widely used for long-term dating in ecosystem research including mangroves (Scheel-Ybert, 2000; Lezine et al., 2002). However, its use in the reconstruction of a specific vegetation type may be limited due to its low ‘floristic resolution’ (Witt, 2002). Nevertheless, even when the time scale focused on is at most centuries, radiocarbon dating remains interesting to know how long the mangrove ecosystem under study has already been in its current place. Alternative radiogenic isotopes for the study of more recent sedimentation are ^{137}Cs (half life = $\pm$30 years), ^{210}Pb (half life = $\pm$22 years) and ^{7}Be (half life = $\pm$53 days) (Lynch et al., 1989; Blake et al., 1999, 2002). We refer to J.C. Ellison (2008) who details the dating techniques and methods for long-term retrospection on mangrove development using sediment cores.

In contrast, stable isotope analysis is based on ratio’s between heavy isotopes that do not decay (e.g. ^{13}C, ^{15}N) and the lighter isotopes (e.g. ^{12}C, ^{14}N). In ecology, stable isotopes are used to trace the cycling or fixation of nutrients such as in research on trophic relationships between organisms and between adjacent ecosystems (Marguillier et al., 1997; Bouillon et al., 2002, 2003; Cocheret de la Morinière et al., 2003; Bouillon et al., 2007; Kristensen et al., 2008). For instance, diet shifts in herbivorous marine animals, detected through stable isotope analysis of specimens caught on different moments, may be an indicator for a changed supply in primary food sources. Isotope analysis can also be applied to dendrochronological research to investigate past environmental factors that are perpetuated in the tree rings under the form of stable or unstable radiogenic isotopes (February, 2000; Miller et al., 2006). Isotopes in microfossils originating from marine sediments may reveal temperature, salinity, ice volume, atmospheric CO_2, and ocean circulation (Stokstad, 2001).

2.7. Substrate cores

Centimeter- to meter-deep soil cores can provide significant insight in past conditions, on a scale from years to millions of years. Apart from indications of soil consolidation or compaction based on the structural and textural characteristics of the soil, research foci can range from biogeochemical trace elements or isotopes (Bouillon et al., 2002; Gonneea et al., 2004; Versteegh et al., 2004), over palynology (Blasco, 1984; Lezine, 1996; Hofmann, 2002; Yulianto et al., 2004; Vedel et al., 2006; A.M. Ellison, 2008; J.C. Ellison, 2008) and species compositions in general (Westgate, 1994), to climatic changes and sea-level rise (Verschuren et al., 2000; Kumaran et al., 2004a,b; Cohen et al., 2005a,b; Torrescano and Islebe, 2006; Engelhart et al., 2007).

The use of substrate cores is however not limited to surface soils, and offers most interesting insights when applied to underwater substrates (Wang et al., 1999; Verschuren et al., 2000). Substrate coring also extends to the study of ice cores that can be well over a hundred meters deep and look back into the climate ten to hundred thousands of years (e.g. Thompson et al., 1998). For both methods the results may incorporating a wide area including mangrove ecosystems that are located relatively near mountains with ice caps or glaciers in tropical regions, or near great lakes. The cost and technology of extraction, preservation and analysis often poses a practical limitation to the study of deep soil or ice cores, in particular for below-surface substrates.

A third form of ‘substrate’ cores is the analysis of corals, which grow slowly and accumulate information on a seasonal time scale. The study of corals may reveal sea surface temperature from oxygen isotopes and elemental ratios, and river discharge and precipitation cycles on land from isotopes (Stokstad, 2001). This also allows the study of oceanic or climatic impacts or consequences of global change, such as sea-level rise (or decrease), ocean surges (e.g. tsunamis), and El-Niño events. Once more, this is a method that is primarily carried out nearby, but not in the mangrove. Yet, many mangrove forests (e.g. in Kenya) are known to host ancient coral reefs.

2.8. Geomorphological and paleontological data

Deltaic-estuarine geomorphology influences the development of mangrove forests. Various settings along which mangroves develop have been identified and described, and include protected shores, bays, estuaries, deltas and river banks (Thom et al., 1975; Thom, 1984). Mud stains and microbial etching on exposed rocks, notches in wave-cut scarps and anomalous landforms often indicate changed environments. In Kenya for example, the presence of coral pillars within the mangrove (e.g. Gazi Bay), in the back mangrove (e.g. Wasini Island), or buried under inhabited terrestrial villages (e.g. Mida Creek), are unambiguous indicators of a former sea-level that used to be at least 10 m higher than at present (Farid Dahdouh-Guebas, unpublished data, 2003), which can have an oceanological cause (sea-level change) or a geological one (tectonics), or a combination.

Next to this type of direct relationships, unlinked paleontological studies can provide elements from the distant past that can help interpret mangrove ecosystem origin or changes. Tephrochronological studies have for instance been applied to date tropical coastal environments (Ward and Little, 2000; Morton, 2002). The study of fossils indicate biogeographical shifts in faunal or floral assemblages (Smith et al., 2001), that may also be interpreted into an ecosystem context.

2.9. Hereditary and evolutionary feature differentiation

The differentiation of hereditary information between populations of a particular species is a measure for the frequency of contact between them, in the form of diaspores (pollen, seeds or entire individuals). This can be viewed over a series of spatial scales, between a few thousand square meters and intercontinental surfaces, and temporal scales, between months and millennia (Gaston, 1996; Triest, 2008). For some species, genetic differentiation may reflect habitat fragmentation, isolation or degradation (Abeysinghe et al., 2000; Gaston, 1996; Triest, 2008). However, this is largely dependent on the biology of the species. Anemogamous-hydrochorous species will evidently not display the same pattern of differentiation as entomogamous-autochorous species.

The analysis of hereditary information based on morphological characteristics or on DNA is also at the basis of phylogeny research, which can be used to date an organism (Roelants and Bossuyt, 2005). Kinship between organisms and evolutionary features can in turn reflect geographical and environmental changes, such as tectonics or sea level (Lin et al., 2002; Bossuyt et al., 2004). However, such results reflect more on the biological species rather than on the site in which they are found. Dating a particular habitat in a certain location through phylogeny of its associated fauna is only possible if the animals are endemic to that site.

3. Retrospective data from the social and human sciences

3.1. Interviews

The information that resides with indigenous people, and in particular with the elders of local communities, is vast and extremely valuable and can easily be accessed through interviews. It is also extremely vulnerable, as information is rapidly lost with their passing away. Western scientific knowledge has long been blind to indigenous forms of knowledge, even though the latter has much to offer for bio-cultural diversity and sustainable resource use (Rist and Dahdouh-Guebas, 2006). Ethnobotanical surveys for instance can reveal a great deal about past and current plant–man relationships (Kovacs, 2000; Dahdouh-Guebas et al., 2000a; Hernández-Cornejo et al., 2005; Walters, 2005; Dahdouh-Guebas et al., 2006; Walters et al., 2008). It can be expanded to surveys on fishery-related or ethnozoological practices and thus reveal general ecosystem changes through time. In addition, interview surveys can be soundly combined with retrospective remote sensing, as ground truthing past imagery is not possible. Simple information such as the ability to wash clothes with lagoon water, as opposed to 30 years earlier, are invaluable sociological indicators for a low lagoon water salinity (Jayatissa et al., 2002; Dahdouh-Guebas et al., 2005b). In another example the origin of a cleared patch of vegetation in Gazi (Kenya) was clarified with local informants' knowledge (Dahdouh-Guebas et al., 2004). Interview analyses have also been used in studying physical, rather than biological, aspects of the natural environment, such as in ethnopedology (WinklerPrins and Sandor, 2003).

3.2. Historic archives

Historic archives are often used in history, archaeology or within other disciplines of the social and human sciences (e.g. Lape, 2002). Countries that used to have overseas territories (such as France, Portugal, Spain, The Netherlands and the United Kingdom) usually keep colonial archives. The Atlas of Mutual Heritage for instance (http://www.atlasofmutualheritage.nl/), which comprises the archives of the Dutch East-India Company (Vereenigde Oost-Indische Compagnie—VOC) and the Dutch West-India Company (West-Indische Compagnie—WIC), contains thousands of plans, maps, views, panoramas, scenes of everyday life, and many more descriptions that can be used as a source of information (e.g. Baldaeus, 1672). Historic expertise is needed to soundly interpret ancient descriptions, or scribbled notions in the margins of 17th century maps (Fig. 2). Sometimes sets of words such as 'till here reaches the sea water and all land is silty' (*tot dusverre komt het zeewater en is alles brak en siltagtig land*), 'drowned land' (*verdroncken landt*) and 'bending rhizophorous belts' (*Deze tweede rhizophorengordel vormt bogten en inhammen en wordt door talrijke smalle straten doorsneden, die veelal de beddingen zijn van op het land ontspringende kreken*, Von Rosenberg, 1867) are unambiguous indications of the presence of a mangrove ecosystem. Probably the oldest known unambiguous references to mangroves going on for several paragraphs read amongst others: *In Persia in the Carmanian district, where the tide is felt, there are trees* [*Rhizophora mucronata*]...[that] *are all eaten away up to the middle by the sea and are held up by their roots, so that they look like a cuttle-fish* (Theophrastus, 370-285 B.C.E.), as cited by A.M. Ellison (2008) in the preface of Aquatic Botany's Special Issue on Mangrove Ecology (Dahdouh-Guebas and Koedam, 2008). Other clues given by Theophrastus (370–285 B.C.) are: *In the island of Tylos, which is situated in the Arabian gulf, they say that on the east side there is such a number of trees when the tide goes out that they make a regular fence* on the coastal protection function of mangroves (Enquiry into Plants Book IV. VII. 7), and *As for the tall fruit-bearing trees found in tidal waters, one would perhaps not assign their feeding to the sea water, but say that it is possible that the roots draw potable water from the ground, and that the sea water surrounding the tree does it no more injury than the surface waters surrounding freshwater plants* on the salt tolerance of mangroves (De Causis Plantarum Book II. 5.2 1–9).

