Proceedings of the International Conference 'Meeting on Mangrove ecology, functioning and Management-MMM3'

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Proceedings of the International Conference: Meeting on Mangrove ecology, functioning and Management (MMM3)

2-6 July 2012, Galle, Sri Lanka

Edited by
Farid DAHDOUH-GUEBAS & Behara SATYANARAYANA
Université Libre de Bruxelles (ULB)
& Vrije Universiteit Brussel (VUB), Brussels, Belgium

This conference is jointly organized by
the Vrije Universiteit Brussel (VUB),
the Université Libre de Bruxelles (ULB),
the Kenya Marine and Fisheries Research Institute (KMFRI),
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Meeting on MANGROVE ecology, functioning and Management

MMM3, Galle, Sri Lanka, 2-6 July 2012

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Cover page photos

Inside an *Avicennia marina* and *Rhizophora mucronata*-dominated mangrove creek in Gazi Bay, Kenya (Elisabeth Robert & Nele Schmitz).

Mangrove leaf, flower and propagule litter (particularly *Bruguiera gymnorrhiza*) in the microtidal mangrove forest of Galle-Unawatuna, Sri Lanka (Diana Di Nitto).

Two *Uca urvillei* males fighting in a *Rhizophora mucronata*-dominated stand in Gazi Bay, Kenya (Arimatéa C. Ximenes).

Sponges attached to *Sonneratia alba* peg roots in Gazi Bay, Kenya (Diana Di Nitto).

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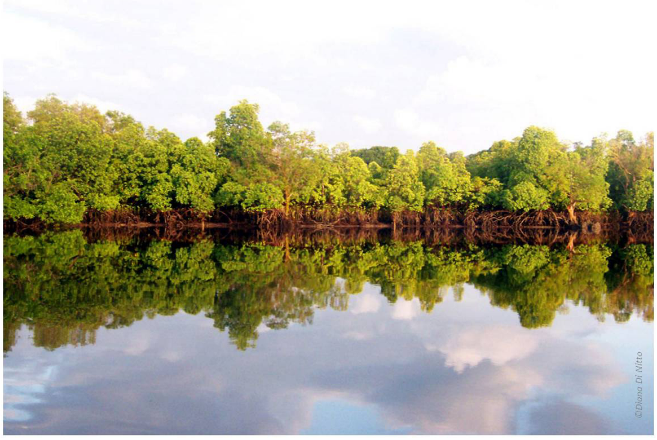
Meeting on Mangrove ecology, functioning and Management

International Conference on Mangroves



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After MMM1 in Mombasa (Kenya) in 2000 and MMM2 in Coolangatta (Australia) in 2006, MMM3 is the 3rd edition of the only recurrent international conference on mangroves

MMM3 Conference: 2-6 July, 2012
Place: Auditorium of the Faculty of Medicine, University of Ruhuna, Karapitiya, Galle, Sri Lanka

MMM3 Workshop: 9-13 July 2012
Place: SFFL - Small Fishers Federation (of Lanka), Pambala-Kakkapalliya

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Registration is open!

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Acknowledgements

Our earnest thanks to all sponsors, who made this conference possible, and to the scientific community that made organizing this symposium a pleasure. Special thanks are due to financial and administrative authorities at the Vrije Universiteit Brussel (VUB), the Université Libre de Bruxelles (ULB), the University of Ruhuna (UoR), and the Kenya Marine and Fisheries Research Institute (KMFRI). The MMM3 Proceedings layout/printing was supported by the Vlaams Instituut voor de Zee (VLIZ).

Foreword by the organizers

MMM is an international conference on mangrove ecosystems that is held every 6 years. Although dealing with a variety of ecological themes, incl. flora, fauna, biogeochemical cycles and human impacts, this conference originally stood for the 'International Meeting on Mangrove Macrobenthos' and was organized by the Università degli Studi di Firenze (Italy) as MMM in Mombasa (Kenya), 7-11 September 2000. Six years later a consortium including Griffith University and University of Queensland organized 'MMM2: Mangrove Macrobenthos Meeting' in Coolangatta (Australia), 25-30 June 2006, where it was decided that the meaning of the MMM could be opened up in order to continue this conference as the first global recurrent conference on mangrove ecosystems. Hence, the name for **MMM3**: **M**eeting on **M**angrove ecology, functioning and **M**anagement. MMM is to be organized by mangrove scientists world-wide, every 6 years, *i.e.* at an interval that allows scientific innovation. It is not aiming at massive attendance but at single sessions covering various topics, with plenty of time for discussion in each of them. As a matter of fact, macrobenthos will still form a solid theme together with vegetation, trophic relationships, restoration and management issues, just like MMM1 and MMM2. The conference is usually accompanied by a mid-conference excursion and followed by a mid-week workshop in a mangrove site aiming at identifying research gaps through joint-fieldwork, analyses and brainstorming.

The conference **MMM3**: International Meeting on Mangrove ecology, functioning and Management is jointly organized by the Vrije Universiteit Brussel (VUB), the Université Libre de Bruxelles (ULB), the University of Ruhuna (UoR) and the Kenya Marine and Fisheries Research Institute (KMFRI), and will be held in the premises of the University of Ruhuna in Galle, Sri Lanka, from 2 to 6 July 2012. It will be followed by a mid-week workshop (9-13 July 2012) in the Pambala-Chilaw Lagoon complex (Sri Lanka) at the premises of the Small Fishers Federation of Lanka in Pambala-Kakkapalliya.

In total, **MMM3** received 190 abstracts (>150 registrations) from all over the world. Due to single session operation throughout the conference, the number of Oral presentations was limited to 38 only. With no choice, several quality research works have been considered for Poster presentations. However, the special session called '**Oral pitching research highlights**' would be able to give you an opportunity to listen to some of the notable works from Poster presentations. In fact, each **MMM3** abstract was peer-reviewed by 1-3 Scientific Committee members and the decisions were taken on the basis of their recommendations as well as conference program.

Hope **MMM3** would become a successful event and benefit all pioneer, young and mature mangrove researchers.

Farid Dahdouh-Guebas, Chair
On behalf of the MMM3 Organizing Committee

Preface

On behalf of the Organising Committee, Scientific Committee and Conference Secretariat, allow me to extend a warm welcome to all participants of the **MMM3:** International **M**eeting on **M**angrove ecology, functioning and **M**anagement.

As a background, MMM is an international conference on mangrove ecosystems that is held every six years. Intended to be the International Meeting on Mangrove Macrobenthos, the first meeting (MMM1) was organised by Università degli Studi di Firenze (Italy) in Mombasa, Kenya from 7-11 September 2000. Six years later, a consortium including Griffith University and University of Queensland organised MMM2 in Coolangatta, Australia, from 25-30 June 2006. During MMM2, it was agreed that the scope of MMM be expanded. This led to **MMM3** which represented the first global recurrent conference on mangrove ecosystems to be held in Galle, Sri Lanka, from 2-6 July 2012.

MMM3 will have thematic sessions on Macrobenthos Studies and Plant-Animal Interactions; Plant and Vegetation Science; Nutrient Cycling, Biogeochemistry and other Environmental Drivers; People-Ecosystem Interactions; Conservation and Management; and Global Climate Change. Maintaining some identity with the objectives of MMM, Macrobenthos Studies continue to be an important theme.

Due to the hardwork and efficient planning of Prof. Dr. Farid Dahdouh-Guebas (Conference Chair), Organising Committee, Scientific Committee and Conference Secretariat, **MMM3** has some wonderful programs for all participants. Each conference day will begin with keynote addresses by prominent mangrove scientists. The conference is grateful to have Prof. Dr. Stefano Cannicci (Italy), Dr. Karen L. McKee (USA), Dr. Daniel M. Alongi (Australia) and Prof. Dr. Jurgenne Primavera (Philippines) as keynote speakers. There will be oral presentation, pitching research highlights and poster presentations.

Unique to most conferences, **MMM3** will have a Young Mangrove Scientist Brainstorm Session and a Mangrove Forest Management and Policy Brainstorm Session during the lunch break of Day 2, a Mid-Conference Excursion on Day 3, and a Scientific Debate on Day 4. There will even be a Best Student Presentation Award. Organisers of the conference are currently negotiating the publication of the **MMM3** papers as a special issue of a peer-reviewed rated scientific journal. For registered participants, a Post-Conference Workshop has been organised jointly with the Small Fishers Federation of Lanka in the Pambala-Chilaw Lagoon Complex of Pambala-Kakkapalliya. Organisers of the conference have gone to the extent of arranging Pre-Conference and Post-Conference Tours for interested participants.

Organisers and participants of **MMM3** are grateful to Inter Research Science Center (Germany), GREEN DYKE Project (Belgium/Sri Lanka), National Institute for Business Management (Sri Lanka), Small Fishers Federation of Lanka (Sri Lanka), Université Libre de Bruxelles (Belgium), University of Ruhuna (Sri Lanka), Vlaams Instituut voor de Zee (Belgium) and Vrije Universiteit Brussel (Belgium) for providing financial or material support to the conference.

On behalf of the International Society for Mangrove Ecosystems (ISME), I would like to convey my best wishes to organisers, participants and sponsors of the conference. Hope that **MMM3** will be a great success so that we can look forward to MMM4.

Prof. Shigeyuki Baba
Executive Director,
International Society for Mangrove Ecosystems
(ISME), Okinawa, Japan

Table of Contents

MMM4

PLENARY PRESENTATIONS

Functions of macrobenthos in mangrove forests: >20 years of research lessons

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Abstract

Mangroves forests can truly be considered as evolutionary hotspots where terrestrial species have re-adapted to marine life, and marine species have undergone the transition to terrestrial species. In fact, mangroves are salt tolerant trees which evolved from rainforest trees over 50 million years ago (Duke 1995; Ellison et al. 1999), unique in their adaptation to the distinct environmental requirements of the intertidal habitat (Tomlinson 1986). These intertidal forests harvest a diverse and distinctive macro-faunal assemblage mainly consisting of marine taxa which developed evolutionary trends from marine to semi-terrestrial and terrestrial life-styles, such as snails, crabs and even fish (Giomi et al. 2012; Ngo-Massou et al. 2012; Ravichandran and Wilson 2012; Vannini and Fratini 2012). As pointed out in recent reviews (Cannicci et al. 2008; Lee 2008), the relevance to mangrove functioning of these faunal assemblages has been totally reconsidered in the last 20 years. A number of recent studies indeed clarified how faunal components of both marine, brachyurans, gastropods and oligochaetes, and terrestrial origin, insects and arachnid, exert a strong influence on ecosystem functions as well as on vegetation structure of mangrove forests (Smith 1987; Smith et al. 1991; Lee 1998; Lee 1999; Kristensen and Alongi 2006; Cannicci et al. 2008; Kristensen 2008; Lee 2008).

Indeed, the evolutionary sea-land bridge represented by mangroves was mostly covered by brachyuran crabs, which evolved intertidal, supratidal and even arboreal habits (Hartnoll 1975; Jones 1984; Dahdouh-Guebas et al. 2002; Fratini et al. 2005; Vermeiren and Sheaves 2012). They literally invaded a wide range of terrestrial mangrove micro-habitats, reaching a very high number of evolutionary units, such as species complexes and cryptic species whose taxonomy and phylogenetic relationships are updated monthly and are still largely unknown (Ragionieri et al. 2009; Ragionieri et al. 2010; Silva et al. 2010; Ragionieri et al. 2012; Fratini et al. 2012). Such an astonishing diversity resulted in the occupation of several ecological niches, fundamental for mangrove ecosystem functioning (Duke et al. 2007; Mukherjee et al. 2012). The role of sesarmid crabs in mangrove structuring processes have been studied since the late 1970s and early 1980s, and the huge number of studies performed ever since on their feeding and burrowing ecology leave no doubts about the great importance of these mainly litter-feeding and burrowing crabs in structuring and functioning Old world ecosystems (Lee 1997; Lee 1998; Dahdouh-Guebas et al. 2011; Van Nedervelde et al. 2012). However, their trophic role is still a matter of debate (Skov and Hartnoll 2002; Meziane et al. 2006) and, as a consequence, their real roles in mangrove food web, litter processing and exportation and,

ultimately, on organic matter dynamics in mangroves are still controversial (Lee 2008, 2012). As an example of their importance, the difference in the standing crop biomass of mangrove forests between the Indo-west-Pacific and Atlantic-east-Pacific systems is thought to be related not only to the different richness in tree species, but also to differences in macrobenthos diversity. Although less diverse, the crab fauna of New World mangroves showed to maintain a critical role in the retention of forest products and organic matter processing, since the crabs of the genus *Ucides* have been shown to have the similar role to the Old World Sesarmidae (Nordhaus et al. 2006).

Since propagule recruitment supports natural regeneration of mangrove forests, determining in the long term the structure and functioning of mangrove ecosystems, seed, seedling and propagule predation has been considered an important factor determining seedling distribution patterns in many mangrove stands (Cannicci et al. 2008; Dahdouh-Guebas et al. 2011; Van der Stocken et al. 2012; Van Nedervelde et al. 2012; Nayar et al. 2012). Crabs are the main actors in this process, but our understanding of the strong impact of gastropods, by means of high and differential consumption of propagules, has greatly developed recently (Fratini et al. 2001; Fratini et al. 2008). At least three models have been proposed to quantify and explain the impact of crabs' propagule predation on vegetation structure of mangrove forests. The 'dominance-predation model' suggests an inverse relationship between the rate of predation of a certain species and its dominance in the forest canopy (Smith 1987), while the 'canopy-gap mediated model' hypothesizes that predation could be more intense under closed canopies than in adjacent relatively large gaps (Osborne and Smith 1990; Clarke and Kerrigan 2002). A third model, the so called 'flooding regime model' (Osborne and Smith 1990; Clarke and Myerscough 1993) considers the time available for semi-terrestrial crabs to forage due to differential aerial exposure of different inundation belts, suggesting that propagule predation may be lower in the lower intertidal than in upper belts. At present, a number of experiments trying to corroborate and/or challenge these three hypotheses are depicting a controversial scenario, whereas many studies offered new and alternative explanations (e.g. McKee 1995; McGuinness 1997; Dahdouh-Guebas et al. 1998; Sousa and Mitchell 1999; Clarke and Kerrigan 2002). Recently some authors suggested a possible 'mutual relationship' between sesarmid crabs and mangroves. Under this model, mangroves provide food and a suitable habitat for the crabs, which in turn reduce competition through propagule predation (Bosire et al. 2005; Cannicci et al. 2008). For mangroves with almost no tidal influence and a subsequent mosaic vegetation, DahdouhGuebas (2001) and Dahdouh-Guebas et al. (2011) proposed a spatio-temporal biocomplexity hypothesis that can explain the role of propagule predators in the shaping of vegetation structure, and how local hydrography and anthropogenic effects may influence the apparently natural process of propagule predation. In fact, Dahdouh-Guebas et al. (2011) illustrated how hydrography changes alter the behaviour of propagule predators and play a role in the shaping of vegetation structure by reconstructing the lagoon water level of a Sri Lankan mangrove site on the base of rainfall data over a period of 50 years. In this way, they could show the importance of spatial and temporal microhabitat variations in opening multiple successional pathways in vegetation dynamics, confirming that a chain of events, rather than the influence of localized biotic and abiotic factors, seems to lead to a particular mangrove vegetation structure or zonation.

In both New and Old world mangroves, Sesarmidae and Ocypodidae process, retain, macerate and ingest large amounts of litter and microalgal mats, contributing consistently to retention of mangrove organic matter and, according to Kristensen (2008), acting as ecosystem engineers. In fact, most species belonging to these two families actively dig and maintain burrows as a refuge from predation and environmental extremes, as well as for reproductive purposes. As shown since the classical work by Smith et al. (1991), crab burrowing activities significantly decrease ammonium and sulphide concentrations in mangrove soil, thus positively benefiting mangrove productivity (Ferreira et al. 2007). Recent studies, however, conducted in both natural and semi-natural conditions, shifted the accent on the ecosystem engineering effects of both feeding and burrowing activities of fiddler crabs (bioturbation). Kristensen and Alongi (2006) were the first to adopt the mesocosm approach to investigate the effects of *Uca vocans* activities on redox sensitive elements such as Fe and S in mangrove sediments. They proved that the continuous mixing and oxidation of surface sediment due to burrowing, feeding and walking activities of crabs caused a higher content of oxidized compounds in the upper 2 cm of soil. This resulted in an enhanced growth rate of *Avicennia marina* saplings when associated with fiddler crabs (Kristensen and Alongi 2006; Kristensen 2008). More recently, however, other mesocosm experiments carried out in East Africa, showed that the beneficial effect of *Uca* spp. activities on mangrove soil biogeochemistry can be strongly impaired by organic waste discharge. In fact, a large set of experiments aimed at understanding the effect of sewage loadings on the biology of macrofauna is now clearly showing that fiddler crabs cannot take advantage of the surplus of organic content present in sewage-polluted mangroves. On the contrary, loadings of organic waste proved to strongly affect survival, feeding behaviour and burrow morphology of fiddler crabs species, resulting in an overall reduced bioturbation action of impacted populations with respect to those of pristine areas (Bartolini et al. 2009; Cannicci et al. 2009; Penha-Lopes et al. 2009a; Penha-Lopes et al. 2009b; Penha-Lopes et al. 2010a; Penha-Lopes et al. 2010b; Bartolini et al. 2011). Crabs inhabiting at pristine conditions, in fact, achieved higher survival than those living in sewage-exposed mesocosms (Penha-Lopes et al. 2009a). Moreover, during their activity period, crabs inside contaminated mesocosms satisfied their feeding demand faster than those of the control cells and such a reduced foraging activity depressed their sediment bioturbation activity (Bartolini et al. 2009). In addition, a study aimed at investigating possible alterations in the ecosystem engineering activities of fiddler crab communities dominating the landward belts of Kenyan mangrove forests, showed how a peri-urban site hosted a higher biomass of crabs, which produced a significantly lower amount of processed sediment compared with pristine sites (Bartolini et al. 2011).

Gastropods are not doing better than crabs in sewage contaminated mesocosms, and *Terebralia palustris* ecosystem engineering activity was depressed as well. In fact, a significant decrease in mobility due to anoxic condition generated by sewage contamination leads to a 3–4 fold decrease in the amount of sediment disturbed (Penha-Lopes et al. 2010a). Furthermore, the growth rate of treated mud whelks decreased significantly with increasing sewage concentrations.
In summary, the described overall depression of macrobenthic ecological engineering activities due to domestic sewage contamination could probably cause long-term ecological implications such as eutrophication caused by benthic microalgae overgrowth and accumulation of toxic compounds (H_2S) due to scarce sediment aeration.

Growing pressures of urban developments along coastlines are strongly increasing the levels of pollution in mangroves forests and the ecological degradation due to several kinds of contaminants can be subtle and difficult to ascertain at certain levels of concentration (Cannicci et al. 2009; Fusi et al. 2012). Thus, an actual risk is to become aware too late of the degradation of mangrove systems and the crucial functions and services they provide to coastal communities.

Decapod crustaceans, gastropods and other infaunal macro-invertebrates proved to be reliable bio-indicators not only for habitat recovery assessment (e.g. Dahdouh-Guebas et al. 2012), and also for cryptic changes (Bartolini et al. 2011) acting as early-warning signals of ecological degradation. The infaunal community structure of contaminated peri-urban mangrove swamps from Kenya and Mozambique proved to differ significantly from nearby pristine mangroves of similar ecological traits. Although some differences at local scales were detected, a trend of decrease in densities of oligochaetes, molluscs and polychaetes was determined, ultimately result in a lower biodiversity in peri-urban sites than in pristine areas (Penha-Lopes et al. 2010c). Differences between peri-urban mangroves and sites not affected by sewage disposal were also investigated in terms of crabs and molluscs abundance and diversity. The results manifested a consistent decrease, especially in Kenya, in gastropod biomass, mainly due to the disappearance of the mud whelk *Terebralia palustris*, while the total biomass of crabs increased significantly at peri-urban sites both in Kenya and Mozambique (Cannicci et al. 2009). Moreover, the peri-urban mangrove systems were richer than the non-urban ones, both in terms of fiddler crabs (*Uca* spp.) which feed on benthic microalgae and bacteria, and sesarmids, such as *Perisesarma guttatum* and *Neosarmatium africanum* (= *meinerti*), which feed on both substratum and leaf litter (Cannicci et al. 2009).

Another important early bio-indicator of heavy organic loads showed to be the shrimp *Palaemon concinnus*, a very abundant inhabitant of East African mangrove creeks, as demonstrated by Penha-Lopes et al. (2011) working in Mozambique. *P. concinnus* populations from peri-urban and pristine mangrove creeks were compared in Mozambique. Surprisingly, the shrimps at the peri-urban location were larger, experienced longer reproductive periods, presented a higher proportion of ovigerous females and a better embryo quality when compared to shrimps inhabiting non-impacted locations. Physiological indices (RNA/ DNA ratio) were similar between shrimps at pristine and peri-urban mangroves. However, a higher level of parasitation by *Pseudione elongata* (Isopoda; Bopyridae) indicated some degree of stress on the host at the peri-urban mangroves, with potential effects on the host population dynamics (Penha-Lopes et al. 2011).

Taken all round, these results indicate that, in East African mangrove systems, domestic wastewater has detectable effects on crabs, molluscs and other macrobenthic taxa, suggesting their usefulness as bioindicators of its effects on the whole system. The presence of 'cryptic ecological degradation' (*sensu* Dahdouh-Guebas et al. 2005) in benthic assemblages and biogeochemical processes at the peri-urban sites indicated the need for further studies concerning the actual potential of natural mangrove forests in excess nutrients metabolization and contaminants retention (Cannicci et al. 2009).

In summary, there is no doubt about the role of macrobenthos in ecosystem functioning of mangrove forests, but macrobenthic species themselves seem to be more strongly, and earlier, impacted than trees by anthropogenic pressure. Moreover, on the stressed populations of crabs and molluscs inhabiting mangroves all over the world, a new pressure is acting, exerted by rapid climate change, through warming, acidification, hypoxia and salinisation of sea water (Rockstrom et al. 2009; Hoegh-Guldberg and Bruno 2010; Diele et al. 2012; Kochey et al. 2012). In particular, marine ectotherms are mostly affected by changes in temperature through the oxygen limitation of thermal tolerance (Pörtner and Farrell 2008) and this can generate potential cascading effects on their overall fitness. At present there are only a few information on the thermal response of mangrove ecosystem engineers (Babbini et al. 2012), and it is nearly impossible is to forecast the effects of climate warming on ecosystem functionality. Preliminary experiments on thermal tolerance of two mangrove ecosystem engineer crabs inhabiting the eulittoral fringe of East and South African mangrove forests, *Perisesarma guttatum* and *Uca urvillei*, suggest that these subtropical mangrove populations are vulnerable to long-term increases in temperature, particularly because of reduced oxygen content in water (Fusi et al. 2012). This thermal vulnerability, merged with the ongoing pressure from direct anthropogenic stress, is likely to lead to a loss of individual fitness with serious consequences for overall mangrove ecosystem functioning.

Keywords
evolutionary hotspot, macrobenthos, propagule predation, urban development, pollution, bioindicator species

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Ecological functioning of mangroves under changing climatic conditions

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Abstract

Mangrove ecosystems are subject to a range of climate change factors, including atmospheric CO_2, air and sea temperatures, precipitation, and sea-level. This presentation will review key processes whereby these external drivers may influence mangrove ecosystems. Examples from select geographic locations will be used to illustrate ways in which these drivers of change might affect mangrove structure and function.

Atmospheric CO_2: Atmospheric concentrations of carbon dioxide (CO_2) have increased from 280 ppm in pre-industrial times to 390 ppm today and are predicted to double sometime during the 21st century (Solomon et al. 2007). Increases in CO_2 concentration may alter the structure and function of mangroves, both within existing forests at tropical latitudes as well as in mixed communities where mangrove distribution overlaps with that of salt marsh at subtropical latitudes. CO_2 has a direct fertilization effect on plants by enhancing net photosynthesis and improving water use efficiency (Bazzaz 1990; Urban 2003). As CO_2 concentrations increase, CO_2 assimilation rates increase due to greater carboxylation efficiency of Rubisco, the enzyme that catalyzes the initial fixation of CO_2. At higher concentrations of CO_2, plants also decrease stomatal openings, thereby reducing loss of water. For C-3 species, the rate of CO_2 assimilation is increased up to a saturation concentration of about 1000 ppm CO_2. C-4 species are typically less responsive to elevated CO_2 concentration because they already possess a CO_2-concentrating mechanism at the site of assimilation. Most mangroves are C-3 species and are potentially responsive to elevated CO_2. Relatively few studies, however, have examined how mangroves respond to higher than ambient CO_2 concentration (Ball and Munns 1992; Farnsworth et al. 1996; Ball et al. 1997; McKee and Rooth 2008). Even fewer studies have investigated how other factors such as competition may modify species responses to CO_2. A change in the relative competitive ability of mangrove species may influence future range distributions at global, regional, and local scales. One study examined elevated CO_2 effects on the black mangrove, *Avicennia germinans*, which occurs at its northernmost limit in the Mississippi River Delta, USA. Seedlings of *A. germinans* responded to higher CO_2 with increased growth when grown alone, but its growth was strongly suppressed when grown in mixture with the C-4 grass, *Spartina alterniflora* (McKee and Rooth 2008). Elevated CO_2 thus had no detectable effect on *A. germinans* when grown in combination with a strong competitor for nitrogen. Fertilization with nitrogen altered tissue chemistry of mangrove seedlings transplanted to the field and led to higher mortality due to crab herbivory (McKee and Rooth 2008). These findings suggest that biological interactions such as competition and herbivory could modify the potential effects of higher CO_2 on *A. germinans* in this particular setting. Predictions of effects of atmospheric CO_2 on mangroves at a global scale, however, are difficult to make due to limited data. Because such studies are technically challenging and expensive, predictions about future response to rising CO_2 will likely depend on modeling approaches. However, it's clear, based on the work conducted so far, that models predicting an increase in abundance of C-3 mangroves in mixed communities are too simplistic. Factors such as

competition and herbivory, as well as environmental stress factors such as flooding and salinity, must be understood and incorporated to develop more complex models.

Climate Change: Global temperature has risen almost 1 °C in this century and is projected to increase from 1.1 to 6.4 °C in the 21st century (Solomon et al. 2007). Global warming will pose many threats and benefits for mangrove ecosystems (Saint-Paul, 2012; Bosire et al. 2012; Record et al. 2012). Warmer temperatures will extend the latitudinal range of mangroves, which are restricted to the tropics and subtropics (Di Nitto et al. 2012). Mangroves already appear to be expanding their range, such as on the Atlantic US coast (Zomlefer et al. 2006) and the east coast of Australia (Wilson 2009), and this expansion corresponds to the poleward extension of temperature zones during recent decades (Hennessey et al. 2004). Latitudinal expansion, however, may be inhibited by barriers to dispersal in some locations, e.g., *A. marina* in Australia and New Zealand (de Lange and de Lange 1994). Changes in temperature may also influence mangrove productivity and phenology, especially at subtropical latitudes. Higher temperatures can alter the photosynthetic efficiency of mangroves, improving it in colder climates but causing declines in net CO_2 assimilation in warmer climates as leaf temperatures exceed an optimum level (Cheeseman 2004; Okimoto et al. 2007). The timing of leaf emergence and success of reproduction may also change with climate warming (Gilman et al. 2008), but this may depend on species-specific characteristics (Wilson 2009). Mangrove physiology and phenology will also be affected by changes in precipitation patterns driven by global warming. Climate models predict increased precipitation at equatorial latitudes, but decreased precipitation at subtropical latitudes, with more frequent summer droughts (Solomon et al. 2007). Extreme events, such as droughts, are likely to have a much greater effect on mangroves than gradual changes in average conditions. Such has been the case in the Mississippi River Delta, USA, where a combination of drought, low sea level, and low river outflow led to wide-spread dieback of the salt marsh dominant, *S. alterniflora* in 2000 (McKee et al. 2004). More drought-tolerant species, such as *A. germinans* and *J. roemerianus* (black needlerush) were unaffected. This event, and the absence of killing freezes during this same time interval, created opportunities for rapid expansion of *A. germinans*. In this case, the extreme weather event was beneficial for mangrove expansion, but this outcome may not be the case for other mangrove species with different physiologies and sensitivities to drought, hypersalinity, and other stressful conditions associated with a decrease in precipitation. Those mangroves predominating in high rainfall environments may be negatively affected by climate extremes that reduce freshwater input and increase salinity, e.g., Micronesia (Drexler and Ewel 2001; Krauss et al. 2007). Mangroves may be particularly vulnerable to climate change in areas where human activities have modified freshwater inflow or tidal exchange.

Rising Sea-Level: Habitat stability of mangroves in relation to sea-level rise is dependent in part on a feedback relationship between hydro-edaphic conditions and the plant community. Tides, currents, and storms transport sediment that contributes to soil elevations through surface accretion. Rates of mineral sedimentation may be altered as sea-level rise accelerates and storm intensity and frequency increase under global warming. Rising sea level also alters flooding and salinity regimes, which in turn influence plant production and decomposition of organic matter. Water movement brings in nutrients and flushes out phytotoxins, actions that influence the productivity of the plant community. Primary producers trap sediment and contribute directly to soil volume through accumulation of organic matter. The atmospheric concentration of CO_2 is the underlying driver of global warming and sea-level rise, but has a direct fertilization effect on plants, as discussed above. The feedback relationship between biotic and abiotic components allows the system to self-adjust soil elevations to prevailing water levels and, consequently, to keep pace with rising sea level (McKee et al. 2007; Krauss et al. 2010; Lovelock et al. 2011; McKee 2011; Khan 2012). If the hydrodynamic setting or other factors affecting production-decomposition processes change, then the ability of the plant community to stabilize the soil and maintain surface elevations relative to water levels will be altered. Historically, the emphasis has been on physical processes such as mineral sedimentation/erosion (Ellison 1993; Parkinson et al. 1994; Cahoon and Lynch 1997; Rogers et al. 2006) or shrink-swell movement due to water flux (Whelan et al. 2005; Rogers and Saintilan 2008) to assess the capacity of mangroves to maintain surface elevations within the intertidal plane. More recent work, however, has shown how biotic processes can directly and indirectly influence elevation dynamics (Cahoon et al. 2003; Krauss et al. 2003; Cahoon et al. 2006; McKee et al. 2007; McKee 2011). Although mineral sedimentation may be affected by vegetation characteristics, biotic processes that contribute directly to soil volume have the greatest potential to influence vertical accretion and elevation change (McKee 2011). These biological processes can be divided into surface and subsurface processes. Surface processes include accumulation of decaying organic matter such as leaf litter or formation of living benthic mats (e.g., microbial, algal, or root matter), which contribute to vertical accretion. Subsurface processes such as root production, root mortality, and decomposition influence soil volume, either contributing to expansion or to subsidence. Although the soil binding capacity of plant roots in coastal systems has been recognized for some time (Scoffin 1970; Spenceley 1977), their role in soil elevation change has only recently been experimentally demonstrated (McKee et al. 2007; Cherry et al. 2009; Langley et al. 2009; McKee 2011). Experimental manipulation of nutrients (nitrogen and phosphorus) in a Belize mangrove forest, for example, altered elevation change rates and patterns through changes in root matter accumulation (McKee et al. 2007). In this mangrove system, subsurface movement indicated expansion where root production was high and subsidence where it was low. Both surface and subsurface land movements must be considered in relation to sea-level trends to assess risk of submergence. In addition, regional variation in sea-level trends and geophysical phenomena must also be included in such assessments. For example, mean sea-level trends based on satellite altimetry shows hotspots with rise rates up to three times higher than the global average, e.g., in the western Pacific (Cazenave and Llovel 2010). A combination of high subsidence and high regional SLR would substantially increase vulnerability of mangroves in such regions. Establishment of a global network of mangrove sites where soil elevation dynamics can be monitored and compared would greatly contribute to a better understanding of how these systems may respond to future sea-level rise (Sharma 2012).

In summary, changes in atmospheric CO_2 concentration, climate, and sea level will lead to complex interactions affecting the structure and function of mangroves (Azad and Matin 2012; Khan 2012). Much of our understanding, however, is based on limited data and observational studies of mangrove flora. Less is known about impacts to fauna and ecosystem-level processes, but changes in the mangrove community will have consequences for dependent fauna as well as for ecosystem functioning. Predicting such effects is problematic, however, since the drivers of change may have contrasting effects on primary production, nutrient cycling, or food-web support. Future progress will be aided by multivariate approaches that allow simultaneous examination of multiple drivers of change along with internal feedback pathways and linkages among physical and biological components.

Keywords
coastline, greenhouse gas, intertidal, land building, swamp, vegetation shift, wetland

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A lifetime of mangrove research, management and advocacy

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Abstract

Apart from a decade of undergraduate teaching, my professional life has been directly or tangentially devoted to mangrove issues. Strife in my native Mindanao pushed my family and me to the peace and quiet of Panay Is. in central Philippines and to research on marine shrimp, the commercial superstars of the mangrove macrobenthos. My early focus was on broodstock development, larval rearing and pond grow-out of penaeids, mainly the mangrove-associated giant tiger prawn *Penaeus monodon* and the white shrimp *P. indicus*: Because brackishwater ponds are the dominant aquaculture system in the Philippines, species whose rearing requirements mimic the estuarine habitat, e.g., fluctuating salinity levels, have become the crops of choice. Published papers from this period include a classification of *P. monodon* egg quality types (Fig. 1: Primavera and Posadas 1981) which allows hatchery technicians to predict larval numbers and the corresponding tank water volume to prepare.

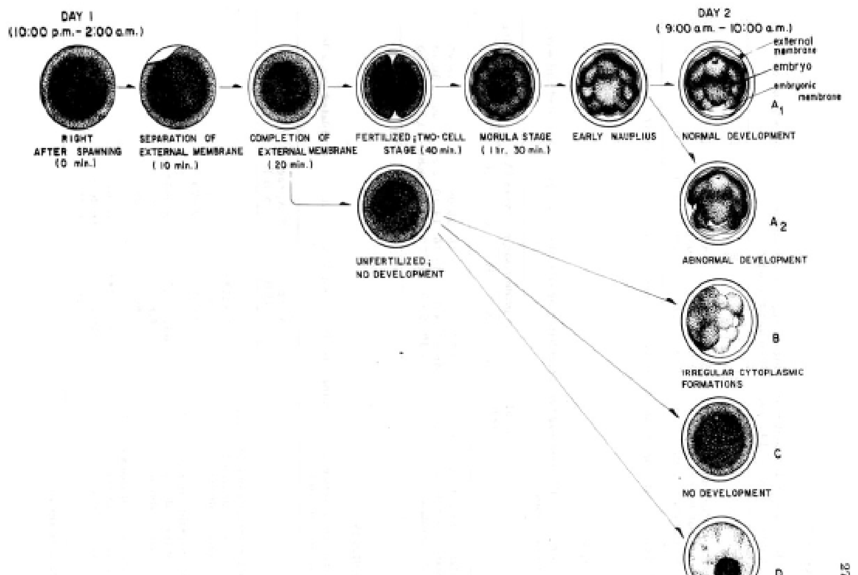

Fig. 1. Development of different egg types of *Penaeus monodon* from immediate post-spawning (between 10:00 p.m. and 2:00 a.m.) to the following morning (9:00 to 10:00 a.m.).

It was during visits to these coastal ponds that I first saw mangroves from an environmental perspective – as the former life of endless hectares of aquaculture ponds in the country (Primavera 1993, 1996, 2000a). With initially reported negative ecological and socio-economic impacts of unplanned aquaculture, including mangrove conversion to ponds (Primavera 1997b, 2006, spreading beyond Philippine shores, I joined international colleagues in reporting these in *Science* (Naylor et al. 1998) and *Nature* (Naylor et al. 2000: Fig. 2).

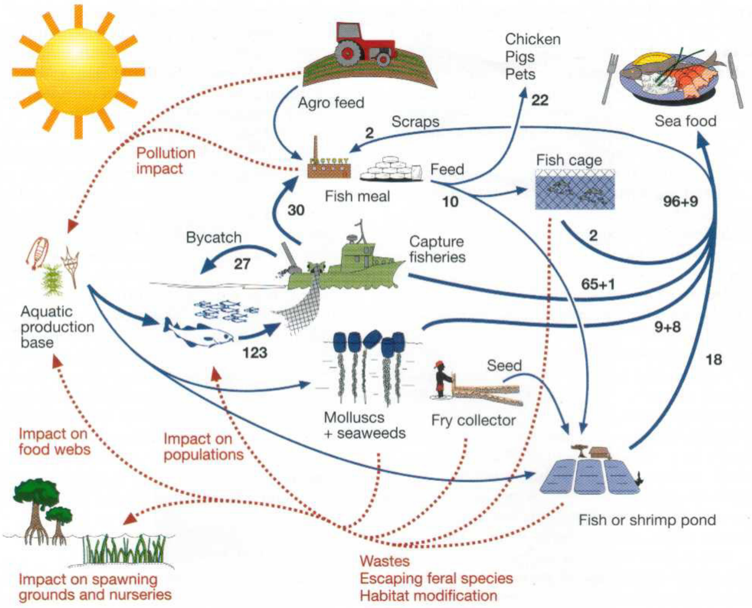

Fig. 2

My studies then shifted from applied (prawn culture) to basic research (prawn biology), such as the use of mangrove structures by juvenile shrimp for shelter as reflected in diel activity patterns (Figs. 3a, b show the original graph in Primavera and Lebata (2000) and its cartoonized form, respectively) for a doctoral thesis on the Role of Mangroves as Prawn Nurseries at the University of the Philippines (Primavera 1996, 1997a, 1998; Primavera and Lebata 1995). These pieces of information have contributed to a poster on the Life Cycle of *Penaeus monodon* (Fig. 4).

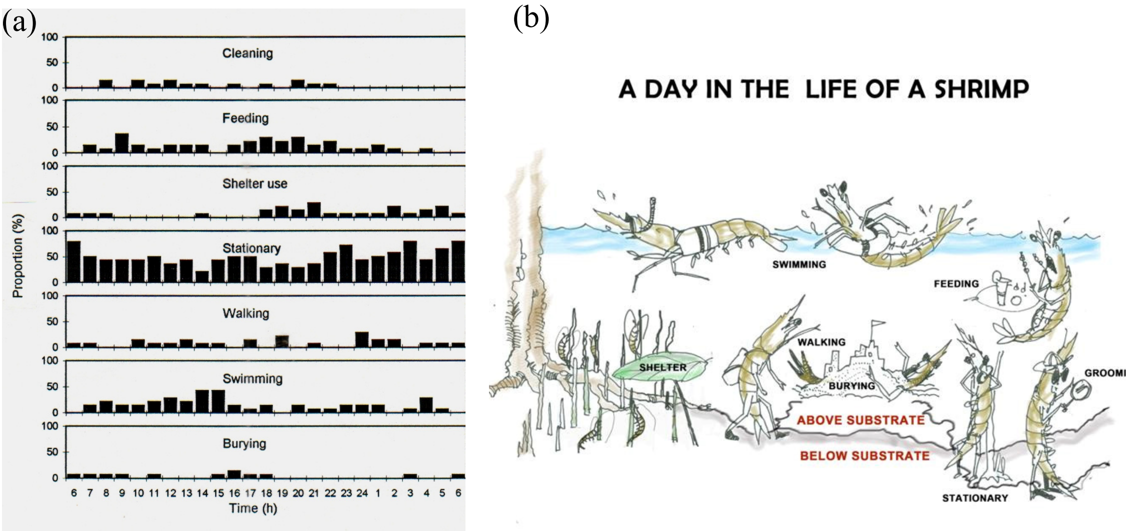

Fig. 3

Before retirement from active research, I looked at the possibility of integrating mangroves and aquaculture (Primavera 2000b) as an alternative to the pro-aquaculture policy of the Philippine government that led to massive clearcutting of mangroves in the 1950s-1970s. Sustainable aquaculture requires 4 hectares of mangroves for every hectare of pond (Saenger et al. 1983). Yet only ~256,000 ha (Long and Giri 2011) of Philippine mangroves remain while culture ponds have increased to ~232,000 ha, giving a little over a 1: 1 mangrove-pond ratio. However, integrating ponds and mangroves is easier said than done. Mangrove-friendly aquaculture, also called Aquasilviculture, combines cultured crops with mangrove trees either in the same stand, or in separate ponds. Whereas mangroves need the regular ebb and flooding of sea water, aquatic species like shrimp and fish require a permanent water column, therefore their requirements are incompatible. Only the mud crab *Scylla*, a member of the macrobenthos which can withstand low tide exposure, can be farmed alongside mangroves in netpen enclosures – provided the trees are fully grown, as crabs like to consume the tender leaves of young plants (Primavera et al. 2009).

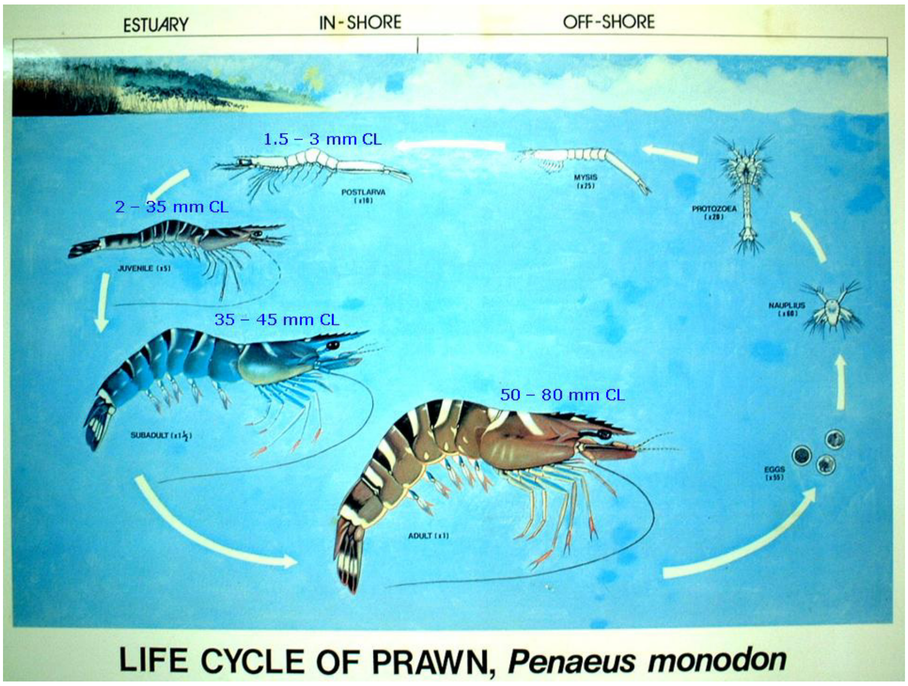

Fig. 4

Mangrove: Shrimp/Fish Pond Ratios (Primavera, 2007)

Mangrove: Pond Ratio	Function	References
8.9:1 7.8:1	N filter: intensive shrimp culture P filter: intensive shrimp culture	Boonsong & Eiumnoh, 1995
7.2:1 21.7:1	N filter: intensive shrimp culture P filter: intensive shrimp culture	Robertson & Phillips, 1995
2.4:1 2.8:1	N filter: semi-intensive shrimp culture P filter: semi-intensive shrimp culture	Robertson & Phillips, 1995
6.4:1	N filter: semi-intensive shrimp culture	Kautsky et al., 1997
5.4-8.2:1	N filter: intensive shrimp culture	Primavera et al., 2007
1.8-2.7:1	N filter: semi-intensive shrimp culture	Primavera et al., 2007
4:1	**Ecosystem health**	**Saenger et al., 1983**
7.4:1	Philippines: 450,000 ha mangroves **(1920)** 60,998 ha ponds **(1940)**	Primavera, 2000
0.5-1:1	Philippines: 120,000-247,360 ha mang. + **(1994)** 232,000 ha ponds	Primavera, 2000; NAMRIA, 2003

The other Aquasilviculture model features mangroves as biofilters for adjacent but separate intensive shrimp/fish ponds, requiring 2-8 hectares and up to 20 hectares, respectively, of mangroves to process the nitrogen and phosphorus effluents produced by one hectare of pond (Primavera et al. 2007). These ratios are even higher than the 4:1 ratio earlier recommended for aquaculture sustainability and environmental health (Table 1).

My mangrove advocacy started in the 1990s, but a complete crossover from research to the environmental NGO community came only after 2000. This was made possible by generous grants from a Pew Fellowship in Marine Conservation (2004) and the Zoological Society of London for the Community-based Mangrove Rehabilitation Project or ZSL-CMRP (2009). In support of mangrove conservation through formal education and local governance, the Pew grant produced instructional mangrove modules for the primary and secondary school levels, and constructed three footwalks in collaboration with local governments in Panay Is. Taking off from the Pew gains, the CMRP expanded coverage to seven towns and shifted focus from local officials to local communities as *de facto* managers of mangroves. The CMRP aimed to increase coastal protection and improve livelihoods through rehabilitation of mangrove greenbelts, reversion of abandoned fish/shrimp ponds, and protection of remaining forest stands. Over four years, it has organized the rearing of 43,400 seedlings of a dozen mangrove species in community nurseries, planted 90,500 mangrove seedlings/saplings in seafront sites and abandoned ponds; facilitated the establishment of two mangrove ecoparks (managed by fisherfolk cooperatives); and produced various information-education-communication materials, e.g., tidal calendars, mangrove manuals, planting guides, leaflets on mangrove laws, videos (Fig. 5: Primavera 2009a, b).

These various rehabilitation, conservation and other mangrove initiatives have been science-based, with adjustments made in consideration of socio-economic realities. For example, natural regeneration is the ecologically correct way to restore abandoned ponds to mangroves, but it takes all of 15-20 years, a luxury of time the Philippines can scarcely afford. Adding to the urgency of environmental rehabilitation is Climate Change that will increase the frequency and severity of the country's yearly quota of 20 typhoons and accelerate sea level rise in many parts of the archipelago.

Fig. 5

Another challenge is restoring the present 1:1 mangrove-pond ratio to 4:1, for ecosystem health and aquaculture sustainability. Past mangrove rehabilitation programs focused on open access, noncontroversial but biophysically suboptimal seafront sites which yield low survival (Primavera 2005). Rather than such problematic seafronts, the best bet to increase mangrove area is by reverting tens of thousands of hectares of abandoned ponds (Primavera and Esteban 2008). Though a socio-political minefield due to tenurial issues, these ponds are the ecologically correct sites for rehabilitation as they were former mangrove forests (Fig. 6) -- planting by ecology, not by convenience.

Other examples of science-based protocols are paradigm shifts from established practices in seafront planting – site selection during neap tide (rather than spring tide), planting in a seaward direction from the beach (rather than landward from the lower intertidal margin), installation of protective barriers, and harvesting excess wildings for nursery rearing.

Much of the knowledge to inform and guide mangrove management (including the contentious debate on aquaculture vs mangrove conservation) is already available, mainly in scientific journals, conference proceedings, and gray literature, but inaccessible to decision-makers and the general public. My career has been devoted to the packaging and dissemination of such information through the products of my Pew and ZSL grants, as well as invited lectures and seminar-workshops for coastal communities, civil society organizations, local government officials, scientific and academic groups, and other stakeholders.

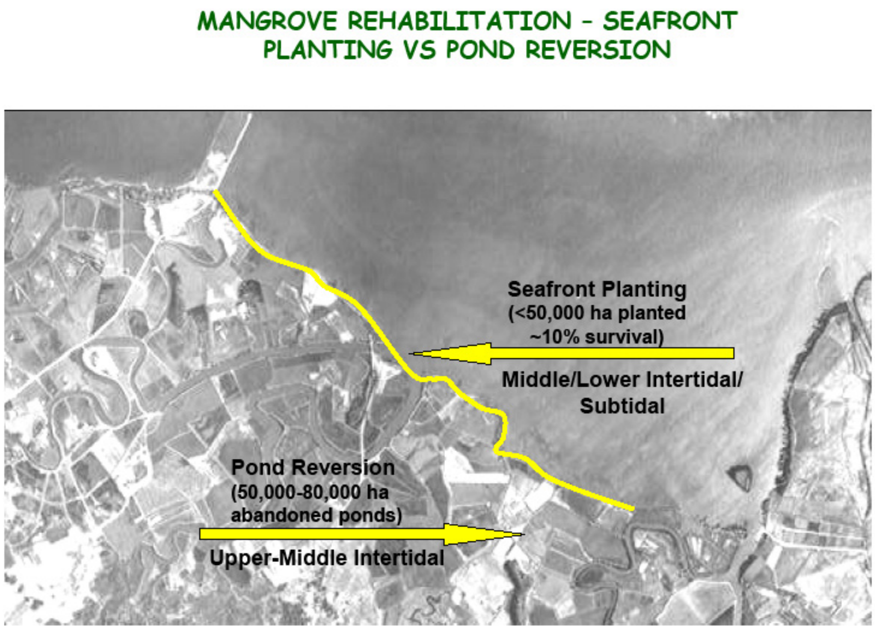

Fig. 6

Nevertheless, a great deal remains to be studied and the following MMM3 presentations are relevant to mangrove rehabilitation and conservation efforts:

i. Mangrove restoration/recovery/regeneration by Nehru and Balasubramanian (2012), Mohamed et al. (2012), Balaji (2012), Dahdouh-Guebas et al. (2012a), Reis-Neto et al. (2012), and Sakaya and Khalid (2012)
ii. Mangrove plantations by Wilson et al. (2012), Alcaria and Bagalihog (2012), Asaeda et al. (2012), Dahdouh-Guebas et al. (2012b), and Gevaña et al. (2012)
iii. Biophysical factors and seedling survival by Abu Hena et al. (2012), Balke et al. (2012), M'rabu et al. (2012a, b), and Ravikamar (2012)

iv. Socio-economics including ecotourism and MPAs by Kathiresan et al. (2012), Mwakha et al. (2012), Rajendran and Kathiresan (2012), Siddique (2012), and Thakur and Yeragi (2012).

Keywords
mangrove macrobenthos, aquasilviculture, community-based mangrove rehabilitation, NGO, sustainable management

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ORGANIZER'S PRESENTATION

Meeting on Mangrove ecology, functioning and Management (MMM3): more than two decades of insight on mangrove research in Kenya, Sri Lanka and beyond

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Abstract

The conference **MMM3**: International Meeting on Mangrove ecology, functioning and Management is jointly organized by the Vrije Universiteit Brussel (VUB), the Université Libre de Bruxelles (ULB), the University of Ruhuna (UoR) and the Kenya Marine and Fisheries Research Institute (KMFRI), and organized by the authors, in the premises of the University of Ruhuna in Galle, Sri Lanka (2-6 July 2012).

After a first edition in 2000 in Mombasa, Kenya (MMM1) and a second edition in Coolangatta, Australia in 2006 (MMM2), this third edition continues what has now become the first and only recurrent international conference on mangrove ecosystems in the world. It is organized every 6 years by mangrove scientists and offers plenty of time for interaction during and in between the single sessions composed of keynote addresses, oral presentations, oral pitching research highlights, junior and senior researcher and mangrove manager debates, poster sessions and excursions. The topics covered range from macrobenthos (incl. plant-animal interactions) which was the historical emphasis of the MMM Conferences, over plant, vegetation and systems ecology, and nutrient cycling, biogeochemistry and other environmental drivers, to carbon sequestration, stocks and payments for ecological services, climate change and people-ecosystem interactions, conservation and of course management. These issues will be further discussed during the mid-week MMM3 Workshop (9-13 July 2012) in the Pambala-Chilaw Lagoon complex (Sri Lanka) at the premises of the Small Fishers Federation of Lanka in Pambala-Kakkapalliya, with the objective of identifying research gaps through joint-fieldwork, analyses and brainstorming.

As the organizers of MMM3 we have the privilege to work with some of the finest mangroves scientists in the world, many of whom are participating in MMM3, and to contribute to the understanding of mangrove ecosystems in Mexico, Jamaica, the French Antilles, Surinam, Brazil, Mauritania, Gambia, Cameroon, Mozambique, Tanzania, Kenya, India, Sri Lanka, Malaysia, Vietnam, China and Australia. Though the MMM conferences are moments in time, in fact they reflect a continuous process of collaborating network nodes. However, most of the authors' work was carried out in Kenya and Sri Lanka with the institutional collaboration reflected by the present authorship and leading to >150 peer-reviewed papers.

Research topics covered in Kenya in general, and in Gazi Bay, in particular - the latter probably one of the most intensively studied mangrove sites in the world,- are focused on plant and animal assemblages and on restoration ecology (incl. aspect of carbon

sequestration). However, a wide range of papers are available ranging from physiology to hydrodynamics and from socio-ecology to animal behaviour. In Sri Lanka mangrove research has focused on plant science, vegetation dynamics and biogeochemical cycles. Overarching issues which have been at the focus of the authors' interest in all research sites were technical and methodological on the one side (such as remote sensing strategies) or societal (such as livelihood, dependence of local communities) on the other side.

This organizer presentation makes an attempt at summarizing research results from more than 2 decades (roughly from 1990 onwards) in order to show which is the current state of understanding in the functioning of mangroves, and in order to identify knowledge gaps. This is particularly important in the light of the global degradation of mangroves under increasing anthropogenic pressure and climate change impacts.

Keywords
MMM3, restoration ecology, physiology, hydrodynamics, socio-ecology, animal behaviour

ORAL AND POSTER PRESENTATIONS

Studies on Sulphate reducing bacteria from Southeast coast of India

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Abstract

A striking feature in mangroves ecosystem is a large anaerobic substratum enriched with anaerobic microorganisms predominantly sulphate reducing bacteria. However, research studies on the role of sulphate reducing bacteria in the functioning of mangrove ecosystem are only scanty. Therefore the present work was undertaken to study occurrence and distribution of sulphate reducing bacteria in luxuriant or degrading mangroves at 10 different sediment depths for four seasons. Sediment soil samples were collected from Pichavaram mangrove forest situated along the southeast coast of India and inoculated in specific Postgate's B liquid medium, prepared completely in anaerobic condition. The sulphate reducing bacteria were enumerated by serial dilution method, after incubation up to 2 to 3 weeks. The results revealed that the sulphate reducing bacterial counts started increasing from 30 cm depth; the counts were higher during post monsoon and summer and lower in pre-monsoon and monsoon. The bacterial counts were higher in luxuriant mangroves than that in degrading stands. The role of sulphate reducing bacteria in mangrove functioning is discussed. The presence of sulphides is a characteristic feature of mangrove sediments and it influences the distribution of mangroves. Tolerance to sulphides varies with mangrove species.

Keywords
sulphate reducing bacteria, ecosystem function, seasonal influence

Mangrove fisheries and livelihoods

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Abstract

This study was conducted to observe the linkage between the coastal mangrove fisheries and livelihoods issues in the coastal district of Cox's Bazar Bangladesh. Studies found that mangrove forest are important in terms of ecosystem service and fishery diversity in the study area. Fishing within the mangrove forest is one of the prime activities in this coastal area while several species of fishes are found. Increases in water quality and other environmental parameters are influenced highly on the fisheries diversity as well as livelihoods security in the study area. In recent years, the dependency on coastal forests and its fishery resources has increased substantially which lead overexploitation of the resources and resulted in degradation of coastal ecosystems including water quality. The highest fisheries diversity was found in pre-monsoon when water quality remains good in condition and stays stable for a month, and then gradually decreased in monsoon and post-monsoon while water quality was comparatively poor. The coastal dwellers have moderate knowledge on water resource management, notwithstanding the forests are exploited unwisely for house hold uses due to poor economy and livelihoods. Studies suggest that good governance on the coastal forest and water quality issues is required at Cox's Bazar which would ensure the livelihoods security of the coastal poor dwellers.

Keywords
ecosystem function, fisheries, livelihood, Bangladesh

Macro-algae in Lawas mangroves, Sarawak, Malaysia: ecosystem functions and economic aspects

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Abstract

Mangrove macro-algae grow epiphytically on pneumatophores, prop roots and stems in the brackish and marine water environment. They are unique to certain mangrove habitats and an understanding of their abundance may indicate the health of mangrove ecosystems. The macro-algae of Lawas mangrove forests are mainly *Bostrychia* spp. followed *Caloglossa* spp., *Enteromorpha* spp., *Catenella* sp. and *Rhizoclonium* sp. The dominate species of mangrove was *Rhizophora* sp. followed by *Ceriops* sp., *Lumnitzera* spp. and *Avicennia alba* in Lawas mangrove forest at Miri, Sarawak. The biomass of macro-algae was 34.16 mg/DW/cm^2 for prop roots surface area of *Rhizophora* sp. and 1.30 mg/DW/cm^2 for pneumatophores surface area of *Avicennia alba* which is comparable with other studies elsewhere. In the past, several studies found that the algal mats associated with mangroves represent a major source of primary producers, energy source in food web, carbon storage, habitat for small invertebrates, sediment trappers and nitrogen fixers. However, in recent years the macro-algae from mangrove habitat have been tested for potential use for volatile constituents and antibiotic activities, bio-indicators of contamination and bio-monitors of metal contamination in estuarine ecosystems. Considering the above factors, the epiphytic macro-algal diversity in this pristine mangrove area of Sarawak could be a biodiversity "hotspot" for marine ranching, examining of marine ecosystem functions and biotechnology potentiality which is being discussed in this paper.

Keywords
mangrove algae, ecosystem function, economic importance, Sarawak, Malaysia

Energy resources of the Sundarbans mangrove ecosystem

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Abstract

The Sundarbans, the largest natural mangrove expanse, is the foremost energy resource producing reserve forest in Bangladesh. Apart from documented fuelwood production (ca. 18 % of the country), a large amount of energy resources are extracted informally and remains unaccounted for. The study is carried out to assess the overall energy support provided by this unique ecosystem. Following a comprehensive literature review, questionnaire survey with relevant stakeholders' was carried out. The survey addressed the following major criteria – (i) the energy resource use pattern within the Sundarbans by the resource collectors and (ii) the SRF based energy resource used in the households and small enterprises in the impact zone (peripheral area along Sundarbans Reserve Forests, SRF). We adopted stratified random sampling with quota allocation to select respondents for survey of households and SRF resource collectors while purposively sampled respondents among enterprises and forest managers. The study revealed that 100% households in the Impact zone are fully or partially dependent on the SRF energy resources. There is significant difference in species wise use within the Sundarbans, at the households and the enterprises. *Ceriops decandra* is the most widely extracted fuel wood species, followed by *Hibiscus tiliaceus*, *Cynometra ramiflora*, *Phoenix paludosa* and *Heritiera fomes*. However, the total energy resources from the Sundarbans are estimated to be 16340 mt of which 12634 mt are recorded while 3706 mt (22.68%) are of informal use. This energy support helps avoiding use of about 119939 mt CO_2eq of fossil fuel. However, value addition to these resources, such as charcoal production from *Ceriops decandra*, can enhance energy provision potential from the mangrove ecosystems. Again, there is immense pressure on these energy resources as alternative energy resources in the adjacent area are very scarce. Reflection on socio-economic context should be incorporated into management planning of these resources to ensure sustainability.

Keywords
energy resources, Sundarbans, fossil fuel

The status of mangrove plantation in San Fernando, Cebu: a case study

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Abstract

The study was conducted in a 14-year old bakauan-bangkau (*Rhizophora stylosa*) plantation in San Isidro, San Fernando, Cebu. The study aimed to assess the ecological and sociological effects of mangrove reforestation established in the area. Interviews were conducted to the plantations owners and fishers through Focus Group Discussion (FGD) and Strip method was used in assessing the mangrove plantation by establishing three sampling plots in two different stand ages. The results showed that the plantation with spacing of 0.5mx0.5m has a density of 33,833 trees per hectare and 9,433 trees in 1 m x 1 m spacing. The stand has an average height and diameter of 5.70 m and 5.39 cm; and 3.65 m and 4.00 cm for stand with a spacing of 1 m x 1 m and 0.5 m x 0.5 m spacing, respectively. In terms of regeneration, plantation with 0.5 m x 0.5 m spacing have adequate regeneration with an average of 11,666 regenerants/ ha compared to 1 m x 1 m with average of 11,333 regenerants/ ha. Epibenthic fauna identified in the mangrove floor and periphery showed a total of 21 individuals belonging to four species of gastropods and a pair of clam. Samples obtained from exposed area outside the plantations recorded 51 individuals belonging to nine species. Associated flora identified adjacent to the plantations included algal species of *Ulva reticulata*, *Galaxaura oblongata*, *Amphiroa* sp., *Gracilaria* sp., and *Sargassum* sp. The avi- fauna observed in the site included birds like kingfishers, egrets, black shama and other shore bird species. Mammals like fruit bats and some crustaceans (shrimps and crab) and mollusk species reportedly found in the area. Benefits claimed by the owners of the bakauan plantations are the increase population of birds, catch of fishes, crabs and mollusk. They also reported sales of propagules from their plantation of about ₱2,000 – ₱7,000. Visitors and guests that are frequenting the area are mostly students from different schools in the nearest municipalities and some colleges and universities in Cebu City. The findings of the study has led to a conclusion that the growth (diameter and height) including regenerants of the 14-year-old bakauan-bangkau plantations have not been affected by the two different spacing used by the planters. Species diversity and population has increased and aesthetic and educational benefits were among the non-monitory benefits mentioned by other planters. A sense of fulfillment was felt having transformed the area from bare to greenery.

Keywords
mangrove plantation, spacing, propogules, fauna

Canopy gaps and the natural regeneration of Matang mangroves

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Abstract

Canopy opening or gap creation by lightning strike is an important form of exogenous disturbance in the mangroves of Matang in Malaysia. The almost circular shaped canopy gaps consist of a group of standing dead trees which decay simultaneously with the growth of new trees. This characteristic is chiefly different with terrestrial forests where canopy gaps are normally created by tree-falls. Lightning strike disturbance in mangroves has created a means for natural regeneration whereby dormant seedlings growing underneath the canopies have had the opportunity to progress and ultimately replacing the canopies of the dead trees. Historical and recent aerial photographs of the Virgin Jungle Reserve of Pulau Kecil in Matang were analyzed to measure gap turnover rate and to calculate canopy turnover. The average (±SD) canopy turnover is 25.5 ± 6.9 years. This finding shows that the continuous dynamics of gap creation and closure have sustainably maintained the condition of the forest. The finding also supports the hypothesis that this disturbance prevents mangroves from reaching more senescent stage, thus, canopy gap creations are justified to be the key driver in the natural regeneration of the tropical *Rhizophora*-dominated mangroves. Curiously compared, the average turnover is almost similar to the existing 30-year rotation cycle system adopted by the Forestry Department for the management of forest compartments in Matang.

Keywords
canopy turnover, canopy gap regeneration, lightning strike disturbance, Matang

Effects of mono-specific plantation of *Rhizophora stylosa* on the mangrove community

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Abstract

The effect of plantation on mangrove communities was studied at the central Philippines. Mangrove species composition and their morphology were investigated both at planted and at natural stands in Olango and Banacon islands. In mono-specific plantations, *Rhizophora stylosa* has been ardently planted for 60 years for surge protection and for fuels. *R. stylosa* was chosen due to the ease of establishment of the species.
At natural stands, the main species at the most outer edge was *Sonneratia alba*, followed by *Avicennia marina* dominating stand in the behind. The density of these stands was relatively scarce, leaving an ample room for the colonization of other species. At planted areas, on the other hand, almost the entire population was composed of *R. stylosa* with same age. Due to dense plantation and higher survival rate of seedlings, trees grew densely in comparison with natural stands of *R. stylosa*, tangling proproots among individuals. It was observed that following introduction in natural stands, *R. stylosa* occupies free space between trees and leave no room for propagation and extension of *S. alba* or *A. marina*. *R. stylosa* also interrupts the use solar radiation by other species and alters the pattern of current and sedimentation. Besides, seeds of planted *R. stylosa* spread by the current of relatively deep water, invade into the natural stands of other species. The morphology of individual *R. stylosa* was substantially affected at dense population, where they were taller and thinner. It seems, therefore, that the mono-specific plantation of *R. stylosa* extremely deteriorates species richness and variety of age distribution.

Keywords
mangrove plantation, *Rhizophora stylosa*, biodiversity, species composition, *Sonneratia alba*

Prediction on recovery pathways of the cyclone-disturbed mangroves in the Ayeyarwady Delta, Myanmar

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Abstract

This study aimed to predict the recovery potential of community-level mangroves after natural disturbance, called Cyclone Nargis, that attacked the Ayeyarwady mangroves in 2nd May, 2008. Firstly, the sprouting abilities of 1662 individuals representing 13 mangrove species were explored. *Avicennia officinalis* showed the highest number of epicomic sprouts per stem, followed by *Sonneratia apetala*, *Heritiera fomes* and *Sonneratia caseolaris* whereas most of the Rhizophoraceae species had limited ability to reproduce vegetative sprouts. Then, three mangrove communities widely observed in the study area were selected, and each was dominated by either *Rhizophora apiculata, Avicennia officinalis, or Heritiera fomes.* Permanent plots were set up for them in order to conduct long-term observation since the cyclone disturbance. The life-history stages of all individuals have been monitored yearly so as to understand their recovery pathways. It was observed that the mortality of *A. officinalis* and *H. fomes* trees after the cyclone disturbance was less than 10 %, whereas that of *R. apiculata* trees was more than 90 %. Based on the results analyzed by the stage-structured population model, the predicted trends of *H. fomes* and *A. officinalis* dominated communities showed increasing whereas that of *R. apiculata* was observed decreasing. The effect of Cyclone Nargis, therefore, differed significantly on the types of mangrove communities, and consequently their recovery pathways were also differently observed. Given management intervention is taken into account, the *R. apiculata* community was demonstrated to be highly vulnerable to the cyclone disturbance, and so should be prioritized for restoration.

Keywords
storm, impact, resilience, trajectory, rehabilitation

Climate change and change in species composition in the Sundarbans mangrove forest, Bangladesh

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Abstract

Sundarbans is the largest unit mangrove forest in the world. It is located in the south west part of Bangladesh in the estuary of river Ganges covering 436,570 ha of land (3.2% of the global mangrove forest). The mangroves are considered for production and protective roles for the local communities and areas. Species compositions of Sundarbans vary throughout the mangrove areas. *Ceriops decandra*, *C. decandra – Excoecaria agallocha* and, *E. agallocha* and *Heritiera fomes* associations cover more areas of mangrove of the Sundarbans. It produces 45% of the total timber and fuel wood in Bangladesh. Between 600,000 and 1,200,000 people earn their livelihood, directly or indirectly from this forest. But these mangroves are frequently hit by cyclone resulted in the complete destruction of mangrove vegetation in some places. Within a very short period of time the Sundarbans mangrove forests have encountered five major unusual tragic events, i.e. cyclone in 1988 and 1991, the Asian tsunami in 2004, cyclone Sidar in 2007 and cyclone Nardis in 2008. These disturbances have caused massive amount of damage to the standing vegetation of the Sundarbans mangrove forest and plantation in coastal afforestation. The climate change and anthropogenic disturbances do degradation the costal mangrove forest (species richness and species composition) significantly. The damage leads towards uncertainty in typical mangrove vegetation recovery. It was identified 23 invasive plant species in the mangrove forest in Sundarbans in Bangladesh. It was also evident that invasive of *Derris trifoliate* appeared problematic in Sundarbans especially towards the sea shore such as Dimer char and Pakhir char. Thus an attempt has taken to carry on a study to review species composition change with disturbance related studies and literatures to find out knowledge gap and thereby provide some suggestions for necessary further studies.

Keywords
species richness, catastrophic disturbances, mangrove degradation, recovery, invasive species

Influence of salinity on biomass production, total phenols, damage markers, and water relations in mangroves

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Abstract

Mangroves of the deltaic and coastal regions of Pakistan are vanishing at a rapid pace. The decline is attributed to increases in salinity due to changes in hydrology, besides overexploitation and other activities. Their restoration in suitable habitats demands an understanding of salt tolerance limits as well as physico-chemical responses. This study highlights the effect of seawater salinity on biomass, water and solute relations and stress markers in three mangroves. Seedlings were raised in nutrient solution for 16 weeks and then treated with six salinity regimes of 0.02, -1.4, -2.8, -3.5, -4.2 and -5.2 MPa (corresponding to 0, 50, 100, 125, 150 and 200% seawater strength) to check their salt tolerance limit. Plants surviving in non-saline control, optimum and maximum salinities were harvested for determining biomass, osmolality, solute composition, total phenols and stress markers (MDA and electrolyte leakage). Seedlings of *Avicennia marina* and *Rhizophora mucronata* survived till 1.5 times the strength of seawater (-4.7 MPa) and died thereafter. On the contrary, *Ceriops tagal* survived till 1.25 times the concentration of seawater (-3.5 MPa). Optimum growth in all species was observed in half strength of seawater (-1.4 MPa) while a 50% growth reduction was observed in 100% seawater. Relative water content (RWC), chlorophyll and photosynthesis decreased while osmolality, lipid peroxidation (MDA) and total phenols increased in higher salinities corresponding to growth reduction. The obtained results confer that *A. marina* being an osmoregulator, is the most salt tolerant plant that could be planted in creeks with higher fluctuations in salinity. Plantation of *R. mucronata* is suggested to be done near seafront where fluctuations in salinity are rare and *C. tagal* being the most sensitive species could be restored in saline areas with fresh water inputs.

Keywords
Avicennia, *Ceriops*, phenols, restoration, *Rhizophora*

Are mangrove crabs true intertidal ectotherms? Different thermal strategies to cope with climate change

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Abstract

Tropical intertidal ecosystems such as mangrove forests are particularly vulnerable to climate change since they are at the interface between the marine and terrestrial environments. Crabs are the most important ecological engineers among macrobenthos species in that ecosystem. They undertake different adaptive strategies to occupy several niches along a terrestrial-marine gradient. Sesarmid crabs, such as *Perisesarma guttatum*, are exposed to tidal cycles and since they are not a burrowing species, they have to cope with cycling exposition to water and air. Ocypodid crabs, such as *Uca urvillei*, are burrowers and active only during day low tides. At high tide, they burrow into their holes until the next ebb tide. Through direct observations in the field, we examined the use of time and space of these species and the thermal exposition at low tide, by recording environmental temperature. Body temperature was also measured to assess the thermal niche of the animals. Observations indicate that different strategies are employed by each species. *U. urvillei* exhibit a broad use of space and time and experience a wide variation in temperature during their feeding, displaying and homing activities. They consistently visit their burrows, and increase the frequency of visits with the incoming tide. In contrast, *P. guttatum*, show a restricted use of space, occupying consistently shaded areas and maintaining a very low activity pattern. Body temperature shows clear patterns of thermoregulation for *P. guttatum* and none for *U. urvillei*. Haemolymph oxygen saturation for the former is, nevertheless, very low in air compared to the one of *U. urvillei*. Moreover, with the incoming tides *U. urvillei* close the burrows, avoiding water inundation and thriving in air during high tide. We describe two life strategies of two species that occupy similar habitats, but display different physiological and behavioural strategies to thermal stress. These differences might underline the role of these species in the mangrove system for coping with climate induced environmental changes.

Keywords
climate change, Ocipodids, Sesarmids, thermal strategy, body temperature

Community based ecological mangrove restoration in Palk Bay

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Abstract

OMCAR Foundation has initiated the ecological mangrove restoration project in southeast coast of India. The project area is located in Agni Estuary. Village leaders, women self help groups and youth groups were organized by OMCAR through village level meetings and awareness programmes. 15 acres of degraded mangroves were selected in the Agni estuary region for mangrove restoration.

The poster explains the time laps photographs of growth of mangroves and how the village women self help groups are involved in the project by backyard nursery and additional livelihood arrangements. The school students were brought to mangrove forest area for mangrove ecology field trips, after which they were involved in mangrove field research data collection, tagging and village awareness programmes.

The project also provide solutions for mangrove fisher families to utilize the solar cookers instead mangrove fuel wood, and ecofriendly paddle pump and toilets to save electricity and ground water quality. A GIS map of mangroves and land use pattern was developed for the mangrove village that help the fisherfolks to understand the importance of mangroves against natural disasters and how to protect it through participatory village development scheme by local government.

The poster briefly represents the successful achievements of the Mangrove restoration project and its impacts on local society.

Keywords

OMCAR, ecological mangrove restoration, growth, livelihood, fisherfolk

Episodic sediment mixing from the tidal flat to the mangrove forest: a disturbance gradient for seedling survival

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Abstract

Mangroves provide important ecosystem services but remain threatened worldwide. A mechanistic understanding of seedling survival in a highly dynamic environment is crucial for improved management and restoration of this rapidly disappearing habitat.
Mangroves grow on recently deposited sediments that consolidate and lead to an increase in surface elevation of a few mm per year. However, sedimentation rates show high seasonal and short term fluctuations including periods with negative sedimentation (i.e. re-suspension of deposited material) hence sheet erosion. The process of episodic erosion and accretion events is known as mixing and forms a physical disturbance agent for mangrove seedlings. In previous research we determined thresholds to mangrove seedling survival by experimentally applying accretion (burial) and erosion (excavation) events.
In this study we build upon earlier experimental work with bimonthly field measurements on sediment dynamics along transects in mangrove forests at the Andaman Coast of southern Thailand. We found that over the period of 10 months, sediment mixing (i.e. abiotic disturbance) was highest on the mudflat and the forest edge and decreased going landwards. This is in line with other ecosystems that develop along a succession gradient such as salt marshes, granitic outcrops or dunes.

Keywords
sediment dynamics, mudflat, succession, biogeomorphology

A survey of the Sunderban mangrove wetlands of India - an environmental treat

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Abstract

The Ganga-Brahmaputra delta at the interface of the Bay of Bengal harbors the world's largest single chunk of mangrove wetland of India and Bangladesh, the Sunderban-a world heritage site as designated by the UNESCO in 2002. Increased anthropogenic influences like withdrawal of river water from the upstream region and increase in organic and inorganic pollutants have further led to deterioration of health of the wetland. Potential benefits of the Sunderban wetland come from its luxuriant resources, which include forestry, agriculture, aquaculture, wildlife, birds and fishes. Energy producing resources include peat and fuel wood. The wetland offers beautiful sites for recreational and tourism activities. It is also an excellent ground for research and education related to conservation and natural balance of various ecosystems. Being highly productive and having genetically diversified ecosystems, the wetland provides important benefits of both goods and services. Gradual environmental degradation, loss of biological diversity, poaching of wild life, felling of mangroves and other fuel wood trees are posing serious threats to the Sunderban for the last few decades. Because of rich resource potential and strategic importance, the Sunderban mangrove wetland is threatened by multiple anthropogenic factors. In addition to its setting in a highly vulnerable, hostile and dynamic coastal environment, multiple manmade activities leading to increasing concentration of pollutants in the aquatic and sediment matrices have become a matter of great concern during the recent decades. It is essential that together with legislation, mass awareness programs through seminars, newspapers and electronic media with local participation be conducted at regular intervals. Under a threatened pollution level, regular monitoring of the pollution status of Sunderban wetland is suggested in order to check its further environmental degradation.

Keywords
biochemical cycle, *Sundari* trees, environmental impact, slum sewage, localized fishing

Quantifying and monitoring vulnerability of Amazon-influenced mangrove coasts. Case study from French Guiana

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Abstract

Sustainable management of mangroves coasts depends on our ability to assess vulnerability of mangroves coasts to oceanic processes, climate change or anthropogenic activities. This challenging work requires quantitative baselines to monitor and predict changes in coastal landforms and impacts on human infrastructures. The case of French Guiana mangroves is specific. In this French department, coasts are relatively preserved from any polluting industry. However, as part of the longest muddy coast of the world, originating from the Amazon sediment dispersal system, the mangrove coasts are exposed to the shifting of giant mud banks from southeast towards northwest, causing an extreme variability of its shoreline. Such regional hydro-sedimentary system generates, all along the Guianese coast, a succession of erosion and accretion phases that control the extent and physiognomy of mangroves. Surprisingly, coastal-fringed mangroves, mainly composed of *Avicennia germinans* trees, seem to regenerate rapidly after an erosion phase, as soon as the following mud deposit is consolidated.
This original context yielded us to attempt to build a spatiotemporal index of coastal vulnerability based on the remote-sensing monitoring over 60 years of mangroves landscape changes. As a preliminary approach, we combined distance measurements of mangrove shorelines in both across-shore (current situation) and along shore (future situation) directions to calculate a vulnerability index. Results suggest that the northern part of the French Guiana coast seem more vulnerable than the southern part; probably because shore-faced mud banks become more elongated along-shore and confine mangrove colonization to their upper fringe part. These findings led us to make hypotheses on the *Avicennia* mangroves functioning. To learn from the past, explain the actual risk and predict vulnerability for next years, the necessity to develop regional strategies based on remote-sensing observations of changes occurring in mangrove coasts is finally explained and discussed. This work is supported by the INFOLITTORAL-1 project.

Keywords
mangrove forest, coastal instability, vulnerability index, remote sensing, muddy Amazon coast

Vulnerability of mangroves in the WIO region to climate change

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Abstract

Mangroves provide an array of ecosystem goods and services, thus supporting the livelihoods of millions of people in the WIO region. The area of mangroves in the WIO region has been estimated at 1.0 Million ha with the most extensive mangroves found in Mozambique, Madagascar and Tanzania (50%, 43% and 25% respectively). However, anthropogenic pressure working synergistically with climate change related impacts have seen widespread mangrove degradation. Different mangrove ecosystems will exhibit varying responses to climate change related impacts depending on their unique physical settings and associated external drivers. Already extensive mangrove die-backs have been reported in the region due to exacerbated sedimentation, flooding and increased frequency and intensity of cyclones. It is important to note that climate change related impacts will not operate singly, but in most cases synergistically to compromise the integrity of mangrove ecosystems. This study aims to estimate the exposure of selected mangrove ecosystems in the WIO region (i.e. Kenya, Tanzania, Mozambique & Madagascar) to climate and human related disturbances. We use spatial multi-criteria evaluation (SMCE) and Fuzzy logic technique, coupled with expert knowledge of how these factors influence mangrove ecosystems, to develop estimates of mangroves exposure to multiple disturbances. These factors included: precipitation/flooding; sea level rise and anomaly; land cover-land use; runoff estimates; slope and elevation. Global and regional spatial data on these factors were processed and synthesized into a composite layer, which showed the spatial gradients of mangroves exposure. Human pressure index seemed to be strongly correlated with Land-use and soil erosion, while there was a Sea Level Anomaly gradient north to south with the southern regions being most vulnerable to SLR. Slope and SLA are strongly positively correlated. Madagascar seems to have a fairly consistent pattern on all DoC which may be attributed to the large latitudinal differences between north and south. The most significant DOC seems to be human related, thus giving hope that opportunities exist for enhancing mangrove resilience to climate change.

Keywords
WIO, climate change, vulnerability, spatial multi-criteria evaluation (SMCE), resilience

Test assembly mechanisms of mangrove communities using geostatistical tools: a study case in the mangrove of Gaoqiao

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Abstract

1. Description of the mechanisms leading to the assembly of plant communities in different ecological types of mangroves remains an important issue for restoration and development of predictive models for mangrove vegetation structure. Although both environment constraints and dispersion processes have been proved to be determining in mangrove communities assembly, it remains difficult to disentangle the importance of the niche *vs.* neutral mechanisms in different ecological types of mangroves.
2. This study was conducted in Gaoqiao, on Leizhou Peninsula in Southern P.R. China. We explored floristic composition, dendrometric parameters and soil properties such as OM, particle size, pH, conductivity, C/N, and bioavailable nutrients in 130 plots, distributed along nine transects across two riverine and one fringe mangrove forests. The sampling covered a total of 934 ha.
3. In order to avoid the bias related to spatial autocorrelation, several geostatistical analyses were performed in order to (1) determine the spatial structure of each species and spatial variability of soil properties, (2) discriminate different habitats in each ecological types (riverine and fringe) and (3) test the niche assembly mechanism in structuring vegetation community based on correlations with soil resources and tree location relative to the different water systems.
4. Geostatistics allowed to define contrasted spatial structure for seven mangrove species (*Aegiceras corniculatum*, *Bruguiera gymnorrhiza*, *Kandelia candel*, *Avicennia marina*, *Rhizophora stylosa* and *Excoecaria agallocha*) and to discriminate two contrasted habitat in each ecological type: the first close to the widest water system, with a low content of organic matter and nutrients, and the second, most sheltered inside the land, which allows a high deposition of small particles and nutrients.
Spatial distribution of tree species and aboveground biomass showed strong associations with both habitats properties, suggesting a major role of the niche assembly mechanism in this community, species being recruited by selective habitats.

Keywords
spatial analysis, mangrove forest, niche assembly mechanism, plant community, soil properties

Distribution of mangroves along environmental gradients on San Andres Island (Colombian Caribbean)

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Abstract

Species richness and distribution along environmental gradients in mangroves have been linked to abiotic and eco-physiological factors. The small surface area of San Andres Island, Colombia, the relatively low environmental variability, as well as the lack of permanent freshwater courses may prevent the formation of a zonation pattern, leading to a homogeneous composition and structure of the forests. The goal of this study was to evaluate the mangrove types, including their structure and floristic composition under the influence of five environmental factors. The primary relationships among tree species and flooding levels, salinity, pH, soil depth, and soil texture were investigated along 86, 500-m2 plots established across 20 transects throughout the San Andres Island shoreline. Canonical Correspondence Analysis identified four mangrove groups, with the first two canonical axes explaining 65% of the variation in the data. The grouping of species along those axes was mainly associated with inundation level and soil depth. Two mangrove groups were classified as fringe mangroves that grow on highly saline and relatively shallow soils under the direct influence of tides. The remaining two were classified as riverine mangroves that grow on lower salinity soils influenced by sporadic freshwater flows and isolated from direct tidal influence. *Rhizophora mangle* L. was present in the four mangrove groups but, on the highest saline soils where fringe mangroves grew, *Avicennia germinans* (L.) L. was dominant. In riverine mangroves, *Laguncularia racemosa* (L.) Gaertn., and *Conocarpus erectus* L. were the most important species.