Despite the valuable information contained in such historic archives, there is no evidence of their utilisation to study any aspect of the essential tropical coastal ecosystems. In fact, there are

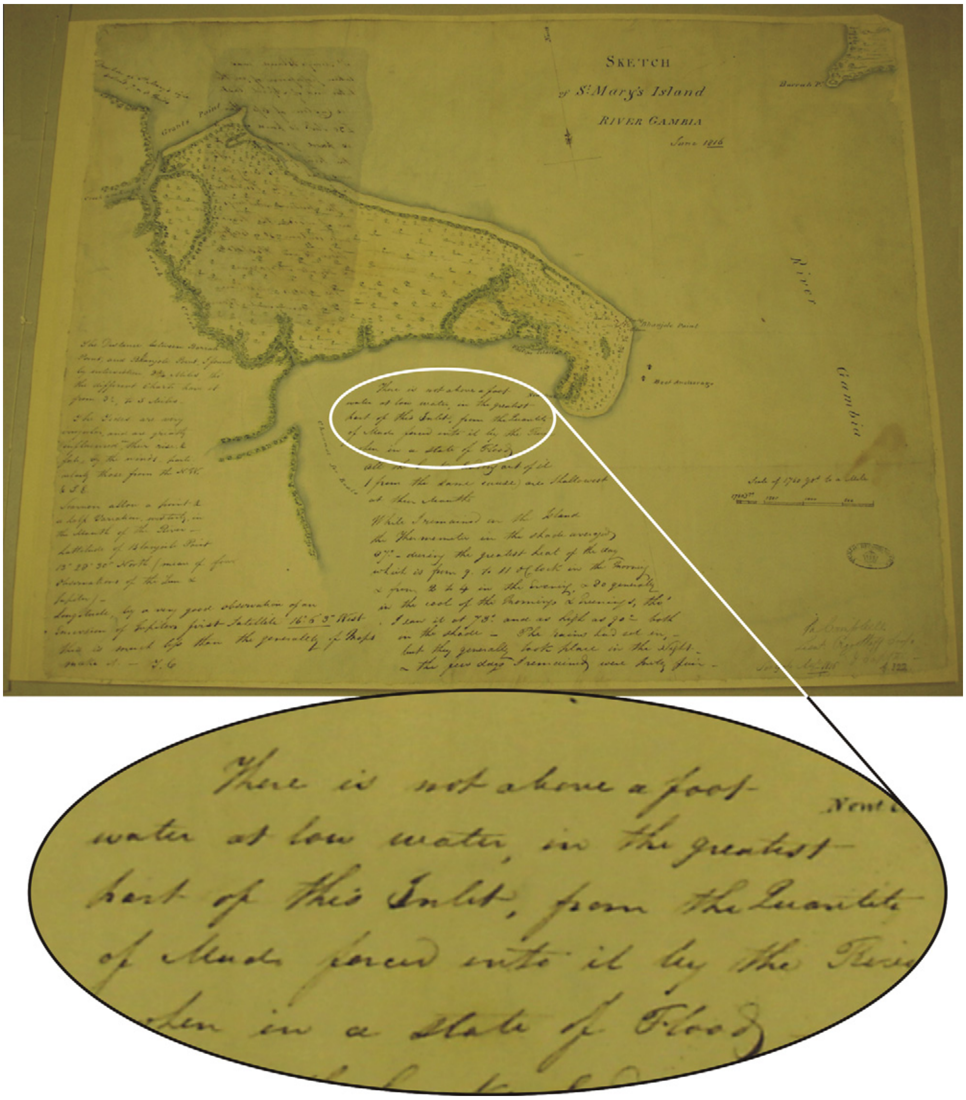

Fig. 2. Map of St. Mary's Island and associated mangrove creeks (drawn by Lieutenant Thomas Campbell, Lt Royal Staff Corps and Captain in Senegal in 1816). The eastern part of the island (Bhanjole Point) is the current location of The Gambia's capital city Banjul. The inset details part of the notes on distances, tides, winds, direction and temperature and is relevant for biological interpretation on mangrove ecosystem dynamics. (Map archive held by the National Archives of the United Kingdom, Kew, England, U.K.: code MPG 1/322).

only 3 peer-reviewed studies listed in Web of Science® (2007) that have attempted to use the archives of the Dutch or English East India Company in a fundamental exact scientific, rather than a historical, social or human scientific context: one incorporating ship logs to study the weather during and after the little ice age (Farrington et al., 1998), one using early chart making to study the evolution of a major delta front (Allison, 1998), and one combining 17th century historic text and map archives with vegetation science, remote sensing, hydrology and socio-economic interviews to infer the dynamics of mangrove lagoons (Dahdouh-Guebas et al., 2005b). In addition, there is one study that uses long-term meteorological observatory records started by the English East India Company to reconstruct atmospheric pressure (Allan et al., 2002). However, the recognition of the archives of the Dutch East-India Company (1602–1800) in UNESCO's Memory of the World Register (Edmondson, 2002; UNESCO, 2003), is indicative of the much larger research potential available using this or other historic archives. Of course, other archives are scattered around the world, but likewise have few studies on mangroves used them (e.g. Alleng, 1998; Plaziat and Augustinus, 2004).

3.3. Spiritual heritage

Archives and heritage of global religions display very little variability, and are in this sense independent from the studied site. However, they can provide insight into the relation between man and environment (Palmer and Finlay, 2003). While they may not directly generate information on a particular ecosystem, faith may provide a framework for the behaviour of people towards nature, and what they are allowed or not allowed to do in this respect. The protection of the forest of Harissa of the Maronite Church in Lebanon for instance, or other examples of sacred forests near monasteries, temples and pagodas, may provide relevant information as to when human impacts on the forest is likely to have ceased or at least diminished (Palmer and Finlay, 2003). Specifically for mangrove forests there are only a few peer-reviewed published papers highlighting local spiritual archives in order to understand the mangrove forest's history. For instance, Kathiresan and Bingham (2001) and Kathiresan (2002) highlight spiritual beliefs associated to *Excoecaria agallocha* L., which is worshipped in the south of India near Chidambaram, and believed to cure leprosy. Certain beliefs or taboos are related to the mangrove in East-Africa as well (e.g. kayas in Kenya). In the Solomon Islands, the bodies of the dead are disposed of and special rites are performed in the mangrove waters (Vannucci, 1997). A last but most fascinating documentation of the spiritual significance of mangroves stems from the *Asmat* communities in Indonesia (see also Walters et al., 2008). According to their legends, the creator of the *Asmat* carved human-like figurines out of a mangrove root, and with the rhythm played on a self-made drum from mangrove wood, these figurines came to life (Mastaller, 1997). Mystic totem poles made from *Rhizophora* wood are still carved by the *Asmat* today (Mastaller, 1997).

3.4. Archaeological and paleoethnobiological data

If present near a study area, archaeological sites can provide elements that can be interpreted in an ecological way. For example, ancient water management practices and people's dependency of and impact on rivers were indicated by archaeological remains nearby (Brohier, 1934; Juleff, 1996; Lezine et al., 2002). Another example is the insight on changes in faunistic assemblages (Keegan et al., 2003) or transgression of mangrove shorelines (Kendrick and Morse, 1990) provided by studying at archaeological excavation sites. In turn, biological information is also known to assist archaeologists, such as in the lichenometric dating of tombs (Winchester and Chaujar, 2002), rock art (Bednarik, 2002), or as in quartz hydration dating (Erickson et al., 2004).

Paleoethnobiological research may provide insight into past pollen records (Coil et al., 2003), biological diversity (Bonzani, 1997), or pre-historic land conversion (Piperno, 1998), all of which are relevant and underexploited in the understanding of changing environments (Lepofsky et al., 2001).