Keywords
mangrove types, structure, diversity, zonation

Ethnoecology and monitoring of Siberut Biosphere Reserve mangroves (Indonesie)

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Abstract

Ecosystems and societies face major emerging challenges as climate change and ecological services degradation. Nowadays, linking local knowledge and global science in multi-scale assessments is at the heart of international debates.
Biosphere reserves (BR) have a potential role to effectively respond to these challenges by undertaking transdiciplinary and comparative research. BR can also promote long term monitoring of key *early warning ecosystems* through the involvement of local communities and the integration of local knowledge in the assessment and monitoring of their own environment.
Siberut is the largest and northernmost of the Mentawai Islands, lying 150 kilometers west of Sumatra. The Mentawai communities located on the south-east side of Siberut Island are highly dependent on the existing natural resources of the mangrove forest. The cumulative and complex bodies of knowledge of these local communities; know-how, practices and representations, has been developed through a long history of interactions and reliance on this ecosystem.
The main objective of this research is to study the interactions between the local communities and the mangrove forest of Siberut Biosphere Reserve and to consider an operational methodology that could allow to monitor and survey changes in the mangrove ecosystem linking the local and the scientific expertise.

Keywords
ethnoecology, biosphere reserves, data management, long-term monitoring

Multi-country comparison of insect herbivore communities and leaf herbivory, on mangroves

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Abstract

The role of herbivorous insects in mangrove ecosystems is underrated and relatively unexplored. This paper compares and contrasts mangrove insect herbivore communities and leaf herbivory levels, across four countries (Australia, Florida, Belize and Panama) as well as examining these patterns along nutrient and latitudinal gradients.

Studies on mangrove herbivores to date have mostly recorded <100 insect herbivore species feeding on them. The actual number feeding on any species is likely to be many hundreds and for mangroves in general, many thousands of species. Mangrove insect faunas are mostly distinctive to this habitat and often specialized on particular species, with <10% of species in common with adjoining terrestrial forests and even <10% of species in common between *Avicennia* and *Rhizophora* species. There are also some emerging patterns across different regions. For example, galls are a conspicuous feature of *Avicennia* species all over the world. In contrast, they are very rare on members of the Rhizophoraceae and other mangroves, though these species support many leaf-miners. Notably, the number of folivorous beetle species collected is low in many locations.

Damage to leaves of *Avicennia* species is generally higher than for Rhizophoraceae species. However for Rhizophoraceae species, damage to apical tips before leaves unfurl from behind the stipules is the dominant cause of leaf loss to herbivores. This reflects very different strategies for dealing with herbivore damage between the species. Damage to Rhizophoraceae apical tips also restricts leaf production and shoot extension but promotes lateral shoots, thus altering both leaf production and tree/canopy architecture. At some sites, wood-borers caused significant leaf loss and conversely at others, leaf-feeders caused significant levels of shoot death.

Herbivory studies should advance to looking at impacts on leaf production rates and upon impacts on the rates of tree growth and their pattern of branching.

Keywords
insect herbivory, Australia, Florida, Belize, Panama

Remote sensing of hurricane impact and early vegetation recovery in the mangrove of Fort-de-France Bay (Martinique, FWI)

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Abstract

The CARIBSAT project aims at conceiving and implementing an instrument to monitor the environment in the Lesser Antilles based on an online geographic atlas supplied by the acquisition and analysis of satellite images, ground environmental data as well as hydro-meteorological reports. More specifically, it is targeted towards the preservation of biodiversity in terrestrial and marine ecosystems, the mitigation of risks associated to natural disasters and the adaptation to climate change. Hurricane Dean (2007) severely impacted mangrove forests along the Bay of Fort-de-France (Martinique, FWI). This event provided an opportunity to assess mangrove resistance and early recovery following hurricane disturbance, both of these processes being yet poorly understood in mangroves worldwide. For this purpose, three sequential maps of mangrove vegetation around the Bay have been implemented by means of satellite image analyses (IKONOS 2006 and 2008, SPOT 5 2006 and 2010) and field measurements. The first vegetation map described 5 pre-hurricane ecological units based on vegetation structure and dominant species. The second map outlined hurricane disturbance using three levels of vegetation damage (weak, medium and strong). It was found that Hurricane Dean impacted 52% of the study area at a medium or strong level. *Avicennia germinans* stands were the most heavily damaged, whereas dwarf *Rhizophora mangle* stands were the most resistant. It appeared that, in addition to wind damage, a massive and long-lasting increase of the water table due to freshwater flow impediment caused massive mortality among *A. germinans* stands. On the map of early (3 years) vegetation recovery, corresponding areas (13 % of the whole mangrove area) appeared as freshwater marsh vegetation. These results will serve to implement a mangrove observatory in Martinique Island, based on remote-sensing survey and vegetation monitoring on reference areas.

Keywords
recruitment, hurricane, disturbance, Caribbean mangrove, teledetection

Urban mangrove dynamics under increasing anthropogenic pressure: analysis of remote sensing data and Brazilian legislation

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Abstract

Mangroves fulfill many necessary functions in the field of production and environment protection as well as regarding social aspects. However this coastal ecosystem is amongst the most threatened around the world. They are subjected to pollution, overexploitation and land conversion to other human uses. Coastal urbanization has also caused important reductions in their extent decreasing consequently their benefits for (sub)tropical coasts. Located at the Southern Brazilian Coast, the Baixada Santista region (State of São Paulo, Brazil) covers an area of 1,329 km², with 1,606,863 inhabitants. GIS-aided analysis of historical series of 1987, 1993, 1997, 2005 and 2011 of Landsat-TM5 satellite images allows quantifying the evolution of the mangrove area in this urban site and detecting the impact of human activities over the years. Object-based approach, using segmentation by region and Bhattacharya supervised classification was achieved with SPRING GIS (Georeferenced Information Processing System - INPE). The stressed mangrove forests studied showed trends to terrestrialisation, and patches of typical mangrove vegetation. *Rhizophora mangle, Laguncularia racemosa* and *Avicennia schaueriana* and associated mangrove species were registered *in situ*. The Landsat satellite images indicated variation in mangrove extent, over time. Main human impacts as industries, ports and residences were mapped. In spite of good Brazilian legislation protecting coastal ecosystems, some recently laws, as CONAMA 2006 and the new Forest Act proposal, are facilitating mangrove area reduction and fragmentation and exposing the population to risks, allowing occupation from low-income housing (*favelas*) in mangrove swamps. The final maps produced in the current study are important tools for the conservation and management of natural resources of coastal zone. The current study might help analyzing human pressure on urban mangroves, offering reliable estimates of mangrove evolution and could assist the local, regional and coastal management.

Keywords
Landsat, change detection, urban mangroves, coastal management

Habitat recovery assessment of reforested mangrove sites in the Gazi Bay, Kenya: a study testing the role of molluscs as bioindicator species

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Abstract

The present study attempts to assess the habitat recovery of 9-12 years old reforested mangrove sites, in terms of successful growth and colonization of flora/fauna, in comparison to natural vegetation in the Gazi Bay, Kenya. Six sites encompassing 2 reforested and 4 natural mangrove vegetation represented by *Ceriops tagal* were investigated. In each site, data on young/adult vegetation, sediment characteristics and the abundance of 3 molluscs - *Terebralia palustris*, *Cerithidea decollata* and *Littoraria* spp., were collected. Adult tree density in the natural sites varied between 5768 and 9294 stems ha^{-1} (basal area: 10.5-16.9 m^2 ha^{-1}), whereas in the reforested sites it was 1120-10800 stems ha^{-1} (basal area: 0.9-11.4 m^2 ha^{-1}). In both areas, the young vegetation with a height ranging from 40 to 130 cm was abundant (3429-59467 stems ha^{-1}). Except for nutrients (ammonia, total nitrogen and phosphate), the soil characteristics such as salinity, organic matter, sediment moisture and fine sediment did not show large variations between the two areas. The PCA based analysis indicated marked differences, although not significant, between the natural sites 1 and 4 (One-Way ANOVA, $F = 0.1$, $P = 0.8$), and between the reforested sites 1 and 2 (One-Way ANOVA, $F = 1.1$, $P = 0.3$). Although mollucan density represented by *C. decollata* and *Littoraria* spp. was high in the reforested site 2 (74 ind m^2), mollucan biomass was maximum in the natural mangrove site 2 (32 g m^2) due to the presence of *T. palustris*. The correlation coefficients drawn between molluscs and soil-vegetation parameters (through the BEST analysis implemented in PRIMER *v*.6) are optimized only for sediment moisture and tree height ($\rho = 0.94$), confirming that food and shelter play a significant role ($P < 0.05$) for their distribution. In addition to soil and vegetation factors being considered to influence the distribution of moullucs, the tree morphology and faunal competition were also found important in the present study. In view of the luxuriant growth by *C. tagal* in reforested site 1, it could be considered as a successful plantation. In contrast, the reforested site 2 was an indicative of environmental stress (for mangrove regeneration as well as their endurance) in the back mangrove environment. Overall, the three mollucan populations tested for habitat recovery assessment in the Gazi Bay have necessitated other field-based observations (e.g. site location, tree foliage, etc) in support.

Keywords
ecological recovery, indicator species, mangrove restoration, molluscs, Gazi Bay, Kenya

Governance of coastal plantations in southern India: long-term ecological vision or short-term economic opportunity?

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Abstract

Bioshields or coastal vegetation structures are currently one of the major coastal habitat modification activities in India, particularly after the December 2004 tsunami. Coastal plantations are being promoted in a large scale as protection against severe natural disasters despite considerable debate over their efficacy as protection measures. In this paper, we analyze the establishment of bioshields in southern India in the context of the Indian Ocean tsunami. We conducted a socio-ecological questionnaire-based survey on government and non-government organizations directly involved in coastal plantation efforts in two tsunami affected states on the east coast of India.

We found that though coastal protection was stated to be the primary cause, socio-economic factors like social forestry were a strong undercurrent for plantation activities. There was scant local support for plantations with regard to coastal protection. Ecological criteria seem to have been undermined during the establishment and maintenance of plantations and there was a lack of awareness about conservation laws relating to coastal forests. In order to strike a balance between ecological and social objectives, we suggest that more research on ecological functionality of coastal forests be carried out. Cross-disciplinary communication and better policies are urgently required for effective management of these coastal plantations.

Keywords
coastal protection, bioshield, tsunami, policy, case study, India

Feasibility of reverse adaptation: physiological and biochemical approach for two mangroves from Sundarbans, India

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Abstract

Mangroves are divergent community of trees or shrubs having convergent adaptation to form dense succession on coastal saline habitat. Sundarbans delta is the largest mangrove forest in Worlds with maximum species diversity. However, elevated substrate-salinity and anthropogenic impulse are causing detrimental effect on some of existing taxa, especially *Heritiera fomes*. The aim of this experiments were to explain comparative ecological fitness for *Heritiera fomes* (taxa in stress) and *Bruguiera gymnorrhiza*, (growing profusely in Indian Sundarbans) from two different habitats *viz*. saline (15-27 ppt) in Sundarbans and mesophytic habitat (1.2- 2 ppt) (Institute's garden) of enough matured plants (12-14 years). A comparative account of photosynthetic efficiency, chlorophyll content, mesophyll and stomatal conductance, specific leaf area, nitrogen use efficiency, total foliar amino acids, isozyme analysis of two antioxidant enzymes (Peroxidase, Superoxide Dismutase) and two hydrolysing enzymes (Esterase, Acid Phosphatase); both quantitative and qualitative and total proteins were estimated form plants of both the habitats. In *B. gymnorrhiza* the optimum PAR acquisition was higher in saline habitat, while maximum assimilation rate was found lower in their mesophytic counterpart. However in *H. fomes*, the peak photosynthesis was found lower in non-saline condition even at higher irradiance. Stomatal Conductance was remarkably reduced by 25-52% compared to their saline counterparts. Salinity imposed increase in level of all four enzymes were observed as revealed by native gel electrophoresis as well as quantitative estimation, however level of increment was lower in *H. fomes*, even though net photosynthesis was higher. PAGE analysis and quantitative estimation showed decrease in total protein amount for both plants in saline; with higher percentage for *B. gymnorrhiza*. This comparative analysis of physiological and biochemical parameters shows 'On the verge of extinction' tag to *Heritiera fomes* might be related to their weaker adaptive efficiency in present days' elevated salinity level in Indian Sundarbans.

Keywords
adaptation, isozymes, photosynthesis, Sundarbans

Salinity imposed biochemical changes towards efficient adaptation of some mangroves of Sundarbans, India

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Abstract

Elevated salinity (~30 ppt) in Indian Sundarbans has detrimental impact on vegetation leading to precarious existence of few existing species like *Heritiera fomes.* In halophytes, osmotic adjustment and efficient ROS scavenging are the essential physiological and biochemical processes for being salinity resistant. An *in vitro* experiment with three mangrove seedlings (*viz*. *Avicennia marina*, *Bruguiera gymnorrhiza* and *Heritiera fomes*) were performed for assessing their adaptability across NaCl gradients. Among the five sets of treatment (0, 100, 200, 300 and 400mM), leaf osmotic potential (ψ) shows consistent hike in *A. marina* and *B. gymnorrhiza* along the salinity rise up to 300mM (77 and 58% respectively from control). But, *H. fomes* reaches its maximum OP value in 200mM NaCl treatment (64% increment from control). The cellular homoeostasis is maintained through osmotic adjustment in salinity stress by two ways: uptake of inorganic ions and accumulation of compatible organic solutes. Free amino acids, which considered as compatible osmoticum, were detected from leaves of the three taxa and *A. marina* and *B. gymnorrhiza* shows a positive correlation up to higher concentration of NaCl treatment (300mM), but in *H. fomes*, this increment restricted up to 200mM. Moreover, it has been established that salt tolerance can be correlated with efficient ROS scavenging ability by enhanced antioxidant enzyme system. The two major antioxidative enzymes (peroxidase and superoxide dismutase) in *A. marina* and *B. gymnorrhiza* expressed excess isoforms and elevated band intensity along the NaCl gradient, whereas in *H. fomes* the numbers of isoforms of both enzymes were either same as control or less. Quantitative estimation of both the enzymes also follows the same trend among the three species investigated. Estimation of leaf OP, major free amino acids and antioxidative enzymes across different salinity gradients might be informative towards the probable reason of extinction and priority area of conservation strategy.

Keywords
free amino acid, osmotic potential, antioxidant enzymes, Sundarbans

Size does matter, but not only size: two alternative dispersal strategies for viviparous mangrove propagules

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Abstract

To the present day, it is much debated whether long-distance dispersal (LDD) of mangrove propagules is an epic, rather than a frequent event, next to more local dispersal. In general, there is a knowledge gap on the whereabouts of a propagule between the moment it releases from the parent tree and its establishment after a certain dispersal period through water. We addressed the fundamental need to understand the dispersal behaviour of viviparous mangrove propagules, in relation to their morphological characteristics, the differences between genera and the link with their different position in the intertidal zone.
We studied the propagules of two dominant mangrove species, *Ceriops tagal* and *Rhizophora mucronata*, that are similar in shape but differ in other morpho-anatomical features. We hypothesized the propagules of both species to have a different hydrodynamic behaviour, resulting in a different dispersal strategy. The dispersal strategies of *C. tagal* and *R. mucronata* propagules were elucidated through a combination of a propagule tracking, predation and root-growth experiment, carried out in the field. *C. tagal* and *R. mucronata* adopted two different dispersal strategies. *C. tagal* releases a large number of propagules, disperses fast (low density and slender morphology) and has a high agility (smaller size) when dispersing through dense root systems. *C. tagal* propagules have a theoretical advantage to disperse over longer distances over the denser, thicker and longer *R. mucronata* propagules. *C. tagal* propagules have, however, lower establishment chances due to slower root-growth, desiccation sensitivity and smaller size. In contrast to *Ceriops*' tactic of "few and fast" dispersal, *R. mucronata* has adopted a dispersal tactic of survival. Fewer propagules are released, but they are more resistant to predators due to their larger size and they can anchor themselves faster due to quicker root-growth. Overall, propagule characteristics of both species result in different and alternative dispersal strategies on a local scale. On a global scale, we hypothesize this might lead to a similar capacity for LDD, ending in successful establishment.

Keywords
Ceriops tagal, *Rhizophora mucronata*, long-distance dispersal, propagule size, tracking

Efficacy of traditional practice of mangrove cultivation in Negombo estuary

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Abstract

Mangroves are cultivated traditionally to produce twigs and branches for "Brush Park" fishery in Negombo estuary, Sri Lanka. Objective of the present study is to determine the efficacy of this practice in terms of its impact on overall mangrove primary productivity and mangrove carbon sequestration of the estuary. Net primary productivity (NPP) was determined by annul litterfall and biomass increment of mangroves at Kadolkele (7^0 11'42 N; 79^0 50'32 E), a natural, nevertheless a secondary stand that had been harvested for "Brush Park" construction twenty years ago and now being protected and Wedikanda (7^0 11'18. N; 79^0 50'04 E), a stand that has been cultivated and maintained by fishermen to extract twigs and branches for "Brush Park" construction. As indicated by complexity index scores, (42.33 at Kadolkelle and 22.48 at Wedikanda), the natural stand is structurally superior to cultivated stand. Selection of species for cultivation, periodic harvesting of branches appears to reduce structural complexity of cultivated stand. Difference of net primary productivity of Kadolkele (2401.29 $\pm$18.46 g $m^{-2}y^{-1}$) and Wedikanda (2122.56 $\pm$ 16.44 g $m^{-2}y^{-1}$) however, is not statistically significant ($p<0.05$), which indicates the traditional wisdom in mangrove cultivation methods. With respect to carbon sink-function, out of 1232.17 $\pm$ 9.23 g of carbon accumulated in mangroves at Kadolkelle per m^2 per year, 55% in wood (682.80 $\pm$ 7.51 g $m^{-2}y^{-1}$), 152.91 $\pm$ 1.94 g $m^{-2}y^{-1}$ in roots, and thus 67% in sequestered form. At Wedikanda, 602.88 ± 6.93 g m^{-2} out of 1116.51$\pm$12.63 g m^{-2} of carbon included annually in the plants is in woody stems and 131.62± 2.03 g m^{-2} in roots, thus 65% of carbon in sequestered form. Annually, the secondary mangrove stands at Kadolkelle (13.5 ha) is capable of sequestering 166.34 t y^{-1} at a rate of 12.32 t ha^{-1} y^-1 while cultivated mangroves at Wedikanda (9.5 ha) 106.06 t y^{-1} at a rate of 11.16 t ha^{-1} y^{-1} and the difference is not statistically significant ($p<0.05$). Cultivated mangrove stands therefore are as productive as the natural stands and their carbon sequestration capacities are comparable, thus manifesting the positive contribution of mangrove cultivation to overall mangrove productivity and carbon sinks. The average annual carbon sequestration by Negombo estuarine mangroves is 11.74 t ha^{-1} y^{-1} and this is equivalent to the amount of carbon emitted as CO_2 by combustion of 19,209 liters of diesel or 22,043 liters of gasoline by motor vehicles.

Keywords
mangrove cultivation, carbon sequestration, vegetation structure

Managing the mangroves economically: ‘use it or lose it’

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Abstract

Being in the constant lime light of environmental scientists, the mangrove forests are now considered to be the potential weapon for fighting natural disasters and climate change. However, these functions and the consequent utilities would remain abstract unless we seek to document them by valuation and monetisation in the system of free market trade. A case study was conducted in Tamil Nadu in India in the Pichavaram mangroves in the year 2010, with the major objective of estimation of the economic value of those mangroves. The Pichavaram mangroves with an area of 1,110 ha possess rich and diverse floral and faunal wealth comprising a criss-cross network of 4,440 rivulets and 51 islets. The required data were collected randomly from 41 experts of two universities in Tamil Nadu and 120 villagers, making a total sample size of 161. The most important present use of the Pichavaram mangroves as cited by the respondents was services of mangrove through their ecological functions like protection against tsunami, floods and heavy winds. In calculating the Total Economic Value of the concerned mangrove area, the values were divided according to direct use values and indirect use values, and were calculated through market pricing, surrogate pricing and Willingness To Pay (WTP). The direct use values involving fishery contribution and eco-tourism values were estimated to be Rs. 1,65,75,000. The indirect use value component comprised support to off-shore fisheries, carbon sequestration and storm-protection function of the mangroves, valued to be Rs. 336,10,51,127. The WTP found out through Contingent Valuation Method (CVM) amounted to Rs. 1,05,185. Thus, the Total Economic Value (TEV) was added upto Rs. 353,52,31,312, which is an indicative price of the huge value of the mangrove resources required for understanding the sustainable exploitation of the mangrove ecosystem for the long-term economic benefit of any country.

Keywords
ecosystem valuation, fisherfolk, voluntary fund donation organization, green economy, carbon trading

Modelling mangrove propagule dispersal: sensitivity analysis and implications for shrimp farm rehabilitation

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Abstract

Propagule dispersal of four mangrove species *Rhizophora mucronata, R. apiculata, Ceriops tagal* and *Avicennia officinalis* in the Pambala-Chilaw Lagoon Complex (Sri Lanka) was studied by combining a hydrodynamic model with species-specific knowledge on propagule dispersal behaviour. Propagule transport was simulated using a finite-volume advection-diffusion model to investigate the effect of dispersal vectors (tidal flow, freshwater discharge and wind), trapping agents (retention by vegetation) and seed characteristics (buoyancy) on propagule dispersal patterns. Sensitivity analysis showed that smaller propagules, like the oval-shaped propagules of *Avicennia officinalis*, dispersed over larger distances and were most sensitive to changing values of retention by mangrove vegetation compared to larger, torpedo-shaped propagules of *Rhizophora* spp. and *C. tagal*. Directional propagule dispersal in this semi-enclosed lagoon with a small tidal range was strongly concentrated towards the edges of the lagoon and channels. Short distance dispersal appeared to be the main dispersal strategy for all four studied species, with most of the propagules being retained within the vegetation. Only a small proportion (max. 5%) of propagules left the lagoon through a channel connecting the lagoon with the open sea. Irrespective of the retention scheme, wind had a significant influence on dispersal distance and direction once propagules enter the lagoon or adjacent channels.
In view of a wider implication of mangrove restoration ecology, simulation of the removal of certain parts of outer dikes of abandoned shrimp farms to promote propagule inflow from adjacent mangroves and consequently allow for natural regeneration, revealed that the specific location (with respect to the vicinity of mangroves and independently suitable hydrodynamic flows) of dike removal significantly affected the resultant inflow of propagules and hence the potential effectiveness of natural regeneration.

Keywords
buoyancy, hydrodynamics, Chilaw Lagoon, Sri Lanka, regeneration

Mangroves facing climate change: landward migration potential in response to projected scenarios of sea level rise

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Abstract

Mangrove forests prominently occupy an intertidal boundary position where the effects of sea level rise will be fast and well visible. This study in East Africa (Gazi Bay, Kenya) addresses the question whether mangroves can be resilient to a rise in sea level by focusing on their potential to migrate towards landwards areas. The combinatory analysis between remote sensing, DGPS-based ground truth and digital terrain models (DTM) unveils how real vegetation assemblages can shift under different projected [minimum (+9cm), relative (+20cm), average (+48cm) and maximum (+88cm)] scenarios of sea level rise (SLR). Under SLR scenarios up to 48 cm by the year 2100, the landward extension remarkably implies an area increase for each of the dominant mangrove assemblages, except for *Avicennia marina* and *Ceriops tagal*, both on the landward side. On one hand, the increase of most species in the first 3 scenarios, including the socio-economically most important species in this area, *Rhizophora mucronata* and *Ceriops tagal* on the seaward side, strongly depends on the colonization rate of these species. On the other hand, a SLR scenario of +88 cm by the year 2100 indicates that the area flooded only by equinoctial tides strongly decreases due to the topographical settings at the edge of the inhabited area. Consequently, the landward *Avicennia*-dominated assemblages will further decrease as a formation if they fail to adapt to a more frequent inundation. The topography is site-specific; however non-invadable areas can be typical for many mangrove settings.

Keywords
topography, DTM, Gazi Bay, inundation, GIS

Impact of typhoon disturbance on key macrobenthos in a monoculture mangrove forest plantation, Can Gio Biosphere Reserve, Vietnam

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Abstract

The intensity of tropical storms may increase due to climate change and damage mangrove forests, particularly monocultures, due to their low structural diversity. Crabs may positively influence the recovery of storm-damaged forests, yet the response of these ecosystem engineers to storm disturbance is largely unknown. Here we compare the crab community of intact mangrove stands with that of typhoon gaps having experienced 100% tree mortality in two adjacent areas in Can Gio, S-Vietnam. In each area, an 18-20 yr old monoculture *Rhizophora apiculata* stand served as control and was compared with typhoon gaps where downed stems had been removed or left on-site. The gaps were 14 and 20 months old when sampled in the dry and rainy season 2008. Four people manually caught crabs during 30 min in each 100 m² plot (7 replicate plots per area, treatment and sampling) and abiotic and biotic measures were taken. Despite complete canopy loss, total crab abundance had not changed (in contrast to biomass) and all forest species were also found in the gaps. Gap-exclusive species existed and average species number and Shannon diversity were higher in the gaps. *Perisesarma eumolpe* was the most abundant crab, both in the forest and in the gaps and a shift from sesarmids (typical forest species) to ocypodids (more prominent in open areas) had not occurred. The persistence of litter-feeding sesarmids is probably linked to woody debris in the gaps, fuelling a mangrove detritus based food web, rather than one based on microphytobenthos with deposit-feeding ocypodids. The continuous abundance of burrowing crabs in the gaps suggests that important ecosystem engineering activities are still performed; however, bioturbation may be less strong as crab size/biomass was smaller in the gaps. Follow-up assessments study the long-term dynamics of the gap fauna as well as the crabs' impact on gap recovery.

Keywords
mangrove crabs, storm disturbance, canopy gap, community structure, diversity

Coastal condition monitoring using indicators of mangrove and saltmarsh health and change

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Abstract

Mangrove and saltmarsh vegetation of tidal wetlands worldwide provide fundamental and highly beneficial ecosystem services including carbon capture and storage, shoreline stabilization, habitat/nursery function, and more. Despite such notable benefits, there are no encompassing condition assessment strategies available. And, nor are there any agreed methods for quantifying and monitoring these habitats that are reliable, systematic, standardized, cost effective and practical. Current evaluations chiefly focus on declining area and increasing loss, as well as targeting key threats to biodiversity. While these approaches are undeniably important, there is a compelling and urgent need to expand on this with a comprehensive strategy for monitoring tidal wetland habitat condition and health.

A new assessment scheme is proposed, coupled with a new monitoring methodology, notably S-VAM (Shoreline Video Assessment Method), for assessment of estuarine and coastal shoreline habitats. This combined strategy is designed to encompass most drivers, and support the monitoring of ecosystem responses, as well as identify key drivers of change. Using various standard descriptors, the area of impact and influence of each driver can be quantified and mapped for each instance of observed change, or impact. And, for each instance, monitoring can continue indefinitely afterwards to determine the longer term success of mitigation intervention and/or natural recovery processes.

Habitat condition and notable ecosystem services continue to deteriorate despite current best efforts to protect threatened areas. This situation will be exacerbated further with the additional pressures associated with global climate change. Where we want to preserve beneficial tidal wetland ecosystems, we must act quickly to identify key stressors and quantify baseline habitat condition. In practice, we have few suitable monitoring methods available, apart from counting species present and measuring canopy density and area. What is required is a protocol that will identify and quantify changes due to natural and human-related pressures. By framing mitigation efforts under such a protocol, this will most likely enhance and build resilience amongst natural stands and plantations.

Keywords
ecosystem service, threats to biodiversity, S-VAM, climate change, resilience

Vegetation structure at Zhanjiang Mangrove National Nature Reserve (ZMNNR), P.R. China: comparison between original and non-original trees using ground-truth, remote sensing and GIS techniques

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Abstract

In order to determine the areas best suitable for future genetic differentiation works at Zhanjiang Mangrove National Nature Reserve (China), the present methodological study has attempted to define a step-wise procedure to distinguish mangrove trees present before planting schemes (Om areas) from trees which were planted, as well as, trees that have naturally established after interaction between planted and non-planted trees (*e.g.,* through pollination) (NOm areas). Subsequently, Corona satellite (mono-band) image from 1967 and a high resolution GeoEye-1 (multi-spectral) image from 2009 digitized mangrove cover areas were overlapped to detect *a priori* ground inventory which consisted in selecting 5x5m plots from 1967 vegetative areas (Om) and the remaining forest in 2009 (NOm). In each plot, the tree structural parameters such as density (ind. ha^{-1}), basal area (m^2. ha^{-1}), height (m), and Complexity Index (CI), were estimated for validating the differences between Om and Nom stands. The data were analyzed through Bray-Curtis similarity and non-metric Multi-dimensional Scaling plots in PRIMER *v*.6. It was possible to identify 3 groups from each hierarchical clustering of the above vegetation indicators (similarity percentages: for density 45%, basal area 25%, and height 65%). The species' distributional patterns have indicated that Om areas are in a state of maturity (total density, 1,868 - 9, 327 ind. ha^{-1} and total basal area, 0.83 - 1.252 m^2. ha^{-1}), and representing characteristics of less disturbed forest. Similarly, high CI values were obtained from Om stands. In addition, the sequential satellite imageries (1967-1971-2000-2009) revealed an increase of 347% in mangrove cover dominated by *Aegiceras corniculatum* (42.4%). Overall, the results suggest that the methodology is straight forward for distinguishing Om stands from and Nom stands, whereby dominant or bimodal species are categorized by their differences in height. Finally, the advantages and limitations of this methodology were highlighted, along with some recommendations for future genetic studies at ZMNNR.

Keywords
original area, non original area, mangrove cover, hierarchical clustering, Leizhou peninsula, China

Vegetation structure of mangroves in the Rio del Rey estuary (Cameroon)

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Abstract

Mangrove forests in Cameroon are mainly concentrated in two areas. If the Cameroon estuary has already been studied by many authors, that's of the Rio del Rey is not. Because of the border conflict between Cameroon and Nigeria, the vegetation characteristics are not well known as very few field data collection were carried out in the area. The objective of this study is to contribute to the knowledge of the vegetation structure of mangroves of the Rio del Rey estuary. The research was conducted in seven localities (Andokat, Bamusso, Kombo'a Mukoko, Masaka, Meme, Mukala Tanda and Ngosso) in the Ndian subdivision. The transects were established perpendicular to the main tidal channels and the Nearest Neighbour method through plots of 20 × 20 m^2 assessed the floristic composition and structure parameters of the vegetation. A total of 18 species, equal for generas have been identified belonging to 9 families and the locality of Meme is the most diverse. The most frequent species are *Acrostichum aureum*, *Dalbergia ecastaphyllum*, *Nypa fruticans* and *Rhizophora racemosa*. Also, *Rhizophora* spp. represents 83.49% and *Avicennia germinans* 14.83% of timber individuals inventoried. The diameter of the trees varies from 3.82 to 102.50cm, the absolute density of 144 to 2108 ind/ha, basal area of 7.03 to 52.34 m^2/ha and height of 3.82 to 37m. Statistical analysis of size distribution by the Newman-Keuls test showed significant differences between some localities that may be assigned to the topography, environmental parameters and to a lesser extent to human activities. The study parameters indicate a good degree of stand development.

Keywords
accompanying species, floristic composition, Ndian, nearest neighbour method, parameter structure

Patterns growth and herbivory in mangrove forests along latitudinal gradients and the consequences of nutrient over-enrichment

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Abstract

Mangroves are the foundation for heterogeneous ecosystems with complex differences in forest structure, biodiversity, biogeochemistry, and hydrology that vary at tidal, latitudinal, and regional scales. In addition to being under intense pressure from coastal development such as direct conversion to agriculture, aquaculture, and tourism, mangroves are threatened globally by climate change and nutrient over-enrichment. Based on a network of long-term fertilization experiments in mangrove forests that span latitudinal gradients in the Atlantic-Caribbean East Pacific (ACEP) and Indo-West Pacific (IWP), our goal is to determine if nutrient loading interacts with climatic differences to alter growth, nutrient dynamics, ecological stoichiometry, and trophic structure. We use latitude and tidal elevation as proxies for climate change and sea-level rise. Increased nutrients have significant effects on ecological processes that affect both mangroves and their fauna. Primary production is nutrient limited at all locations, but the nutrient limiting growth varies regionally and locally. Nutrient enrichment alters patterns of primary and secondary consumption in some but not all cases. Herbivory levels are comparable to values reported for other tropical forests. The fauna is characterized by endophytic specialists including miners, gallers, and borers. Latitudinal differences in herbivory emerge but are not the same for IWP vs. ACEP for all species or feeding guilds within a region. In the IWP, herbivory of *Avicennia marina* correlated significantly with latitudinal differences in air temperature, but not with nutrient availability or rainfall. In the ACEP, significant differences in feeding damage on leaves of *Rhizophora mangle* by the omnivorous mangrove tree crab, *Aratus pisonii,* across latitudinal and tidal gradients was correlated positively with crab density and forest productivity and negatively with damage imposed by herbivores. We found that a trophic cascade based on the complex size- and stage-structured population dynamics of *A. pisonii* plays a pivotal role in mangrove foodwebs in the Neotropics.

Keywords
effect size, folivory, loss of yield, shoot elongation, space-for-time substitution

Investigation of the population genetics of *Rhizophora mangle* (Rhizophoraceae) along the Brazilian coast using microsatellite markers

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Abstract

Mangroves are heterogenic environments composed by different animals and plants adapted to unique conditions such as variable salt concentration, flooding, and slimy and anaerobic soil. Although mangroves provide important ecosystem services (e.g. pollution filters, prevention of coastal erosion and flooding), and are used by many species of fish and crustacean as breeding and feeding habitats, human activities have destroyed ~35% of these forests in the world only during the last two decades. In spite of having the second largest mangrove area in the world, only three genera of angiosperms can be found in mangrove ecosystems, *Rhizophora*, *Avicennia*, and *Laguncularia*. The aim of this study was to investigate the population structure of *Rhizophora mangle* on the Brazilian coast. We developed 44 *R. mangle* consistent microsatellites primers, in which 19 were polymorphic. So far, five of these markers were used to study the population structure of three *R. mangle* populations from the Brazilian coast (30 individuals from Bragança-PA, 25 from Vera Cruz-BA and 35 from Cananéia-SP). Also, we calculated how much each *loci* was informative using the PIC calculator. The Fstat 2.9.3.2 software was used to calculate Nei's estimation of heterozygosity and Weir & Cockerham estimations. PIC values varied from 0.108 to 0.567. Fit, Fst and Fis. Genetic diversity is distributed between populations (Fst = 0.457) and it is lower within each population (Fis = 0.186). Therefore, the genetic differentiation between populations was higher than the differentiation within each population. These results were expected because of the geographic distribution of the mangroves where samples were collected. More microsatellite *loci* will be used to study the population dynamic of these *R. mangle* populations.

Keywords
Rhizophora mangle, genetic structure

Barcoding needs morphology and vice versa: the case of a new East African Sesarmid crab species

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Abstract

In 2003 a DNA-based identification system, founded on the mitochondrial gene, cytochrome c oxidase subunit 1 (mtDNA COxI), was proposed by Hebert and co-workers (2003) as a method for diagnosing species identification. Numerous studies validated this method demonstrating that congeneric species of animals/plants regularly possess substantial sequence divergence in their COI genes, generally higher that 2%. Notwithstanding, the method is bound to fail in some specific circumstances, indicating as, in our opinion, a DNA-based system must be firmly anchored within the knowledge and techniques of traditional taxonomy. Moreover, in the specific case of identifying hybrid species, due to the exclusively maternal inheritance of mtDNA, a system that also takes the nuclear genome into account needs to be adopted.

In accordance with this hypothesis, in this study we show the case of a new species of sesarmid found in Tanzanian and Kenyan mangroves of Ras Dege and Gazi Bay, respectively. The species, at a first sight, was morphologically identified as *Parasesarma lenzii*, described by Crosnier in 1965 for Madagascar. However, its genetic COxI-based comparison to *P. lenzii* specimen from Singapore revealed that our specimens did not belong to this species. In addition, based on the barcoding the collected specimens were genetically identified as *P. leptosoma*, although they looked morphologically very different from this species. Which were the reasons of these conflicting results? For resolving this question, we enlarged genetic comparisons to a total of twenty specimens of sesarmid crabs, mainly from East Africa. On the whole, three mitochondrial genes (COxI, and the large and the small rRNA subunit, 16S and 12S) and one nuclear gene (the rRNA 28S) were sequenced. The highest divergence values between species pair are generally associated to the COxI, while, conversely, the 28S is the most conservative: however, the opposite trend was recorded for the comparison between the new species and *P. leptosoma*. Results are also discussed in terms of phylogenetic relationships and speciation modality.

Keywords
Sesarmidae, systematic, mitochondrial DNA, nuclear marker, taxonomy

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New findings and current taxonomic uncertainties about Sesarmidae of East African mangroves

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Abstract

Sesarmidae is the most specious crab family present in the mangrove forests of the Old World. In addition, sesarmids are by far the most studied mangrove crabs from an ecological, ethological, physiological and population genetics point of view. Also the taxonomy and systematics of this taxon are extensively studied, combining morphological, morphometric and genetic tools.
As a result of this massive work, at present, the family Sesarmidae includes around 30 genera, some of them widely distributed throughout the Indo-Pacific area, and a large number of species. However, these numbers are subject to a rapid increase, since new species, as well as, new genera are frequently found. The rapidly growing taxonomic information about sesarmids, however, is pointing out the need for a revision of some existing genera, while the discovery of cryptic and pseudo-cryptic species also contributed to change the systematics of Sesarmidae. In this poster we will present the current classification of the East African sesarmid crabs, underlying the gaps in our knowledge about nomenclature and phylogenetic relationships.

Keywords
systematic, taxonomy, phylogenetic relationships, cryptic species

Robust baselines of mangrove extent do not exist for conservation policy

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Abstract

Conservation policies that financially incentivize the protection of ecosystem services require accounting mechanisms based on accurate data of ecosystem extent. Conservation may fail if uncertain 'evidence' is used to set inappropriate goals. However, an extensive literature review and statistical analysis shows that robust data does not exist for many ecosystems, especially mangroves. Instead, a huge range of uncertainty exists in mangrove statistics from different sources – such uncertainty means a solid baseline of mangrove loss cannot be determined. For example, estimates of Indonesia's mangrove extent differ between 24 237 km^2 (15% of global mangrove cover) and 40 000 km^2 (31% of global mangrove cover) within the same year. Also, predictions of mangrove loss in The Philippines vary from 0% per year to a decline in area of 12.44% per year. Due to such uncertainty, trends can be cherry-picked to bolster arguments that favour no, low or excessive conservation of mangroves. We identify four causes of information uncertainty affecting mangrove statistics: a) lack of robust monitoring methodology, b) lack of transparency when reporting secondary literature, c) data assumptions, and d) propagation of erroneous results through the literature. We require greater transparency and traceability when reporting mangrove area statistics, and greater collaboration between the academic and government researchers producing national-level mangrove estimates. A regional, standardized remote sensing methodology will allow, for example, ASEAN nations to rapidly assess their mangrove resources for their better protection, will increase the transparency of produced environmental statistics, and ultimately increase acceptance by decision-makers.

Keywords
deforestation, Landsat, REDD+, trend, uncertainty, UNFCCC

High-resolution mapping of mangrove topography and vegetation community structure

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Abstract

Mangrove vegetation establishment and spatial distribution is constrained by multiple physical processes such as tidal inundation frequency and duration (linked to surface elevation), as well as wave and current action. However, such constraints are site-specific, and few studies are able to rigorously quantify such relationships. We present a novel mapping methodology to investigate elevation/hydrology-vegetation linkages at Mandai, a 17 ha mangrove patch in NW Singapore. In summer 2011 a Nikon Total Station was used to construct a high-resolution topographic map of Mandai mangrove and the surrounding mudflat. This instrument has also recorded the position and elevation (at mm precision) of every tree in the mangrove forest above 5 cm dbh. Information recorded includes species, dbh and mortality. Overlaying both datasets in a GIS framework allows us to deduce relationships between vegetation patterns and physical parameters such as elevation and distance from shore. These novel datasets also have multiple future uses: 1) the high-precision elevation map and intensive vegetation distribution data are providing the base layers for a sea level rise vulnerability model of Mandai, 2) all mapped trees have been tagged, providing researchers with a rigorously studied permanent mangrove forest plot for long-term vegetation studies, and 3) mangrove restoration practitioners have been trained in this mapping protocol – it is planned to apply this methodology to restoration sites to predict where species-specific "Ecological Mangrove Restoration" will be most successful.

Keywords
elevation, restoration, Singapore, surveying, zonation

First structural and functional study of unexplored mangroves in the Iles Eparses, Southwest Indian Ocean

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Abstract

The Iles Eparses, literally scattered islands, are a collection of French overseas territories off the coast of Madagascar, Southwest Indian Ocean. Without permanent inhabitants and preserved from human activities, these remote islands, currently placed under a strict environmental protection policy, are of a considerable ecological interest. Privileged sites for marine biodiversity, the Iles Eparses constitute also a unique natural lab for mangrove, largely unexplored until now.
- On Europa Island (22°20' latitude north, 30 km^2), the mangrove ecosystem develops in very constrained conditions due to substrate characteristics and scarce arrival of freshwater. In this particular context and a reduced number of mangrove species, the mangrove establishes however in a wide range of facies, displaying an apparent imbalance between mangrove structure and functioning and current environmental context.
- On Juan de Nova Island (5 km^2), 600km further up north, it is very recently (2010) that mangrove has been discovered. Disconnected from the seaside, different mangrove communities exhibit very peculiar functioning and structural parameters, i.e. natural enrichment in nutrients and monospecific composition for each mangrove stand. On the other hand, if the *current* biodiversity of mangrove is poor on Juan de Nova Island (2 species), the *potential* biodiversity appears to be high since all mangrove species characteristics of the western Indian Ocean region are present among the strandline debris, including viable disseminules, deposited all around the Island.
Thanks to an interdisciplinary boat trip conducted by CNRS-INEE in 2011, we did have the opportunity to analyze for the first time mangrove ecosystem of the Iles eparses, from biodiversity, structural and functional points of view. Preliminary observations and results are exposed in this communication.

Keywords
environmental protection, ecological imbalance, mangrove discovery

Macrobenthos assemblages in Cameroonian mangrove forests. First evidence from the Wouri estuary, Douala

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Abstract

West African mangrove macrobenthos are understudied compared to other mangrove systems. Few studies address a comprehensive and inclusive monitoring of macrobenthos assemblages of these systems. Here, we aim to fill this gap by focusing on the Cameroonian mangroves surrounding Douala City in Wouri estuary. This forest is one of the largest systems along the West African coast and is probably also one of the most impacted given the vicinity to the fast developing Doula City often clearing mangrove trees for land use. We studied macrobenthos through a survey carried out at two sites near Douala city: Wouri bridge (WB) and Bois de Singes (BS). We used visual census focused on two of the main components of macrobenthos: crabs and molluscs. We identified the vegetation belts present in the mangrove and adjacent mangrove-associate vegetation where mangrove macrobenthos were present: three belts dominated respectively by *Avicennia* sp., *Pandanus* sp. and *Rhizophora* sp. in WB forest, and only one dominated by *Rhizophora* sp. in BS forest. Observation plots were made along these vegetation belts in order to characterize them at macrobenthos level. Several sesarmid species among crabs occurred in these belts and represented the genera *Perisesarma*, *Chiromantes*, *Metograpus*, *Armases* and *Sesarma* as well as two species of gastropods: *Pachymelania fusca* and *Tympanotonus radula*. No ocypodid crabs were found, which is in contrast with their presence in the East African mangrove systems. We also detected a crab species not yet described. Differences in macrobenthos assemblages were recorded between vegetation belts and sites, the latter probably due to different positions and age of the forest. For the mangrove associated *Pandanus* belt we recorded the highest presence of the crab *Chiromantes buettikoferi,* possibly a phytothelmic species since they seem dwell on leaf axes of *Pandanus*. This work represents one the first descriptions of macrobenthos assemblages for Cameroonian mangrove forest.

Keywords
mangrove macrobenthos, crabs, molluscs, Cameroon, Wouri estuary

Thermal response of mangrove macrobenthos: explaining processes in endangered coastal systems

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Abstract

Rapid climate change has a strong impact on marine ecosystems, through warming, acidification and hypoxia of sea water. Marine ectotherms are mostly affected by changes in temperature, which directly influences oxygen availability and the ability to utilize oxygen affecting their overall fitness. As a consequence, understanding the thermal response of organisms is crucial to forecast the effects of climate change on ecosystem functionality. Here we focus on the thermal tolerance of adult males, females and gravid females, of two mangrove ecosystem engineers inhabiting the East African mangroves, the amphibious crabs *Perisesarma guttatum* (Sesarmidae) and *Uca urvillei* (Ocipodidae). In order to assess their sensitivity to acute temperature fluctuations across a wide latitudinal gradient, we studied the thermal window of Kenyan and South African populations of both species. The metabolic rate, haemolymph oxygen saturation and heart rate were measured in the laboratory along a temperature ramp (17-37 °C) in water and in air. Additionally, we characterized the environmental temperature range which the animals are subjected to and compared this to their relative body temperatures. In order to evaluate the species sensitivity, we fit the environmental data with the thermal model constructed by our experiments. The results show different responses for sex in both species and particularly a stenothermic response in water compared to air, with a pronounced latitudinal effect, with the South African populations better adapted to lower temperatures than the Kenyan ones. Females with eggs show a higher metabolic rate than males and females with no eggs, representing the most vulnerable adult life stage. The results suggest that these subtropical mangrove populations are vulnerable to long-term increases in temperature, particularly because of reduced oxygen content in water as it warms. This is likely to lead to a loss of fitness with serious consequences for the persistence of such populations and the overall mangrove ecosystem functioning.

Keywords
climate change, aerobic scope, ecosystem engineer, ecosystem functionality, mangrove macrobenthos, fitness

Carbon stock assessment of a community-initiated mangrove plantation in Banacon Island, Bohol, Philippines

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Abstract

Restoration of degraded mangroves has significant role in climate change mitigation particularly in carbon absorption. In Bohol Province, Philippines, a small coastal island community named Banacon has initiated a mangrove amelioration project in late 1950s upon recognizing the problem of dwindling wood supply for fuel and house construction. From barely 15 hectares of limited land, the local people of Banacon had successfully developed 1,715 ha of *Rhizophora stylosa* plantations along the degraded coasts of their island despite of limited technical and financial support from the government. This effort therefore led to the recognition of Banacon as one of the largest man-made mangrove forests in Southeast Asia and recipient of the Philippine Wetland Conservation Award in 2003. Recognizing the potentials of these plantations towards incentive-based conservation mechanisms such as the payment for environmental service (PES) project, carbon stock assessment was done. Using standard sampling techniques and allometric equations designed for mangrove trees, aboveground carbon density was measured across stand ages namely, 15, 20 and 40 year-old plantations. Mature natural stands were also included in the assessment. On the average, 40 year-old plantation has the largest estimate with 370.7 ton ha^{-1}, followed by 15 year-old plantation with 208.5 ton ha^{-1}, then by natural stand with 189.7 ton ha^{-1}, and lastly with 20-year old plantation with 174. ton ha^{-1}. Surprisingly, the 15-year old plantation has larger carbon stocks than 20-year old and natural stands which can be attributed to lesser utilization being done in this particular site. Overall, mangroves of Banacon store huge amount of carbon. Local community should therefore continue to participate in reforestation activities and forest management planning in order to sustainably manage these stands.

Keywords
bakauan, best practice, coastal rehabilitation, forest conservation, local community

Status of mangroves of the Sundarbans: some ecological observations

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Abstract

Mangroves are typical halophytic trees and shrubs which grow in the inter-tidal and adjacent saline communities of the tropics and subtropics. They may grow throughout the tropics in suitable areas, particularly the estuaries of large rivers that run over a shallow continental shelf, e.g. the mouths of the Ganga and Brahmaputra rivers (the Sundarbans). The original area of the undivided Sundarbans towards the end of nineteenth century was about 20,500 sq. km. In recent estimates, the area of the entire Sundarbans has been reduced to only 8373 sq. km which is distributed as 4264 sq. km in India and 4109 sq. km in Bangladesh. The Indian Sundarbans is bounded by Hooghly on the West and Ichamati - Raimangal - Harinbhanga on the east. About 34 true mangrove species belonging to 22 genera and 16 families occur in the Sundarbans. In an empirical study on a small island Lothian of the western Sundarbans indicates that tidal inundation significantly effects density of five species, namely, *Avicennia marina, Ceriops decandra, Excoecaria agallocha, Phoenix paludosa* and *Suaeda maritima,* which has a significant impact on biomass production. Sites having infrequent tidal inundation produce low biomass. *Avicennia alba* concentrates in the northern coastal tip of Lothian Island while *A. marina* is densely populated throughout the coastal areas. *A. officinalis* does not show any particular trend, the density is high at few spots. The middle and southern portion of the island show the densely populated components of the mixed vegetation i.e. *Aegiceras corniculatum, Aegialitis rotundifolia, Ceriops decandra, Excoecaria agallocha, Phoenix paludosa, Sesuvium portulacastrum* and *Suaeda maritima.* Very high concentration of soil salinity is observed in the northern tip, high up to the middle portion of the island and low in the southern region. All most all the soil nutrients except potassium are concentrated in the northern region of the island.

Keywords
Sundarbans, biomass, tidal inundation, soil nutrients

Biology of crab embryos in mangrove forests: from evolutionary trends to climate change perspectives

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Abstract

The knowledge of natural systems require an integrated and extensive understanding in order to better disclose all single components and the network of associated processes. Moreover, with the aim to assess the mechanisms of ecosystem functioning and the resilience and vulnerability in the light of current trend of climate change, becomes essential to address our focus on the most sensible but crucial features. In this light, to extend our knowledge on mangrove ecosystem, we extensively investigated the biology of early ontogenetic stages in a key-stone taxa of mangrove macrobenthos, the brachyuran crabs. We performed a meta-analysis on 159 species from deep-water to terrestrial crabs using the level of terrestrialization, size of crabs, number of eggs, size of clutches and larval strategies as factors. We demonstrated that the embryos of terrestrial species have shifted to air-breathing, overtaking the problem of water viscosity within the masses and that the egg size evolution is solely dependent to the larval retention strategies, regardless of their degree of terrestrialisation.

We selected Sesarmidae as a model family and, for the first time, we compared air and water respiration of developing embryos. Data from eight sesarmid species show a clear landward trend in air-breathing, with more efficient oxygen extraction in air respect to water in the more terrestrial species, confirming that an adaptation to air respiration is present also in early ontogenetic stages. Besides, we assessed and compared the thermal tolerance of the eggs and larvae of two mangrove brachyuran species, *Uca urvillei* and *Perisesarma guttatum* at mid and low latitudinal ranges to make prediction over the whole species resilience in the context of global climate change. With this contribution we want to underline the importance of a wide-ranging life history approach for the understanding of essential process in complex ecosystems as the mangrove forests.

Keywords
crabs, embryos development, parental care, climate change, life history, adaptive strategy

Above ground: Below ground productivity ratios in natural mangrove forest of Gazi Bay, Kenya

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Abstract

Mangroves, a land-ocean interface ecosystem occupy only 0.4% of forested areas globally but among the most productive ecosystems on earth accounting for about 11% of the total input of terrestrial carbon into the oceans. The above ground carbon stock in mangroves has been estimated to be as high as 8000 g C/m^2; with similar figures reported for below ground components. In the context of climate change mitigation and carbon offset, there is need to estimate rates of carbon sequestration and storage across major carbon sinks. In this study in-growth cores and tagging techniques were used to estimate rates of roots and shoot productivity. For above ground productivity, tagging of shoots methods combined with measurements of stem diameters was used. Periodic measurements of environmental variables across the zones were also done. This study provides estimates of below and above ground productivity which can be used as a proxy for estimating the sequestered carbon. Among the four forest zones, *S. alba* had the highest productivity: 10.3 ± 0.7 t ha^{-1} yr^{-1} while *Ceriops tagal* had the lowest productivity 2.6 ± 0.8 t ha^{-1} yr^{-1}. There was significant difference in above ground productivity across zones $p = 0.001$, df = 5 and a significant difference in below ground productivity across zones $p = 0.035$, df = 5 while total productivity between zones is highly significant $p = 0.01$,df = 5. There was a positive weak correlation between below ground and above ground productivity ($R^2 = 3.9$ %). Results of this work will be used to model long-term carbon capture and storage in the mangrove forest of Gazi Bay. This model will give more accurate estimates of carbon stocks that would be available for sale through the voluntary carbon markets. The results are compared with similar studies elsewhere in the world.

Keywords
productivity zone, carbon stock, core and tagging

Forest composition and structure in the mangroves at Matang, West Peninsular Malaysia, after a century of sustainable management

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Abstract

The Matang Mangrove Forest Reserve (MMFR) on the West coast of Peninsular Malaysia is managed for more than a century and is a perfect example showing that mangrove forests can be sustainably exploited for wood production. The present work was aimed at assessing silvimetric parameters in forests of different ages in order to provide additional guidelines, if any, on the management of mangroves in this vicinity. Different parameters such as the diameter, height, density and biomass were thus measured in three different aged stands: fifteen (MF15), twenty (MF20) and thirty years old (MF30). In addition, the Virgin Forest Reserve (VFR) was used as a control as this forest has not been exploited for at least 80 years. Since *Bruguiera parviflora*, *B. cylindrica*, *Rhizophora mucronata* and *Excoecaria agallocha* do not constitute a significant proportion of the stand density (less than 5%); the results of this study only focus on *R. apiculata*. This study shows that the management of the MMFR can be improved by conducting the artificial thinning earlier in order to limit the losses of exploitable wood due to natural thinning. Indeed, the tree density dropped from 6726 trees ha-1, the initial stocking, to 2204 trees ha-1 in the MF15. Thus, there has been a loss of about 67% of the trees before the first artificial thinning. These trees, although having small diameters, could have been exploited for specific purposes. In addition, the initial density of seedlings should be reduced in order to avoid a waste of seedlings and to increase wood production. Finally, it appeared that in some scientific articles, there is a confusion between the number of trees ha-1 and the number of stems ha-1, considering respectively multiple-stemmed tree as a unique tree or each stem of a multiple-stemmed tree as a separate tree. This could lead to erroneous conclusions and therefore it is important that researchers wisely use these terms.

Keywords
sustainable management, Matang, Malaysia, plot-based method, density, size distribution

Stand structure and carbon stocks in a *Pelliciera rhizophorae* dominated mangrove forest in Montijo Gulf Ramsar site, Panama

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Abstract

Better assessment of different mangrove forests is needed to quantify global mangrove carbon stocks. Furthermore, the Ramsar Convention on Wetlands has made it one of its priorities to encourage the participating parties to work on the assessment of mangrove carbon sequestration and storage capacity. Forest structure and carbon stocks were examined in a *Pelliciera rhizophorae* dominated mangrove forest in Montijo Gulf Ramsar site, Pacific Coast, Panama. Three 20 by 20 m plots were set up along three 200 m long transects extending from the river to the hinterland. A forest inventory was conducted including the measurement of tree height and diameter of stems (D130) for all trees with a diameter greater than 10 cm. In 5 by 5 m subplots all trees with a diameter between 2.5 and 10 cm were recorded and measured. Above- and belowground carbon stocks were estimated using existing allometric equations. Despite comparatively low species diversity (*P. rhizophorae*, *Rhizophora racemosa*, *Avicennia germinans* and *Mora oleifera*) there was a considerable variation in forest structure. *Pelliciera rhizophorae* dominated the plots located closer to the river with tree densities (> 10 cm diameter) between 350 and 1200 trees ha^{-1}. Further inland, species composition shifted towards a *R. racemosa* dominated forest. Across all plots *P. rhizophorae* was smaller in diameter and height than *R. racemosa*. Aboveground carbon stocks varied fourfold among plots, from 40 Mg C ha^{-1} to 160 Mg C ha^{-1} (average: 88 Mg C ha^{-1}). Average belowground carbon stock was 33 Mg C ha^{-1}. Lower carbon stocks of *P. rhizophorae* are explained by lower diameter and height but also by a lower wood density compared to the other species. The amount of carbon stored in this *P. rhizophorae* dominated mangrove forest, located within the Montijo Gulf Ramsar site, is within the range reported for other mangrove forests in Central America and the Caribbean.

Keywords
carbon storage, biomass estimation, mangrove forest structure, diameter-height-curves, allometry

Mapping Functional-Structural Models to Fields of Neighborhood

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Abstract

Morphological plasticity of mangroves is unrivaled within the plant kingdom. After forest degradation due to changes in hydrology, mangrove trees recolonising such areas often tend to exhibit a shrub-like architecture. Subsequent tree generations, however, may shift back to tree architecture thereby re-establishing the functionality of a forest.

Due to its complex nature this morphological plasticity as well as the consequences for forest regeneration are best studied using simulation models. However, since current mangrove models are not taking into account morphological plasticity, we propose here a functional-structural modelling (FSM) approach, which has proven successful at incorporating structural detail on other species.

We have adopted major routines from the Universal Individual-Based Model (UIBM), which was originally developed for constructing plant species from trait databases. Due to a lack of a traitbase for mangroves, we chose the species with the best trait information available, i.e. *Rhizophora apiculata*, as template species.

The developed FSM simulates the annual growth of a pair of *Rhizophora apiculata* trees at competitive distance. The aboveground structure is simulated using phytomers comprised of an internode, foliage and a set of meristems. At the whole organ level carbon partitioning is driven by allometric relationships, whereas at lower level partitioning is dependent on apical dominance and branching order. Incorporated functions include: photosynthesis, respiration and organ ageing/death.

Due to the level of physiological processes described by the model, FSM is computationally expensive and not well suited for simulation of larger numbers of trees. FSM results for varying tree distances are therefore used to parameterize the field of neighborhood underlying the well-known KiWi mangrove forest model. In the context of this modelling effort, but also because of the ongoing interest in the FON approach in general, we have made the KiWi model open-source (kiwi.sourceforge.net).

Mapping FSM to FON allows us to scale up effects of morphological plasticity to the forest stand. Once a mangrove traitbase is available FSM-FON mapping can develop into a general approach for modelling multi-species mangrove forests.

Keywords
morphological plasticity, functional-structural model, FON, KiWi

Excluding random walks in the foraging behaviour of the Portunid crab *Thalamita crenata*: modelisation and simulation based on real data

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★Equal contribution

Abstract

Thalamita crenata is a portunid crab present in a wide range of mangrove swamps in the Indo- Pacific region. In Mida Creek (Kenya) it is living on the intertidal flat in front of the *Sonneratia alba* mangroves. *T. crenata* has a home range of approximately 5 m and is able to return to its home burrow based on visual cues and underwater landmark memory, as evidenced by previous studies. We analysed different paths walked by *T. crenata* and investigated distances, distance ratios and directions. This paper was not meant to confirm or reject the ability of *T. crenata* to home, but to exemplify how during previous research undertakings we were able to reject the hypothesis of the species' random walk behaviour by simulating the behaviour of "random crabs". To exclude random behaviour we programmed different model versions that resampled observed 'turning angles' (0 – 23°) and 'flight lengths' (0 – 69 cm) *at random* (called semi-random) or that used the full ranges (360° turning angles and up to flight lengths of 2 m). Observed angles and flight lengths relied on detailed *in situ* recordings of foraging behaviour of real crabs. Using traditional and circular statistics we provided evidence of significant differences between the real and the random crabs for the distance to the home burrow as a function of distance from an experimental release point resulting from a dislocation of 5 m, for the ratios of total distance covered over shortest straight distance (the 'straightness index'), and for the homeward components, which reflect clustering around a certain direction. The simulation program that we used was written in NetLogo and analysis performed using NetLogo's BehaviourSpace and R-extension.

Keywords
Portunidae, random walk, circular statistics, NetLogo, R-extension, Kenya

Distribution of mangrove species: effects of environmental variables

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Abstract

Mangroves are the rainforests by the sea and vital for healthy coastal ecosystems. Sundarbans shelters one of the most important mangrove communities of the world. The present investigation reports the distribution of mangrove species in relation to various edaphic and tidal factors. Species density, soil physico-chemical parameters and tidal inundation were explored in 40 different sites of the Lothian Island in the Indian Sundarbans. It is a small island of nearly 38 sq. km. area. Total twenty-one species (13 true mangroves and 8 mangrove associates) are recorded. One-way analysis of variance (ANOVA) revealed that tidal inundation significantly affects the density of five species. Stepwise regression of species densities with soil parameters accounts for a variation of 42% or higher. Calcium, phosphorus, nitrogen, pH, salinity and sand are important soil parameters explaining the maximum variation in species densities and therefore selected for further gradient analysis. It is revealed that species like *Aegiceras corniculatum*, *Avicennia alba* and *Heritiera fomes* have restricted distribution along these gradients, while *Avicennia marina* has wider amplitudes, being insensitive to the gradient. Maps predicting species densities and concentration of important soil parameters throughout the island were prepared with Arc GIS 8 software using a statistical method named 'kriging'. Prediction maps show very high soil salinity in the northern mudflat region where *Avicennia alba* forms a distinct monospecific seaward fringe. No other distinct zone is recognized in present investigation. A majority of the species are concentrated in the middle and southern-ridged portion of the island. It can be concluded that *Avicennia marina* has the widest ecological amplitudes; hence it does not require much site selection during reforestation programs.

Keywords
ANOVA, stepwise regression, ecological amplitude, prediction maps

Bioremediation and mangrove: an original method for wastewater treatment

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Abstract

The use of mangrove as natural domestic wastewater treatment is currently proposed as an alternative solution applicable to the tropical littoral regions. Characterized by high productivity, mangrove trees have a natural ability to absorb nutrients in excess, without any apparent functional or structural disturbances. Mayotte, (French Island, Indian Ocean), is surrounded by a vast lagoon sheltered by mangrove forests. The recent population increases have lead to a strong degradation of the environment, associated to productions and diffusions of untreated wastewater in the lagoon.
In this context, a pilot project was designed, (i) to estimate domestic wastewater remediation capacities of mangroves and (ii) to protect this ecosystem with strong ecological and patrimonial values. The originality of this work relies essentially on the development of a new technique of purification, based on the filtration capacity of mangroves, adapted to the tropical insularity.
After 18 months of experiment, the supply of domestic pretreated wastewater on mangrove ecosystem resulted in an increase of mangrove trees growth and an increase of photosynthetic pigment concentrations, correlated with a higher photosynthetic efficiency. The structure and activity of crab populations, engineer species of mangrove ecosystems, did not seem to be affected by wastewater supplies. The analysis of nitrogen kinetic through 15N isotopic tracing showed that nitrogen is absorbed by mangrove trees (*Ceriops tagal* and *Rhizophora mucronata*), preferentially under the form of NH4, which is the main form in domestic wastewater.
Taking into account these results and other data and experiments not presented here (water and sediment analyses, bacteriological characterization), mangrove ecosystems seem to be efficient as domestic wastewater treatment on the short term. Additional experiments and long term surveys are required to fully evaluate the wastewater impact on mangroves and the remediation capacity of this ecosystem.

Keywords
ecoremediation, ecological engineering, wastewater, mangle, pilot site

Desolation of the mangroves forest: a case study of Indus River Delta, Pakistan

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Abstract

Degradation of river Mangroves forest of Indus delta is constantly rising since last two decades. Covered area of the mangroves forest is reducing. Fishes and wood of Mangroves forest are economic sources of the Delta. An average annual production of Mangroves trees, agriculture commodity and fruit are gradually reduced. An acre of delta mangroves is three times more economical than an acre of agricultural land. Coastal Mangroves forests are protective wall from *soil erosion*, *tropical Cyclones*, *Tides, Waves* and *Tsunamis*.
According to a research that Salinity at the mangrove forest has reached 3.8 to 4.2, percent but on the contrary Salinity of Arabian Sea is 3.6 percent. Salinity of water near the coastal area of the Karachi is at 35,500-to -36,900 Parts per Million (PPM) and has increased to 41,000-to-42,000 PPM in back waters and tidal creeks. More than 1,200,000 acres of the delta is now under threat the of brackish water intrusion. Currently about 550,000 acres of fertile land of both coastal districts are under affect of saline water. About 38% area of Indus river mangroves forest has been reduced.
But now situation is entirely change. Due to climate change sea level of Arabian Sea is continually rising; the brackish water of Arabian Sea is increasing on surface and sub-surface area of the delta. So the fertile soil of the Delta is converting onto infertile soil. Construction of different water reserve projects on the River Indus are main cause of the shortage in River Indus. People are migrating from the area, the study shows that availability of fresh water in the River Indus may push backward to the intrusion of brackish water of Arabian Sea and will helps for the survival of the fruit plants, agriculture land, natural fishing hatchery and mangrove forests.

Keywords
desolation, mangroves forest, Indus River delta, Pakistan

Marketing the mangroves: can carbon payments make conservation work?

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Abstract

Payments for ecosystem services (PES) schemes offer a new way to help conserve valuable habitats, including mangroves. Their proponents argue that they can help correct market failures and incentivize sustainable management of public resources. Their critics accuse them of commodifying nature and of allowing appropriation of commonly owned areas by governments or private interests. This paper presents a case study of the early development of a community level mangrove PES scheme at Gazi Bay, Kenya. The scheme, called Mikoko Pamoja, is based on payments for carbon offsetting and is among the first in the world to receive accreditation. The paper looks at the key technical challenges that were considered in establishing Mikoko Pamoja and the areas of ignorance that remain, including sources of uncertainties in the carbon fluxes and risks of leakage and carbon losses over time. It also considers the social and political challenges that were encountered and the prospects for similar schemes both locally and at larger scales (through for example the REDD + process).

Keywords
carbon, payments, REDD, leakage, additionality

Risk coping strategies of small-scale fishing communities in the Sundarbans mangrove forest in Bangladesh: implications for poverty reduction and resources sustainability

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Abstract

Drawing from a case study on small-scale fishing communities in the Sundarbans mangrove forest in Bangladesh, the present study identifies the risk factors affecting fisher's livelihoods, how they cope with different covariate and idiosyncratic shocks, what implications these strategies have on the well-being of the fishers and resources sustainability of the forest. The findings show that, fishing in the forest is inherently risky and mangrove fishers face unsettling shocks that is emanated from both natural and anthropogenic sources. In absence of effective buffer against crises, ongoing risk exposure and recurrent shock is the major cause of poverty in the fishing communities that in turn contributes to the resource degradation. In this study, we argue that minimizing risks exposure and creating buffer for small-scale fishers is vital in pursuing the twofold goals of poverty reduction and resources sustainability in the Sundarbans.

Keywords
small-scale fishers, Bangladesh, Sundarbans, risk, poverty

A study on the impact of anthropogenic activities on the sustainability, habitat preference and distribution of bird fauna associated with mangrove reserve in Kadolkele, Negombo, Sri Lanka

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Abstract

Habitat preference of birds in a disturbed mangrove ecosystem was investigated for a period of four months in seven different habitats dominated by *Excoecaria* spp., *Avicennia* spp., *Rhizophora* spp., *Lumnitzera* spp., Grasses, mangrove associates, garden vegetation and pond habitats. Bird counts were taken three times a day; morning, afternoon and evening at each site 2 days per week for 6 weeks. Sixty species of birds were identified and composed of re- resident birds (80%), re-vagrants 8.33%. No winter visitors were observed. A significant proportion of the birds are Resident (80%) and Common (90%) birds and the House Crow, *Corvus splendens* was the most abundant species (50.53%). Only one endemic bird (Sri Lanka Junglefowl- *Gallus lafayettii*) was found in the area. Order Passeriformes was the most prominent (33.3% of species) and highly abundant (75.60%) order of birds. Highest abundance and species richness were recorded from *Avicennia* zone followed by the pond habitat. The closeness to the human inhabited area could have an impact on the distribution pattern and abundance of birds in this habitat. *Avicennia* zone was the most preferred area by the birds followed by pond habitats while least preferred habitat was the grass and *Lumnitzera* zone. The study revealed that the disturbed mangrove environment is dominated by common resident birds.

Keywords
mangrove birds, Negombo estuary, habitat preference, sustainability, anthropogenic

Comparison of population structures of widely distributed sea-dispersal plants with mangrove species

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Abstract

"Pantropical Plants with Sea-drifted Seeds" (PPSS) are characterized by their extremely wide distribution ranges over littoral areas of the tropics over the globe. A small number of species from some families are known in this plant group, and their wide distribution ranges have been thought to be formed by long distance seed dispersal by ocean currents. To clarify how this intriguing distribution patterns have been maintained, we studied some representative species of PPSS, namely, *Hibiscus tiliaceus* (Malvaceae), *Canavalia rosea* (Fabaceae), *Ipomoea pes-caprae* (Convolvulaceae) with *Rhizophora* (Rhizophoraceae) that is a widely distributed mangrove genus. Using samples obtained from wide range of distribution range, we investigated genetic structures of these species using some molecular markers. Comparing results obtained from the species, common phylogeographic patterns were observed. Firstly, analyses of chloroplast DNA sequences showed that a few common haplotypes distributed over very wide range, sometimes over different oceanic regions. This result suggests that long distance seed dispersal by ocean currents was responsible to maintain the extremely wide distribution range of PPSS and *Rhizophora* species. Secondly, genetic structures were observed between populations over the East Pacific and over the American continents in some analyses. Both the wide ocean space and continental land mass can be barriers to prevent gene flow by sea-drifted seeds. Thirdly, some PPSS species as well as *Rhizophora* species shared common haplotypes with their closely related species. Secondary contact between species and their sister species can be a force to increase the genetic diversity of the sister species. Although population structures were similar between PPSS and *Rhizophora* species, phylogenetic history was deeper in *Rhizophora* than in other PPSS species.

Keywords
comparative phylogeography, pantropical plants with sea-drifted seeds

Formation of a research network for conservation of genetic diversity of mangroves: knowledge gaps, studies, and future directions

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Abstract

There is a general consensus that major mangrove species are widely distributed in the tropical and subtropical regions. However, the status of genetic diversity of mangroves is still relatively unknown. In the last 25 years, mangroves have been devastated at an alarming rate (1-2% yr^{-1} in Asia in 1990s) prompting several rehabilitation programs. Both mangrove degradation and planting activities can disrupt and alter natural gene flow, thus, threatening genetic diversity even before it is studied. In an attempt to shed knowledge on genetic diversity of mangroves, the Chiba University in collaboration with its international partners, initiated mangrove sampling primarily in SE Asia as well as in some parts of the Atlantic-East Pacific (AEP) since the early 2000s. An international network for conservation genetics of mangroves was launched in February 2010 supported by Japan-East Asia Network of Exchange for Students and Youths (JENESYS) Programme promoted by the Japan Society for the Promotion of Science (JSPS). The network aims to provide a global scale understanding of the genetic diversity of major mangrove species. To date, samples totaling about 30 populations for 6 groups of major mangroves were collected. Our collection is composed of 30 individuals from one population representing one population per 1,000 km^2. We used molecular methods such as cpDNA and nucDNA sequencing in analyzing the phylogeography, speciation, genetic structure and distribution patterns of some major mangroves (e.g. *Rhizophora*, *Bruguiera, Xylocarpus* and *Sonneratia* spp.). We have also developed SSR markers using genomic data obtained by Next Generation Sequencing techniques, and started studies to investigate gene flow between populations and population differentiation in finer scale. In the future, we aim to strengthen the network through biannual workshops, collaborative international research, and co-publications.

Keywords
population structure, comparative phylogeography

Seasonal changes in macrobenthos at Basatin mangrove creeks, Bay of Nayband, The Persian Gulf, Iran

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Abstract

This study was aimed at examining the seasonal changes in macrobenthos of Basatin mangrove creeks in Bay of Nayband, for one year from July, 2010 to May, 2011. The faunal samples, in three replicates, were collected through sieving from 25 × 25 cm2 quadrates at three stations in mouth, middle and end of creek. A separate portion of sediment was collected and analyzed for textural and total organic content in each station. The environmental parameters such as water temperature, salinity, pH and dissolved oxygen were also measured by a Horiba multi-probe.
Altogether 33 macrobenthic species (belonging to four phyla) were collected and identified of which Gastropoda dominated the population (11 species), followed by polycheates (9 species), crustaceans (7 species), and Bivalvia (6 species); however in summer, the most abundant macrobenthic was *Paphia galus* from Bivalvia at 2096 individuals/ m^{-2}.
The sediment was composed of fine sand (90.2%) in the mouth of Basatin creek and silty-clay (67.7%) in the end of it.
The correlation between physic-chemical parameters and faunal abundance was tested with Pearson correlation and indicated that pH was significant ($P < 0.05$) in controlling the distribution of macrobenthic species encountered.
Results of biodiversity indices revealed that the higher average of Shanon index belong to Gastropoda in Autumn season and in the mouth of creek (0.961) otherwise Simpson index belongs to bivalvia and Summer season and the mouth of creek (0.584) and Margalef index belongs to Bivalvia but in Autumn season and in the end of creek (16.61). The construction of small bridges was impacted on abundance and distribution of macrobenthos into Basatin mangrove creek.

Keywords
macrobenthos, Basatin mangrove creek, Bay of Nayband, The Persian Gulf

Carbon sequestration potential of mangroves and their sediments in southeast coast of India

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Abstract

Mangroves are among the most carbon-rich forests in the tropics. We have studied the carbon sequestration potential of *Rhizophora mucronata* and *Avicennia marina* as influenced by age, season, growth and sediment characteristics as well as the impact of mangrove vegetation on seasonal carbon burial in southeast coast of India. The data reveals that *A. marina* performs better to display 75% more in rates of carbon sequestration potential, than *R. mucronata* does. In addition to biomass carbon, the mangrove sediment is also high in the levels of carbon, as compared to barren non-mangrove soil. The total carbon is 98.2% higher in mature mangroves and 41.8% in planted mangroves than that in non-mangrove barren soil; and the total organic carbon was as high as 2.5-fold in mature mangroves, 2-fold in planted mangroves as compared to un-vegetated soil. The levels of carbon do exhibit seasonal variation. In general, pre-monsoon and post-monsoon have high levels of carbons as compared to the extreme seasons do. Mangrove forest biomass and sediment is important sink of carbon within the tropical coastal zone, but increasing soil temperature due to global warming will have a negative impact on the carbon sequestration potential of the mangrove habitat as evident by the negative correlation between temperature and carbon sequestration potential of mangrove system. This work reveals that the carbon burial is rapid at the annual rate of 2.8% for total carbon, and 6.7% for total organic carbon in the mangrove-planted sediment. Clearing of mangroves can rapidly result in significantly reduced carbon stores and hence the present work has reiterated the importance of mangrove vegetation and its planting efforts for conserving the sediment carbon and as a counter-measure of mitigating the climate change in the tropical coastal domain.

Keywords
organic carbon, mangrove sediment, carbon burial, *Rhizophora*, *Avicennia*

Reproductive biology of the most-at-risk mangrove species (*Rhizophora annamalayana*) and its parental species

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Abstract

Rhizophora annamalayana is a natural mangrove hybrid, derived from *Rhizophora apiculata* and *R. mucronata*, and it is the only endemic species of Indian mangroves confined to Pichavaram mangrove forest of Tamil Nadu. This species is extremely poor in producing propagules, thereby making its propagation difficult. There is an urgent need to recover the species from fast disappearance. Hence, further research is at progress to find out the causes for the extremely poor fruit setting and the ways to overcome the difficulty. Daily growth of floral bud was 40µm in *R. mucronata*, 30µm in *R. annamalayana* and 20µm in *R. apiculata*. From bud initiation to flower, the time taken was 28 days in *R. apiculata*, 24 days in *R. annamalayana* and 21 days in *R. apiculata*. From flower opening to fertilization, the duration took 59 days in *R. annamalayana*, 55 days in *R. mucronata* and 47 days in *R. apiculata*. From fertilized flower to produce mature hypocotyls, the time taken was 45 days in *R. apiculata* and 110 days in *R. mucronata*. The period taken for development from bud primordium to maturation of the hypocotyls was 178 days in *R. mucronata* and 128 days in *R. apiculata*. Hypocotyls elongated at 1.62 mm day^{-1} in *R. mucronata* and 4.1 mm day^{-1} in *R. apiculata*. Anthesis and anther dehiscence took up to 5 days in all three species. Stigma receptivity peaked during anthesis; receptivity was lost within 8h in *R. annamalayana* and *R. mucronata*. *R. annamalayana* exhibited only 3% of viable pollen and it was 100% in *R. mucronata*, 53% in *R. apiculata*. *Lucilia caesar* is the most probable pollinators of *R. mucronata*. Flies such as *Monobia quadridens* and *Vespa tropica* and butter fly like *Ocybadistes walkeri* are confined to flowers of *R. annamalayana* facilitating cross-pollination. In *R. apiculata,* anthesis occurred inside the flowers, confirming the condition of cleistogamy.

Keywords
Rhizophora annamalayana, mangrove hybrid, endemic species, phenology, pollination

Testing mangrove forest structure development and various forest management options in Gazi (Kenya) by combining KiWi individual-based modelling with >20 years of field data

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Abstract

Recurrent data on mangrove stand development are rare because long-term monitoring data is generally lacking. However, in Gazi (Kenya), several plantations of *Rhizophora mucronata*, *Ceriops tagal*, *Avicennia marina* and *Sonneratia alba* have been established and monitored since 1990. We used KiWi, an individual-based model to hindcast the development of some of these monospecific stands planted at regular intervals, and we used field data on plant development and floristic recruitment under natural conditions to parameterize the KiWi model for each species. Next, starting from the conditions used for planting mangroves in Gazi, we investigated densities and basal areas of planted species as well as the non-planted species that were recruited naturally at different time intervals. We then compared the development of planted forests with or without recruitment and with or without thinning as a forestry approach to management. This study uses a unique combination of field data analyses with simulation experiments in order to demonstrate the mangrove stand development and investigate various forest management options over time. Such information is important for effective mangrove restoration and management.

Keywords
monospecific, restoration, forest management, IBM, ABM, prediction

How does tree competition and stand dynamics lead to spatial patterns in monospecific mangroves?

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Abstract

Information on mangrove succession and stand development is rare because long-term monitoring data is often lacking. Such information is important in order to plan management measures effectively. Novel approaches are required to bridge this gap of knowledge based on existing data sets. This study uses a unique combination of field data analyses with simulation experiments in order to demonstrate how information on mangrove dynamics can be extracted if data is sparse. The paper provides a baseline characterization of stand development in a monospecific pioneer mangrove stand of *Kandelia obovata*. Point pattern analyses revealed that self-thinning has started but has not yet lead to a regularity of spatial tree distribution in the entire stand; trees located in smaller clumps hinder each other in growth but do not lead to a significant size class differentiation in 10 years. However, after ca. 2 decades this size class differentiation starts to become visible. In order to understand and predict the future stand development, simulation experiments were carried out by means of the individual-based model KiWi which was parameterized to Far East Asian mangroves for the first time. It was found that the total biomass production per unit land area is not influenced by the initial density, but is determined by the relative mortality rate and increasing regularity in the spatial distribution pattern of individual trees.

Keywords
IBM, ABM, intraspecific competition, KiWi, point pattern analysis, self-thinning, *Kandelia obovata*

Mangrove habitat suitability under climate change in the Bay of Bengal rim

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Abstract

Mangroves are widely recognized as one of the vital ecosystems to foster climate change adaptation and mitigation. However, changing climate itself poses threat to these protective mangroves. Future mangrove conservation plans is in need of information on how mangroves will respond to climate changes. With predicted change in precipitation pattern, temperature regime and other resultant effects the habitat suitability of the mangroves will be altered under changed climate. To envisage the impact, datasets of present extent of mangroves and the current climatic and physical setting along the Bay of Bengal coast were incorporated in MaxENT software to model suitability of mangrove habitats. The trained mangrove suitability model was then projected under IPCC SRES A2 and B2 climatic scenarios at 2020, 2050 and 2080. Outputs of two different climate models CCCMA and HadCM were used to account for variations in climate prediction. The outputs of the projection were processed using DIVA-GIS software to produce interpretable maps. For HadCM outputs, the mangrove habitat suitability, compared to current extent, was estimated to be reduced to less than 30% by 2020 and almost diminished to 0% by 2050 for both A2 and B2 scenario. However, for CCCMA outputs, the suitable mangrove area reduction was estimated to be 45% and 55% under A2 and B2 scenarios respectively by 2020; And by 2080, the suitability was reduced to 25% to 2-3% respectively for B2 and A2 scenarios. Though significant decline of mangrove area was predicted, the environment friendly B2 scenario is better for mangrove habitat suitability. Change in precipitation pattern was inferred to be most significant contributor to this diminishing trend of mangrove habitat suitability. With careful considerations for local conditions, the outputs of this study can be used to support decision making regarding mangrove conservation, coastal zone management and climate change adaptation as a whole.

Keywords
climate change, Bay of Bengal, MaxENT

Effect of industrial waste on early growth and phytoremediation potential of *Avicennia marina* (Forssk.) Vierh.