4. Transdisciplinary retrospective approaches

The effort to obtain and analyse archived material can be considerable. It is appropriate to evaluate the added value of such a procedure and these steps. When retrospection is the only means of obtaining information about causes of actual phenomena the added value is obvious. In fact this applies to most environmental issues where either long-term processes take place or where direct experimentation is not possible, or both. Mangroves are a highly dynamic environment in space and time, in which recognizable natural landmarks that are stable over time are few. Historically they were left out of human land development, which renders them underdocumented and quite featureless in terms of human landmarks. Yet, the various approaches presented here have contributed to our understanding of their development. We encourage scientists to share, where possible, transdisciplinary research approaches rather than interdisciplinary ones, because as evidenced in this paper, there is more potential for transdisciplinary studies than what is used today in mangrove research.

Interdisciplinarity within some science domains is obviously not new, as some research fields are commonly used in pairs with others. One example is the calibration of sediment stratigraphy and palynology (or other biotic distributions in the sediment) by dating techniques (Mulrennan and Woodroffe, 1998; Ellison, 1999; Stevenson, 2004; Horton et al., 2005), or dendrochronology calibration by radiocarbon dating (e.g. Biondi and Fessenden, 1999; Stein et al., 2000). Another example are combinatory retrospective approaches such as remote sensing–geobotany–geomorphology (Souza-Filho and El-Robini, 2000; Souza-Filho and Paradella, 2002, 2003), dendrochronology–isotope analysis (February, 2000) or dendrochronology–fish catch data (Drake et al., 2002).

However, the use of transdisciplinarity is a completely different story, and is heavily underexploited, as indicated for instance by the restricted use of historic archives detailed above. The variety of retrospective methods from different disciplines over a wide series of retrospective scales indicates that seldom one cannot look back in time (Fig. 3). Particularly in the light of ecosystem or environmental change innovative combinations are possible (Table 1). That transdisciplinary approaches on mangrove ecosys-

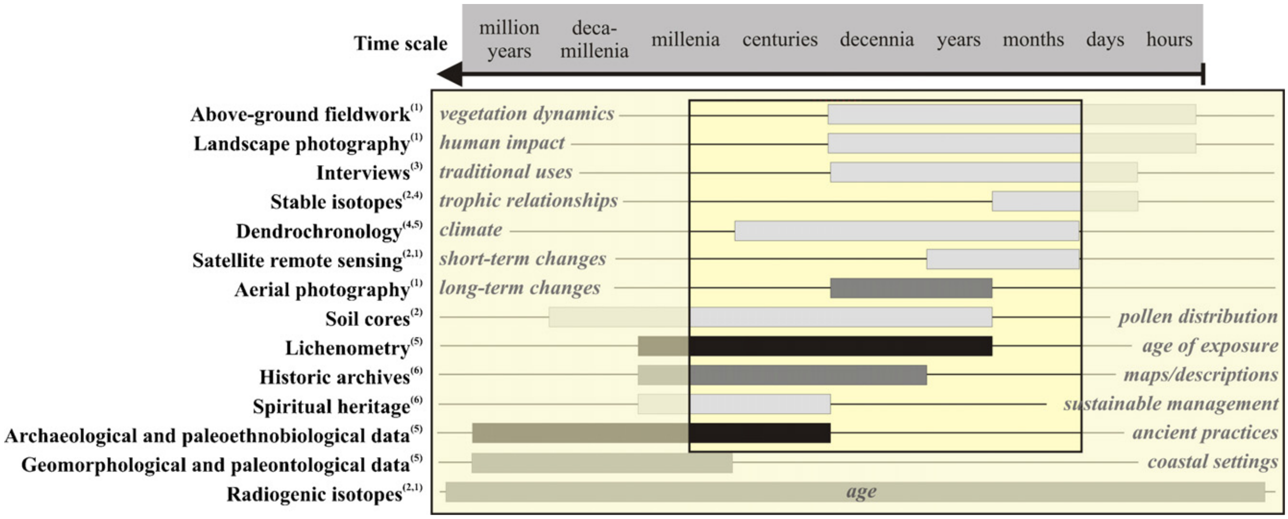

Fig. 3. Data sources for retrospective research, with examples or application fields (grey italics). The temporal scale is not continuous, but functionally classified (between hours and millions of years) with respect to the data sources. The square window represents the most relevant temporal window in the light of mangrove ecosystem change, and illustrates the transdisciplinarity of the data sources over basic, applied, social and human sciences. The degrees of availability of the data sources are indicated using colours—light grey: always available or can be collected; dark grey: is often available but depends on specificities, e.g. although available in most countries, aerial photography may be absent for particular years and sites; black: is much less universal and often not available. Limitations to the data sources that may not be overcome are indicated in superscipt: (1) limited by available data collected in the past such as species lists, imagery of environmental parameters (retroprojection of present fieldwork can mislead and cannot be validated); (2) limited by high cost of extraction, analysis or purchase; (3) limited by people's memory and life time, and by the respondents' reliability and possible bias; (4) limited to biological and chemical assimilation processes; (5) limited by the natural availability of the data; (6) limited by the nature and organisation of the archive database, the type of information displayed and the spatial resolution. For each data source an example of what can be studied is indicated in italic (I refer to the text for detailed explanation and references to scientific literature).

Table 1

Suggestions (based on best professional judgement) of methods and approaches (as ordered and numbered in the text) to be combined, if present, for arbitrarily summarized objectives (in alphabetic order) of studies on mangrove forests

Study objective	2.1. Above-ground observations	2.2. Lichenometry	2.3. Dendrochronology	2.4. Landscape photography	2.5. Aerial photography	2.5. Satellite remote sensing	2.6. Stable isotopes	2.6. Radiogenic isotopes	2.7. Substrate cores	2.8. Geomorphological and paleontological data	2.9. Hereditary and evolutionary feature differentiation	3.1. Interviews	3.2. Historic archives	3.3. Spiritual heritage	3.4. Archaeological data	3.4. Paleoethnobiological data	Number of rated peer-reviewed mangrove studies (Web of Science®) with the respective topic in the title, abstract or keywords (based on the term 'mangrove' plus words from the first column, their synonyms or their wildcards), and that use the added value of retrospection to investigate this topic
Canopy gap dynamics	●	●		●	●	●						●					0 out of 15 (0%)
Changes in fisheries catches	●				●							●					6 out of 17 (35%)
Changes in utilisation patterns (use, wood, non-wood)	●			●								●	●	●	●	●	9 out of 20 (45%)
Dependency of subsistence users	●			●								●	●	●		●	4 out of 5 (80%)
Evaluation of natural tree mortality	●	●	●		●	●		●	●			●					0 out of 8 (0%)
Evaluation of tree logging	●	●			●	●		●				●					4 out of 8 (50%)
Forest management policy	●				●	●						●	●	●			11 out of 22 (50%)
Historic environmental impacts			●		●	●	●	●	●	●		●	●				9 out of 11 (82%)
Natural hazards	●			●	●	●		●	●	●		●	●	●			7 out of 17 (41%)
Past climatic impacts			●				●	●	●	●		●	●	●	●		18 out of 24 (75%)
Phytoremediation	●					●	●	●	●			●					0 out of 4 (0%)
Reafforestation (replanting)	●			●	●	●					●	●					5 out of 13 (39%)
Recent environmental impacts	●					●	●	●	●			●					10 out of 17 (59%)
Sea-level rise or changes	●							●	●	●			●				117 out of 125 (94%)
Vegetation structure: succession	●			●	●	●			●			●					13 out of 20 (65%)

In each case transdisciplinary and retrospection provides an added value for interpretation within the research theme

Table 2
Examples of mangrove and non-mangroves case-studies that adopt transdisciplinary retrospective research approaches thereby creating an added value for insight into a particular study topic

Study topic	Mangrove study and research approaches used	Non-mangrove study and research approaches used
Hydrographical changes	Transitions in ancient inland freshwater resource management using historic text and map archives, vegetation science, remote sensing, hydrology and socio-economic interviews (Dahdouh-Guebas et al., 2005b)	River behaviour and Holocene alluviation (Wales, UK) using archaeological evidence, C-14 dates, terrace mapping, heavy metal analysis, grain size analysis and historical maps (Taylor and Lewin, 1996)
Protection against wind, storms, hurricanes,...	Hurricane impacts using vegetation science and interviews in an analytical hierarchy process approach (Kovacs et al., 2004)	Role of scattered vegetation in wind erosion control (northern Burkina Faso) using vegetation science, pedology, erosion modelling and interviews (Leenders et al., 2005; Visser et al., 2005)
Forest management based on vegetation history	Forecasting of future vegetation structure development using on aerial photography, social surveys, and distribution of trees (Dahdouh-Guebas et al., 2004)	Development, distribution, structure and composition of upland forests (Scottish Highlands) and its consideration in management using cultural records, historic maps, vegetation science and geographical information systems (Holl and Smith, 2007)
Shoreline position	Shoreline evolution using historic map archives and remote sensing (Allison, 1998)	Sandy beach evolution (Maine, USA) using side-scan sonar, seismic reflection profiles, ground-penetrating radar, soil cores, historic maps and aerial photographs (Kelley et al., 2005)
Climate change	Adapting to a changing climate using climatology, biological sampling and management (Meynecke, 2005)	Wind speed and navigation using meteorology, climatology and historic text archives (Farrington et al., 1998)