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Abstract

Discharge of industrial waste in streams, river and coastal areas may alter the physical and chemical properties of water, which may affect the growth of mangrove. Therefore, it was anticipated that if these wastes used as organic substitute on mangrove species *A. marina*, what will be the response of this species against particular industrial waste. For this purpose a greenhouse study was conducted to measure the effect of industrial waste on seed germination and growth rate of dominant mangrove species *Avicennia marina.* This study also evaluates the potential of *Avicennia marina* for Phytoremediation. Four types of industrial wastes were used to prepare polluted sea water. The results of the final germination revealed 90% germination in all treatment except ash and marble wastes. It was observed that Converter slag showed overall better results while chemical industrial sludge-ash showed most deleterious effect on all growth parameters among treatments. The results declared significant increase in shoot length ($P<0.001$), root length, fresh weight of shoot and dry weight of shoot and root ($P<0.01$) and fresh root weight ($P<0.05$). The concentrations of heavy metal varied significantly, depending upon the type of waste however, minimum values of all metals were obtained in marble waste. In contrast to marble waste Zn, Co, Mn and Pb were found maximum in prepared polluted sea water, soil, shoot and root in chemical industry sludge-ash while Fe was higher in converter slag treatment. The calculated values of Biological Accumulation Coefficient (BAC), Biological Transfer Coefficient (BTC) and Bio-concentration Factor (BCF) showed that *Avicennia marina* can efficiently act as a Phytoremediation species for selected heavy metals in Pakistan mangrove ecosystem. However, there should be a limit to add chemical pollutant in this ecosystem.

Keywords
phytoremediation, *Avicennia marina,* industrial waste, heavy metals

Mangroves and climate change: Effects of increasing temperature on biology, density and distribution of *Perisesarma guttatum* (A. Milne Edwards, 1869) and *Uca urvillei* (H. Milne-Edwards, 1852) crabs at Gazi Bay, Kenya

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Abstract

Despite the importance of mangrove crabs to the general mangrove ecosystem functioning and viability, little is known on the expected effects of climate change on these animals. Questions then arise on what effects, if any, would temperature, salinity, sea-level rise and low pH value have on those animals resident in mangrove sediment. As part of a wider EU project on "Coastal Research Network on Environmental Changes – CREC", experiments were carried out at Gazi Bay, Kenya to determine thermal tolerance of adults and eggs of *Perisesarma guttatum* and *Uca urvillei* crabs which were maintained at different temperatures between 17-37°C and respiration measured using a closed chamber system. After 8 and 3 hours acclimation at 27°C for adults and eggs respectively, respiration rates were recorded and used as a proxy for their basal metabolism. Crabs were counted in $1m^2$ quadrats while megalopae were collected using air-filter traps in *Rhizophora mucronata, Ceriops tagal* and *Avicennia marina* zones. The results suggest that males of *P. guttatum* and *U. urvillei* had a temperature range of 27-31°C and 27-33°C (P>0.05) respectively in both air and water media and temperature show significance at 35°C (P<0.0004) beyond which the crabs got stressed as indicated by increased metabolism suggesting that the former is more sensitive to temperature variation than the later which has a wide thermal tolerance window. *U.urvillei* and *P. guttatum* recorded highest densities of 66.25/m² and 11.75/m² respectively in the *R. mucronata* zone although *P. guttatum* density in *C. tagal* and *R. mucronata* wasn't significant (P>0.05*).U. urvillei* density was lowest in *C. tagal* and landward *A. marina*. Full moon day and the transition phase between the North East and South East Monsoon revealed significant effect on megalopae density (P<0.000). These results are crucial in understanding and predicting of future physiological responses of mangrove crab populations to climate change affecting mangroves.

Keywords
mangrove crabs, thermal sensitivity, density, megalopae, Gazi Bay

Successive cambia in the mangrove *Avicennia*: a study on the three-dimensional structure of the cambia and the functioning of the internal phloem tissue

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Abstract

Background: Mangrove trees form unique forest at the edge of the land and sea. Amongst mangrove trees, the genus *Avicennia* L. stands out by successive cambia *i.e. having not one cambial layer but subsequent active cambia* and the organization of successive cambia seems to be very complex in three dimensional aspects and even in transverse sections. Further, secondary growth by successive cambia can offer *Avicennia* ecological advantages. Mangrove trees are subjected to variable demand for water transport in both time and space. Embolism *i.e. air bubble formation in the xylem sap, enlargement and therewith block the water transport,* is not a permanent process and plants can overcome the embolism removing the air bubbles in the embolized vessels. Among the different mechanisms suggested, osmotically driven mechanism *i.e. helps the embolized vessel in refilling making an osmotic gradient across the pit membrane, by which the water-filled vessel and gas-filled vessel is separated,* is widely accepted. Moreover, sugar molecules in the phloem conduits or/and wood parenchyma, supply to the embolized vessel segment that induces the water flow into the gas-filled vessel from adjacent water-filled vessel. Physiology of the phloem, then, has become more interesting for further investigations. Tracing method *i.e. introducing a tracer (this can be a dye, radio-isotopes or fluorescein) into the phloem,* has become a promising tool in terms of investigation the phloem physiology. If the tracer is a dye then its subsequent distribution can be readily followed from its colour.
Aims: This study aimed (i) at clarifying the organization of the three-dimensional structure of successive cambia of the mangrove species *Avicennia marina* (Forssk.) Vierh. at the cellular level through serial sectioning of wood stem (ii) to search the best method for the insertion of liquid (0.1% safranin solution) in to the phloem using *Bougainvillea* sp. (iii) to investigate whether the sugar molecules produced in the successive bands of parenchyma and phloem cells in *Avicennia marina* are involved, as osmotic driving force, in refilling embolized vessels and hence, in securing hydraulic conductivity.
Results: (i) The number of cells and the cell types markedly vary with vertical distance, especially in the branching points of the vascular tissue. These changes with vertical distance are due to cellular changes in parenchyma, sclerenchyma and fiber cells. (ii) the flap technique with mid vein is the best method to perfuse the dye into the plant. The distance travelled by the dye was 11 cm (SE +/- 1.52) relative to the point where it was perfused. (iii) the hypothesis that sugar molecules, in the successive phloem and parenchyma bands, help in refilling embolized vessels, through making an osmotic gradient, was not supported by the results.

Conclusion: (i) Parenchyma cells and xylem fiber cells arrangement and number of cells play the major role during the switching/changing of the branching pattern of the vascular tissues with vertical distance. (ii) The dye can be perused into the plant but selective labeling of the phloem is doubtful. The best method for the perfusion is the flap technique with mid vein (iii) the water loss from the non-covered parts of the stem (transpiration) seems to play a major role in the creation of embolisms. Prevention of water loss from the stem helps to keep an optimal hydraulic conductivity.
On account of the functional significance, given by the different cell types and arrangement of cells in successive cambia, hydraulic structure, promising optimal conductivity help *Avicennia* to cope with conflicting environmental conditions. Hence, *Avicennia* has become more eurytopic locally. These adaptations may also help us to clarify the large latitudinal distribution of *Avicennia.*

Keywords
mangrove forest, *Avicennia*, successive cambia

Long-term mangrove forest development in Sri Lanka: early predictions evaluated against outcomes using VHR remote sensing and VHR ground-truth data

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Abstract

Whereas anthropogenic impacts on the mangroves are often directly visible, some indirect impacts like biodiversity change are witnessed only over a period of time and therefore require medium to long-term monitoring. This study focuses on testing the predictions made 10 yr ago concerning the evolution of a mangrove forest in Galle-Unawatuna, Sri Lanka. The very high resolution (VHR) ground inventory revealed that the adult mangrove species composition is dominated by *Rhizophora apiculata*, *Excoecaria agallocha*, *Bruguiera gymnorrhiza* and *B. sexangula*, with a total density of 216 to 267 stems 0.1 ha^{-1} and a basal area of 1.19 to 1.44 m^2 0.1 ha^{-1}. However, both young and juvenile vegetation in most sectors were dominated solely by *B. gymnorrhiza* (128 to 869 stems and 356 to 1482 propagules 0.1 ha^{-1}). The recent decadal changes between 1994 and 2004 observed through IKONOS imagery and ground truthing confirmed many of the predictions and showed dynamic shifts in young/adult vegetation of *B. gymnorrhiza*. Although dominance of *R. apiculata* and *E. agallocha* has been seen to alternate over decades (1956 to 2004), the emerging growth of *B. gymnorrhiza* might cause yet another transition of this mangrove area into a *Bruguiera*-dominated forest in the near future, resulting in the conclusion that the 'moving mosaic' pattern of mangrove species distribution at Galle-Unawatuna still persists. We maintain that this mangrove forest is probably one of the most dynamic in the world in terms of species turnover. To our knowledge, the present study represents one of the few long-term field-based monitoring research projects on mangroves using VHR remote sensing and VHR fieldwork at decadal intervals, and is probably the only study testing forest development predictions made in the past.

Keywords
decadal changes, forecasting, Galle-Unawatuna, mangrove distribution, remote sensing, species-environment relationship, Sri Lanka

Present status of mangrove ecosystem in and around Mumbai (West Coast of India)

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Abstract

Mumbai is one of the metropolitan of India located on western coast at 18^{0} 53' north to 19^{0} 16'north latitude and from 72^{0} E to 72^{0} 59 E longitude. Mumbai endowed with coast line of 100km which is intended with creek and estuaries. Once upon a time plentiful density and diversity of Mangroves was present on most of the coastal area of Mumbai. At present patches of mangroves exist at Mahim and Gorai creek, and at coastal belt of Versova, Sewri, Colaba, and Bandra. Moderate mangrove patches are also present around Mumbai in coastal areas of Elephanta Island, Uran, Vashi, Vasai, Thane and Bhyander creeks. Although 15 species of mangroves identified in and around Mumbai, most of the coastal areas harbor *Avicennia marina*. It has been noticed *A. marina* tolerate polluted coastal water at Mahim creek and other coastal zones in Mumbai. Due to heavy development of housing construction, most of the mangrove density in and around Mumbai is reducing day by day. Recent oil spill incidences in coastal waters of Mumbai found to damage the mangrove ecosystem. In marshy areas of Sewri, Elephanta Island and Vashi heavy coasting of oil on leaves and lower part of mangrove tree is recorded. Further, young mangrove trees found dead at some of these areas. Efforts are in progress to save the mangrove ecosystem in and around Mumbai by adopting various means. The state Government of Maharashtra recently declared 3000 hectares of Mangrove as protected forests. Detailed account of present status of mangroves ecosystem of Mumbai has been given in this paper.

Keywords
Mumbai, India, Mahim, creek

Does 'you are what they eat' apply to mangrove Sesarmid crabs?

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Abstract

The long-held role of sesarmid crabs in processing large quantities of detritus in tropical mangrove forests has recently been questioned, based on the large difference in carbon stable isotope ($\delta^{13}C$) values between mangrove leaf litter and crab tissues. This view has added to the recent notion that the detritus of vascular plants including mangroves might be 'trophic cul de sacs' that contribute little to coastal productivity. These views are, however, contradicted by the common observation that mangrove sesarmid crabs consume large quantities of low-quality leaf litter, and the ecological dilemma of acknowledging a significant carbon source (and trophic niche) not utilized by any consumer. A review of the stable isotope data suggests that despite the widespread occurrence of a large difference between crab and mangrove $\delta^{13}C$ values (range of $\Delta \delta^{13}C$ between +4 and +7‰), this difference is relatively consistent irrespective of crab-mangrove identities or geographic location. I hereby present a plausible explanation for resolving this ecological enigma.

Keywords
detritivory, stable isotope analysis, leaf litter, trophic fractionation

Spatial heterogeneity in mangroves assessed by GeoEye-1 satellite data: a case-study in Zhanjiang Mangrove National Nature Reserve (ZMNNR), P.R. China

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Abstract

Mangrove forests, which are declining across the globe essentially because of human intervention, require an evaluation of their past and present status (e.g. areal extent, species-level distribution, etc.) to implement better conservation/management strategies. In this paper, the mangrove cover changes at Gaoqiao (under the jurisdiction of Zhanjiang Mangrove National Nature Reserve - ZMNNR, P.R. China) were assessed through time using 1967 (Corona KH-4B), 2000 (Landsat ETM+), and 2009 (GeoEye-1) satellite imagery. The results indicate an important decline in mangrove cover (434 ha) between 1967 and 2009 due to agriculture (paddy) and aquaculture practices. Moreover, the mangroves delimited by dike construction were prevented from expanding landward. However, between 2000 and 2009, the seaward mangroves increased from 583 to 775 ha because expansion of aquaculture took place at the expense of agricultural areas located landward of the dike. In the land-use/cover map based on ground-truth data (5 m × 5 m plot-based tree measurements) (August-September, 2009) and spectral reflectance values (obtained from pansharpened GeoEye-1), both *Bruguiera gymnorrhiza* and small *Aegiceras corniculatum* are distinguishable at 73-100% accuracy, whereas tall *A. corniculatum* is at only 53% due to its mixed vegetation stands close to *B. gymnorrhiza* (classification accuracy: 85%). Among others, clay, sand and organic matter in the sediment showed significant differences (Kruskal-Wallis/ANOVA, $P < 0.05$) between the three mangrove classes. Distribution of tall *A. corniculatum* on the convex side of creeks (with rich clay and organic matter) and small *A. corniculatum* on the concave side (with sand) are apparent. Overall, the advantage of very high resolution satellite images like GeoEye-1 for mangrove spatial heterogeneity assessment and/or species-level discrimination is well demonstrated, along with its difficulty to provide a precise classification for non-dominant species (e.g. *Sonneratia apetala*) at Gaoqiao. Despite the limitations such as geometric distortion and single band information, the 42-year old Corona declassified images are invaluable for land-use/cover change detections against recent satellite data sets.

Keywords
change detection, declassified imagery, remote sensing, Gaoqiao, China

One year survey of CO_2 fluxes from sediments and water column in mangrove ecosystem (New Caledonia)

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Abstract

Mangrove swamps are a highly productive ecosystem, which may impact global carbon cycling. Mangrove productivity reaches up to 218±72 $TgC.yr^{-1}$ but uncertainties remain on its fate (Bouillon et al., 2008). These authors have shown that known and quantified organic carbon sinks, i.e. export, burial and mineralization, only accounted for less than 50% of the estimated net primary production. Some pathways were, thus, suggested to be underestimated. Mineralization may be one of those because of data scarcity. The main purposes of our study are to quantify and to understand the spatio-temporal variability of CO_2 fluxes at both sediment-air and water-air interfaces; CO_2 fluxes being used as a proxy for organic carbon mineralization. To reach our goals, CO_2 fluxes, as well as physico-chemical characteristics of sediments and water, were measured regularly during more than one year, in a mangrove of New-Caledonia that presents a typical zonation of the ecosystem in this country. Concerning fluxes at the sediment-air interface, measurements were done using both transparent and opaque chambers, connected to an InfraRed Gaz Analyzer (IRGA), in four mangrove areas: salt-flat, *Salicornia*, *Avicennia* and *Rhizophora* stands. On the La Foa River, which crosses the studied mangrove, fluxes were determined using a floating chamber, also connected to an IRGA, according to an upstream-downstream transect. Our results suggest that throughout the year, sediments and river are a CO_2 net source for the atmosphere (57.45±29.9 $mmolC.m^{-2}.d^{-1}$ and 180.7±186.4 $mmolC.m^{-2}.d^{-1}$, respectively). However, a very high variability has been observed at both interfaces. Tides, water quality, and climatic conditions seem to control air-water CO_2 fluxes, while organic carbon and water contents of sediments, as well as, the presence of a biofilm at sediment surface seem to be key parameters. Considering the quantity of parameters that may influence CO_2 fluxes, quantitative studies are still necessary to improve mangrove carbon budget.

Keywords
greenhouse gas, biogeochemistry, climate change

Variation of air temperature on conserved and impacted mangroves: preliminary results on the Southern coast of São Paulo State, Brazil

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Abstract

Mangrove ecosystems have suffered significant changes, by natural and anthropogenic pressures. These changes alter the vegetation cover and consequently the microclimate. The air temperature influences the vegetation growth and development. The aim of the current study is to analyze the variation of air temperature in two areas of Cananéia-Iguape Coastal System, located on the Southern coast of São Paulo State (Brazil): an impacted mangrove forest; and a conserved mangrove forest in a protected area. Data have been obtained from a meteorological tower since 2008 in the impacted area and since April 2011 in the conserved area. In both areas have been used sensors CS215 - Campbell Scientific, recorded every 10 minutes during three periods: from 02 to 26 May; from 28 June to 22 July; and from 02 to 26 August 2011. In both areas, data were obtained at 2m high, below the canopy. Data were tested using Pearson linear correlation, with a significance level of 5%, obtaining positive correlations with r = 0.865. The impacted mangrove forest showed extreme values, with the maximum absolute temperature of 33.0 °C at 3 p.m., whereas in the conserved mangrove forest the maximum absolute temperature was 30.2 °C, both registered in August. On the other hand, the minimum temperature in the impacted area recorded was 6.5 ºC, and in the conserved area it was 11.3°C, both registered in June. The results indicated the amplitudes were lower in the conserved environment, showing less variation in air temperature. During the three monitored periods, in conserved area the values were 12.5 °C, 18.5 °C and 24.4 ºC, while in the impacted mangrove were 14.8 °C, 18.9 °C and 26.7 °C, to May, June-July and August, respectively. The conclusion was the state of mangrove canopy conservation contributes to reduce the thermal amplitude, minimizing energy losses in microclimate. This monitoring has been done to provide mid-term information in order to improve the understanding of the mangrove forest microclimate and finally to assist this (sub)tropical wetland conservation.

Keywords
conservation status, canopy, microclimate data, monitoring

Variation in sea level and effects on surface elevation gains in coastal wetlands

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Abstract

Increases in sea level are a threat to mangrove ecosystems. Variation in the intensity of La Nina-El Nino activity alters sea level on the Australian coast as well as affecting rainfall. Here we used variations in sea level in South East Queensland (SEQ) over time to test the effects of increasing sea level on surface elevation gain and component processes (surface accretion and subsidence) in mangrove forests in a range of different environmental settings in Moreton Bay. We found that soil surface elevation increased with increasing mean sea level (which varied over 25 cm during the study) on the western side of the bay but not on the eastern side of the bay. In contrast surface accretion increased with mean sea level throughout the bay. Soil subsidence was higher in the western bay than the eastern bay and greater at periods of lower sea levels and lower values of the Southern Oscillation Index (low rainfall). Our data suggest that there are complex interactions between sea level and climate that influence mangrove forests capacity to keep pace with sea level rise.

Keywords
sea level rise, Moreton Bay, accretion, subsidence, ENSO

Insect pest infestation on mangrove forests of Kenya: identification, threats and impacts

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Abstract

Insect infestation in mangroves is one of the least investigated and thus least understood management problem faced by mangroves. In Kenya, the problem of insect pest infestation on *Sonneratia alba* (J. Smith) has persisted for long with very little efforts put into understanding its threat, impacts and management options. *S. alba* is pioneer species facing the open sea in many mangrove formations in Kenya and therefore assists the economic importance of mangroves. Consequently decimation of this species may lead to coastal erosion and strongly reduce the ability of carbon sequestration. Recently, a massive insect infestation event occurred in Pemba Tanzania where infested trees experienced massive defoliation such wide scale that it caused alarm to mangrove experts in the region. Despite the evident threat, there is scanty information on mangrove insect infestation in the region. This study reports the initial findings on the insect pest infestation on *S. alba* forests of Kenya: identification of the insect pest, threats and impacts caused by the infestation. Since pest detection, identification and impact evaluation are vital steps to meaningfully determine option targets in forest management. Our approach is to investigate (1) the insect(s) responsible for the infestation, (2) the infestation mechanism used by the insect(s), (3) the kind of damage it causes to trees (branch and tree level) and, (4) the trees' response to infestation. Adult moths were captured using a trap that we devised in the field and larvae were reared from infected branches to adult stage for the purpose of identification. External inspection of infested branches was conducted in order to understand the insect(s) infestation mechanisms. Girdling experiments are also ongoing in order to understand damages caused to trees and the response of infested trees towards the infestation. We also designed a scoring criterion that we used to evaluate the status of health in the *S. alba* mangroves. Species identification of the insect is ongoing after we successfully trapped the elusive adult moth in Gazi Bay. Rearing of larvae from infested branches is on going with a good level of success. Scoring results indicate that *S. alba* zone had 55 % infestation level with no difference in infestation level between mono species forest plots and the mixed species forest plots.

Keywords
insect infestation, *Sonneratia alba*, mangrove management, Kenya

Mangrove die-back due to massive sedimentation and its impact on associated biodiversity

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Abstract

Mangrove forests provide an array of ecosystem goods and services which significantly support the economies of tropical coastal countries. However, a multiplicity of anthropogenic pressures and more recently global environmental changes continue to threaten the integrity of mangrove ecosystems. Emerging scientific evidence strongly suggests that the 1997/8 and 2000 rains in the Western Indian Ocean (WIO) Region previously attributed to El-Niño were mainly caused by the Indian Ocean Dipole (IOD), a phenomenon which its frequency and intensity have increased over the years due to climate change. The abnormally high rainfall experienced during this time combined with poor land management, caused massive sedimentation due to erosion of terrigenous sediments leading to extensive mangrove die-back in several areas in the WIO Region. The extent and impact of this die-back on mangrove-associated biodiversity has not been assessed to date. The objective of this study was to assess the impact of the die-back on mangrove associated biodiversity at Mwache Creek, Mombasa, Kenya, where a large area of mangroves of about 200 ha was decimated. Biodiversity in impacted sites was compared to reference sites (natural forests) in order to assess the impact of IOD related massive sedimentation to mangrove-associated biodiversity namely crabs and molluscs since these faunal groups serve as important bioindicators of ecosystem change. In parallel, abiotic parameters, such as temperature, conductivity, total dissolved oxygen (TDSO), salinity, ammonium (NH_4^+), phosphate (PO_4^{3-}) nitrite (NO_3^-), nitrate (NO_2^-) and sediment grain size were sampled to test which of them was altered by the die-back due to sedimentation and the relationship between these alterations and the purported change in macrobenthic biodiversity. Transects (sea-landward transect) were laid 10 m apart to ensure independence of sampling units in both impacted and natural sites. Along each transect, 5 m² quadrats were made after every 100 m. Within the 5 m² quadrats, one 2 m × 2 m sub-quadrat was randomly placed for actual sampling where relevant physico-chemical variables were measured and mangrove biodiversity determined as an indicator of ecosystem change. Obtained data was square root transformed in order to achieve normal distribution. To check for partial distribution trends, a PCA (for abiotic data) and NMDS (for biotic data) was used and then subjected to 3-way-PARMANOVA to test for statistical differences. Further, a Canonical analysis of principal coordinates (CAP) was employed to confirm the consistency in the variation in the biotic factors. In the abiotic data, a DistLM routine ("best fit" and "BIC model") was employed to single out the abiotic factors contributing to the changes in biotic composition. Environmental factors showed a strong variability among transects whereas faunal assemblages significantly differed among the treatments (impacted and none impacted). Salinity, temperature and total dissolved oxygen (TDSO) were the environmental factors that contributed to the changes in biotic composition

among the treatments whereas *Uca inversa, U. annulipes, Cerithidea decollata* and *Perisesarma guttatum* contributed more to the differences in faunal composition between treatments. The degradation seems to have significantly reduced crab and mollusc species richness and densities and led to loss of other mangrove associated faunal species in the impacted site.

Keywords
anthropogenic pressure, global environmental change, El-Niño, mangrove die-back, WIO, bioindicator species, sedimentation, ecosystem change

Eco-floristic survey of mangrove population of Sundarbans, West Bengal, India with reference to their management for rural development

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Abstract

Mangroves are the specialized vegetational constituents which grow in the littoral regions of the world confined mainly to the tropics, sometimes even to sub-tropical zones. Only a few countries in the world have mangrove vegetation with inherent halophytic characteristics. Mangroves play an important role for the protection of the coastal environment as they check the intensity of tropical cyclones, soil erosion, encroachment of sea towards land, etc. These are also rich source of timber, fuel, tannin, etc. Besides these, mangrove forests provide congenial habitat for the fishes, prawns and a number of wild flora and fauna. Mangrove of India constitutes 7% of the world mangroves covering an area of 6740 sq. km. Indian subcontinent is fortunate to harbor unique mangrove flora in Sundarbans of West Bengal and a few other estuarine areas. Sundarbans, i.e. the delta of the Ganga-Brahmaputra river system in India and Bangladesh occupies probably the largest single block mangroves in the world. A significant part of the mangrove of the eastern region is within Bangladesh, the rest being confined to West Bengal in India. The characteristics of most of the mangrove flora with the pneumatophores, viviparous germination, specialized anatomical features and physiological adaptations make them distinct from the rest.

Despite the uniqueness of the mangrove vegetation and its habitat of the Sundarbans delta, unfortunately very little work has so far been done on the ecological perspective of this remarkable vegetation. The encroachment, injudicious utilization and lack of proper management in earlier years have already led to considerable depletion of its pristine glory. It is indeed an irony that only a few individual species of *Heritiera* are the relics to which the name Sundarbans owes its derivation. “Sundarbans” - the term was coined either from the forests of “Sundri” (*Heritiera fomes* Buch. Ham.) or from the forests of “Beautiful Plants” or from the forests of “Sumudra” (Ocean). The eco-floristic survey of Sundarbans reveals the following major mangrove elements: *Acanthus ilicifolius, Aegialitis rotundifolia, Aegiceras majus, Avicennia alba, A. officinalis, Bruguiera gymnorrhiza, Carapa obovata, C. moluccensis, Cynometra ramiflora, Excoecaria agallocha, Heritiera minor, Nypa fruticans, Oryza coarctata, Phoenix paludosa, Rhizophora conjugata, R. mucronata*, *Sonneratia apetala*, *Suaeda maritima,* etc.

An in-depth understanding of the biological characteristics of vegetation, its succession and the ecological pattern is essential to work out a proper management practice for the conservation of mangroves and judicious utilization of the Sundarbans area. These mangrove forests have some vital importance like protective functions as well as supplying the natural gifts like timber, honey, fishes and prawns for better socio-economic potentialities of the surrounding village folks. Therefore, conservation of these natural forests is essentially required for the welfare of these complex ecoclimates and for proper management for national development. It is now high time to conserve the existing mangrove forests and take up reclamation and re-vegetative programmes to save these plant resources and maintain ecological balance. The present paper will highlight the recent problems and future prospects

of plant resources in the context of environmental degradation and global warming for biodiversity conservation.

Keywords
Sundarbans, encroachment, injudicious utilization, eco-floristic survey, management

Nutrient cycling and use by the species *Rhizophora mucronata* in two contrasted mangrove settings from the French Scattered Islands, Western Indian Ocean

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Abstract

The islands of Europa and Juan de Nova (JDN) located in the Mozambique Channel host very distinct mangrove ecosystems. On Europa, a 700 ha mangrove forest grows on the edge of an open lagoon while JDN has only a small *Rhizophora mucronata* stand enclosed in a 2.5km² sinkhole located 80m inland and connected to the sea through galleries in the karstic ground. Europa receives little nutrient and freshwater inputs while Juan de Nova has a small brackish groundwater reservoir and ancient guano deposits exploited in the 1900's. This study aims at comparing nutrient cycling in these two systems and at investigating the physiological responses of the species *R. mucronata* to these different conditions of nutrient and freshwater availability. Nutrient concentrations, resorption efficiency (RE), nutrient use efficiency (NUE), as well as carbon and nitrogen stable isotope signatures ($\delta^{13}C$ and $\delta^{15}N$) were measured in mangrove leaves, sediment and/or waters from both systems. Data show higher loads of ammonium and phosphate in the creek waters of JDN (86.2µM and 13.8µM, respectively) compared to Europa (~5.5 µM and 0.4µM, respectively). However, N:P ratios of mature green leaves were similar in both systems (~14) and $\delta^{15}N$ ratios suggest that mineralization of mangrove litter rather guano is the major nitrogen source in both systems. Also, despite the higher ammonium and phosphate concentrations in JDN, the RE and NUE of both nitrogen and phosphorus were unexpectedly 1.5 to 3 times higher in the trees of JDN than in those of Europa. These data suggest that the JDN mangrove is actually more nutrient limited than in Europa. It is likely that the peculiar hydrological functioning of the sinkhole only allows rare inundation of the entire *R. mucronata* stand and that trees thus mainly rely on the nutrient-poor groundwater source.

Keywords
nitrogen, phosphorus, nutrient limitation, nutrient-use, resorption efficiency

Photosynthesis in mangrove seedlings ceases underwater

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Abstract

Flooding and tidal highs are common phenomena in mangrove habitats. Often in such cases underwater stress becomes a survival factor for mangrove seedlings which experience whole plant submergence and the shoots remain obstructed underwater. The present study was set to investigate whether and how variable selected mangrove seedlings survive underwater photosynthesis in different salinity media of 100% seawater (SW100), 66% seawater (SW66), 33% seawater (SW33) and freshwater (SW0). Survival and photosynthesis variably declined to cessation accompanied by leaf decay, indicating considerable tissue degeneration with increase in salinity and underwater duration. *Bruguiera gymnorrhiza* seedlings were superior surviving 7 days of underwater photosynthesis in SW100. *Avicennia marina* seedlings survived 7 days of underwater photosynthesis only in salinities of up to SW66. *Heritiera littoralis* seedlings did not survive underwater in salinities beyond SW33 in which photosynthesis collapsed within the first days. There were significant differences in maximum variable quantum yield (Fv/Fm) both within different salinity treatments over the duration of underwater stress and interactively between salinities and underwater duration. *A. marina* seedlings had decreasingly higher values of Fv/Fm in all salinity treatments over the duration of underwater, followed by *B. gymnorrhiza* and *H. littoralis* which had the least performance. But, *B. gymnorrhiza* survived photosynthetically longer underwater. Upon reliving from underwater on the 21^{st} day, one of each three seedlings of *B. gymnorrhiza* from SW0 and SW33 and *A. marina* from SW0 indicated signs of recovery following a seven day course of normal watering twice a day as they sustained green stems and new buds were forming. This restricted performance of underwater photosynthesis may explain the immediate effect of sub-lethal conditions that mangrove seedlings face in events of unprecedented flooding and consequent subsidence with an ultimate degeneration of the succession niche.

Keywords
leaf decay, photosynthetic yield, salinity, submergence, survival

How mangroves act as a filter toward trace metals between open-cast mining and lagoon

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Abstract

Mangroves of New-Caledonia act as a buffer between a lagoon of more than 20,000 km^2 and the Island, which is characterized by ultramafic rocks and lateritic soils that are exploited for their richness in some trace metals. New-Caledonia is currently the third nickel-producing country in the world. Open-cast mining occurs all around the Island, and processes of erosion and sedimentation, which occur naturally along the coastline, are strongly amplified by mining activities. Due to their position, at the interface between land and sea, mangroves receive extensive amounts of particles emanating from rivers through estuaries. The purpose of this study is to understand the distribution and partitioning of some heavy metals (Fe, Mn, Ni, Cr) in sediments and pore-waters in various mangroves of the Island, with and without mining activities in their watershed. Quantitative analyses on bulk and after selective extraction were carried out on cores collected beneath *Rhizophora stylosa* stands, *Avicennia marina* stands, and within salt-flats. Ni concentrations in mangrove sediments are 10 to 100 times higher downstream mining areas (mean value of ~44 $\mu mol\ g^{-1}$) than in mangroves developing downstream of a catchment not composed of ultramafic rocks (mean value of ~1 $\mu mol\ g^{-1}$). The organic content and the length of immersion by tides appear to be the main factors controlling distribution and partioning of heavy metals in mangrove sediments. There are gradients of these two parameters along the intertidal zone, from the salt-flat to the *Rhizophora* stands, which induce different redox conditions. Heavy metals are deposited in the mangrove mainly as oxides and/or oxy-hydroxydes that are subsequently dissolved during organic matter decomposition. Dissolved metals are then precipitated with organic and sulphide compounds. To conclude, organic diagenesis in mangrove sediments leads to the transfer of heavy metals from oxide form to organic and sulphide forms.

Keywords
geochemistry, zonation, anthropogenic pressure, developing country

Connectivity of *Scylla serrata* in Kenya and the Indian Ocean

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Abstract

Most of the studies conducted on the genetic population structure and gene flow of marine organisms have been focused on the genetic analysis of mitochondrial markers. Fratini et al. (2002, 2010) studied the genetic differentiation of *Scylla serrata* in the east African coast and found that the populations were genetically not homogenous. To better understand the population structure and the gene flow of *S. serrata* in and around the Indian Ocean, we propose to take more samples in Eastern Africa (Kenya) and to add more sequences from the entire Indian Ocean. The study area is located in the Southern part of the Kenyan coast. Samples were taken in Lamu Archipelago, Mida Creek, Kilifi, Mombasa, Gazi Bay and Shimoni. More samples were also received from South Africa, Madagascar, Zanzibar, Malaysia, Indonesia and China. On one hand, the results of this study will be compared with the results of Fratini et al. (2002, 2010) in order to determine boundaries of populations and verify whether those genetic patterns are stable over time at a local scale (e.g. in Kenya). In the first analysis, no significant differences have been reported between the three periods of sampling (2000, 2009 and 2011) which could means that the patterns are stable over time. However tests of deviation from neutral molecular evolution seemed to indicate a departure from the neutral hypothesis for five of the six stations, which could involve population expansion or selection. Haplotype diversity show high values, unlike the nucleotide diversity, which could be a sign of a recent population expansion. Finally, the populations seem to be homogenous along the Kenyan coast and no structure has been detected. On the other hand, more samples from the wider Indian Ocean will be added into the database to better document the global geographic distribution (larger scale) of *S. serrata* around the Indian Ocean.

Keywords
mud crab, population genetics, connectivity, mitochondrial markers

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Impact of flood on *Rhizophora* plantation in Batticaloa, Sri Lanka

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Abstract

Planting mangroves for restoration became popular after the 2004-tsunami in Batticaloa. About 9500 individuals *Rhizophora* were planted at ten sites around the Batticaloa lagoon, and only 794 (8 %) remained at the end of 2010, only at Urani. Heavy rain flooded Batticaloa in January and again in February 2011. This study assesses the impact of flood on the planted mangroves.

The study site was Puthupalam-Urani stretch of 2.5 km, located in the Manmunai North Divisional Secretariat division. Field survey was carried out one week after the first and second inundations.

Inundation height was recorded. For each plant height and status (green, percentage of browning of shoot and dead) were recorded. 25 water samples were collected at 100 m intervals in this area.

Mean height of the first inundation was 1.84±0.06 m and this remained for 5-7 days. Mean height of the plant was 1.53±0.43 m. During this inundation, 79 % of the plants had been fully submerged and 21 % partially submerged. 52 % of plants had more than 90 % of browning of shoot. 81.3% of plants were dead.

Mean height of the second inundation was1.68±0.08 m and this remained for 4-6 days. Mean height of the remaining plant was 1.63±0.62 m. During this inundation 24 % of the plants had been fully submerged and 76 % partially submerged. 32 % of the remained plants had more than 90 % of browning of shoot. 31 % of remained plants were dead due to the second inundation.

Majority of the isolated individuals were lost whereas majority of the survived plants were from the centre of big patches. Salinity was almost zero during the periods.

Inundation seems to be the main reason for death of plants, but physical forces cannot be overlooked as the survivors are from centre of patches.

Keywords
plant-group, browning, inundation, survival

Impacts of climate-induced mangrove expansion on the ecological functions of salt marshes

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Abstract

The advancement of species poleward, presumably due to global climate warming, has recently been documented in several regions of the world. In coastal ecosystems, one unique distributional shift is the movement of *Avicennia germinans* (black mangrove) northward into temperate *Spartina alterniflora* salt marshes. In the Mississippi River Delta Complex of the northern Gulf of Mexico, black mangroves were historically restricted to the southernmost barrier islands and beaches by winter freeze events; however, in recent years a noticeable expansion has been observed. Given the sparse documentation of the ecosystem-level effects of black mangroves expansion within coastal salt marshes, our goal was to quantify the impacts of this expansion on ecological processes including surface sediment accretion, organic matter production, organic matter decomposition, and carbon assimilation, as well as several edaphic characteristics. Our results indicate that presently black mangrove expansion has had no major impacts on the ecosystem processes we measured. Sediment accretion rates, belowground production, decomposition rates, and carbon assimilation were similar between *Avicennia* and *Spartina* stands located within the same hydrologic setting. While decomposition rates were similar between habitats, mangrove leaves and roots decomposed more quickly than *Spartina* leaves and roots. Some differences were documented in edaphic parameters between habitats. Elevation, redox potential, bulk density, and soil ammonium were slightly higher, while soil moisture and porewater salinity were somewhat lower, where black mangroves had expanded into the surrounding salt marsh. Because the expanding black mangrove stands are small in stature as well as areal extent, significant effects on ecosystem processes may presently be muted. However, if stands continue to grow in vertical and horizontal extent, effects on ecosystem processes may occur in the future. Our research provides a baseline from which future ecosystem responses may be evaluated as mangrove populations continue to develop.

Keywords
climate change, ecotone, function, structure

Fruit size and predispersal herbivory by insects influence recruitment of the mangrove *Avicennia marina*

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Abstract

Seedling establishment and early growth are critical to mangrove forest regeneration, but this recruitment can be strongly dependent on factors that occur before the fruit abscises from the tree. Observations in mangrove forests of temperate Australia suggest that fruit size of the mangrove *Avicennia marina* varies among trees and forests and from year to year. In addition, developing fruit are commonly consumed by larvae oviposited into the fruit by insects, and this predispersal herbivory also appears to vary spatially and temporally. The objective of this study was to quantify spatial and temporal variation in fruit size and herbivory and to determine using field experiments how these factors might influence local and regional patterns of mangrove recruitment. Surveys of fruit in several forests over four years that varied in levels of rainfall revealed that fruit size varied substantially within and among trees and forests and that years of higher rainfall produced larger fruit. Insect herbivory was also spatially variable but did not vary among years and was independent of fruit size. Field experiments were done where I supplied propagules of different sizes and amounts of herbivore damage in an orthogonal design to mangrove forests and then monitored seedling establishment, growth and survivorship for one year. Seedling establishment, growth and mortality were dependent on propagule size and herbivory, with large, undamaged propagules establishing better, growing taller and surviving best. The influence of predispersal herbivory on seedling performance was, however, not dependent on propagule size, and propagule size appeared to have a greater influence on seedling performance than herbivore damage. These results show that conditions in the predispersal environment can strongly influence mangrove recruitment and that years of high rainfall and low herbivory are likely to be those that produce the strongest recruitment pulses that might drive forest regeneration.

Keywords
El Niño, disturbance, forest regeneration, precipitation, propagule predation

Mangrove invasion of salt marsh in temperate Australia: predicting patterns of seedling recruitment under fluctuating environmental conditions

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Abstract

Surveys in estuaries of southeast Australia have revealed a decline in salt marsh habitat and a concurrent landward "invasion" of these marshes by the native mangrove *Avicennia marina*. A leading explanation for this invasion is that environmental change, particularly increased run-off of nutrients and freshwater due to human modification of the coastal landscape, has reduced stressful abiotic conditions of salt marshes and facilitated the recruitment of *A. marina*, allowing competitive displacement of the species of plants that characteristically dominate the marsh. To examine this explanation, in a series of field experiments over four years I manipulated salt marsh vegetation and nutrients along tidal elevation gradients with varying abiotic stresses and species of plants, supplied mangrove propagules to these areas, and monitored the establishment, stress response and growth of seedlings. Seedling establishment was universally poor in areas without marsh vegetation. Marsh vegetation facilitated seedling establishment at low tidal elevations, but largely precluded recruitment at high tidal elevations. Nutrients did not influence seedling establishment, but reduced physiological stress (as determined by chlorophyll fluorescence) and promoted early growth of established seedlings, catalyzing the demographic transition from seedling to sapling, with some individuals producing fruit after only two years. Marsh vegetation and nutrients thus ameliorate harsh abiotic conditions and facilitate landward recruitment and spread of mangroves into low tidal elevations of adjacent salt marshes. Importantly, mangrove recruitment was temporally variable, and years with heavy rainfall had substantially greater recruitment than years of drought. Given that the southeast coast of Australia is predicted to be one of the regions most influenced by environmental change over the next century, due to a combination of population growth and increased warming and rainfall under climate change, understanding the ecological processes responsible for mangrove invasion will help to predict distributional shifts from seaward to landward and with increasing latitude.

Keywords
El Niño, eutrophication, disturbance regime, non-indigenous species, woody encroachment

Disturbances in a mangrove ecosystem – implications in the long term recovery patterns and climate change

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Abstract

Stability of an ecosystem is determined by its resilience, regenerative capacity and numerous weak trophic links, amongst other natural and human induced factors. The Tudor creek mangroves, a typical peri-urban mangrove, are exposed to both episodic natural and recurrent human disturbances, including decades' long exposure to raw domestic sewage, sporadic unregulated-harvesting and episodic siltation. This study evaluates the regeneration patterns within extended gaps and the understorey. An evaluation on species mix and regeneration patterns is also done. Preliminary analysis of aerial photographs (1969 and 1992) and a satellite image (2005) indicate a 12.5% decline in closed canopy mangrove between 1969 and 1992, and a 55% decline between 1992 and 2005. Distribution of adult trees was variable, with mixed stands and large canopy openings in the mid intertidal range. Species composition of seedlings and saplings did not always reflect the overstorey species composition and varied with gap sizes. Gap sizes range between 10 - 50m² have higher or mostly adequate regeneration, while gaps smaller than 10m² and bigger than 60m² have lower regeneration levels. *Rhizophora mucronata* seedlings and saplings occurred in the understorey under all cover types and inundation regime, conferring advantages to this species under the current disturbance regime. This may favour its establishment in relation to other species. *A. marina* and *Ceriops tagal* saplings and seedlings are restricted to the forest edges and gaps. The current status of the forest is reminiscent of a recovery phase, a multiphase succession stage, after a major disturbance event, accompanied by recurrent anthropogenic pressure. This study shows that species composition depends in part on the balance between natural large-scale and recurrent small-scale human disturbances. Therefore, impacts of climate change, coupled with anthropogenic influences may have long term implication in species composition and recovery rates in mangrove ecosystems.

Keywords
disturbance, anthropogenic, regeneration, understorey, climate change

Litterfall in a peri-urban mangrove receiving raw domestic sewage, Mombasa, Kenya?

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Abstract

The productivity of an under-valued, over-exploited and sewage polluted peri-urban mangrove through litterfall studies. The study site has been exposed to raw domestic sewage for decades, dozed every tidal cycle, the loading exponentially reducing with distance from the source. Litter from three common mangrove species, *Rhizophora mucronata*, *Avicennia marina* and *Sonneratia alba* were monitored over a period of two years. Litter fall, in both content and quantity was seasonal, with high rates occurring in the dry North Easterly Monsoon (NEM) season, January-April (ca. 5.10 ± 1.36 g DW m^{-2} day^{-1}) and lower rates in the cool and wet South Easterly Monsoon (SEM) season, June-October (ca. 2.53 ± 0.47 g DW m^{-2} day^{-1}). Productivity varied significantly between species, *R. mucronata* recording the highest annual rate of 15.34 ± 3.34 t $ha^{-1}yr^{-1}$. No significant differences in litter fall was observed between *A. marina* and *S. alba*, (11.44 ± 2.90 and 9.69 ± 5.26 t $ha^{-1}yr^{-1}$ respectively). Sewage exposure did not impact on litterfall rates for all species. However, a strong correlation exists between the leaf C:N ratio and leaf $\delta^{15}N$ signature. Higher C:N ratio for *R. mucronata* corresponding with lower leaf $\delta^{15}N$ (3.88 ± 0.64‰) signature, and lower C:N ration for *A. marina* and *S. alba* (6.48 ± 0.03‰ and 6.76 ± 0.24‰ respectively) corresponding with higher $\delta^{15}N$ signature, reflecting species specific response to sewage exposure. The forest has a more open N cycle, favouring $\delta^{15}N$ accumulation within the system. However, the level of sewage exposure did not appear to impact litterfall rates. The mean annual litter fall was estimated at 12.16 ± 2.89 t $ha^{-1}yr^{-1}$ for the whole stand. This study shows that sewage exposure does not necessarily translate into elevated productivity in mangroves, but may alter leaf total nitrogen content depending on species, possibly altering the decay of litter, affecting nutrient cycling within the system.

Keywords
peri-urban, litter fall, sewage, nutrients, $\delta^{15}N$

Are mangroves sustainable as peri-urban forests? A case study of Mombasa, Kenya

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Abstract

Mangroves are robust life support systems in the tropics and the subtropics, endowed with appreciable level of resilience to disturbances. The emerging peri-urban nature of coastal areas is gradually becoming the norm, with little attention from researchers. The Tudor creek mangroves in Kenya represent a typical peri-urban mangrove system. Our studies through questionnaire and field surveys reveal that the mangroves have been exposed to raw domestic sewage for decades, subjected to unregulated wood exploitation and impacted by natural climatic events – the abnormal rains of 1997-98 and 2006 associated with the El Niño Southern Oscillation (ENSO) causing significant siltation in mangrove forests. We establish that in an urban setting, no link or bond exist between the resource user and the resource or the natural system. Under these circumstances resource exploitation is intense and "efficient", driven by short term economic benefits. This greatly undermines traditional or customary resource and biodiversity values and compromises the indigenous management principles, promoting destructive unsustainable harvesting or exploitation practices. The outcome is the under-valuing of ecosystem goods and services in addition to degrading the ecosystem structure, function and the capacity to recover after disturbance. Therefore management of mangroves for wood extraction in urban settings may not be a viable or sustainable option. This conflicts with functions of mangrove ecosystems, otherwise important in 'resource limited' urban environments. It is recommended that a *participatory* and *adaptive management* approach, accounting for and considering multiple uses and users is the viable way to manage peri-urban mangroves. This will ensure social and ecological resilience in the long-run. However, this may require specific legislative, education and institutional interventions, scaling up and allocating costs as all levels of management.

Keywords
firewood, utilization, exploitation, harvest, peri-urban, sustainable

Genetic diversity of *Avicennia schaueriana* and *A. germinans* along the Brazilian coast: population structure, migration and admixture

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Abstract

Conservation biology, as others "crisis disciplines", has expanded its repertoire of techniques and tools to provide multidisciplinary information to support conservation decisions. The development of molecular biology, for instance, has made possible the establishment of conservation genetics as an important branch of this discipline. In this context, our main objective is to better understand the processes that shape the genetic diversity of *Avicennia schaueriana*, an American Atlantic restricted mangrove species, and *A. germinans,* whose distribution approximately coincides with the western mangrove forests distribution. We developed specific polymorphic microsatellite markers for each species, 10 and 14, respectively, and sampled 515 individuals from the entire distribution of mangrove forests in Brazil, covering more than 4800km of coastline. After performing frequentist and bayesian analyses, we observed that the genetic diversity of the 11 sample locales of *A. schaueriana* is structured in five gene pools (populations, in a broad sense) which do not necessarily correspond to geographically close localities. We also found a high rate of migrants and admixed individuals, as expected by the mangrove trees' water-based dispersal, showing the connectivity among these groups despite the geographic distances among localities. Using similar approaches, we analyzed four samples of *A. germinans* from the northern Brazilian coast, which include two geographically close locales but with different tide influence. We found a high level of inbreeding but also some admixed individuals and migrants, and a substantial population structure including between the two physically close samples. These results highlight the role of the tide as an important factor that shapes the genetic diversity of *A. germinans.* We found no evidence of ongoing hybridization between *A. schaueriana* and *A. germinans.* We are currently using other genetic molecular markers to deepen the knowledge about evolutionary factors of *Avicennia* and, then, support long-term future management and conservation efforts.

Keywords
black mangrove, population genetics, SSR

What is a mangrove? A global expert-based approach on definition, functionality and resilience of the ecosystem

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Abstract

Mangroves vary considerably in their attributes (species composition, structure, function, dynamics and resource use) across the globe. Thereby it is difficult for one person or a few individuals to arrive at a synthesis view on mangroves as an ecosystem. It is perhaps even more challenging to comprehend the resilience of mangroves to a suite of disturbances given the alarming rate of their decline. In addition, currently there is little or no consensus on which attributes to focus on while studying ecological functionality of any ecosystem. This is particularly problematic for a pan-tropical ecosystem like mangroves given: (i) their varied ecological settings and structure, (ii) their occurrence in a zone of flux (at the interface of rivers, land and the sea).
In order to resolve these gaps in knowledge we invited 106 experts from around the globe to participate in an online iterative survey based on the Delphi method. The Delphi method is a group consensus technique widely used in medical sciences and nursing. The advantage of this method lies in its anonymous and iterative nature. The experts were chosen based on (i) their research experience and (ii) number of peer-reviewed publications related to mangrove ecology. The participants were encouraged to offer a worldwide and varied view with respect to the above complexity. Thirty three (33) experts participated in the first round. Experts were asked to contribute to their opinion on open ended questions (e.g. definition of mangrove ecosystem) or rank items on a Likert Scale of 1 to 5 for close-ended questions. The results of this initiative will help us develop a better understanding of the 'whole ecosystem' of mangroves rather than gather knowledge 'on a sum of its parts'. We also evaluate whether the issues raised by the experts may or may not have a bearing on mangrove management policies.

Keywords
Delphi method, ecosystem function, species composition, threats, Likert scale, ecosystem service

Caught in the net: ecological functionality of mangroves

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Abstract

The relationship between biodiversity and ecosystem functioning (hereafter EF) has emerged as one of the central topics in current ecological research owing to the alarming rates of species loss. While the major proportion (72.96%) of EF studies has been carried out on terrestrial ecosystems, aquatic ecosystems including estuarine ecosystems like mangroves have received scant attention. The aim of this current research is to understand the EF of mangroves which are known for providing a host of ecosystem services. Mangroves merit urgent research attention since more than 35% of the world's mangroves have been lost in the past two decades alone. Using a novel approach of utilizing tools developed in Social Sciences (Social Network Analysis - SNA) we attempt to answer the following fundamental questions in mangrove ecology: i) Which functions are important in a mangrove? ii) Which species are more functional than others? iii) Are there keystone species in mangroves? We begin by defining which functional elements exist in a generic mangrove based on a meta-analysis of published literature. Then we use SNA to build a theoretical network of mangrove species and their functions. This research is perhaps the first systematic attempt to analyze the functionality of mangroves from a multi-functional perspective using tools outside the domain of ecological sciences. The outcomes of this study are also expected to serve as a guideline to policy makers and restoration ecologists working on mangroves worldwide.

Keywords
Social Network Analysis, ecosystem function, functional elements

Are the mangroves in the Galle-Unawatuna area (Sri Lanka) at risk? A social-ecological approach involving local stakeholders for a better conservation policy

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Abstract

Despite the known ecological and economic importance of mangrove ecosystems, research is still lacking as to what extent local populations depends on various forest products, or how this might be related to their economic status, age, or gender relations. In present study, the percentage of people depending on such resources in the Galle-Unawatuna area (Sri Lanka) for their subsistence needs was assessed through a survey. The results indicated that local people rely on mangroves to a greater extent for fishery products, fuelwood, and edible plants, than for house/boat construction material, medicinal and other non-timber forest products. All wealth classes (i.e. poor, middle and rich) use the resources, although greater dependency of the poor is common. A positive linear relationship, although not significant ($R^2 = 0.22$; $P = 0.69$), was observed between people's age (≥40 years) and mangrove resource use, along with a gendered division of labour. In addition, the use of mangrove resources is not necessarily poverty-driven: preference and tradition also play important roles. However, the physical infrastructure developments (i.e. construction of a cement factory, dam and road) have had several negative impacts ranging from water quality deterioration and dynamic shifts in mangrove vegetation to reduced fish production in the vicinity. Given our results, amendments to the existing rules governing forest conservation are recommended in order to provide long-term benefits for local livelihoods as well as ecosystem.

Keywords
Galle-Unawatuna, natural resources, infrastructure, coastal development, socio-economics, Sri Lanka, stakeholder, ethnobiology, management

Estimating the value of goods and services in a marine protected area: the case of Watamu Marine National Park and Reserve, Kenya

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Abstract

Marine and coastal ecosystems provide a range of goods and services that support the human population livelihood. They are however exposed to anthropogenic threats such as conversion to other land uses, pollution, overexploitation and unsustainable management practices and to the impacts of climate change and other natural causes. Often, decision-making by Marine Park management undervalues ecosystem services. This study determined the value of goods and services within the Watamu Marine Park and Reserve and the cost of biodiversity conservation. The methods used for valuation were also reviewed. A total economic value (TEV) of EUR 103,853.01 ± 63.30 ha^{-1} $year^{-1}$ was determined, excluding the values of fuelwood, timber, carbon sequestration and coastal protection that we derived in different units. Recreational value was the highest, totalling more than two thirds of the TEV. Despite the high cost of biodiversity conservation, low funding was allocated to the administration of the Park, lowering the capacity of protecting biodiversity. This study forms a step towards integrating protected areas into wider landscapes, seascapes and sectoral plans and strategies while demonstrating that MPAs constitute an important national economic benefit.

Keywords
protected areas, marine park, reserve, total economic value, biodiversity

Enhancing resilience of the coastline through removing stress, rehabilitation and mangrove planting

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Abstract

This article evaluates the results of mangrove planting on newly deposited mudbank as alternative option for coastal protection. On approximately 2 ha mangrove juveniles of the Black mangrove (*Avicennia germinans L)* have been planted. The planting location has been chosen according to a certain criteria, one of which is that the natural regeneration at the selected location and for the given period of time would not be take place. In this respect a new set of criteria has been worked out for mangrove juveniles to be planted on the selected location. Monitoring has shown that the survival rate of these plants depends of many factors occurring under certain conditions and in certain period of the year. One of the parameter affecting the growth of the mangrove regards the soil forming process on the new formed mudbank. Formed gullies on the mudbank combined with waves during spring tide sweep plants of the first line away, whilst during the dry periods high salinity may become the major dead cause of the plants. These sets of criteria if applied during the following planting succession it believed that the dead rate of the juveniles will drop drastically. In this respect action of human being can enhance the resilience of the coast and hence increase their own protection from the rising sea level and flooding.

Keywords
mudbank, planting technique, regeneration, monitoring, coastline protection

Species preferences of the crab *Sesarmops intermedius* to seedling predation in mangrove ecosystem of Kerala, India

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Abstract

Sesarmid crabs play a vital role in nutrient cycling in mangrove ecosystem. This process is mainly carried out through litter consumption and seedling predation. The crab *Sesarmops intermedius* is an aggressive predator of mangrove propagules and seedlings. This activity causes severe seedling mortality in the mangrove ecosystem. It has been observed that this crab shows species preferences with respect to seedling predation. The present study was conducted in Kunhimangalam mangrove ecosystem in Kannur district of Kerala to identify these preferences with respect to four dominant mangrove species, *viz*.: *Aegiceras corniculatum*, *Avicennia officinalis*, *Excoecaria agallocha* and *Rhizophora mucronata*. Twenty day old seedlings of the above four plant species were reared in a field nursery. They were exposed to crabs under different set of controlled treatments: enclosures, exclosure controls and open controls. An $1m^2$ enclosed area with known crab density functioned as an enclosure and that with out crab, an exclosure. Open control was an $1m^2$ area marked on the forest floor. Attack on seedlings and rate of mortality were tallied daily for 15 days. *Sesarmops intermedius* exhibited the highest feeding preference to seedlings of *Excoecaria agallocha* (100%) seedlings over those of *Aegiceras corniculatum* (93.75%), *Avicennia officinalis* (62.5%) and *Rhizophora mucronata* (56.25%). It was found that the preference worked as a fatal for *Excoecaria agallocha* when the crab density was $>8\ m^{-2}$ and when it was $<3\ m^{-2}$, it positively controlled the overcrowding of the seedlings. Influence of preferences shown by the crab will be assessed with reference to species composition of mangrove forests in Kunhimangalam, the study area.

Keywords
crab herbivory, seedlings, feeding preference, control treatments, mangrove vegetation

Population structure and multivariate analysis of *Avicennia marina* *(*Forssk.) Vierh. Pakistan

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Abstract

Mangrove forests are gradually decreasing day by day along the coast of Pakistan due to various known and unknown disturbances. The present studies focused on population structure and regeneration characteristics of mangrove forests in Pakistan with the application of multivariate methods. Twenty eight stands at six different sites were selected for qualitative measurements. A 10 x10 feet^2 quadrats were made randomly and a small quadrat (1 X 1 m^2) was laid inside the main quadrat for quantitative sampling of pneumatophores. The relationships between environmental factors and vegetation were also investigated. The group structure was exposed by an agglomerative clustering technique while major trends were disclosed by PCA ordination. Size class structure of *A. marina* and associated tree species for individual stands exhibited a few gaps. Relationships between tree density and basal area were non-significant while number and height of pneumatophores exhibited significant correlation ($P<0.05$). The overall density of *A. marina* (2960 trees/ha) and *R. mucronata (*3895.43 trees/ha) were more characteristics with basin mangrove stands while density of *C. tagal* (865 trees/ha) lower than riverine forests. The basal area of all mangrove species was closed to dwarf mangrove forests however, tree height ranged between fringe and dwarf mangrove trees. The results of the cluster analysis showed that the six groups of tree vegetation were associated with density/ha and to more or lesser extent with physico-chemical variables. The present study will help in the management and conservation planning of mangrove forests of Pakistan.

Keywords
population structure, regeneration, multivariate, PCA ordination

Mangrove forest regeneration in tsunami impacted sites of Nicobar Islands, India

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Abstract

Anthropogenic disturbances on the mangrove ecosystem are well documented and it has been reported that the mangrove forests are disappearing around the globe at an alarming rate of 1% per year. Natural disturbance like tsunami coupled with the man-made disturbances can drive the mangrove forests to an unrecoverable condition. The paper presents the post tsunami scenario of mangrove forest regeneration in the Nicobar Islands, India. In total, 25 locations over eight Islands were identified and surveyed for recording the re-colonization of mangrove species. The regeneration of mangrove species was quantified by laying plots of varying sizes (100m^2 to 5000m^2) and saplings of ≥1.3m were enumerated. To find out the pre-tsunami status of mangrove species distribution, plots were established in the scorched mangrove habitats and the snags were enumerated. In total, 17 species of mangroves were recorded from the re-colonization sites of which five were recorded for the first time from these Islands. Thirty per cent of the mangrove species recorded prior to tsunami could not be found during the present survey. The abundance of various species in the tsunami impacted sites was much lesser than the pre-tsunami situation. Definite pattern has been observed in the re-colonization of mangrove species. *Rhizophora* spp. dominating the proximal zone, a combination of *Rhizophora* spp. and *Bruguiera gymnorrhiza* dominating the middle zone and, *B. gymnorrhiza*, *Lumnitzera* spp., *Sonneratia* spp. were dominating the back mangrove zone. We suggest a continuous monitoring programme for these sites which could provide a better perspective on the re-colonization pattern of mangrove species.

Keywords
tsunami, Nicobar Islands, regeneration, habitat loss

Mangrove spatial structure in a monospecific stands of the black mangrove *Avicennia germinans* (L.) Stearn in the Cameroon estuary

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Abstract

One of the major components of forest stand structure is the spatial arrangement of tree positions and the distribution pattern of species. *Avicennia* (Acanthaceae) is considered an important colonizer of new estuarine areas. This genus comprises about eight species of which only one, namely the black mangrove *Avicennia germinans* (L.) Stearn, occurs in Cameroon mangrove forests. Through extension its complex of pneumatophores this species causes solidification of the soft substrate, hence facilitating the stabilization of coastal zones. In spite of this ecological importance, little is known about the patterning of *A. germinans* forest stands. In this contribution, we characterized the stand structure of this species in the Cameroon estuary. We located two sites in the landward margin and one on the seaward edge. There, we established 20 plots of 40 m × 40 m along belt transects, and subdivided each plot into 16 subplots of 10 m × 10 m. We measured the diameter, height and spatial coordinates of all *A. germinans* stems and finally determined the type of spatial arrangement of trees based on the on Ripley's *K*-function. Regarding the structural parameters, our results showed that the mean tree diameter, basal area and height were considerably higher on the seaward edge than in the landward margin. In the Cameroon estuary, trees of *A. germinans* were randomly distributed on almost one-half of the sampling plots and clumped at some scales on the remaining plots. Why our study did not exactly examine the key factor structuring the population of *A. germinans*, we assume that the zonation pattern of this species is driven by the great dispersal events and high rate of seedling mortality. In addition to our findings, it is important to develop a more complete characterization of the stand structure of *A. germinans*. We believe this objective can be achieved by analyzing endogenic organization processes (phenology, seed production, wood structure, growth, etc.) that occur within the growing environment of this species.

Keywords
vegetation structure, spatial pattern, *Avicennia germinans*, Cameroon estuary

Very-high-resolution diameter, biomass and carbon stock mapping on the two-thousand hectare mangroves of the Cameroon estuary

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Abstract

In the current context of climate change, along with the sea level rise, mapping coastal vegetation such as mangroves constitute an important topic. In this context, several efforts have been made to map the structural and functional parameters of these coastal forests. But, they solely focused on mapping leaf area index (LAI), tree height and standing biomass. In this contribution, we have used parameter inversion from satellite image (Very High Resolution QuickBird data) texture (performed via Fourier Transform Textural Ordination (FOTO) method) to produce a landscape scale map of mangrove tree diameter and carbon stocks over a study region of *ca.* 2260 ha in Cameroon estuary. Moreover, in agreement with previous publications, we used the same methodological approach to map the mangrove canopy and aboveground biomass. The resulting map clearly depicted canopy heterogeneity across the mangrove forest. These different patterns represented the areas covered by medium (9 m ≤ tree height ≤ 15 m) and high (up to 15 m height) stature forests. The trends in landscape features, instead of being the result of human-induced disturbances or different soil characteristics, are mostly related to the past history of the studied forests. The estimates indicate that most of the standing biomass (100-200 t DM ha^{-1}) resides in medium-stature mangrove stands (7-14 cm). Aboveground C storage shows two well-defined peaks around values of 100 t ha^{-1} and 200 t ha^{-1}. Comparison between the FOTO-inverted and ground truth data revealed that mean tree diameter and aboveground biomass had a bias of about -0.007 cm and 1.06 t DM ha^{-1}, respectively. With regard to the REDD (reduction of carbon emissions due to deforestation and forest degradation) policies, these findings would serve local policy-makers as a way to monitor and manage mangrove forests. Interestingly, they are in a straight line with the interesting prospect of recording several regional databases featuring field-measured forest parameters and corresponding forest canopy images.

Keywords
remote sensing, fast Fourier transform, canopy texture, mangrove diameter, aboveground biomass, carbon storage, Cameroon estuary

Diversity of crabs and molluscs macrofauna in mangrove of Wouri estuary (Douala - Cameroon)

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Abstract

According to their specific richness and multiple ecological roles, crabs and molluscs appear, with trees, as most significant biotic components in the functioning of these ecosystems. Mangroves of the Wouri estuary undergo for decades important damages and data available on invertebrates are fragmented and gone back up to more than thirty years. The aim of this works is to check off and to identify crabs and molluscs which colonize mangrove of Douala city. Two intrusive methods of capture (sight Harvest and excavation) have been used in 10 × 10 m² plots for crabs. Two quadrats of 1 × 1 m² were surrounded inside every plot for molluscs counts. 2046 crabs and 14405 molluscs have been inventoried on 600 m² and 12 m² respectively. 16451 individuals belong to 24 species fairly distributed between both groups. Five families of crabs and six families of molluscs were identified. The family of Sesarmidae (eight species) and Pachymelaniidae (four species) are the most diversified whereas Sesarmidae (94.6%) and Potamididae (45.6%) are the most abundant taxa. Also, *Sesarma angolense* (23.6%) and *Tympanotonus fuscatus* (38%) are the most abundant species while *Perisesarma alberti* and *Pachymelania fusca* are the most frequent species. The current study enriched the inventory of the Cameroon macrofauna with nine species (three of crabs and six of molluscs), one genus (*Melanoïdes*) and one family (Melanopsidae) to molluscs.

Keywords
abundance, excavation, inventory, macrofauna, sight harvest

Human-induced environmental change affecting macrobenthic communities in the Segara Anakan Lagoon, Java, Indonesia

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Abstract

The Segara Anakan Lagoon is the last large mangrove-fringed estuarine system in Java, Indonesia. It is affected by deforestation, high riverine sediment input, overfishing and effluents from households and industry including Indonesia´s largest oil refinery. We investigated the influence of mangrove vegetation, food quality, abiotic water and sediment properties, and organic pollutants on macrobenthic invertebrates.
Benthic species richness was high compared to other Indo-West Pacific mangroves. However, diversity indices were low to medium and an increasing dominance of opportunistic species was recorded over a period of five years. A high spatio-temporal variation of macrobenthic density and community composition was mainly related to pore water salinity and sediment $\delta^{13}C_{org}$, $\delta^{15}N$ and C_{org}/N. The distribution of facultatively leaf-eating crabs was related to tree, seedling and undergrowth density, but the occurrence of single crab and tree species was not correlated. Experiments revealed that these crabs preferentially feed on leaves with a high amount and/or freshness of nitrogenous compounds (amino acids, hexosamines, total nitrogen, $\delta^{15}N$).
Changes in vegetation and sediment organic matter appear to be important controls of macrobenthic community composition promoting opportunistic species in Segara Anakan. Most of the organic contaminants in water, sediment and biota were polycyclic aromatic compounds. Their concentration in water and sediment reached toxic levels close to the oil refinery. Polycyclic aromatic hydrocarbons (PAHs) mainly consisted of alkylated PAHs which are more abundant in crude oil and more persistent in the environment than the better-known parent PAHs. A total of 51 organic contaminants were recorded in five abundant benthic invertebrates. The gastropod *Telescopium telescopium* and the bivalve *Polymesoda erosa* stored highest number of contaminants suggesting their suitability as bioindicators for coastal pollution. Uptake and biomagnification of as yet hardly investigated organic contaminants and their impact on benthic biodiversity will be the subject of future studies.

Keywords
environmental change, macrobenthic diversity, food quality, industrial pollution, time series investigation

Advocating for sustainability in mangroves utilization: a case study of Kilifi District, Kenya

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Abstract

The growing multiuse complexity in the values and interests in mangrove forests has led to an increase in users' conflicts as well as a number of management challenges. This study was carried out in 2010 with an aim of developing sound management mechanisms for mangrove forest in Kilifi district, Kenya based on the locals' interests and the existing policies. Through a desktop literature review and engagement of mangrove resource users and government officials in stakeholders' workshops, the study identified values, users' conflicts, management regimes and challenges in Kenya. Inadequate local community participation and private sector involvement, coastal land use changes and inadequate legislation and enforcement mechanisms were mentioned as the major hindrance to sustainable utilization of the resource. In addition, the study reviews relevant existing legislations governing the management of mangroves, identifies gaps and give recommendation on possibilities of filling.

Keywords
users' conflicts, sustainable management, policy, legislation

Assessing the link between the local people and the mangroves status of Mtwapa Creek, Kenya

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Abstract

The sustenance potential of the mangroves of Mtwapa Creek was evaluated amidst disturbance arising from human activities within and around the mangrove area. This was done through assessment of tree abundance, dispersion pattern and regeneration status along belt transects in 3 forest patches (Gung'ombe, Kitumbo and Kidongo). A socio-economic survey was then done in the villages along the creek to determine the influence of the local people on the status of the forest. The results showed relatively good recruitment rates in regeneration and high mature stand stem density but of poor form and low utilization class poles even for the principal species, *Rhizophora mucronata*. While other locals considered the status of the forest as stable or improving, 55% of the local people say it is degraded. However, most people are not aware of the causes with only 12% attributing the status to cutting. In addition, most of the locals are farmers and not fishermen which do not however underscore the importance of the study but indicates possibilities of other factors such as siltation of mangroves from farmland and not necessarily overexploitation influencing sustainability.

Keywords
sustainability, degradation, disturbance, regeneration

Survey and biodiversity identification of mangrove ecosystem in Lagos Lagoon and eastern part of Badagry Creek, Nigeria

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Abstract

Mangroves are salt-tolerant characteristic complex plant communities occurring in sheltered coast line areas in the tropical and sub-tropical inter-tidal regions of the world such as bays, estuaries, lagoons and creeks. Study was carried out on the survey and identification of mangroves in Lagos Lagoon in 2010. Global Positioning System (GPS) and other relevant equipments were used to determine the geographical coordinates, abundance and distribution of mangrove species within the study areas. Seven stations (Ebute Oko, Majidun, Badore, Langbasa, Agbeki, Bayeku and Oreta) and three stations (Okun Akaraba, Okun Ilase and Okun Ibese) were selected in Lagos Lagoon and Badagry Creek respectively. All these stations were closed to coastal communities expect Bayeku and Agbeki that were found on the middle of the Lagoon. The analyses on physico-chemical parameters of the water samples from these stations revealed that the salinity range between 0.3‰ (Majidun) and 14.0‰ (Okun Ibese) and conductivity ranged between 5.69 mS/cm (Agbeki) and 23.5 mS/cm (Okun Ibese). Low transparency was recorded for all the stations which were an indication that mangrove trees can be found at low water depth. All these stations were alkaline (pH > 7) in nature. According to APG 111 taxonomy classification of mangrove species, red mangroves (Rhizophoraceae) and black mangroves (Acanthaceae) were mostly present in all these stations with red mangroves (*Rhizophora racemosa*) dominating in the North. Also discovered along the Lagoon is Nypa palm (*Nypa fruticans*) which was scantly found. Mollusks like periwinkles (*Tympanotonus fuscatus*) and oysters (*Crassostrea* sp.), crustanceans like purple mangroves crab (*Goniopsis pelii*) and fish fauna like Tilapia (*Sarotherodon melanotheron*), mudskipper (*Petriopthalmus barbatum),* red snapper *(Lutjanus goreensis*) and *Mugil cephalus* were found at bottom and wall of the mangrove trees. Economics activities that surround these communities are fishing, aquaculture (acadja), sand mining, dredging, logging and shipping and urban development that had led to the destruction of mangrove ecosystem in this lagoon.

Keywords
GPS, red mangrove, black mangrove, white mangrove, *Nypa fruticans*

Phylogeography of *Bruguiera gymnorrhiza*

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Abstract

Bruguiera gymnorrhiza (L.) Lam. is one of the most widely distributed major mangrove species in the Indo-West Pacific (IWP). The vast distribution range of *B. gymnorrhiza* is attributed to its sea-drifting and dispersing propagules. Using both chloroplast and nuclear DNA markers, Minobe et al. (2009) suggested distinct genetic structure over Malay Peninsula. However, there was no clear structure within either the larger Pacific or the East Indian Oceanic regions. Moreover, the number of populations used in the study was very small despite the vast distribution range of the species, and the molecular markers was too short to detect fine scale genetic structures within each oceanic region. Furthermore, the phylogenetic relationship of *B. gymnorrhiza* with the putative sister species, *B. sexangula*, has not been clearly understood. To obtain comprehensive understanding on genetic structure of *B. gymnorrhiza*, we used samples collected from wide range of in IWP by our research network. We analyzed genetic structure using two cpDNA markers and 6 SSR markers. Our results revealed a clear genetic structure between the east and west side of Malay Peninsula, although there was a mixture of patterns observed in some populations. In Phuket, Thailand, for example, a simple mixture of two genotypes is suggested by both nuclear and cpDNA markers rather than admixture. This result raises a question about artificial transfer of plants with different genotype into this area. The NJ tree based on genetic distance (Da) showed that geographically close populations formed clusters. There was a significant correlation between genetic distance and geographic distance both in the Pacific and in the Indian Oceanic regions.

Keywords
Bruguiera sexangula, population structure

Benthos diversity in Yanbu mangrove conservation sites - Red Sea shoreline

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Abstract

The mangrove stands (*Avicennia marina*) and adjacent habitats in Yanbu region are considered to be significant of their type along Red Sea coast between Jeddah and Gulf of Aqaba. The mangrove stands fringing the Yanbu shoreline are not dense communities due to the climatic effects of the desert and of high salinity of Red Sea. The mangrove trees at Yanbu tend to be shrubby and their height is limited due to lack of river estuaries. A monitoring program for three conservation areas in Yanbu mangrove region (designated as CA1, CA2 & CA3) was designed with studies on sediments and on macro-benthos to recognize the benthic species that may serve as the baseline data for future studies. Thirty species/taxa of macrobenthos were identified in the region during the one-year study period. The population density of macrobenthos was marked with the polychaete worms dominance (33%), followed by nematodes (28%) and pelecypod shells (20%). Two major animal groups shared dominance at CA1 with the pelecypod shells (44%) and nematode worms (43%), CA2 was dominated by nematode worms (40%) and CA3 had 66% of polychaete worms. The species diversity was very low for all three areas with the lowest value (1.04) for CA1. The high silt and clay fraction in sediments at CA1 accounts for the dominance of two species, namely, nematode and a species of mud dwelling shell, *Brachidontes variabilis*. The dominance of polychaete worms at CA3 was attributed to high percentage (82%) of sand. The grain size of the sediment tends to limit the existence of benthos species, as other environmental parameters were within the normal range and at the moment not critical to community structure in the mangrove conservation areas. The macrobenthos population was highest in the Yanbu port area and lowest in the community area, which had been recently dredged.

Keywords
species diversity, Shannon Index, population evenness

Contribution of plant species to carbon sequestration function of mangrove ecosystems in Sri Lanka

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Abstract

High primary productivity of mangroves facilitates carbon sequestration function of mangrove ecosystems. Present study is the first one in Sri Lanka that aims at determining the amount of carbon sequestered by mangrove plants. Allometric relationships and harvest method were used to determine mangrove plant biomass. Carbon content was determined by $K_2Cr_2O_7$ oxidation. Except for the leaves, approximately 50% of biomass is composed of organic carbon. *Lumnitzera racemosa* was found to occur in five mangrove areas that represented three climatic zones. *Avicennia marina* (36.62 t/ha), *Rhizophora mucronata* (27.09 t/ha) and *L. racemosa* (9.43 t/ha) are the species that contribute most to retain carbon in Negombo estuary. *L. racemosa* (30.1 t/ha at Rekawa and 42.24 t/ha at Pambala/Chilaw lagoon), *Ceriops tagal* (16.91 t/ha at Rekawa) and *Avicennia officinalis* were found to be the most significant species in terms of carbon retention. The greatest carbon retaining species at Kala Oya mangrove ecosystems were *L. racemosa* (59.55 t/ha), *Excoecaria agallocha* (42.73 t/ha) and *R. mucronata* (45.75 t/ha). Malwathu Oya estuarine mangroves were dominated by *Sonneratia alba* (92.81 t/ha) and *A. marina* (41.53 t/ha) while *R. apiculata* (79.66 t/ha) and *E. agallocha* (25.98 t/ha) at Batticaloa lagoon retained the most carbon. Among the eleven species considered in the present study, *L. racemosa* and *R. mucronata* were proven to be superior in their capacity of carbon retention in all three climatic zones while *Bruguiera cylindrica* and *B. gymnorrhiza* contributed the least. In terms of carbon sequestration by the ecosystems, Kala Oya mangroves with 204 t/ha of carbon, ranks the highest, followed by Malwathu Oya (165 t/ha) and Batticaloa lagoon (150 t/ha) mangroves. Remote location in sparsely populated areas with poor accessibility, partly due to war situation prevailed in these three areas for the past three decades would have saved these mangroves from human interference unlike mangrove areas in Negombo estuary, situated in a very populous area on the western coast and mangrove wood is predominantly used for “Brush Park” construction, a traditional fishing device used in this estuary, records the least amount (80 t/ha) of retained carbon in mangrove plant biomass.

Keywords
carbon sequestration, Sri Lanka

Bottlenecks in conserving mangroves associated with the Puttalam Estuary, with special reference to the Seguwantivu Conservation Forest

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Abstract

Puttalam district records one of the highest concentrations of mangroves in Sri Lanka that is vital for providing a multitude of ecosystem services including livelihoods, food security and coastal defense. As a mitigation measure to curtail their rapid destruction from the prawn farming industry, 1039.5 ha of mangrove area were gazetted as Conservation Forests (CF) under the Forest Conservation Ordinance (FCO) in 2000 and 2002 period. Of the nine CFs, five are associated with the Puttalam estuary proper while four are located adjacent to the Mundal Lake. 385.37 ha Seguwantivu is the largest of the CFs and is placed within the Mi Oya river delta.

Although the e CFs can be considered as “No-take zones” where all extractive uses are prohibited, as protected areas that remain in isolation, surrounded by radically altered habitat, are facing serious viability problems. Unavailability of an integrated conservation and management plan with proper ownership for the Estuarine ecosystem is the main bottleneck obstructing the mangrove forest survival and the sustainable utilization of estuarine resources. It has been found that over 60% of the existing prawn farms are un-unauthorized and majority is presently being converted in to saltpans due to low risk and high economic returns of the slat industry. Analysis of forest offenses related to mangroves indicates that considerable area in Seguwantivu has been cleared for expansion of saltpans. Land ownership issue is a major impediment in implementing legislative provisions for protecting the forests. Therefore, it is vital to clearly demarcate CF boundaries and to undertake biological and socio-economic assessments, before preparing management plans as mandated in the FCO. Further haphazardly developed policies by government institutions for tourism, energy, fishery, forestry and wildlife as well as coast conservation need to be mainstreamed and re-assessed to address conservation issues as well as the present and future needs of an expanding population depending on the estuarine resources.

Keywords
Puttalam district, conservation forest, management, policy

Colombia mangroves: recent advances towards their understanding

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Abstract

Throughout the last 14 years researchers at the National University of Colombia in Medellin, have developed several studies on mangrove ecosystems, particularly in San Andrés Island, La Guajira, the Cispatá Bay, the Gulf of Urabá and the Pacific coast of Colombia. They focused on species composition, structure and dynamics and their relationship with the physical environment in different time scales. We have applied remote sensing analysis, the importance of pollen deposited in superficial and deep sediments to understand the coastal vegetation dynamics in the Holocene, dating of sediments with ^{14}C and ^{210}Pb, the establishment of temporary plots and the time-space monitoring, rates of erosion, sedimentation, species recruitment as well as mortality, among other techniques. The expressions of vegetation and the epifauna associated to red mangrove roots in San Andrés Island (including vegetation, and the short term coverage dynamics), pollen of superficial sediments and mangrove vegetation, long-term coverage dynamics, and socio-economic aspects related to Colombian coastal Non Timber Forest Products showed that pollen spectra can be accurately used to describe different mangrove environments, and fossil based palaeoecological reconstructions. Our report on pollen in surface sediments - the first for the Colombian Caribbean - is valuable for further interpretations of marine records, and reconstruction of past environmental and climate changes. In respect to epifaunal communities we showed that geomorphological characteristics, presence or absence of freshwater currents, tides and rainfall mainly, as well as anthropogenic factors can influence their development. Larval dispersion and the proximity to other ecosystems are crucial to population variations, and only some organisms adapted to extreme conditions, settle down and maintain in the area. Our group will undertake more studies in the gulf of Urabá, the coastal vegetation dynamics and the fine interpretation of sea level rise through palynology, as well as conservation biology and carbon dynamics in these ecosystems.

Keywords
dynamics, palynology, coastal ecosystems, Colombia

Minimum temperature requirements per aridity class of the mangrove genera *Avicennia* and *Rhizophora* at their upper latitudinal limits

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Abstract

In earlier studies we found no common isotherms that define the range limits of the two mangrove genera *Avicennia* and *Rhizophora*. However, along the same coastline where other environmental conditions are similar, the coldest month and yearly average of air temperature (AT) and sea surface temperature (SST) are warmer at *Rhizophora* limits than at the correspondent *Avicennia* limits. In addition, there is an impact of aridity on temperature requirements of mangroves at their latitudinal limits. Today, we present the minimum temperature requirements per aridity class (defined below) of the mangrove genera *Avicennia* and *Rhizophora* at their upper latitudinal limits. Our hypotheses are (1) the minimum temperature required by mangroves increases with increasing aridity, and (2) *Rhizophora* requires higher temperatures than *Avicennia* for each aridity class.
We divided all *Avicennia* and *Rhizophora* limits into four aridity classes based on precipitation: (1) limits with a wet climate, (2) limits with a moderate wet climate, (3) limits with a dry climate and (4) limits with a very dry climate. Next, we derived seven temperature-based variables from monthly values of AT and SST. Finally, we extracted the limiting isotherms per aridity class for each mangrove genus.
For all aridity classes except one, we could define a limiting temperature. The average of mean AT and mean SST for *Rhizophora* was ranging from 21.6°C for the wet class to at least 26.8°C for the very dry class. At the very dry *Avicennia* limits, the coldest month AT (15.7°C) and the average of mean AT and mean SST (> 23.8°C) were at least 2.7°C warmer than at the wet *Avicennia* limits. Differences of limiting temperatures between *Avicennia* and *Rhizophora* limits were larger with increasing aridity class. To conclude, we found different temperatures limits for *Avicennia* and *Rhizophora* based on aridity class, and we could derive two useful schemes of minimum temperature requirements per aridity class for both mangrove genera.

Keywords
biogeography, climate, habitat compensation, niche

Predicting future latitudinal limits of mangroves in South-Africa with species distribution modelling

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Abstract

In South-Africa, mangrove forests occur along the east coast and reach their southern latitudinal limit of the West-Indian Ocean at 32.6°S. These mangrove forests consist of three species: *Avicennia marina*, *Bruguiera gymnorrhiza* and *Rhizophora mucronata*. Due to coastal geomorphology and wave action, mangroves are restricted to estuaries. Hence, the mangrove distribution of South-Africa is an ensemble of fragmented, small forest patches. The drivers of the regional distribution had not been identified yet. Today we present (1) whether and how climate may affect the patchy distribution and the latitudinal limits of the mangrove forest and its species in South-Africa, and (2) if and where global warming will create climatically suitable sites for mangroves beyond the current limits by using species distribution modelling (SDM). SDM is a tool to explain observed patterns of species occurrences by using environmental information in correlative models. We used three modelling techniques: generalized linear, generalized additive models and gradient boosting machines. Three climate variables were selected as predictors in the SDMs: (1) monthly minimum temperature of the coldest month, (2) growing degree days (GDD) and (3) water balance. Climate variables for the future projections were derived from climate projections for two socio-economic scenarios (A2a and B2a). All modelling techniques accurately predicted the current leading edge of the mangrove species and forest. GDD turned out to be the most important variable to project the distribution of the mangrove forest and species in South-Africa by the majority of the modelling techniques we applied. Hence, a too short growing season is likely to limit the distribution of mangrove species in South-Africa. Global warming will create climatically suitable sites south of the current latitudinal limits for the mangrove species *A. marina* and *B. gymnorrhiza*, but for the latitudinal limit of *R. mucronata* different outcomes were projected depending on the modelling techniques and climate scenarios.