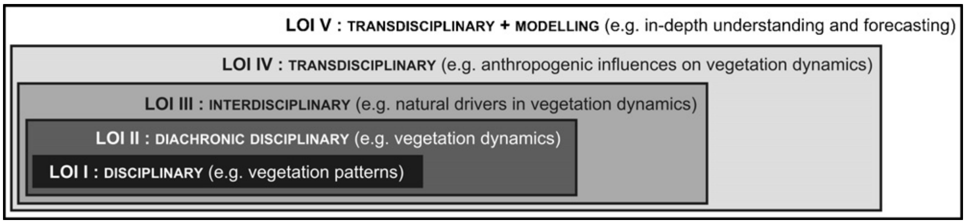

Fig. 4. Levels of insight (LOI) gained with increase of combinatory approaches involving various disciplines from basic and applied as well as from social and human sciences. The ideal situation is that each higher LOI level contains all lower LOI levels. A simple example from vegetation science illustrates that a basic descriptive disciplinary level of insight (LOI), LOI I, may teach us something about contemporary patterns in vegetation. A diachronic approach looking back in time may increase the LOI to II enabling the study of vegetation dynamics. LOI III requires the involvement of another discipline allowing the explanation of natural and anthropogenic factors (through basic and applied sciences) driving vegetation dynamics, whereas LOI IV is gained when information is gained directly from people (using scientific methods from social and human sciences) and their influence on vegetation dynamics. Finally, when all factors are put together and the approach is enriched with a modelling component the LOI increases to V, enabling in-depth understanding and forecasting. Modelling could be applied without ever including socio-ecologic data from local communities, but ideally the higher LOI levels should include all of the lower LOI levels in an attempt to improve insight. See text for specific references illustrating the levels of insight.

tems has or could provide an enhanced insight can be illustrated best by highlighting matches with non-mangroves case-studies that combined data from basic and applied sciences with data from social and human sciences to gain better understanding in certain research topic (Table 2).

As a matter of fact, some combinatory uses of data sources obviously call for the expertise and technology to analyse and interpret them without bias (e.g. historic expertise for ancient archives, see Fig. 2). In other cases data or analyses are very costly or certain other limitations may apply and may pose a restriction on their use (Fig. 3). However, in the majority of cases data sources that are almost always available, and that can always be explored easily and cheaply, are present: above-ground fieldwork observations, interviews, aerial photography, historic and religious archives.

We maintain that the level of disciplinarity used in research is a factor in gaining insight into the functioning of the ecosystem (Fig. 4). The example from vegetation science to illustrate the level of insight (LOI) gained (Fig. 4) can be completed by the following references:

- LOI I: e.g. Triest (2008), Nagelkerken et al. (2008);
- LOI II: e.g. Komiyama et al. (2008);
- LOI III: e.g. Bosire et al. (2008), Cannicci et al. (2008), A.M. Ellison (2008), J.C. Ellison (2008), Gilman et al. (2008), Krauss et al. (2008), Kristensen et al. (2008);
- LOI IV: e.g. Walters et al. (2008);
- LOI V: e.g. Berger et al. (2008).

This overview exemplifies that there is a huge potential for transdisciplinary research (i.e. as defined above) in order to better understand mangrove ecosystems and their dynamics, and although presented for the mangrove habitat here, we maintain it might be valid for a wide range of ecosystems worldwide.

Acknowledgements

The authors thank the fellows of the Research Foundation in Flanders (FWO-Vlaanderen) Franky Bossuyt and Nele Schmitz, the Editor-in-Chief Jan Vermaat as well as two anonymous reviewers for critical comments. Stad Oostende and FWO are acknowledged for providing financial support to collect historic maps from different archive institutes in Europe (archive research done in collaboration with Danae Maniatis and Preetika Hirani).

References

Abeysinghe, P.D., Triest, L., De Greef, B., Koedam, N., Hettiarachchi, S., 2000. Comparative genetical and geographic variation of the mangrove tree *Bruguiera* in Sri Lanka. Aquat. Bot. 67, 131–141.

Adger, W.N., Hughes, T.P., Folke, C., Carpenter, S.R., Rockström, J., 2005. Social–ecological resilience to coastal disasters. Science 309, 1036–1039.

Allan, R.J., Reason, C.J.C., Carroll, P., Jones, P.D., 2002. A reconstruction of Madras (Chennai) mean sea-level pressure using instrumental records from the late 18th and early 19th centuries. Int. J. Climatol. 22, 1119–1142.

Alleng, G.P., 1998. Historical development of the Port Royal mangrove wetland, Jamaica. J. Coast. Res. 14, 951–959.

Allison, M.A., 1998. Historical changes in the Ganges-Brahmaputra delta front. J. Coast. Res. 14, 1269–1275.

Badola, R., Hussain, S.A., 2005. Valuing ecosystem functions: an empirical study on the storm protection function of Bhitarkanika mangrove ecosystem. India. Environ. Conserv. 32, 85–92.

Baldaeus, P., 1672. Naauwkerige beschryvinge van Malabar en Chromandel, der zelver aangrenzende ryken, en het machtige eyland Ceylon: nevens een omstandige en grondigh doorzochte ontdekking en wederlegginge van de afgodery der Oost-Indische heydenen. Janssonius van Waasberghe, Amsterdam (in ancient Dutch).

Bandaranayake, W.M., 1998. Traditional and medicinal uses of mangroves. Mangroves Salt Marshes 2, 133–148.

Bandaranayake, W.M., 2002. Bioactivities, bioactive compounds and chemical constituents of mangrove plants. Wetlands Ecol. Manage. 10, 421–452.

Baran, E., 1999. A review of quantified relationships between mangroves and coastal resources. Phuket Mar. Biol. Centre Res. Bull. 62, 57–64.

Barbier, E.B., 2000. Valuing the environment as input: review of applications to mangrove-fishery linkages. Ecol. Econ. 35, 47–61.

Bednarik, R.G., 2002. The dating of rock art: a critique. J. Archaeol. Sci. 29, 1213–1233.

Benson, S., Coxson, D.S., 2002. Lichen colonization and gap structure in wet-temperate rainforests of northern interior British Columbia. Bryologist 105, 673–692.

Berger, U., Rivera-Monroy, V.H., Doyle, T.W., Dahdouh-Guebas, F., Duke, N.C., Fontalvo-Herazo, M.L., Hildenbrandt, H., Koedam, N., Mehlig, U., Piou, C., Twilley, R.R., 2008. Advances and limitations of individual-based models to analyze and predict dynamics of mangrove forests: A review. Aquat. Bot. 89, 260–274.

Biondi, F., Fessenden, J.E., 1999. Radiocarbon analysis of *Pinus lagunae* tree rings: Implications for tropical dendrochronology. Radiocarbon 41, 241–249.

Blake, W.H., Walling, D.E., He, Q., 1999. Fallout beryllium-7 as a tracer in soil erosion investigations. Appl. Radiat. Isot. 51, 599–605.

Blake, W.H., Walling, D.E., He, Q., 2002. Using cosmogenic beryllium-7 as a tracer in sediment budget investigations. Geografiska Annaler Ser. A – Phys. Geogr. 84A, 89–102.

Blasco, F., 1984. Mangrove evolution and palynology. In: Snedaker, S.C., Snedaker, J.G. (Eds.), The Mangrove Ecosystem: Research Methods. UNESCO, Paris, pp. 36–49.

Blasco, F., Gauquelin, T., Rasolofoharinoro, M., Denis, J., Aizpuru, M., Caldairou, V., 1998. Recent advances in mangrove studies using remote sensing data. Mar. Freshwater Res. 49, 287–296.

Bonzani, R.M., 1997. Plant diversity in the archaeological record: A means toward defining hunter-gatherer mobility strategies. J. Archaeol. Sci. 24, 1129–1139.

Bosire, J.O., Dahdouh-Guebas, F., Walton, M., Crona, B.I., Lewis III, R.R., Field, C., Kairo, J.G., Koedam, N., 2008. Functionality of restored mangroves: A review. Aquat. Bot. 89, 251–259.

Bossuyt, F., Meegaskumbura, M., Beenaerts, N., Gower, D.J., Pethiyagoda, R., Roelants, K., Mannaert, A., Wilkinson, M., Bahir, M.M., Manamendra-Arachchi, K., Ng, P.K.L., Schneider, C.J., Oommen, O.V., Milinkovitch, M.C., 2004. Local endemism within the Western Ghats–Sri Lanka biodiversity hotspot. Science 306, 479–481.