Keywords
biogeography, climate change, niche, range edge

Floral composition of mangrove of Andaman and Nicobar Islands (India) with special references to natural hybrids of Genus *Rhizophora*

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Abstract

A recent survey of mangroves in Andaman and Nicobar islands was carried out by the authors in 21 selected sites. Total 42 mangrove species (17 major mangrove species, 10 minor mangrove species and 15 mangrove associates) were recorded including one new record of *Sonneratia ovata* Back from Havelock Island based on Tomlinson classification. Nine previously recorded species namely *Ceriops decandra*, *Aegialitis rotundifolia*, *Kandelia candel*, *Aagalia cuculata*, *Bruguiera sexangula*, *Cynometra ramiflora*, *Cerbera manghas* and *Brownlowia tersa* are not encountered during the present survey. During the survey some interesting observations were recorded in the natural hybrids of genus *Rhizophora* and their parents. Two forms of *Rhizophora* hybrids with respect to style length, number of stamens and leaf size were recorded from Havelock Island. In addition to that series of intermediate forms between *R. mucronata* and *R. stylosa* with respect to style length and two forms of *R. apiculata*, style with red tip and style with normal tip, were also recorded from Havelock Island. These observations have not been reported earlier. Although, the two forms of hybrids showed the characters of two known *Rhizophora* hybrids, *R. x lamarckii* (hybrid between *R. apiculata* and *R. stylosa*) and *R. x annamalayana* (hybrid between *R. apiculata* and *R. mucronata*) respectively, they showed some variation also. It appears that variations among the hybrids are the result of hybridization between series of intermediate forms between *R. stylosa* and *R. mucronata* and two forms of *R. apiculata*. However further taxonomical and molecular analysis are needed to confirm it. All indentified species were described with their key characters, illustration and distribution in Andaman and Nicobar islands

Keywords
diversity, *Rhizophora*, hybrid

Weaver ants as potential controlling agent of the mangrove apple fruit borer

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Abstract

The pulp of the fruit of the Mangrove Apple, *Sonneratia caseolaris* (L.) Engl., is tasty and nutritious and hence, can be used to prepare a fruit drink. However, it has not been commercialized, or even practiced widely at homes, due to the fact that fruits of mangrove apple are frequently infested by a fruit borer. If this pest problem can be solved, the fruits can be used for small scale industry motivating mangrove dwellers to protect this species that is destroyed now at alarming rate. Ants of the genus *Oecophylla*, which are commonly named 'weaver ants', are predators of other insects and are able to protect a variety of terrestrial plants against pest insects. However, observations on the ecology of these ants in Sri Lankan mangrove forests are lacking. A study of *Oecophylla smaragdina* was carried out in *S. caseolaris* vegetations in wet zone of Sri Lanka to determine if these ants can protect their host plant (*S. caseolaris*) from the fruit borer that is unique to *S. caseolaris* fruits. Fruit damage and the number of colonies of *O. smaragdina* ants were measured on trees at three sites. At all sites, the results showed a negative correlation between number of weaver ant colonies in mangrove apple trees with the abundance of the fruit borer eggs laid on fruits as well as with the percentage damage of fruits. These data indicate that promoting weaver ant colonies might be effective in controlling the *fruit borer*.

Keywords
Oecophylla smaragdina, Sonneratia caseolaris, fruit borer, Sri Lanka

Socio-economics of mangrove-dependent people on the southeast coast of India

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Abstract

Mangrove forests support coastal fisheries and socio-economics of the coastal people. One-year survey was made from eighty families from eight mangrove villages along southeast coast of India. The average level of literacy of traditional fishermen was higher (82%) in the age group of 20-40 years than in that of above 40 years (41%). The old people (>40 years) are largely involved in fishing whereas the young people are migrating to other countries for non-fishing livelihoods. This change of attitude is due to poor fish catch and low income in the mangrove waters studied. This issue of recent origin is attributed by the local people to the following reasons: (1) untreated discharges from aquaculture industries; (2) reduced influx of fresh water and tidal water in to the mangrove estuary; (3) shallowness of the mangrove water bodies due to siltation and sedimentation; and (4) increasing fishing pressure due to increased participation of non-traditional fishermen. All these issues deserve immediate research intervention for providing appropriate remedial measures. Globally there is a decline in mangroves, often linked to the loss of fish resources, anthropogenic pressure and climate change. Over exploitation of juvenile fishes which has an adverse impact on fishery resources is a serious problem in several mangroves especially in the Sundarbans. Therefore, a continuous monitoring is highly required for the fish resources of the mangrove waters and the fishing pressure, in order to bring out a sustainable model for management of fishery resources in the mangrove waters. Such studies are also necessary for global mangrove waters to bring out a workable model for better management strategy. The activities that integrate mangrove rehabilitation with fishery development, such as canal fishing, crab fattening, oyster, mussel and clam cultures must be promoted within the mangrove water bodies. This will increase the income generation of the local community along with mangrove resource conservation.

Keywords
fishery resources, socio-economics, conservation, management

Growth dynamics of mangroves in South Africa: a matter of latitudinal importance?

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Abstract

Unregulated harvesting continues to be a chief threat to mangrove forests as well as the ecological services they provide. It is important to determine the rate at which the seedlings and subsequent regeneration classes grow and to determine the suite of conditions that are best suited for growth. In South Africa and other parts of the world *Avicennia marina* is harvested for firewood by local communities. In countries, at the limits of mangrove distribution, this species is usually the most dominant and wide spread. The objectives of this study were to determine variations in growth rates of mangroves along a latitudinal gradient. Long term monitoring sites were setup at St Lucia, Mngazana and Nxaxo estuaries. Growth rates were determined for *A. marina*, the most widely distributed mangrove species in South Africa and the world. The average growth rate for this species at St Lucia was 3.77 ± 0.39 $cm.month^{-1}$, at Mngazana was 1.01 ± 0.05 $cm.month^{-1}$ and at Nxaxo Estuary was 1.03 ± 0.43 $cm.month^{-1}$. The growth of Regeneration Class 1 (0-51 cm) of *Avicennia* at Mngazana Estuary was correlated to sediment moisture content ($r = 0.8$, $p<0.05$) and the amount of silt found in the site (silt: $r = -7.2$, $p<0.05$). The higher growth rate at St Lucia may be a consequence of the localised flooding of some areas due to prolonged mouth closure as opposed to higher temperatures. Therefore an increase in water depth has stimulated higher growth rates of individuals at St Lucia.

Keywords
St Lucia, *Avicennia marina*, temperature, distributional limit

Mangroves beyond their distribution. Is it a case of invasion at Nahoon Estuary, South Africa?

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Abstract

The southern distributional limit of mangroves in Africa is reached at Nahoon Estuary in South Africa. However, the original stand of mangroves at this estuary was planted from material collected at Durban Bay in the 1970's. Further expansion of the mangroves at Nahoon Estuary was a result of natural dispersal of propagules from the planted trees. The species planted here are *Avicennia marina*, *Bruguiera gymnorrhiza* and *Rhizophora mucronata*. The latter two species are restricted to population numbers less than 50 individuals for *B. gymnorrhiza* and less than five individuals for *R. mucronata*. The spread and growth of *Avicennia marina* has not been previously documented at this estuary and this study is expected to provide insight into the rate of spread, the competitive interactions between this species and naturally occurring salt marsh species. In light of the pressures of climate change, it is expected that mangroves may migrate from tropical to temperate regions, as well as on a local scale landward. Predictions are that as mangroves move there will be localized competition between the mangroves and the salt marsh as they occupy the same habitat. This would result in competition for resources between salt marsh species and mangroves, causing either the eradication of the salt marsh in these areas or a change in species composition and biodiversity.

Keywords
Avicennia marina, competition, temperature, salt marsh

Organic matter dynamics and ecological changes in mangrove ecosystem - a case study from India

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Abstract

Mangroves are intermediate coastal ecosystems strategically located at the interface between land and sea, and play an important role in the organic matter cycling. Several studies have shown that hydrobiogeochemical alteration has affected organic matter distribution and result in the mangrove species diversity. A study has been attempted to understand the dynamics and cycling of sedimentary organic matter in the Pichavaram-Vellar-Coleroon mangrove-estuarine complex in south-eastern, India. In order to evaluate the sources and fate of organic matter (OM) in the Pichavaram mangrove-estuarine ecosystem, C_{org}, N_{tot}, C/N_{atm}, stable isotopes ($\delta^{13}C_{org}$ and $\delta^{15}N_{org}$) and organic biomarkers of five ^{210}Pb dated sediment cores were investigated. In mangrove sediments, C_{org}, N_{tot}, and C/N_{atm} concentration in mangroves and estuaries varied in space and time. OM in the sediments is rapidly decomposed or remineralized in these environments. The rate of C_{org} burial is more in mangrove forests than estuaries. In general, the mangrove sediments extracts have higher biomarkers concentration (22.6 ± 13.3μg/g) than the estuarine sediments (6.42 ± 4.92μg/g). In both estuarine and mangrove sediments, triterpenol is the dominant biomarker, and constitutes 55% and 53% of the total lipid extracts, respectively. The high abundance and unimodal distribution of the long-chained *n*-alkanes, high Carbon Preference Index (CPI >8) and Terrestrial Aquatic Ratio (TAR 2.4 - 41) values indicate the presence of higher plant matter is preserved in the sediments. The presence of *n*-alkanols (C_{26}, $C_{28,}$ C_{30}), and abundance of phytosterols (β-sitosterol and stigmasterol) and triterpenoids (taraxerol, β-amyrin, germanicol and lupeol) indicate mangrove vegetation as the primary source of sedimentary OM in these sediments. In contrast, the bimodal distribution of *n*-alkanes, lower CPI (0.75 to 0.90) and TAR (1.9 - 5.7) values, and the ternary plot of $\Sigma C_{27,}$ ΣC_{28} and ΣC_{27} sterols indicate that phytoplankton/algal derived OM is more pronounced in estuarine sediments. Drastic changes in freshwater input from the Coleroon River in the last decade leads to increase in salinity and replacement of the less salt tolerant *Rhizophora* vegetation to more salt tolerant species like *Avicennia* and *Suaeda.*

Keywords
organic matter cycling, organic biomarker, mangrove sediment, estuarine sediment, Terrestrial Aquatic Ratio

Investigation of possible bioshields to protect vulnerable sections of the Sri Lankan coast

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Abstract

The 26th December 2004, a tsunami generated by an earthquake of intensity of 9.3 on the Richter scale hit the coastal of peninsular countries along the Indian Ocean. It caused 227 898 deaths along the countries affected. Some researches and publications hypothesized that coastal vegetation such as mangroves, if wide enough, could provide a protection against the flood and reduce the disastrous effects of a tsunami.
The aim of the present study was to create a vulnerability indicator to classify the entire coast of Sri Lanka against this kind of extreme events. To achieve this, a visual classification of land cover was done for the entire coastal area of the island using Google Earth imagery and ground-truth. The Global Digital Elevation Model (GDEM) from ASTER satellite data was used for elevation data. Based on these two datasets and data from literature on wave height and friction, a vulnerability indicator and vulnerability maps were created. The field study of bioshields was done based on literature and on field work realized in July and August 2010. The results show that the model can realistically detect the affected and non affected area on the coast. Vulnerability among coastal areas varies between 12 and 88%. Caveats of the model include the lack of variation of tsunami wave height along the coastline and overestimation of vulnerability where water bodies occur beyond the coastline. The investigation of potential bioshields reveal that the most interesting barrier which can be built is a mix of vegetation between *Pandanus odoratissimus* L. and *Casuarina equisetifolia* L. as it can provide a maximum effect of mitigation against the flood.

Keywords
tsunami, bioshield, vulnerability indicator, land use/cover, mixed vegetation

Evaluating the local use of mangroves as a source firewood in Sri Lanka

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Abstract

Mangrove ecosystems provide an array of products and services that support the well-being of the livelihood of coastal communities. Mangrove wood is one of the major products from Mangrove ecosystems and it is used as firewood, studs for houses, rafters, joists, telegraph poles, fences, bridges, railway sleepers, poles for fish traps, and for canoes and boats. Among the mangrove products, the fire wood has become one of the top uses of mangrove woods in Sri Lanka and extraction of firewood is generally practiced by mangrove dwellers in unsustainable way. The objective of this study was to study the intensity of collection and selectivity of species in firewood extraction from mangrove forests and its possible impacts on mangrove forests in Sri Lanka.
Three mangrove forests with higher species diversity as one from each of southern, western and eastern coasts (i.e. Rekawa, Pambala and Batticaloa Lagoons respectively) were selected. A questionnaire survey associated with *in situ* observations on the 'firewood use' was conducted in villages around each of the mangrove forests to find the species selection and the intensity of extraction in firewood extraction by mangrove dwellers. At the same time, firewood qualities such as Hardness, Cleavability Combustibility, Calorific value, Smokiness and extent of Cracking and Sparking etc. of mangrove wood available in the three forests were assessed in the laboratory in order to rank true mangrove species in the firewood quality.
The results revealed a higher variability among true mangroves in fire wood qualities placing Rhizoporaceae species at the top and *Excoecaria agallocha* at the bottom. As the extraction of fire wood is carried out in unsustainable way, the selective extraction of high quality fire wood may lead the forest to be dominated by low quality fire wood species. As an example, the *E. agallocha* is never used as a fire wood and the timber of this species is not used for any other purpose also. The ultimate result of such selective human impacts could lead the mangrove forests to be degraded in terms of biological diversity.

Keywords
firewood, Sri Lanka, cryptic ecological degradation

Survey on the distribution and species composition of mangroves in Sri Lanka in relation to the salinity of associated surface water

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Abstract

The species composition of mangrove ecosystems in Sri Lanka can be considered as remarkably high when it is compared with the extent of the mangrove cover of the country. Over 20 species of true mangroves (i.e. about one third of the global species composition) and a large number of mangrove associates are reported in less than 12000 ha (i.e. not more than 0.0006% of the global coverage) of mangrove forests. Such a higher diversity is reported by recent studies restricted to southern and westerns coasts of the country. Mangrove ecosystems on the north and east coasts of the country were not subjected to scientific surveys over the last 30 year period due the civil war in those areas. Now this civil war is over and accesses to all the places are open. These circumstances led us to study the species composition of mangroves in Sri Lanka, particularly on the north and east coasts, in order to get an actual assessment on the species richness of mangrove communities in Sri Lanka and at the same time to find out whether there is any relationship between the species diversity and the salinity regime of the associated lagoon/estuary.
All of the separate mangrove ecosystems along the 1760km long coastline of the country that cover the three existing climatic zones (wet, dry, arid, and intermediate), were visited. The species of true mangroves and mangrove associates in all the sites with different physiognomic aspects in each lagoon/estuary were identified and recorded separately. The salinity of surface water at 4-5 different places in each lagoon/estuary was measured once a three months (i.e. in different seasons) over one year period. The data were analyzed to find the relationship between the salinity of lagoon/estuary water and species richness and/or species composition.
The results revealed that species diversity of mangroves along the north and east coasts is less than that of the south and west coasts. When the lagoons/estuaries in different climatic zones were clustered and analyzed, we found that the intermediate zone and dry zone possess respectively the highest and lowest species diversity in mangroves. These findings emphasize that, in conservation point of view, a higher attention should be paid on mangrove ecosystems in the intermediate zone.

Keywords
true mangroves, mangrove associates, Sri Lanka, species composition, salinity, conservation

Rejuvenation and restoration mangroves in coastal region

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Abstract

Strategies for safe-guarding coastal ecosystem: The need for protection, restoration and regeneration of mangroves has been since long under top priority by the ecologists and the social scientists. Our target revenue sub-divisions are namely *Nizampatnam, Repalle, Bapatla* and *Karlapalem* in *Guntur District* and *Chirala* & *Vetapalem* in *Prakasam District* in lines of disaster preparedness and mitigation activities. The felt need is to sensitize the coastal villages to prevent the degradation and depletion of ecosystem against preventable destructive practices such as:

- extensive consumption for cattle feed/fodder
- regular usage for cooking fuel by way of fire wood
- usage of timber for thatched sheds
- timber for building fishing boats/materials and,
- fencing material for houses and backyard

Since the protection and restoration program is community based in the coastal villages, the people concerned are involved as the direct beneficiaries as well as the stake-holders.

- Women and youth of the reference communities along the coastal villages are formed into *Community based Organizations*. They are to be enlightened on the basic principles of restoration of mangroves to safeguard and promote the endangered coastal ecosystem. Self explanatory literature (in the form of IEC materials) has also been adequately provided to them all.
- The high school going school children in the age group of 12 – 15 years are formed into *Eco clubs*. The members are sensitized by organizing regular sessions on the principles of eco conservation.
- Propagation of Marine Regulation Zone (MRZ) and the Coastal Regulation Act and other notifications to safe-guard the coastal zone.
- After the tsunami calamity, it was felt that the loss in this region was nominal because of the existing mangrove habitations. Sociologists felt that people are to be educated and empowered on safe-guarding the endangered species - *Rhizophora* and *Avicennia,* the local verities.

Keywords
coast, regeneration, sensitization, disasters

Variations in the crab diversity of the mangrove environment from Tamil Nadu, Southeast coast of India

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Abstract

The macro benthic faunal composition in the mangrove forest is diverse. Crabs are the most dominant species in many mangrove forests which constitute about 80% of the macro faunal biomass. Biodiversity of crabs in eight different mangrove environment of Tamil Nadu was investigated for the first time. Maximum number of crab species (46) was recorded in the Pichavaram and minimum (4) in Punnakayal mangroves. Two families of the crabs Grapsidae and the Ocypodidae are particularly associated with mangrove ecosystem. Among the crab species *Sesarma* and *Uca* species were dominant in almost all the stations. Grapsid crabs were the most dominant species. Neritic and *Avicennia* zones showed more number of crab species but less number of species was noted in slightly saline zone. The substrate suitability, tidal inundations and mangrove distribution were the possible factors for distribution of crabs in Tamil Nadu mangroves.

Keywords
species composition, zonation, distribution, population density, biosphere

Use of plant growth promoting bacteria to enhance survival and growth performance of plantation in mangrove afforestation and restoration

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Abstract

Mangrove plants in a large tract of mangrove areas in India exhibit stunted growth. Even artificial plantations of the mangroves also exhibit poor performance and productivity. One of the problems with the conservation of mangroves is lack of knowledge about the beneficial microbes that are involved in establishment of mangrove seedlings. Microbes may play vital role in supplying nutrients in utilizable forms from soil to the plants. The important functions of the microbes are in nitrogen fixation, phosphate solubilization and plant growth hormone synthesis, which are essential for better colonization of mangroves. Such beneficial marine microbes in mangroves have been largely unexplored, except cyanobacteria. Therefore, it is extremely vital to understand the microbial ecology of mangroves for better mangrove afforestation and restoration programes. Such microbial intervention has already been successfully demonstrated in our country for other plant species and there has been serious effort made in this aspect. Therefore, the present study was undertaken of current importance. The research work attempted in selection of plant growth promoting microorganisms specific to mangroves and developed technology for the growth improvement through microbial supplementation and demonstrated the techniques in the field for replication by other agencies.

Keywords
plant growth promoting bacteria, mangrove afforestation and restoration, nitrogen fixers, phosphate solubilisers

Potential geographic distribution of *Rhizophora apiculata* Blume under different future climate change and sea level rise scenarios

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Abstract

Species distribution models (SDMs) are a common tool used to link occurrence data and environmental predictors to project species' potential geographic distributions in response to climate change. While SDMs have been applied to many taxa, there are few examples of SDMs for mangroves. We present one of the first examples of a mangrove SDM for *Rhizophora apiculata* Blume. Occurrence data from the online Mangrove Reference Database and Herbarium were used to fit the models. We chose a suite of predictor variables that were relevant to the biology of the species and were not correlated: minimum annual air temperature, mean annual precipitation, horizontal tide, distance from coast, and river discharge. Models were fitted to 70% of the occurrence data using MaxEnt software and current climate data from the Worldclim database. The remaining 30% of the occurrence data were set aside as a holdout dataset for model validation. We projected *R. apiculata*'s future potential distribution in 2080 under different future climate and sea-level rise (0, 1, 3, and 6 m) scenarios.
The model exhibited excellent predictive performance with an Area Under the Operating Curve value of 0.917 ± 0.03. An analysis estimating the relative contributions of each predictor to the model showed that the first and second most important predictors were distance to coast and minimum annual air temperature, respectively. Under all future climate and sea level rise scenarios, the projected percentage of coastal *R. apiculata* occurrences increased by 5-9%. These areas of increased occurrences were primarily along the western coasts of India and northern Australia. These projections may be optimistic because the models do not account for dispersal limitation or localities projected to be inundated with sea level rise that have unsuitable substrate (e.g., developed urban areas).

Keywords
climate envelope, southeast Asia, Australia

Analyses of the mangrove's recover process in abandoned salt pounds constructed areas, in the Ceará river, Northeast Brazil

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Abstract

The mangroves are among the most productive and biologically important ecosystems in the world supplying unique conditions and services to all tropical coastal system and the population living in their vicinities. In the Ceará River, Northeast Brazil, during the last century, mangrove ecosystems lost extensive areas, due the exploitation of salt pounds. With the decline of this economic activity, the salt pounds have been abandoned, and mangroves recovered part of these areas. The current study focus on how did the mangrove recovered the area of the Ceará river estuary in this last years by analyses of aerial photographs from 1968 and 1980, and Landsat satellite image from 2009, using remote sensing techniques and the open source software gvSIG®. Thematic maps were elaborated, showing the temporal mangrove recover and the expansion of the urban area. The space-temporal analyses revealed important anthropogenic changes in the landscape during the last four decades. Semi-structured interviews were used to understand the relations between human local community and mangrove ecosystem. The population that lives near the river suffers the impacts from the degradation of the mangrove area. The inadequate garbage dumping in the river´s bank causes the accumulation of waste material, trapped in the mangrove´s roots system, deteriorating the environment quality in flood areas. These facts expose the continued human pressures on the mangrove ecosystem and their consequences, reverberating the deficiencies of the urban development process that interfere directly in social welfare of the community and the health of the mangrove ecosystem.

Keywords
urban development, human pressure, remote sensing, semi-structured interviews, tropical ecosystem

Nesting materials of indigenous cichlids in Batticaloa lagoon, Sri Lanka

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Abstract

Etroplus suratensis and *E. maculatus* are indigenous cichlids found in Sri Lanka. The two *Etroplus* species are sympatric and show segregation of habitat. The aim of this study was to investigate the nesting materials used by the by the two *Etroplus* spp., for which quantitative data were collected during a period of one year from an inlet of the Batticaloa Lagoon, Sri Lanka.

Data revealed that There was variation in the frequency of nesting material used by *E. maculatus* (G = 88.55, df = 8, p<0.0001). *Excoecaria* pole, Coconut fallen and Coconut were used significantly more as nesting material by *E. maculatus*. There was no significant difference among these four nesting materials (df=3, p=0.347). There was no significant difference when the above nesting materials were excluded in the G test (G=16.44, df=8, p=0.06).

The nesting materials of *E. maculatus* can be categorized into three types: mangrove materials, coconut materials and others. Nesting materials of *E. suratensis* can be classified into the four types: mangroves materials, coconut materials, other plant materials and others. Coconut materials were the highest (45.34%) followed by mangroves materials (39.13%). Other plant material were 10.55% and others consisted of carapace of crab, brick and polythene bag comprised of 4.96% of total nesting materials.

The results of the above study reiterate the fact that mangroves are essential for the existence of *Etroplus* species since they are very important to the cichlids to nest.

Keywords

nest building, litterfall, suitable substrate

Relationships between nesting and vegetation of three cichlids in Batticaloa lagoon Sri Lanka

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Abstract

The aim of this study was to investigate the relationship between nesting activity and the vegetation. A line transect, 300 m in length parallel to the western shore was put up. There are total of 30 sites, including 3 *Avicennia,* 7 *Cocos*, 5 *Excoecaria*, 3 *Derris,* 2 *Delicodendron,* 5 *Sonneratia*, and 5 non-vegetational, were included in the study. Quantitative data were collected during a period of one year from an inlet of the Batticaloa Lagoon, Sri Lanka.

This study showed that nesting activity for three cichlids *Etroplus maculates*, *E. suratensis* and *Oreochromis mossambicus* was considerably high in the area of mangrove vegetation. The presence of mangroves in the lagoon shore had many advantages to the cichlids. Total number of nests of *E. maculatus* and *O. mossambicus* in each site of the transect was significantly different (F_{29}=1.58, p=0.034) and (F_{29}=1.79, p=0.010) respectively (One-way ANOVA). The total number of nests of *E. suratensis* that were found in each of the thirty sites was not significantly different (F_{29}=1.38, p=0.101) (One way ANOVA).

Non-vegetational sites were not preferred by the fish to nest. There were 5 non-vegetational sites in the study area. Both *E. maculatus* and *E. suratensis* had almost all 5 non-vegetational sites in a cluster that consisted of less number of nests. Whereas, *O. mossambicus* had 4 non-vegetational sites in lower numbers in a cluster. In fact, *O. mossambicus* had the highest number of nests found in a non-vegetational site. It showed that all three cichlids need vegetational sites for nesting but *O. mossambicus* seem to nest in the non-vegetational sites as well.

Keywords
nest distribution, site selection, availability

The ecological success of the mangrove *Avicennia*: the perfect combination of well-adapted wood anatomical characteristics and special radial growth?

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Abstract

The mangrove *Avicennia*, the only mangrove genus with successive cambia, has the broadest distribution of all mangroves genera. This pattern is repeated at local scale where *Avicennia* trees can grow more landinward and at places with more stressful environmental conditions if compared to other mangroves. This study wants to address the questions: "Why is *Avicennia* able to survive at locations where other mangrove genera are not able to grow?" and "What makes *Avicennia* so well adapted to highly stressful conditions?". To address these questions, we (i) made a wood anatomical comparison between different mangrove genera and between mangrove genera and their respective closest relatives, and (ii) investigate the three-dimensional structure of *Avicennia*'s water transport system through (micro)CT-scanning. We furthermore analyzed the link between successive cambia and stressful environmental conditions through a database analysis, studied *Avicennia*'s special growth using dendrometers and addressed the functionality of the internal phloem by MRI scanning. We can conclude that (i) the water transport system of *Avicennia* is, more than in other mangrove genera, adapted to extreme environmental conditions and that (ii) *Avicennia*'s highly complex three-dimensional structure of xylem and phloem tissue most probably offers advantages in stressful environments as was proven by a clear link between species with successive cambia and dry or salty habitats. Overall, the vessel characteristics, the structure of the transport tissues as well as the special way of radial growth seem to offer *Avicennia* the necessary characteristics to survive in extreme conditions. These insights are of special importance in the understanding of the mangrove ecosystem but also bring understanding in the survival strategies and mechanisms of radial growth of trees in general.

Keywords
ecophysiology, environment, tree growth, water transport, wood anatomy

Copepod community in Versova mangrove, Mumbai, West coast of India, a baseline study

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Abstract

This paper evaluates the copepod community and ecological parameters from four stations in Versova mangrove which forms a benchmark study for future ecological assessment. Besides being one of the most productive natural ecosystems of the world the mangroves protect the coast from erosion. Habitat degradation due to anthropogenic interference and industrial effluents is evident in the Mumbai coastal ecosystems. Enrichment of coastal waters takes place when mangroves are present by adding dissolved organic matter as nutrient by decomposition of detritus. Salinity varied from 18.1 to 37.1 psu. Average dissolved oxygen value was 5.7 mg/l but low values ranging from 1.6 to 3.7 mg/l was recorded during July August. Phosphate varied from 1.1 to 44.2µg at/l and nitrate varied from 0.1 to 43µg at/l. Ammonia was high ranging from 0.3 to 77.0µg at/l. The values were very high in monsoon may be due to land drainage. High suspended load was observed which ranged from 8 to 782mg/l during pre-monsoon months. Density of zooplankton (399/m^3) and copepods (98/m^3) were low during the period of high ammonia and low oxygen concentration. The system is thoroughly flushed out in monsoon. Versova mangrove supported a rich copepod population during pre and post monsoon contributing 20.8 to 29.9% of total zooplankton. Copepod density is nearly 130 times higher than that of the nearby coastal waters and average density fluctuated between 108 to 467964/m^3. This is mainly due to the swarming of *Oithona* spp. and epibenthic copepod *Mesochra* sp. The species diversity is less only 17 species whereas 47 species were recorded from the nearby creek and 60 species from the coastal waters. *Bestiolina similis* was the dominant species followed by *Acartia* and *Oithona* spp. Species diversity index varied between 0.22 and 1.62. Highest niche breadth was observed for *B. similis*.

Keywords
ecology, nutrients, copepod

Sonneratia alba tree with peg roots facing the Indian Ocean at Gazi Bay, Kenya
(Fleur Van Nedervelde)

Spatial variation in the morphological structure of monospecific stands of the mangrove *Avicennia marina* in an arid-zone world heritage area: challenges for management and conservation

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Abstract

For management purposes, mangroves are generally treated as uniform units with little consideration of variation at the forest scale. Spatial variation in the morphological structure (e.g. density, areal extent, height etc.) of mangrove patches is likely to lead to differences in the ecological role of, and ecosystem services (e.g. primary productivity, nutrient cycling, sediment trapping etc.) provided by, mangroves. Variation in patch structure arises in response to differences in the physical environment over a range of scales; however, changes in stand morphology in response to regional-scale gradients in the environment have rarely been reported. Here we quantify spatial patterns of stand morphology within the Shark Bay World Heritage Area (SBWHA), Western Australia, which is an arid area with strong regional-scale gradients in the physical environment. A range of morphological variables (e.g. height, density, number of stems, leaf size etc.) were measured at 12 sites across Shark Bay which represents a putative gradient in physical and oceanographic conditions from oceanic on the western side of the bay to metahaline on the eastern side of the bay. Data were tested using both univariate and multivariate analyses. Most morphological variables displayed considerable variation between sites and differences were generally significant for all comparisons. The multivariate analysis of the combined suite of morphological variables also found a significant difference between sites and pairwise tests revealed significant differences for almost all comparisons. Additionally Canonical Analysis of Principal Coordinates (CAP) revealed a significant difference in the multivariate structure of mangrove patches between salinity zones. The results suggest that mangrove stand structure varies over regional scales and is influenced by background physical conditions. It is likely that the functional roles of these patches differ across the region, and thus, treating monospecific stands as uniform 'units' may not be an appropriate management strategy.

Keywords
Shark Bay Marine Park, spatial pattern, management unit

DNA markers for understanding mangrove genetics

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Abstract

Knowledge of genetic diversity within and among populations is important for conservation management. To ensure the optimal conservation of the mangrove forests in any region, it is essential to explore the genetic diversity of the populations. Population genetic studies of mangroves are also essential for evaluating afforestation, domestication, and breeding programmes. Several species of mangroves at high risk of extinction may disappear well before the next decade if existing protective measures are not enforced. It is in this context, the understanding of mangroves for their genetic diversity is a matter of urgency. Mangroves display significant inter- and intra-specific variations as evident by the molecular markers such as AFLP and RAPD. Microsatellite markers are the tools being used for understanding the genetic variations. RFLP is also a genetic marker which allows direct detection of variation at the DNA level. Species of *Rhizophora* and *Avicennia* are important components of the mangrove forest vegetation. There are several natural hybrids of *Rhizophora* species but their parental species are not clearly understood. In this regard, we attempted two molecular markers such as microsatellite and RFLP to find out the genetic relationship between the species of *Rhizophora* including a natural hybrid. Genetic diversity of *Avicennia* species at both intra- and inter-populations along the east coast of India using RAPD as a molecular marker was also attempted. The results are discussed in the paper.

Keywords
molecular markers, genetic variation, hybrid disputes, mangrove conservation

Mangrove management at the Gulf of Kutchch, India for coastal protection and resilience to climate change

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Abstract

Over the past 50 years, approximately one-third of the world's mangrove forests have been lost, but most data show very variable loss rates and there is considerable margin of error in most estimates. Mangroves are a valuable ecological and economic resource, being important nursery grounds and breeding sites; a renewable source of wood; accumulation sites for sediment, contaminants, carbon and nutrients; and offer protection against coastal erosion. The destruction of mangroves is usually positively related to human population density. Major reasons for destruction are urban development, aquaculture, mining and overexploitation for timber, fish, crustaceans and shellfish. Over the next 25 years, unrestricted clear felling, aquaculture, and overexploitation of fisheries will be the greatest threats, with lesser problems being alteration of hydrology, pollution. In addition to that mangroves are even more endangered to future sea-level rise caused by global warming. The Gujarat Forestry Development Project aims at an integrated management of natural resources that include an appropriate mix of forest and non-forest lands and biodiversity objectives. In Gujarat, a state with inadequate forest cover and quality, the urgency to continue to strengthen these efforts is obvious. Focus area is the Gulf of Kutchch. Its northern coast has tidal flats while the southern coast is characterized by coral reefs, islands and extensive mudflats large areas, which are part of the Marine National Park and Sanctuary. There are still some patchy natural mangroves areas, which are not well protected showing signs of depletion and degradation.

Realizing the importance of mangrove forests, the state government undertook plantation of mangroves since 1969. The main objective is the increase of coastal protection. Actually with financial support of JICA and giz[IS] in the framework of the Gujarat Forestry Development Project 15,000 ha of mangroves are planned to plant in this area, using mainly *Avicennia marina*. Planting is successfully performed with the application of the *Otla* technique, which are raised platforms of mud of 1 x 1 m in the inter-tidal zone, with about 80 seedling/m^2. As no subsequent thinning is done and replantation is mainly practiced as monoculture, the intended function of mangroves for coastal protection is endangered. The consequences of this inadequate management for mangrove rehabilitation will be discussed, as these areas are highly vulnerable to climate change impacts. On the other, healthy coastal wetland ecosystems, such as mangrove forests, can reduce that vulnerability as they provide protection from climate impacts like storms or sea level rise.

Keywords
rehabilitation, *Avicennia marina*, green belt, otla technique, mangrove loss

Discrimination of mangrove vegetation habitat types (Northeast Brazil) using CBERS-2B images and the Normalized Difference Vegetation Index (NDVI)

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Abstract

Mangrove forests constitute one of the major coastal vegetations of the (sub) tropics and have been widely studied by remote sensing. The images from the Brazil Earth Resources Satellite (CBERS) constitute a new and freely remote sense tool for the monitoring of mangroves. In this study we discriminated mangrove vegetation habitats of the São Francisco River Estuary (Northeast Brazil) and estimate their canopy closure using CBERS images and the normalized difference vegetation index (NDVI). The CBERS-2B images (2008) were pre-processed (radiometric, atmospheric and geometric corrections) and then, used to calculate the NDVI. Multiple classes of mangrove habitats were discriminated based on NDVI values, qualitative field data and visual interpretation of a high resolution (2.5 m) color composite of satellite images (CBERS-2B and SPOT-5). The canopy closure percent was estimated based on the minimum and maximum NDVI values recorded for the mangrove vegetation. Four habitat types within the mangrove vegetation were discriminated. Habitat type 1 ($0.2 \leq$ NDVI<0.3) shows canopy closure from 0% to 25% and mangroves with exposed sediment, herbaceous vegetation (*Juncus* sp.) and *Acrostichum aureum* patches. Habitat type 2 ($0.3 \leq$ NDVI<0.45), with canopy closure from 25% to 50%, shows sparse mangrove. Habitat type 3 ($0.45 \leq$ NDVI<0.57), with canopy closure from 50% to 75%, exhibits dense canopy cover, but with small gaps or spaces, a high occurrence of *Rhizophora mangle* trees, and it constitutes the dominant habitat in the study area. Habitat type 4 ($0.57 \leq$ NDVI<0.64), with canopy closure from 75% to 100%, showed dense canopy cover without gaps/spaces and occurrence of dense patches of *A. aureum* within the true mangrove vegetation. We concluded that the use of CBERS images and NDVI is a good remote sensing method for assessing the spatial arrangement of mangrove canopy and can be used to discriminate different types within mangrove vegetations *sensu lato*.

Keywords
remote sensing, wetland, vegetation assessment, satellite image, GIS

Satellite remote sensing and GIS to assess anthropogenic pressures and aid mangrove forest management: a case study at the São Francisco River Estuary (Northeast Brazil)

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Abstract

The São Francisco River Estuary (Northeast Brazil) is an important mangrove forest area for economically-important fisheries, despite the occurrence of anthropogenic pressures that put at risk the conservation of mangroves. In this work we assessed and mapped anthropogenic pressures on the São Francisco Estuary mangroves using remote sensing techniques and analyses in a GIS environment. Satellite images (SPOT 5 and CBERS 2B) of 2008 were processed and principal components analysis, IHS transformation, supervised classification and visual interpretation were applied while producing a land use/cover map. Fieldwork was accomplished for ground-truthing the map and collect qualitative information about the mangrove vegetation. Our results indicated that 93% (178.8 km^2) of the coastal landscape is occupied by natural cover such as: restinga formations (147.3 km^2, 77%), mangrove forests (30.1 km^2, 15.7%) and grass/sediment flats (1.4 km^2, 0.7%), while 7% (13.6 km^2) is occupied by humans through aquaculture (4.6 km^2, 2.4%) and agriculture (9 km^2, 4.7%). About 57% of the human uses (7.7 km^2) are spatially distributed among mangrove forests. Aquaculture farms (4.6 km^2) of the exotic shrimp *Litopenaeus vannamei* are pressuring the southwest mangroves which exhibited the tallest *Rhizophora mangle* stands (tree height >15 m) in the study area in 2009. Additionally, coconut cultivations (3.2 km^2) are pressuring the northeast mangroves which show stands with high occurrence of the introgressive species *Acrostichum aureum*. More than 25% of the mangrove study area might be eliminated if these human uses were built on land previously occupied by mangroves. We concluded that the São Francisco Estuary requires a coastal management plan which considers as priority the preservation of the mangroves instead of the expansion of human uses, the cultivation of native species in the current aquaculture uses and the rehabilitation of areas with disturbed mangrove vegetation.

Keywords
coastal landscape, land use/cover, aquaculture, human interference, coastal management

Arid zone mangrove macrofaunal assemblages in Gulf of Kachchh, Gujarat, West cost of India

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Abstract

The present study was carried out to determine the physico-chemical characteristics of water and sediment, textural aspects of sediments and associated faunal resources in western mangroves of Kachchh-Gujarat, west coast of India, for a period of two years during 2008-2009. Surface water and sediment temperatures varied from 17oC to 37oC and from 18.4oC to 37oC respectively. Tidal amplitude varied from 0.03m to 3.78 m. Salinity varied from 34.0 to 44 ‰ and the pH in water and sediment ranged between 7.0 and 8.9 and 6.29 and 8.45 respectively. Variation in dissolved oxygen content was from 3.42 to 5.85 ml l-1. On concentrations of nutrients viz. nitrate (0.23 to 7.26 4M), nitrite (0.04 to 0.874M), phosphate (0.13 to 3.12 4M) and reactive silicate (4.23 to 19.02 4M) also varied independently. Total organic carbon varied from 0.29% to 2.56% and the total inorganic phosphorus ranged between 0.12 mg g-1 and 1.97 mg g-1. Total nitrogen varied from 0.02 mg g-1 to 1.95 mg g-1 respectively in all the 3 stations. In total one hundred and four species of phytoplankton were identified. Among them 82 species diatoms (Bacillariophyceae), 16 species dinoflagellates (Dinophyceae), 3 species blue greens (Cyanophyceae) and 2 species were green algae. The density in all the three sites varied from 94,166.67 to 2,44,500 cells l-1. The total benthic macrofauna consisting of 62 species in 5 groups, viz. crustaceans (18), gastropods (17), bivalves (16), polychaetes (9) and fishes (2), was recorded in western Kachchh mangroves near Gujarat. The population densities of benthic macrofauna ranged from 424 to 2393 ind.m-2, the diversity ranged from 1.84 to 2.45 bits ind.-1, the richness varied between 0.82 and 0.98,and the evenness varied between 0.64 and 0.81. Two maximum diversity values were recorded during winter and summer.