Bouillon, S., Raman, A.V., Dauby, P., Dehairs, F., 2002. Carbon and nitrogen stable isotope ratios of subtidal benthic invertebrates in an estuarine mangrove ecosystem (Andhra Pradesh, India). Estuar. Coast. Shelf Sci. 54, 901–913.

Bouillon, S., Dahdouh-Guebas, F., Rao, A.V.V.S., Koedam, N., Dehairs, F., 2003. Sources of organic carbon in mangrove sediments: variability and possible ecological implications. Hydrobiologia 495, 33–39.

Bouillon, S., Connolly, R.M., Lee, S.Y., 2007. Organic matter exchange and cycling in mangrove ecosystems: recent insights from stable isotope studies. J. Sea Res., doi:10.1016/j.seares.2007.05.001.

Briffa, K.R., Schweingruber, F.H., Jones, P.D., Osborn, T.J., Harris, I.C., Shiyatov, S.G., Vaganov, E.A., Grudd, H., 1998. Trees tell of past climates: but are they speaking less clearly today? Philos. Trans. R. Soc. London Ser. B – Biol. Sci. 353, 65–73.

Brohier, R.L., 1934. Ancient Irrigation Works in Ceylon. Ceylon Government Press, Colombo.

Brook, B.W., Bowman, D.M.J.S., 2006. Postcards from the past: charting the landscape-scale conversion of tropical Australian savanna to closed forest during the 20th century. Landscape Ecol. 21, 1253–1266.

Bull, W.B., Brandon, M.T., 1998. Lichen dating of earthquake-generated regional rockfall events, Southern Alps, New Zealand. Geol. Soc. Am. Bull. 110, 60–84.

Burns, K.A., Garrity, S.D., Levings, S.C., 1993. How many years until mangrove ecosystems recover from catastrophic oil spills? Mar. Pollut. Bull. 26, 239–248.

Butler, D.R., DeChano, L.M., 2001. Environmental change in Glacier National Park, Montana: an assessment through repeat photography from fire lookouts. Phys. Geogr. 22, 291–304.

Cannicci, S., Burrows, D., Fratini, S., Smith III, T.J., Offenberg, J., Dahdouh-Guebas, F., 2008. Faunistic impact on vegetation structure and ecosystem function in mangrove forests: A review. Aquat. Bot. 89, 186–200.

Chapman, V.J., 1976. Mangrove vegetation. J. Cramer, Vaduz.

Cherubini, P., Gartner, B.L., Tognetti, R., Bräker, O.U., Schoch, W., Innes, J.L., 2003. Identification, measurement and interpretation of tree rings in woody species from mediterranean climates. Biol. Rev. 78, 119–148.

Chowdhury, M.Q., Schmitz, N., Verheyden, A., Sass-Klaassen, U., Koedam, N., Beeckman, H. Nature and periodicity of growth rings in two Bangladeshi mangrove species. IAWA J., in press.

Clarke, P.J., 1995. The population dynamics of the mangrove *Avicennia marina*, demographic synthesis and predictive modelling. Hydrobiologia 295, 83–88.

Cocheret de la Morinière, E., Pollux, B.J.A., Nagelkerken, I., Hemminga, M.A., Huiskes, A.H.L., van der Velde, G., 2003. Ontogenetic dietary changes of coral reef fishes in the mangrove-seagrass-reef continuum: stable isotopes and gut-content analysis. Estuar. Coast. Shelf Sci. 55, 309–321.

Cohen, M.C.L., Behling, H., Lara, R.J., 2005a. Amazonian mangrove dynamics during the last millennium: the relative sea-level and the Little Ice Age. Rev. Palaeobot. Palynol. 136, 93–108.

Cohen, M., Souza Filho, P.W.M., Lara, R., Behling, H., Angulo, R.J., 2005b. A model of Holocene mangrove development and relative sea-level changes on the Bragança Peninsula (northern Brazil). Wetlands Ecol. Manage. 13, 433–443.

Coil, J., Korstanje, M.A., Archer, S., Hastorf, C.A., 2003. Laboratory goals and considerations for multiple microfossil extraction in archaeology. J. Archaeol. Sci. 30, 991–1008.

Cormier-Salem, M.C., 1999. The mangrove: an area to be cleared… for social scientists. Hydrobiologia 413, 135–142.

Dahdouh-Guebas, F., Mathenge, C., Kairo, J.G., Koedam, N., 2000a. Utilization of mangrove wood products around Mida Creek (Kenya) amongst subsistence and commercial users. Econ. Bot. 54, 513–527.

Dahdouh-Guebas, F., Verheyden, A., De Genst, W., Hettiarachchi, S., Koedam, N., 2000b. Four decade vegetation dynamics in Sri Lankan mangroves as detected from sequential aerial photography: a case study in Galle. Bull. Mar. Sci. 67, 741–759.

Dahdouh-Guebas, F., 2002. The use of remote sensing and GIS in the sustainable management of tropical coastal ecosystems. Environ. Dev. Sustainability 4, 93–112.

Dahdouh-Guebas, F., Koedam, N., 2002. A synthesis of existent and potential mangrove vegetation structure dynamics from Kenyan, Sri Lankan and Mauritanian case-studies. Meded. Zitt. K. Acad. overzeese Wet./Bull. Séanc. Acad. r. Sci. Outre-Mer 48, 487–511.

Dahdouh-Guebas, F., Kairo, J.G., Jayatissa, L.P., Cannicci, S., Koedam, N., 2002a. An ordination study to view vegetation structure dynamics in disturbed and undisturbed mangrove forests in Kenya and Sri Lanka. Plant Ecol. 161, 123–135.

Dahdouh-Guebas, F., Zetterström, T., Rönnbäck, P., Troell, M., Wickramasinghe, A., Koedam, N., 2002b. Recent changes in land-use in the Pambala-Chilaw Lagoon complex (Sri Lanka) investigated using remote sensing and GIS: conservation of mangroves vs. development of shrimp farming. Environ. Dev. Sustainability 4, 185–200.

Dahdouh-Guebas, F., Van Pottelbergh, I., Kairo, J.G., Cannicci, S., Koedam, N., 2004. Human-impacted mangroves in Gazi (Kenya): predicting future vegetation based on retrospective remote sensing, social surveys, and distribution of trees. Mar. Ecol. Prog. Ser. 272, 77–92.

Dahdouh-Guebas, F., Van Hiel, E., Chan, J.C.-W., Jayatissa, L.P., Koedam, N., 2005a. Qualitative distinction of congeneric and introgressive mangrove species in mixed patchy forest assemblages using high spatial resolution remotely sensed imagery (IKONOS). Syst. Biodivers. 2, 113–119.

Dahdouh-Guebas, F., Hettiarachchi, S., Lo Seen, D., Batelaan, O., Sooriyarachchi, S., Jayatissa, L.P., Koedam, N., 2005b. Transitions in ancient inland freshwater resource management in Sri Lanka affect biota and human populations in and around coastal lagoons. Curr. Biol. 15, 579–586.

Dahdouh-Guebas, F., Jayatissa, L.P., Di Nitto, D., Bosire, J.O., Lo Seen, D., Koedam, N., 2005c. How effective were mangroves as a defence against the recent tsunami? Curr. Biol. 15, R443–R447.

Dahdouh-Guebas, F., Collin, S., Lo Seen, D., Rönnbäck, P., Depommier, D., Ravishankar, T., Koedam, N., 2006. Analysing ethnobotanical and fishery-related importance of mangroves of the East-Godavari Delta (Andhra Pradesh, India) for conservation and management purposes. J. Ethnobiol. Ethnomed. 2, 24.

Dahdouh-Guebas, F., Koedam, N., 2006. Coastal vegetation and the Asian tsunami. Science 311, 37–38.

Dahdouh-Guebas, F., Koedam, N. (Eds.), 2008. Aquatic Botany special issue on Mangrove Ecology – Applications in Forestry and Coastal Zone Management. Aquat. Bot. 89, 77–274.

Danielsen, F., Sørensen, M.K., Olwig, M.F., Selvam, V., Parish, F., Burgess, N.D., Hiraishi, T., Karunagaran, V.M., Rasmussen, M.S., Hansen, L.B., Quarto, A., Suryadiputra, N., 2005. The asian tsunami: a protective role for coastal vegetation. Science 310, 643.

Drake, D.C., Naiman, R.J., Helfield, J.M., 2002. Reconstructing salmon abundance in rivers: an initial dendrochronological evaluation. Ecology 83, 2971–2977.

Duke, N.C., Meynecke, J.-O., Dittmann, S., Ellison, A.M., Anger, K., Berger, U., Cannicci, S., Diele, K., Ewel, K.C., Field, C.D., Koedam, N., Lee, S.Y., Marchand, C., Nordhaus, I., Dahdouh-Guebas, F., 2007. A world without mangroves? Science 317, 41–42.

Edmondson, R., 2002. Memory of the World: General Guidelines (Revised edition 2002). UNESCO, Paris.

Ellison, A.M., Farnsworth, E.J., 1996. Anthropogenic disturbance of Caribbean mangrove ecosystems: past impacts, present trends, and future predictions. Biotropica 24, 549–565.

Ellison, A.M., 2008. Preface. Aquat. Bot. doi:10.1016/j.aquabot.2008.01.001, this issue.

Ellison, J.C., 1997. Mangrove community characteristics and litter production in Bermuda. In: Kjerfve, B., de Lacerda, L.D., Diop, E.H.S. (Eds.), Mangrove Ecosystem Studies in Latin America and Africa. UNESCO, Paris, pp. 8–17.

Ellison, J.C., 1999. Impacts of sediment burial on mangroves. Mar. Pollut. Bull. 37, 420–426.

Ellison, J.C., 2008. Long-term retrospection on mangrove development using sediment cores and pollen analysis: A review. Aquat. Bot. 89, 93–104.

Engelhart, S.E., Horton, B.P., Roberts, D.H., Bryant, C.L., Reide Corbett, D., 2007. Mangrove pollen of Indonesia and its suitability as a sea-level indicator. Mar. Geol. 242, 65–81.

Erickson, A.A., Bell, S.S., Dawes, C.J., 2004. Does mangrove leaf chemistry help explain crab herbivory patterns? Biotropica 36 (3), 333–343.

Ewel, K.C., Twilley, R.R., Ong, J.E., 1998. Different kinds of mangrove forests provide different goods and services. Global Ecol. Biogeogr. Lett. 7, 83–94.

Farrington, A.J., Lubker, S., Radok, U., Woodruff, S., 1998. South Atlantic winds and weather during and following the little ice age—a pilot study of English East India Company (EEIC) ship logs. Meteorol. Atmos. Phys. 67, 253–257.

Farnsworth, E.J., Ellison, A.M., 1997. The global conservation status of mangroves. Ambio 26, 328–334.

February, E.C., 2000. Archaeological charcoal and dendrochronology to reconstruct past environments of southern Africa. S. Afr. J. Sci. 96, 111–116.

Finn, M., 1996. The mangrove mesocosm of Biosphere 2: design, establishment and primary results. Ecol. Eng. 6, 21–56.

Firestone, R.B., Shirley, V.S., 1996. Table of Isotopes, 8th edition. John Wiley & Sons Inc., New York.

Gilbert, A.J., Janssen, R., 1998. Use of environmental functions to communicate the values of a mangrove ecosystem under different management regimes. Ecol. Econ. 25, 323–346.

Gilman, E.L., Ellison, J., Duke, N.C., Field, C., 2008. Threats to mangroves from climate change and adaptation options: A review. Aquat. Bot. 89, 237–250.

Gaston, K.J., 1996. Biodiversity. A biology of Numbers and Difference. Blackwell Science Ltd., Oxford.

Gonneea, M.E., Paytan, A., Herrera-Silveira, J.A., 2004. Tracing organic matter sources and carbon burial in mangrove sediments over the past 160 years. Estuar. Coast. Shelf Sci. 61, 211–227.

Gore, A.P., Johnson, E.A., Lo, H.P., 1985. Estimating the time a dead tree has been on the ground. Ecology 66, 1981–1983.

Green, E.P., Mumby, P.J., Edwards, A.J., Clark, C.D., 2000. Remote sensing handbook for tropical coastal management. Coastal Management Sourcebooks, vol. 3. UNESCO, Paris.

Hernández-Cornejo, R., Koedam, N., Ruiz Luna, A., Troell, M., Dahdouh-Guebas, F., 2005. Remote sensing and ethnobotanical assessment of the mangrove forest changes in the Navachiste-San Ignacio-Macapule lagoon complex, Sinaloa, Mexico. Ecol. Soc. 10, 16.

Hofmann, C.-C., 2002. Pollen distribution in sub-recent sedimentary environments of the Orinoco Delta (Venezuela)—an actuo-palaeobotanical study. Rev. Palaeobot. Palynol. 119, 191–217.

Holl, K., Smith, M., 2007. Scottish upland forests: history lessons for the future. Forest Ecol. Manage. 249, 45–53.

Horton, B.P., Gibbard, P.L., Mile, G.M., Morley, R.J., Purintavaragul, C., Stargardt, J.M., 2005. Holocene sea levels and palaeoenvironments, Malay-Thai Peninsula, southeast Asia. Holocene 15, 1–15.

Hughes, T.P., Bellwood, D.R., Folke, C., Steneck, R.S., Wilson, J., 2005. New paradigms for supporting the resilience of marine ecosystems. Tree 20, 380–386.

Hyyppä, J., Hyyppä, H., Inkinen, M., Engdahl, M., Linko, S., Zhu, Y.H., 2000. Accuracy comparison of various remote sensing data sources in the retrieval of forest stand attributes. Forest Ecol. Manage. 128, 109–120.

Jayatissa, L.P., Guero, M.C., Hettiarachchi, S., Koedam, N., 2002. Changes in vegetation cover and socio-economic transitions in a coastal lagoon (Kalametiya, Sri Lanka), as observed by teledetection and ground truthing, can be attributed to an upstream irrigation scheme. Environ. Dev. Sustainability 4, 167–183.

Johnson, E.A., Greene, D.F., 1991. A method for studying dead bole dynamics in *Pinus contorta* var. *latifolia* – *Picea engelmannii* forests. J. Veg. Sci. 2, 523–530.

Juleff, G., 1996. An ancient wind-powered iron smelting technology in Sri Lanka. Nature 379, 60–63.

Kairo, J.G., Dahdouh-Guebas, F., Gwada, P.O., Ochieng, C., Koedam, N., 2002. Regeneration status of mangrove forests in Mida Creek, Kenya: a compromised or secured future? Ambio 31, 562–568.

Kathiresan, K., Bingham, B.L., 2001. Biology of mangroves and mangrove ecosystems. Adv. Mar. Biol. 40, 81–251.

Kathiresan, K., 2002. Greeing the blue mud. Rev. Biol. Trop. 50, 869–874.

Keegan, W.F., Portell, R.W., Slapcinsky, J., 2003. Changes in invertebrate taxa at two pre-Columbian sites in southwestern Jamaica, AD 800–1500. J. Archaeol. Sci. 30, 1607–1617.

Kelley, J.T., Barber, D.C., Belknap, D.F., FitzGerald, D.M., van Heteren, S., Dickson, S.M., 2005. Sand budgets at geological, historical and contemporary time scales for a developed beach system, Saco Bay, Maine, USA. Mar. Geol. 117–142.

Kendrick, G.W., Morse, K., 1990. Evidence of recent mangrove decline from an archaeological site in Western Australia (Australia). Austr. J. Ecol. 15, 349–354.

Komiyama, A., Ong, J.E., Poungparn, S., 2008. Allometry, biomass, and productivity of mangrove forests: A review. Aquat. Bot. 89, 128–137.

Kovacs, J.M., 2000. Perceptions of environmental change in a tropical coastal wetland. Land Degr. Dev. 11, 209–220.

Kovacs, J.M., Malczewski, J., Flores-Verdugo, F., 2004. Examining local ecological knowledge of hurricane impacts in a mangrove forest using an analytical hierarchy process (AHP) approach. J Coast. Res. 20, 792–800.

Kovacs, J.M., Wang, J., Flores-Verdugo, F., 2005. Mapping mangrove leaf area index at the species level using IKONOS and LAI-2000 sensors for the Agua Brava Lagoon, Mexican Pacific. Estuar. Coast. Shelf Sci. 62, 377–384.

Krauss, K.W., Lovelock, C.E., McKee, K.L., López-Hoffman, L., Ewe, S.M.L., Sousa, W.P., 2008. Environmental drivers in mangrove establishment and early development: A review. Aquat. Bot. 89, 105–127.

Kristensen, E., Bouillon, S., Dittmar, T., Marchand, C., 2008. Organic carbon dynamics in mangrove ecosystems: A review. Aquat. Bot. 89, 201–219.

Kumaran, K.P.N., Shindikar, M., Limaye, R.B., 2004a. Fossil record of marine manglicolous fungi from Malvan (Konkan) west coast of India. Indian J. Mar. Sci. 33, 257–261.

Kumaran, K.P.N., Shindikar, M., Limaye, R.B., 2004b. Mangrove associated lignite beds of Malvan, Konkan: Evidence for higher sea-level during the Late Tertiary (Neogene) along the west coast of India. Curr. Sci. 86, 335–340.

Lape, P.V., 2002. Historic maps and archaeology as a means of understanding late precolonial settlement in the Banda Islands, Indonesia. Asian Perspect. 41, 43–70.

Leenders, J.K., Visser, S.M., Stroosnijder, L., 2005. Farmers' perceptions of the role of scattered vegetation in wind erosion control on arable land in Burkina Faso. Land Degr. Dev. 16, 327–337.

Lepofsky, D., Moss, M.L., Lyons, N., 2001. The unrealized potential of paleoethnobotany in the archaeology of northwestern North America: perspectives from Cape Addington, Alaska. Arctic Anthropol. 38, 48–59.

Lewis III, R.R., 1982. Mangrove forests. In: Lewis, III, R.R. (Ed.), Creation and Restoration of Coastal Plant Communities. CRC Press, Boca Raton, pp. 154–171.

Lewis III, R.R., Hodgson, A.B., Mauseth, G.S., 2005. Project facilitates the natural reseeding of mangrove forests (Florida). Ecol. Restor. 23, 276–277.

Lezine, A.M., 1996. The West African mangrove: An indicator of sea-level fluctuations and regional climate changes during the last deglaciation. Bull. Soc. Géol. France 167, 743–752.

Lezine, A.M., Saliege, J.F., Mathieu, R., Tagliatela, T.L., Mery, S., Charpentier, V., Cleuziou, S., 2002. Mangroves of Oman during the late Holocene: climatic implications and impact on human settlements. Veg. History Archaeobot. 11 (3), 221–232.

Lin, S.M., Chen, C.A., Lue, K.Y., 2002. Molecular phylogeny and biogeography of the grass lizards genus *Takydromus* (Reptilia: Lacertidae) of East Asia. Mol. Phylogenet. Evol. 22, 276–288.

Lynch, J.C., Meriwether, J.R., McKee, B.A., Vera-Herrera, F., Twilley, R.R., 1989. Recent accretion in mangrove ecosystems based on ^{137}Cs and ^{210}Pb. Estuaries 12, 284–299.

MacFarlane, G.R., Pulkownik, A., Burchett, M.D., 2003. Accumulation and distribution of heavy metals in the grey mangrove, *Avicennia marina* (Forsk.) Vierh.: biological indicator potential. Environ. Pollut. 123, 139–151.

Manson, F.J., Loneragan, N.R., McLeod, I.M., Kenyon, R.A., 2001. Assessing techniques for estimating the extent of mangroves: topographic maps, aerial photographs and Landsat TM images. Mar. Freshwater Res. 52, 787–792.

Marguillier, S., van der Velde, G., Dehairs, F., Hemminga, M.A., Rajagopal, S., 1997. Trophic relationships in an interlinked mangrove-seagrass ecosystem as traced by δ^{13}C and δ^{15}N. Mar. Ecol. Prog. Ser. 151, 115–121.

Mastaller, M., 1997. Mangroves, the Forgotten Forest Between Land and Sea. Tropical Press Sdn. Bhd., Kuala Lumpur.

Menezes, M., Berger, U., Worbes, M., 2003. Annual growth rings and long-term growth patterns of mangrove trees from the Bragança peninsula, North Brazil. Wetlands Ecol. Manage. 11, 233–242.

Meynecke, J.-O., 2005. Change under climate change—a strategy to strengthen Australian ecosystems. In: Burk, A.R. (Ed.), Trends in Biodiversity Research. Nova Science Publishers, Hauppauge, pp. 41–80.

Miller, D.L., Mora, C.I., Grissino-Mayer, H.D., Mock, C.J., Uhle, M.E., Sharp, Z., 2006. Tree-ring isotope records of tropical cyclone activity. PNAS 103, 14294–14297.

Moberg, F., Rönnbäck, P., 2003. Ecosystem services of the tropical seascape: interactions, substitutions and restoration. Ocean Coast. Manage. 46, 27–46.

Morton, R.A., 2002. Coastal geoindicators of environmental change in the humid tropics. Environ. Geol. 42 (7), 711–724.

Moseley, R.K., 2006. Historical landscape change in northwestern Yunnan, China—using repeat photography to assess the perceptions and realities of biodiversity loss. Mountain Res. Dev. 26, 214–219.

Mulrennan, M.E., Woodroffe, C.D., 1998. Holocene development of the lower Mary River plains, Northern Territory, Australia. Holocene 8, 565–579.

Mumby, P.J., Green, E.P., Edwards, A.J., Clark, C.D., 1999. The cost-effectiveness of remote sensing for tropical coastal resources assessment and management. J. Environ. Manage. 55, 157–166.

Nagelkerken, I., Blaber, S.J.M., Bouillon, S., Green, P., Haywood, M., Kirton, L.G., Meynecke, J.-O., Pawlik, J., Penrose, H.M., Sasekumar, A., Somerfield, P.J., 2008. The habitat function of mangroves for terrestrial and marine fauna: A review. Aquat. Bot. 89, 155–185.

Naylor, R.L., Goldburg, R.J., Mooney, H., Beveridge, M., Clay, J., Folke, C., Kautsky, N., Lubcheno, J., Primavera, J., Williams, M., 2000a. Nature's subsidies to shrimp and salmon farming. Science 282, 883–884.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Moony, H., Troell, M., 2000b. Effect of aquaculture on world fish supplies. Nature 405, 1017–1024.

Palmer, J., Finlay, V., 2003. Faith in Conservation: New Approaches to Religions and the Environment. The International Bank for Reconstruction and Development/ The World Bank, Washington, DC.

Parr, T.W., Sier, A.R.J., Battarbee, R.W., Mackay, A., Burgess, J., 2003. Detecting environmental change: science and society—perspectives on long-term research and monitoring in the 21st century. Sci. Total Environ. 310, 1–8.

Piperno, D.R., 1998. Paleoethnobotany in the Neotropics from microfossils: new insights into ancient plant use and agricultural origins in the tropical forest. J. World Prehistory 12, 393–449.

Plaziat, J., Augustinus, P.G.E.F., 2004. Evolution of progradation/erosion along the French Guiana mangrove coast: a comparison of mapped shorelines since the 18th century with Holocene data. Mar. Geol. 208, 127–143.

Primavera, J.H., 2005. Mangroves, fishponds, and the quest for sustainability. Science 310, 57–59.

Ramsey, E.W., Laine, S.C., 1997. Comparison of LANDSAT Thematic Mapper and high resolution photography to identify change in complex coastal wetland. J. Coast. Res. 13, 281–292.

Rist, S., Dahdouh-Guebas, F., 2006. Ethnosciences—a step towards the integration of scientific and traditional forms of knowledge in the management of natural resources for the future. Environ. Dev. Sustainability 8, 467–493.

Roelants, K., Bossuyt, F., 2005. Archaeobatrachian paraphyly and Pangaean diversification of crown-group frogs. Syst. Biol. 54, 111–126.

Rogers, G.F., Malde, H.E., Turner, R.M., 1984. Bibliography of Repeat Photography for Evaluating Landscape Change. University of Utah Press, Salt Lake City.

Rönnbäck, P., 1999. The ecological basis for economic value of seafood production supported by mangrove ecosystems. Ecol. Econ. 29, 235–252.

Scheel-Ybert, R., 2000. Vegetation stability in the Southeastern Brazilian coastal area from 5500 to 1400 ^{14}C yr BP deduced from charcoal analysis. Rev. Palaeobot. Palynol. 110, 111–138.

Semeniuk, V., 1994. Predicting the effect of sea-level rise on mangroves in Northwestern Australia. J. Coast. Res. 10, 1050–1076.

Smith, J., Lamanna, B., Metthew, C., Lacovara, K.J., Dodson, P., Smith, J.R., Poole, J.C., Giegengack, R., Attia, Y., 2001. A giant sauropod dinosaur from an upper cretaceous mangrove deposit in Egypt. Science 292, 1704–1706.

Schmitz, N., Verheyden, A., Beeckman, H., Kairo, J.G., Koedam, N., 2006. Influence of a salinity gradient on the vessel characters of the mangrove species *Rhizophora mucronata* Lam. Ann. Bot. 98, 1321–1330.

Schmitz, N., Verheyden, A., Kairo, J.G., Beeckman, H., Koedam, N., 2007a. Successive cambia development in *Avicennia marina* (Forssk.) Vierh. is not climatically driven in the seasonal climate at Gazi Bay, Kenya. Dendrochronologia 25, 87–96.

Schmitz, N., Robert, E.M.R., Verheyden, A., Kairo, J.G., Beeckman, H., Koedam, N., 2007b. A patchy growth via successive and simultaneous cambia: key to success of the most widespread mangrove species *Avicennia marina*? Ann. Bot., doi:10.1093/aob/mcm280.

Souza-Filho, P.W.M., El-Robini, M., 2000. Geomorphology of the Brangaça coastal zone, Northeastern Pará State. Revista Brasiliera de Geociências 30, 518–522.

Souza-Filho, P.W.M., Paradella, W.R., 2002. Recognition of the main geobotanical features along the Brangaça mangrove coast (Brazialian Amazon Region) from Landsat TM and RADARSAT-1 data. Wetlands Ecol. Manage. 10, 123–132.

Souza-Filho, P.W.M., Paradella, W.R., 2003. Use of synthetic aperture radar for recognition of coastal geomorphological features, land-use assessment and shoreline changes in Bragança coast, Pará, Northern Brazil. Anais da Academia Brasileira de Ciências 75, 341–356.

Stafford-Deitsch, J., 1996. Mangrove: The Forgotten Habitat. Immel Publishing Limited, London.

Stein, M., Goldstein, S.L., Schramm, A., 2000. Radiocarbon calibration beyond the dendrochronology range. Radiocarbon 42, 415–422.

Stephens, S.L., Skinner, C.N., Gill, S.J., 2003. Dendrochronology-based fire history of Jeffrey pine-mixed conifer forests in the Sierra San Pedro Martir, Mexico. Can. J. Forest Res. 33, 1090–1101.

Stevenson, J., 2004. A late-Holocene record of human impact from the southwest coast of New Caledonia. Holocene 14, 888–898.

Stevenson, N.J., Lewis, R.R., Burbridge, P.R., 1999. Disused shrimp ponds and mangrove rehabilitation. In: Streever, W. (Ed.), An International Perspective on Wetland Restoration. Kluwer Academic Publishers, Dordrecht.

Stokstad, E., 2001. Myriad ways to reconstruct past climate. Science 292, 658–659.

Swetnam, T.W., Allen, C.D., Betancourt, J.L., 1999. Applied historical ecology: using the past to manage for the future. Ecol. Appl. 9, 1189–1206.

Taylor, M.P., Lewin, J., 1996. River behaviour and Holocene alluviation: The River Severn at Welshpool, mid-Wales, UK. Earth Proc. Landforms 21, 77–91.

Thampanya, U., Vermaat, J.E., Sinsakul, S., Panapitukkul, N., 2006. Coastal erosion and mangrove progradation of Southern Thailand. Estuar. Coast. Shelf Sci. 68, 75–85.

Theophrastus, 1916. Enquiry into Plants and Minor Works on Odours and Weather Signs. Translated by Hort, A. (1916) Harvard University Press, Cambridge, US.

Theophrastus, 1976. De Causis Plantarum. Translated by Einarson, B., Link, G.K.K. (1976) Harvard University Press, Cambridge, US.

Thom, B.G., Wright, L.D., Coleman, J.M., 1975. Mangrove ecology and deltaic-estuarine geomorphology: Cambridge Gulf-Old River, Western Australia. J. Ecol. 63, 203–232.

Thom, B.G., 1984. Coastal landforms and geomorphic processes. In: Snedaker, S.C., Snedaker, J.G. (Eds.), The Mangrove Ecosystem: Research Methods. UNESCO, Paris, pp. 3–17.

Thompson, L.G., Davis, M.E., Mosley-Thompson, E., Sowers, T.A., Henderson, K.A., Zagorodnov, V.S., Lin, P.-N., Mikhalenko, V.N., Campen, R.K., Bolzan, J.F., Cole-Dai, J., Francou, B., 1998. A 25,000-year tropical climate history from Bolivian ice cores. Science 282, 1858–1864.

Torrescano, N., Islebe, G.A., 2006. Tropical forest and mangrove history from southeastern Mexico: a 5000 yr pollen record and implications for sea level rise. Veg. History Archaeobot. 15, 191–195.

Triest, L., 2008. Molecular ecology and biogeography of mangrove trees towards conceptual insights on gene flow and barriers: A review. Aquat. Bot. 89, 138–154.

Turner, R.E., Lewis III, R.R., 1997. Hydrologic restoration of coastal wetlands. Wetlands Ecol. Manage. 4, 65–72.

UNESCO, 2003.In: Sixth Meeting of the International Advisory Committee of the Memory of the World Programme (Gdansk, Poland, 28–30 August 2003). UNESCO, Paris.

Vanhecke, L., Charlier, G., Verhelst, L., 1981. Landschappen in Vlaanderen, vroeger en nu./Paysages de Flandre, jadis et aujourd'hui. National Botanical Gardens of Belgium, Meise.

Vannucci, M., 1997. Supporting appropriate mangrove management. International News Letter of Coastal Management-Intercoast Network, Special edition 1, pp. 1–3.

Vedel, V., Behling, H., Cohen, M., Lara, R., 2006. Holocene mangrove dynamics and sea-level changes in northern Brazil, inferences from the Taperebal core in northeastern Para State. Veg. History Archaeobot. 15, 115–123.

Verheyden, A., Kairo, J.G., Beeckman, H., Koedam, N., 2004a. Growth rings, growth ring formation and age determination in the mangrove *Rhizophora mucronata*. Ann. Bot. 94, 59–66.

Verheyden, A., Helle, G., Schleser, G.H., Dehairs, F., Beeckman, H., Koedam, N., 2004b. Annual cyclicity in high-resolution stable carbon and oxygen isotope ratios in the wood of the mangrove tree *Rhizophora mucronata*. Plant Cell Environ. 27, 1525–1536.

Verheyden, A., Roggeman, M., Bouillon, S., Elskens, M., Beeckman, H., Koedam, N., 2005a. Comparison between δ13C of α-cellulose and bulk wood in the mangrove tree *Rhizophora mucronata*: Implications for dendrochemistry. Chem. Geol. 219, 275–282.

Verheyden, A., De Ridder, F., Schmitz, N., Beeckman, H., Koedam, N., 2005b. High-resolution time series of vessel density in Kenyan mangrove trees reveal a link with climate. New Phytol. 167, 425–435.

Verschuren, D., Laird, K.R., Cumming, B.F., 2000. Rainfall and drought in equatorial east Africa during the past 1,100 years. Nature 403, 410–414.

Versteegh, G.J.M., Schefuss, E., Dupont, L., Marret, F., Sinninghe Damsté, J.S., Jansen, J.H.F., 2004. Taraxerol and Rhizophora pollen as proxies for tracing past mangrove ecosystems. Geochimica et Cosmochimica Acta 68, 411–422.

Visser, S.M., Sterk, G., Karssenberg, D., 2005. Wind erosion modelling in a Sahelian environment. Environ. Modelling Software 20, 69–84.

Von Rosenberg, C.B.H., 1867. Reis naar de Zuidoostereilanden gedaan in 1865 op last der Regering van Nederlandsch-Indie. Martinus Nijhoff, 's Gravenhage (in Dutch).

Walters, B.B., 2005. Patterns of local wood use and cutting of Philippine mangrove forests. Econ. Bot. 59, 66–76.

Walters, B.B., Rönnbäck, P., Kovacs, J.M., Crona, B., Hussain, S.A., Badola, R., Primavera, J.H., Barbier, E., Dahdouh-Guebas, F., 2008. Ethnobiology, socio-economics and management of mangrove forests: A review. Aquat. Bot. 89, 220–236.

Westgate, J.W., 1994. Eocene forest swamp. Res. Exploration 10, 80–91.

Wang, L., Sousa, W.P., Gong, P., Biging, G.S., 2004. Comparison of IKONOS and QuickBird images for mapping mangrove species on the Caribbean coast of Panama. Remote Sensing Environ. 91, 432–440.

Wang, X., van der Kaars, S., Kershaw, P., Bird, M., Jansen, F., 1999. A record of fire, vegetation and climate through the last three glacial cycles from Lombok Ridge core G6-4, eastern Indian Ocean, Indonesia. Palaeogeogr. Palaeoclimatol. Palaeoecol. 147, 241–256.

Ward, W.T., Little, I.P., 2000. Sea-rafted pumice on the Australian east coast: numerical classification and stratigraphy. Austr. J. Earth Sci. 47, 95–109.

Winchester, V., Chaujar, R.K., 2002. Lichenometric dating of slope movements, Nant Ffrancon, North Wales. Geomorphology 47, 61–74.

WinklerPrins, A.M.G.A., Sandor, J.A. (Eds.), 2003. Ethnopedology. Geoderma. Elsevier, Amsterdam.

Witt, B., 2002. Century-scale environmental reconstruction by using stable carbon isotopes: just one method from the big bag of tricks. Austr. J. Bot. 50, 441–454.

Wolanski, E., Gereta, E., 2001. Water quantity and quality as the factors driving the Serengeti ecosystem, Tanzania. In: Harper, D., Boar, R., Everard, M., Hickley, P. (Eds.), Hydrobiologia 458: Science and the Sustainable Management of Shallow Tropical Waters. Kluwer Academic Publishers, Dordrecht, pp. 169–180.

Woodroffe, C.D., 1999. Response of mangrove shorelines to sea-level change. Tropics 8, 159–177.

Yu, K.-F., Zhao, J.-X., Liu, T.-S., Wang, P.-X., Qian, J.-L., Chen, T.-G., 2004. Alpha-cullulose (13C variation in mangrove tree rings correlates well with annual sea level trand between 1982 and 1999. Geophys. Res. Lett. 31, L11203.

Yulianto, E., Sukapti, W.S., Rahardjo, A.T., Noeradi, D., Siregar, D.A., Suparan, P., Hirakawa, K., 2004. Mangrove shoreline responses to Holocene environmental change, Makassar Strait, Indonesia. Rev. Palaeobot. Palynol. 131, 251–268.