Keywords
Gulf of Kachchh, macrofauna

Coringa mangroves in relation to local environmental conditions on the East coast of India

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Abstract

This study aimed at investigating mangrove species distribution vis-à-vis environmental conditions and was carried out at 12 sampling sites encompassing Coringa (Wildlife Sanctuary), Gaderu/seaward channels and Gautami-Godavari estuary (~235 km^2). At each site (located at 4 km intervals), the tree structural measurements included stem density (number/0.1 ha), basal area (m^2/0.1ha), relative density (%), relative dominance (%), absolute and relative frequency (%), and Importance Value (I.V.) (sum of relative density, dominance and frequency, using the PCQ-Method); along with physico-chemical observations on water salinity, sediment texture (sand/silt/clay), organic matter and elevation. The mangrove species composition was represented by 9 species amongst which *Avicennia marina*, *A. officinalis* and *Excoecaria agallocha* were abundant and distributed throughout the forest. The (mean) stem density (also diversity) is rich in the sites belonging to Gaderu/seaward channels (8 species, 327 nos./0.1ha), followed by Coringa (4 species, 260 nos./0.1ha) and the estuary (3 species, 240 nos./0.1ha). In contrast, higher basal area in Coringa (4.1 m^2/0.1ha) is attributable to the local protection status. Based on the I.V., *A. marina* ranked first with its sheer dominance in 8 out of 12 sites followed by *A. officinalis* (2 sites) and *E. agallocha* (2 sites), respectively. The sediments are of silty-clay in nature, where silt levels increased in the direction of Gautami-Godavari estuary and clay characterized the mangroves proper. The Gaderu/seaward channels with a strong neritic incursion had higher salinity (>20‰) compared to Coringa and/or the estuary. There are four mangrove species associations (Bray-Curtis similarity: 30%) of which Group-1 represents the widespread distribution of *A. marina*, *A. officinalis* and *E. agallocha*, while Group-2 (*Lumnitzera racemosa*, *Ceriops decandra* and *Aegiceras corniculatum*), Group-3 (*Sonneratia apetala*), and Group-4 (*A. alba* and *Rhizophora apiculata*) are seen only at the individual sites. The Principle Component Analysis (PCA) also revealed significant differences in the environmental conditions that are ultimately responsible for the varied mangrove species distribution at Coringa, Gaderu/seaward channels and Gautami-Godavari estuary.
In view of possible vegetation (mangrove) structural changes with changes in the local environmental conditions (due to sustained human intervention), it is necessary to evaluate their distributional patterns on long-term field-based observations. Therefore the present results would also be able to assist for future investigations in terms of better monitoring/management at Coringa.

Keywords
Coringa, estuary, floristic, neritic incursion, ground-truth, India

A socio-ecological assessment aiming at improved forest resource management and sustainable ecotourism development in the mangroves of Tanbi Wetland National Park, The Gambia, West Africa

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Abstract

Although mangroves dominated by *Avicennia germinans* and *Rhizophora mangle* are extending over 6,000 ha in the Tanbi Wetland National Park (TWNP) (The Gambia), their importance for local populations (both peri-urban and urban) is not well documented. For the first time, the present study evaluates the different mangrove resources in and around Banjul (i.e. timber, non-timber, edible and ethnomedicinal products) and their utilization patterns, including the possibility of ecotourism development. The questionnaire-based results have indicated that more than 80% of peri-urban population rely on mangroves for timber and non-timber products and consider them as very important for their livelihoods ($\chi^2 = 7.852$; $P < 0.05$). However, at the same time urban households demonstrate limited knowledge on mangrove species and their ecological/economic benefits. Among others, fishing (including the oyster - *Crassostrea cf. gasar* collection) and tourism are the major income-generating activities found in the TWNP. The age-old practices of agriculture in some parts of the TWNP are linked to land scarcity, increased family size, and alternative sources of income. The recent focus on ecotourism (i.e. boardwalk construction inside the mangroves near Banjul city) received a positive response from the local stakeholders (i.e. users, government and non-government organizations), with their appropriate roles in sharing the revenue, rights and responsibilities of this project. Though the guidelines for conservation and management of the TWNP seem to be compatible, the harmony between local people and sustainable resource utilization should be ascertained.

Keywords
socio-ecology, Tanbi Wetland National Park, resource utilization, participatory methods, The Gambia

Participation of local communities in mangrove forest rehabilitation in Pattani Bay, Pattani Province, Southern Thailand: learning from successes, failures and its sustainability

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Abstract

The approach and achievements of a project on community participation in mangrove forest rehabilitation in Pattani Bay, a wetland of international importance in Southern Thailand, are described. By working together with local communities in three villages around the Bay, this project aimed to restore severely degraded sites of former mangroves along the bay. This 3-year project followed an approach of combined environmental rehabilitation and socio-economic improvements, placing greater emphasis on the process than on outputs and facilitating initiatives of the community rather than ideas of the project team. Local ownership of the project and effective community participation were considered crucial to achieve sustainable impacts. The project focussed its main activities on strengthening of community organization, building of environmental awareness, mangrove rehabilitation through hydrological restoration and replanting of seedlings, support to alternative livelihood initiatives, and information dissemination. Although far from completely successful, the project has been able to support several income-generating activities of the communities, successfully enhanced their environmental awareness and received their cooperation in the replanting of 30 ha of community forest for which a community-based management plan has been prepared. The paper discussed the successes, failures and its sustainability of the project after almost 2 decades.

Keywords
community participation, mangrove rehabilitation, Pattani Bay, Pattani Province, Thailand

Diel and tidal changes in intertidal fish fauna composition from mangrove creeks of Qeshm Island, Persian Gulf, Iran

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Abstract

Information on the mangrove-associated fish fauna from the northernmost edge of mangrove distribution in the Indian Ocean is virtually non-existent. We studied temporal changes in fish community structure from 4 Iranian intertidal mangrove creeks by setting block nets at high water (December 2011-Januaray 2012) at Qeshm Island by considering tide and time of day: spring tide day, spring tide night, neap tide day, neap tide night. First results from our winter sampling (wet season) found a total of 20 fish species from 17 families. *Liza subviridis, Leiognathus daurus, Gerres poieti* and *Scatophagus argus* were the most abundant species. The fish assemblage was dominated by small-sized fish. The number of species and diversity H´ was highest at spring tide-night and lowest at neap tide-day. Diversity H´ ranged between 1.1 at neap tide-day and 1.9 at spring tide-night. Evenness J´ was lowest at spring tide night (0.7) due to entering more rare species which increased dominant species in quantitative proportion. An overlap in species composition (80% similarity) was found for spring tide day and also neap tide assemblages were different from the spring tide ones.
Preliminary result indicate that diel and tidal changes in fish community structure in an arid environment along the Persian Gulf show the similar pattern like Brazilian and Colombian mangroves which are located in a tropical rainy environment.

Keywords
fish migration, community structure, mangrove creeks, Strait of Hormuz

Comparative studies on crown foliage dynamics of three mangrove species of the Family Rhizophoraceae in Okinawa Island, Japan

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Abstract

The leaf area available for photosynthesis plays a crucial role in biomass production. Therefore, it is necessary to investigate the dynamics of crown foliage to understand the productivity of mangroves, which play an important role in the subtropical and tropical coastlines of the world. The crown foliage dynamics such as leaf recruitment, survival and leaf area growth, of *Rhizophora stylosa* Griff., *Bruguiera gymnorrhiza* (L.) Lamk. and *Kandelia obovata* (S., L.) Yong were investigated from April 2008 to March 2009. These studies have been done using both sample tree (direct observation) and litterfall (indirect observation) methods. Newly flushed leaves occurred successively throughout the year, with a maximum in summer and a minimum in winter for three species. The maximum leaf area was significantly the same in all seasons except for *B. gymnorrhiza*. The half-expansion period and the intrinsic rate of increase were respectively longer and lower in winter than in other seasons for three species. Therefore, leaves flushed in summer grew faster at their initial stage and attained their maximum leaf area sooner than those flushed in winter. This most likely results from the difference in temperature between summer and winter. The crown foliage area was almost stable throughout the year for three species. The homeostatic control of the crown foliage area may be accompanied by the regulation of leaf recruitment and death. The mean leaf longevity was estimated to be 11 month for *R. stylosa*, 13 month for *B. gymnorrhiza* and 9.0 month for *K. obovata*. Therefore, the present results suggest the existence of integrated mechanisms that maintain the crown foliage area of three species. Integrating crown foliage dynamics into forest models represents an important step towards incorporating physiological-mechanisms into the models for predicting growth responses to environmental changes and for understanding the complex responses of tree morphology, growth and production.

Keywords
crown leaf area, litterfall, leaf longevity, leaf survival

Impact of climate change on mangrove forest and regional co-operation in South Asia

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Abstract

Climate change has emerged as a major challenge for the humanity and an area of critical concern in South Asia. The mangrove forests in South Asia are extremely vulnerable to climate change. Sunderbans is well known for being one of the largest mangrove forest area covering 10,000 sq.km .It is the seat of Royal Bengal tiger and has a large number of flora and fauna. This area has crucial ecological and environmental importance. It has helped to maintain the metrological and hydrolological balance of the region by providing the forest cover. Keeping into mind its importance UNESCO has declared it as a World Heritage Site. In the same way mangrove forest are there in India, Maldives and Sri Lanka. In order to mitigate the impact of climate change on mangrove forest local, national and regional efforts are required. Since this problem affects a number of states national solutions may not be enough and regional collaborative efforts to mitigate the adverse impact of climate change are inevitable. The regional organization in South Asia i.e., South Asian Association for Regional Co-operation (SAARC) has taken several initiatives in this direction. Climate change was the main theme of the sixteenth SAARC summit held in Thimpu, Bhutan in April 2010. The summit declaration was subtitled "Towards a green and happy South Asia" and emphasized on the steps to be taken to improve the condition of forests at the regional level. This research paper will examine the crucial importance of mangrove forest in South Asia with special focus on Sunderbans. It will analyze the impact of climate change on mangroves. The paper will focus on the initiatives taken by regional co-operation in South Asia-SAARC to deal with them. In the end it will high light the best practice to deal with climate change and mangroves in other regional associations e.g. Association of South East Asian Nations (ASEAN).

Keywords
climate change, regional collaboration

Development of SSR markers for five mangrove species using next-generation sequencing with preliminary results of analyses of genetic diversity

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Abstract

SSR (Short Sequence Repeat, equivalent to “Microsatellite”) marker is one of the most powerful and popular markers in conservation genetics to analyze genetic diversity, mating system and population structure. However, obtaining enough numbers of good SSR markers for wild plants are sometimes difficult because of complicated process of experiments. Since the development of so-called “Lian method” (Lian et al. 2006), compound SSR can be obtained relatively easier by more simple way, but it is still sometimes difficult to get enough numbers of markers as the markers are obtained “by chance”. We sometimes repeated numbers of experiments in vain, yet still finally find it difficult to get markers using this method. Here, we report the results of SSR marker development by using Next Generation Sequencer (NGS), which have become popular in the past few years. We developed SSR markers for 5 mangrove species (*Bruguiera sexangula*, *Rhizophora mucronata*, *Xylocarpus granatum*, *Sonneratia alba*, *Acrostichum aureum*) using Roche 454 GS Junior which can produce data with relatively long mean read length (ca. 350bp). The massive number of sequences obtained from each species was separated into nrDNA and cpDNA then subsequently searched for candidate SSR regions through a software (QDD ver.2.1.). For the five species, more than 50 candidate SSR markers were obtained for one species. We compare the time and cost necessary for SSR marker development, and show that NGS is more effective than other methods. Results of brief population analyses for 5 major mangrove species also will be reported.

Keywords
Roche 454, QDD

Destruction of hundred year's oldest mangrove Chakaria Sunderban forest: socio-economic impact on coastal communities

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Abstract

Chakaria Sunderban is the oldest and second largest mangrove forest of Bangladesh, located in the south-eastern part of the country alongside the coastline of the Bay of Bengal in Cox's Bazar district. In 1903, 8,510 ha of forest came under institutional regulation, where 7490 ha were reserve mangrove forest and 1020 ha were protected forest. British Government leased 1600 ha of land to landless families for their settlement in 1926. Maps from 1926 and 1975 show that these communities maintained forest coverage. The forest possesses a unique ecosystem and a secure area for wildlife, as well as providing goods and services for people's livelihoods. The annual economic value was estimated to be between $200,000 and $900,000 per ha, and thus the whole forest had vast economic value.

In 1977, 2251 ha of mangrove forest were converted into shrimp farming and, again in 1982, another 694 ha were cleared for shrimp farming. About 3577 ha of mangrove forest, was leased for shrimp farming during 1985-1988 and the rest portion was leased during 1995-1996. In the subsequent years, the entire mangrove forest of Chakaria Sunderban was cleared mainly for shrimp farming with little salt bed and minor human settlement.

Although the shrimp culture has been created some employment opportunities for few local people, but only shrimp farmers are mostly benefited from this activities. This study is revealed that the destruction of Chakaria Sunderban greatly effect on the socio-economic condition of 90 percents of local communities. For years, local people have depended upon the mangrove forest for direct and indirect benefits. Many household necessities, such as firewood, timber, medicinal plants, honey and other minor products have been provided by this mangrove forest. The area was a very good habitat for different types of birds, mammals, reptiles, amphibians, and fish. However, increase of coastal pollution, decline of fish stock, increase of natural calamity and salinity intrusion due to the destruction of Chakaria Sunderban forest directly or indirectly affect on socio-economics of local communities.

Keywords
Chakaria Sunderban, destruction, socio-economic impact, coastal communities

Mangrove restoration boosts ecosystem services and conservation incentives

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Abstract

Mangrove conservation in developing countries is challenged by the lack of strong political and livelihood incentives to counter the problem of subsistence logging and cash-driven land conversion. This presentation will argue that the ecosystem services framework provides opportunity for boosting environmental conservation and sustainable development by demonstrating positive links between human welfare and the state of the natural environment. An 8-year research programme in Kenya has found ecosystem benefits from replanting mangroves, including: (i) Biodiversity: faunal diversity rose from 7 to >100 species within 7 years of planting; (ii) Secondary production: facilitation of new colonization by trees, and over-yielding of animal biomass in species-rich plantations; (iii) Coastal protection: accelerated sediment accretion following planting; and (iv) Carbon sequestration: stimulation of above- and below-ground carbon by planting; (v) Natural regeneration: significant boosting of natural tree recruitment. The implication of these results will be discussed in the context of recent publications that have questioned the ecological and monetary benefit of restoring coastal wetlands for ecosystem service provisioning. The presentation will highlight a follow-on project (Swahili Seas) that is using knowledge of ecosystem service provisioning to secure monetary support for a community-led initiative for mangrove conservation. Similar Payment for Ecosystem Service schemes may provide subsistence incentives for community-led conservation of coastal ecosystems in developing countries.

Keywords
biodiversity, restoration, carbon, fauna, ecosystem service

Global phylogeography of *Rhizophora* species

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Abstract

To reveal the global phylogeographic pattern of mangroves, we investigated the genus *Rhizophora* that is one of the most representative mangrove plants. Phylogenetic analysis using about 4 kbp of cpDNA sequences showed that the presence of the two distinct clades. One of them was composed of three species of the Indo-West Pacific region (IWP), *R. apiculata, R. mucronata* and *R. stylosa*. The other one was composed of the two species of the Atlantic-East Pacific region (AEP), *R. mangle* and *R. racemosa*, and surprisingly *R. samoensis* that is one of IWP species. Analysis of geographic distribution of haplotypes clearly showed the distinctive genetic diversification between the Pacific and Atlantic populations in both *R. mangle* and *R. racemosa* in the AEP. This result suggests that the American continent is a strong geographic barrier that prevents gene flow by sea- dispersal for *Rhizophora* species. On the other hand, an identical haplotype was found among the Atlantic populations of the AEP species, and another identical one was shared among populations of the Pacific *R. mangle* and *R. samoensis* from South Pacific. These results suggest that recent transoceanic long distance seed dispersal would be responsible for maintaining the wide distribution range of *R. mangle*, and that *R. samoensis* may not be distinguished from *R. mangle*. In the analyses using microsatellite markers, genetically differentiated populations of *R. mangle* were further detected in the South Atlantic. Although there are no known land barriers, the bifurcating South Equatorial Current at the northeastern horn of Brazil might be a potential barrier to gene flow and may promote the genetic differentiation of these populations. Other recent results obtained from IWP species will also be introduced in the presentation.

Keywords
comparative phylogeography, IWP, AEP

Forest structure and regeneration of gray mangrove (*Avicennia marina*) in Red Sea coastal region of Egypt

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Abstract

In the Red Sea coastal region of Egypt, established mangrove communities are uniquely different from mangrove forests in other parts of the world because of their low biodiversity and harsh habitat of arid and highly saline conditions. Therefore mangrove forests in this area appear in patchy and scattered patterns at mouths of wadi or in sheltered lagoons with rare and irregular flooding. Most of them are pure forests of *Avicennia marina*, occasionally mixed with *Rhizophora mucronata* in the southern part of the Red Sea. In this study, we investigated the forest structure of *A. marina* and discuss the regeneration strategy and the forest dynamics of this unique mangrove species. At the study site, we established the study plot in an *A. marina* mangrove forest and classified each mature individual (trees more than 5 years old) into grazed tree and ungrazed tree by eye. We also measured the tree height, diameter, and branch spread at four cardinal points. The mean height of grazed trees was 0.80 ± 0.25 m and that of ungrazed trees was 2.38 ± 1.14 m respectively. The grazed trees tended to be dwarfer than the ungrazed trees. This result suggests grazing by camels reduces the height of mangrove tree and there is severe effect of the high grazing pressure by camels on tree growth. In addition, these dwarf trees were growing intensively at the landside forest edge and no regeneration was observed under the forest canopy of these trees. It is suggested that the camel grazing prevented the seedling growth on the landside edge of the forest.

Keywords
Avicennia marina, forest structure, seedling bank, camel grazing, Egypt's Red Sea coast

The role of mangrove habitat in the life of women in Akshi village, Maharashtra State, India

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Abstract

The present investigation is carried out in the mangrove mudflat of Akshi village, Maharashtra state, India, during 2008-2009(Latitude 17 72' N & Longitude 73, 64' E). Mangrove habitat of Akshi region is salt tolerant ecosystem of tropical intertidal region. Unique features of this habitat is extreme shallowness in some region, mild waves and it's semi-enclosed nature of ecosystem. Sedimentation is well developed and rich in nutrients and hence support variety of resident and migratory fauna. Mangrove habitat is the life line of the coastal living people in Akshi village, especially of women as fishing in mangrove area is the domain of women while sea is the domain of men. Women are involved in artisanal fishing, collecting oysters, crabs, assisting fishermen, post harvest activities as well as family and community welfare. They play central role and therefore get main focus on their overall activities. Women and mangrove mudflat have maintained closely woven fabric due to their close associationship. Women mainly depend on oyster (*Saccostrea cucullata*), prawn (*Penaeus indicus*) and crab (*Scylla serrata*) which are commercially important and fetch good amount of money. Women spend average 7hrs/day for fishing and fishery related activities which is 11/2 hrs more than men in this region.
Mangroves have made the Akshi region more attractive and therefore tourism has increased in this region. This has forced the women to imbibe a foreign culture. Now their lifestyle is changing and so are the requirements. Earlier they required to fish mainly for family. There is more demand of fish, oyster and crab. So their work is getting harder and more time consuming. This finally leads to ecological degradation. Increased requirement of food delicacies in restaurants, households, tourists hinge around the fishing activities of women. So mangrove habitat has given them protective, steady and sure income generating environment and therefore stability in life.

Keywords
mangrove habitat, women, tourism

Phylogeography of *Xylocarpus granatum*

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Abstract

The genus *Xylocarpus* (Meliaceae) includes two mangrove species *X. granatum* and *X. moluccensis*, and both of them are listed as endangered species in recent red lists. *X. granatum* is one of the most widely distributed species of mangroves in the Indo-West Pacific (IWP) region. Although some studies on mangrove species suggested that there were some effective barriers to the long-distance seed dispersal in the IWP region, few researches suggested the genetic structures of mangrove species over the whole range of IWP. In this study, we aim to grasp the perspective of the genetic structure of *X. granatum* using samples collected by our research network. The goal of this study is to clarify the barriers for gene flow for *X. granatum*, and to reveal the effectiveness of long-distance seed dispersal to maintain the distribution range throughout the IWP region. Using the population samples collected from Mozambique, India, Myanmar, Thailand, Vietnam, Singapore, Malaysia, Indonesia and Fiji phylogenetic relationships between *Xylocarpus* species and genetic diversity within/among populations were estimated using two chloroplast markers, accD-psaI and trnD-trnT. The chloroplast markers clearly suggested the difference between *X. granatum* and *X. moluccensis*. However, no clear genetic differences were obtained over the wide range of distribution, and in *X. granatum*, a single haplotype is distributed over the distribution range. This may suggest that the large distribution range of the species is maintained by the long-distance dispersal. Results of further analyses using nuclear markers will be reported.

Keywords
Xylocarpus moluccensis, phylogeography

Application of remote sensing and GIS for detection of long-term mangrove shoreline changes in Ca Mau, Vietnam

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Abstract

Along 3,200 km coastline of Vietnam, Ca Mau tip supports a large area of mangroves and has a high value of biodiversity and scenic beauty. This area is affected by erosion along the East Sea coast and accretion along the West Sea shoreline leading to the loss of huge stretches of mangroves along East Sea and, in some cases, loss of ecosystems services provided by mangroves. In this study, we used remote sensed images of aerial (1953), Landsat (1979, 1988, and 2000) and SPOT (1992, 1995, 2004, 2008 or 2009, and 2011) and Digital Shoreline Analysis System (DSAS) to quantify the rate of mangrove shoreline change for 58-year period. To achieve this, a hypothetical baseline was created similar to the actual margin geometry. There are 1114 transects sampled at 100-m intervals along the mangrove shoreline and two statistical methods namely End Point Rate (EPR) and Linear Regression Rate (LRR) were used to calculate the change in rates of mangrove shorelines and distance from 1953 to 2011. A two tailed paired t-test was used to compare the results of the two methods and showed that the results are statistically different (P value = 0.006, t = 2.751, df = 1069). The study confirms that, erosion and accretion respectively are significant at the Eastern and Western Sea sides. Along 60 km of mangrove shoreline at the East Sea side, an average LRR of erosion was found as -33.24m/year. For the accretion trend at the Western side, the net LRR rate was 43.76m/year. This will be useful to predict coastal vulnerability to sea level rise, enable advanced site specific planning for the coastline and mitigate threats to coastal development and human safety.

Keywords
Ca Mau, erosion, accretion, DSAS

Biological and environmental drivers in mangrove propagule dispersal and recruitment: a field and modelling approach

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Abstract

Mangrove propagule dispersal is a key driver of the architecture and functioning of mangrove populations and communities. Nevertheless, there is a lack of information on hydrochorous dispersal of propagules, covering the period between propagule abscission from the tree and propagule stranding. The relative importance of current velocity, waves, wind and the absence/presence of roots/pneumatophores on propagule movement out of the forest and on open water remain understudied. Such knowledge is however crucial, to obtain fundamental insight in relative dispersal behavior between species, and for the construction of mathematical (individual based) dispersal models.

In this study, experiments were conducted in a flume tank to establish the effect of water velocity, presence/absence of wind and the density of roots/pneumatophores (0, 5, 10 and 20 m^{-2}) on the dispersal speed of a propagule. Propagules of four mangrove species were used to elucidate the effect of propagule morphology. In a first experiment, dispersal velocities were calculated for two different water flow velocities (15 cm s^{-1} and 30 cm s^{-1}). In a second experiment wind was added as an additional dispersal force, firstly, in the same direction as the water flow, secondly, opposite to the water flow. The isolated effect of wind as a driver in propagule dispersal, was investigated as well by using a zero water flow. In the third experiment, the behavior and dispersal speed of mangrove propagules was examined, simulating three different root densities in the flume facility. Additionally, we added waves to the water flow for a fixed root density.

We demonstrated that wind significantly affects the dispersal speed of mangrove propagules, and that the combined effect of wind and water flow strongly depends on the species under consideration, as well as on the floating behavior within a single species. Propagules that float vertically, are much less influenced by wind than their horizontally floating counterparts. For root retention, propagules of various species show widely varying dispersal speeds for the same root density.

Keywords
propagule dispersal, flume tank, wind, hydrodynamics, root retention, hydrochory

The propagule dispersal black box - driving factors and complexities: a review

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Abstract

The literature abounds with statements on the ecological and (socio)economical importance of mangrove forests, as well as on the multiple threats they are facing. Within the ecological framework of mangrove stands, most papers have focused on all but the dispersal phase of a mangrove life-cycle. However, understanding the architecture and functioning of mangrove populations and communities also requires knowledge on the characteristics of mangrove propagule dispersal. There is a lack of information on the period between the abscission of a propagule from the parent tree, over its hydrochorous dispersal to its subsequent establishment. Although some case-studies have been devoted to the analysis of one or a few important driving factors of propagule dispersal, thus far no publication that deals with all important aspects of this critical life stage has been published. This review presents an overview of most – if not all – factors, known and unknown, as well as their complex interplay, influencing the fate of a dispersing propagule. We put forward a summarizing scheme of driving factors and their synergisms based on available "dispersal literature", supplemented with a series of factors of which the role may not be underestimated or should at least be investigated. The reasons for a review on this subject are manifold. Firstly, we suggest a conceptual scheme of factors enabling us to highlight lacunae in the propagule dispersal literature. Secondly, it may constitute the basis to improve and encourage the expertise on mathematical modeling of spatio-temporal mangrove dynamics, providing the possibility to explore propagule dispersal within its ecological context. The value of mathematical models is high, since they enable us to better understand and predict the response of mangrove vegetation to future climatic and sea level rise scenarios and to analyze the (in)direct impact of anthropogenic activities on a local, regional, and global scale; moreover, it must be emphasized that the understanding of some fundamental aspects can only be improved by translating them into computer languages. In this way, finally, and maybe most importantly, this review may already contribute to mangrove conservation and in the formulation of local management strategies against the light of actual knowledge.

Keywords
biogeography, dispersal dynamics, driving factor, modelling, conservation, global climate change, sea level rise

The bidirectional relationship between mangrove vegetation and Sesarmid crabs: complex interaction amongst density and composition of vegetation, crab density and propagule density

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Abstract

Some authors refer to 'crabs' as keystone species. To better understand the reciprocated relation between crabs and vegetation in mangrove forest, we did some experiments in Gazi Bay, Kenya.
We focus on the confirmation, consolidation or rejection of four hypotheses:
(a) The dominance-predation hypothesis predicts that the propagule predation rate is lower where canopy is dominated by conspecific plants. We measured the consumption time of 200 *Avicennia marina* and *Ceriops tagal* propagules under different covers;
(b) Crab density influences propagule predation rates.
(c) Crab size influences food competition: the bigger crab, the more competitive it is. We observed which crab (the bigger or the smaller) in a pair, took the *A. marina* propagule first;
(d) Vegetation densities influence crab densities.
We found that (a) *C. tagal* and *A. marina* propagules are consumed faster under adult conspecifics ($p<0.001$). Those results do not confirm the dominance-predation hypothesis, (b) there is a high correlation between crab density and predation rate (for *C. tagal* propagules: $p<6.4*10^{-7}$; *A. marina* propagules: $p<1.1*10^{-8}$). This is within the logical expectations and previous observations, (c) within 11 crab couples 8 presented a more competitive crab ($p<0.05$) but there are no competition differences with size (4 times the large one and 4 times the small one "won"). The more competitive crab seems to be the "fearless", not the bigger one and (d) crab density is highly negatively correlated ($p<2.2*10^{-16}$) to *A. marina* trees and pneumatophores densities. The structure of *A. marina* stands generates different pneumatophore densities that seem to determine crab density through space competition.
We therefore conclude that there is a mutual relationship between stand characteristics and crab fauna, where stand composition and density influence predation and crab density, crab density impacts predation rates and crab size does not influence competition for mangrove propagules.

Keywords
competition, decapods, *Neosarmatium* sp., dominance-predation hypothesis, Gazi Bay, distribution

The tree-climbing behavior of *Cerithidea decollata* (Mollusca: Potamididae): how does this snail decide when to climb and where to stop?

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Abstract

Cerithidea decollata is a mangrove snail creeping on the ground during the low tide and resting on mangrove trees the whole high tide, migrating thus twice a day along the trunks for avoiding to be submersed. The snails start climbing on the trunks before the tide water arrival, reaching a height always between 20 and 40 cm above the level that water will reach. This migratory pattern is thus extremely variable, depending on the tide height: in particular, it is more evident at spring than at neap tide and at lower than at upper shore levels.
In the last years, we performed a series of observations and experiments in the Kenyan mangroves of Mida Creek (Kenya) for clarifying various aspects of the migratory behavior of *C. decollata*. In primis, translocation experiments were designed to test whether snails rely on internal information or on external, direct cues, to adapt their behavior to local adaptations. Then, after having demonstrated the existence of a biological clock, we addressed the complex question of how these snails determine which height to reach on the trunk for avoiding to be submersed. We did a series of tests to assess which external (chemical or visual cues) or internal (energetic cost or memorization of the path length) factors might guide this snails in reaching this task. We used artificial trees (plastic pipes), 2 meters long, along which snails climbed and crawled just as on their own trees for experiments aiming at altering internal and external cues (i.e. we lowered, raised or tilted the pipes were, and we overloaded the snails).
Overall, our tests indicated that the snails do not rely on external information but only on internal ones. Moreover, this snail seems to “foreseen” when and where the incoming tide will arrived and not to set its migratory behavior on information from the previous tides.

Keywords
mangrove snail, *Cerithidea decollata*, migration

Spatial distribution patterns of intertidal crabs in tropical estuaries as a baseline for estuarine health monitoring

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Abstract

Scientifically based protocols for ecosystem health monitoring, applicable across estuaries, are critical to ensure future sustainable use of tropical estuaries. Despite the potential of intertidal crabs as rapid health indicators, integration of this key faunal group in monitoring schemes has been hampered by a lack of a generally applicable model of their spatial distribution patterns within estuaries. The current project aimed to develop a conceptual model of the spatial distribution patterns of intertidal crabs as a baseline for management. Therefore, a novel photographic technique allowing large scale, high resolution mapping of intertidal crabs in the low intertidal was developed. This enabled successful modelling of distinct, temporally stable habitat associations of intertidal crabs in Stuart Creek, North Queensland, Australia. These habitat associations were found to be predictable across 8 dry tropical estuaries with various degrees of human interference along 160 km of North Queensland coast. Additionally, stable isotope diet analysis allowed implications of environmental change for energy flow through this benthic component to be modelled, indicating a strong shift in community composition and energy flow in systems modified by harbour walls and agricultural irrigation. The resulting baseline model hence provides a scientific framework for informed monitoring and management as well as further ecological research on the role of intertidal crabs in tropical estuaries.

Keywords
intertidal crabs, habitat associations, monitoring, energy flow

A global standardized network for monitoring mangrove vulnerability to sea-level rise

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Abstract

Sea-level rise (SLR) threatens human populations around the world and mangroves sensitive to increased inundation. Mangrove vulnerability to SLR is quantified by the Revised Relative SLR, which is the sum of eustatic sea-level rise, deep subsidence, and surface and shallow subsurface processes. While the quantification of spatial variability in SLR and deep subsidence is well advanced, surface and shallow subsurface processes contributing to wetland surface elevation change vary substantially across space, and quantification remains the 'missing piece' of the puzzle needed to assess site-specific vulnerability to sea-level rise and the processes controlling it. In this presentation we provide a brief comparison of methods to measure surface and shallow subsurface processes (surface elevation change), and focus on the Rod Surface Elevation Table–accretion Marker Horizon (RSET-MH) method to provide sufficiently precise and comparable vulnerability data sets across global mangrove systems. We discuss previous research conducted using the RSET-MH method over the past 20 years, and show that significant new opportunities for modelling and policy will arise with a coordinated global monitoring network. Finally, we discuss the development of a global monitoring network, including the costs for setup, data sharing opportunities and the unprecedented research, conservation, and global climate change policy mitigation and adaptation opportunities that could result from a 'bottom-up' coastal wetland SLR monitoring network.

Keywords
adaptation, conservation, geomorphology, mitigation, policy

Elucidating the influence of reproductive traits on population genetic structure in mangroves from the Malay Peninsula

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Abstract

Mangroves have a high potential for long distance dispersal due to their intertidal habitat and water-dispersed seeds (i.e. hydrochory). However, among mangrove species, hydrochory characteristics (e.g. floatation duration) and pollination syndromes differ greatly. Since the vector for propagule dispersal is nearly identical for all mangrove species, differences in genetic structure among species found in the same localities could be attributed largely to differences in reproductive traits. Until now, there have been limited inter-species or -genera genetic studies relating reproductive traits to difference in patterns of gene flow. Here, we sampled four mangroves species with widely varied reproductive traits - *Avicennia alba* (insect-pollinated; relatively short flotation period), *Sonneratia alba* (bat-pollinated; relatively short flotation period), *Bruguiera gymnorrhiza* (bird-pollinated; relatively long flotation period) and *Rhizophora mucronata* (insect-pollinated; relatively long flotation period) - from the Malay Peninsula. Initial data will be presented for selected target species to demonstrate the impact of reproductive traits on gene flow.

Keywords
genetic diversity, microsatellite, SSR

Better than nothing: biomass and carbon storage in natural and planted mangroves in Kiên Giang Province, Viet Nam

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Abstract

The mangrove vegetation in Kiên Giang Province on the western Mekong Delta coast of Viet Nam was poorly known, and has suffered drastic contraction in area via conversion and coastal erosion. In some counter to this trend, planting of *Rhizophora apiculata*, *Sonneratia caseolaris* and *Avicennia alba* has occurred periodically in recent times, with mixed success, particularly in *Avicennia* plantings on the open coast. Concerns within Kiên Giang to find avenues to value the remaining vegetation led to a rapid survey of mangrove vegetation, biomass and carbon storage, from field data and a set of allometric equations. Values varied reflecting the range of vegetation present, but in places above ground biomass (AGB) exceeded 300 t DW ha^{-1} and estimated total carbon store exceeded 200 t ha^{-1}. Much of the vegetation is young so the potential is higher than reported values. Natural colonizing vegetation on the open coast is slow to gain biomass, but does so over time with increasing diversity of species. Planted stands of *R. apiculata* and *S. caseolaris* were found to be a reliable and fast source of mangrove biomass gain, with 16-18 year old *R. apiculata* stands having an AGB > 200 t ha^{-1}. However, cutting of trees is ubiquitous and in the worst cases impacts on stand biomass (up to c. 45 %). Worse, large scale conversion continues and the coast is retracting fast through erosion on large fronts, squeezing the mangrove vegetation thinner and thinner. The diminishment becomes the major problem for financial valuation, despite the potential of the vegetation. However, work such as this shows that even in cases where only a proportion of the mangrove remains, the biomass/carbon benefits should still be given currency in arguments for protecting what is left and as support for schemes to enhance mangrove vegetation.

Keywords
REDD, climate change, forests, blue carbon, protection

Delimitation of global mangrove biogeographic regions based on species composition using Self-Organizing Maps

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Abstract

There are a number of delimitations of the world's mangroves into biogeographic regions, but mangrove scientists never used Self-Organizing Maps (SOM) method for this. We chose the SOM method because of characteristics of dimension reduction of the input data, unsupervised-learning algorithms for clustering, and because of the possibilities to obtain new insights using the geovisualisation tools. Because of their characteristics SOM are adequate tools for our aim, which is to determine global biogeographic regions of mangroves at different taxonomic levels. We aim to define global biogeographic regions based on two levels (genus and species) using SOM based on similarity of species composition. Our methodology is to use the input data of distribution of plant species for each country with the presence/absence data extracted from the Mangrove Reference Database and Herbarium (Massó i Alemán et al., 2010), which includes the World Atlas of Mangroves (Spalding et al., 2010) and many other distribution references from peer-reviewed literature, herbarium sheets and personal observations. The k-means algorithm was utilized for identifying the clusters. In our simulations, we used the Davies-Bouldin index which is known to be suitable for the evaluation of k-means partitioning and to indicate good clustering results.

Keywords
neural network, Kohonen map, geovisualization, bioregions

References

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Spalding M, Kainuma M, Collins L (2010) World Atlas of Mangroves. Earthscan, London, United Kingdom

Self-Organizing Maps to determine global distribution patterns of mangrove plant species and analysis of threats using socio-economic indicators

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Abstract

Commonly, the distribution of each mangrove species is shown by localizing them in a geographic map using coordinates and this information is not so much explored using socio-economic influences. Furthermore, it is difficult to visualize which species of mangroves have the same distribution on a global scale and how the socio-economic influences can affect the species with a restricted distribution. Therefore, we ask the following questions: Which species are more affected by human pressure? Which biogeographic regions are more threatened? Which human impacts are influencing the degradation of mangroves? In order to answer these questions, we used the technique of neural networks called Self-Organizing Maps (SOM), because it is an efficient tool for geovisualizing high-dimensional data. In addition, SOM approximate the probability density function of input data and it has been used as an alternative to traditional statistical methods to efficiently deal with datasets ruled by complex, non-linear relationships. The input data are the distribution of plant species that contain the presence/absence data for each country extracted from the Mangrove Reference Database and Herbarium (Massó i Alemán et al., 2010), which includes the World Atlas of Mangroves (Spalding et al., 2010) and many other distribution references from peer-reviewed literature, herbarium sheets and personal observations. We confronted this information on species distribution with socio-economic country indicators such as population density, mangrove degradation, coastal population size and density, etc. In conclusion, the novelty of this work was to use a global approach to analyzing mangrove distribution, analyze it using SOM, a method widely used by researches in several areas of science, but never by mangrove scientists, and explain mangrove degradation using socio-economic indicators.

Keywords
neural network, Kohonen map, geovisualization, high-dimensional data, change detection

References

Massó i Alemán S, Bourgeois C, Appeltans W, Vanhoorne B, De Hauwere N, Stoffelen P, Heughebaert A, Dahdouh-Guebas F (2010) The 'Mangrove Reference Database and Herbarium'. Plant Ecology and Evolution 143: 225-232

Spalding M, Kainuma M, Collins L (2010) World Atlas of Mangroves. Earthscan, London, United Kingdom

Modern landscape process of mangrove wetlands based on retroactive investigation from local residents and remote sensing imagery

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Abstract

1. Understanding the dynamic and structure of mangrove landscape remains an important issue in ecology of mangroves and is essential to improve restoration and reforestation of degraded sites around the world. Most of the sites have been highly disturbed by various human activities, very few natural mangrove communities remain today in China and it is very difficult to disentangle anthropogenic from natural mechanisms leading to the distribution observed today, and the impact of such anthropogenic influences on the resilience of this ecosystem in the future.
2. In the present study, a retroactive investigation method coupled with remote sensing technology was used to understand the land use pattern and the distribution of species in the mangrove of Gaoqiao, Southern China. We explore both species and forest boundaries in different phases, based firstly on the interpretation of past aerial photographs and current high spatial resolution imagery, and secondly, documented on interviews with local elder people. Information acquired from these interviews is then diagnosed with the remnant of mangrove in the underground. The results are expressed by GIS technology.
3. Reclamation land from the mangrove and extensive development of aquaculture has proven to be the main reason of mangroves decrease in this area. The results obtained by retrospective remote sensing and interviews showed a radical change in the natural zonation of species, mainly caused by the construction of dykes that have had a major impact on the hydrodynamics and then, on the forest substrate. These modifications of the environment have changed the situation of competition between species, sometimes resulting in the reversal of the species zonation.
4. Interviews and investigations with local elder people conducted here proved to be a very interesting tool, allowing us to do the monitor of landscape dynamic and process and to detect the drive force of land use or coverage change (LUCC) as well.

Keywords
landscape process, retroactive investigation, remote sensing

mmm4

MMM4: USA Welcomes You

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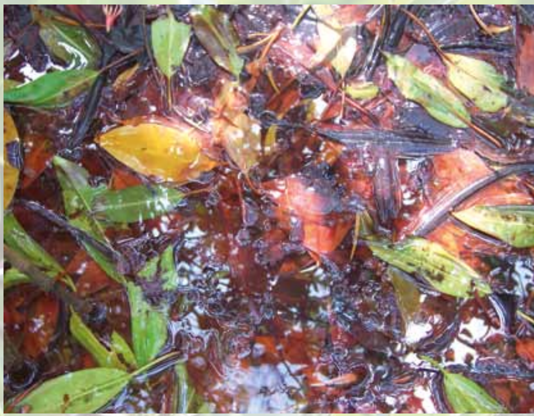
Abstract

This final presentation introduces the intention of the Smithsonian Institution to jointly organize MMM4 with Florida Atlantic University and USGS in Florida, USA. The presentation includes a regional overview, a brief summary of mangrove studies and mangrove sites, as well as a background on the would-be organizers, potentially collaborating organizations, and tentative conference themes for MMM4 in 2016. For the conference themes, we propose that MMM4 focus on examining how mangroves and mangrove macrobenthos are responding to climate change. For example, how will global warming, sea-level rise, storm patterns, and/or nutrient enrichment affect the following: 1) poleward expansion of mangroves and mangrove macrobenthos; 2) inland migration of coastal wetlands; 3) changes in the geographic boundaries of mangrove and salt marsh species through time; 4) ecosystem structure and function of coastal wetlands along tidal and latitudinal gradients; 3) vegetation patterns, community structure, and foodweb dynamics; 5) carbon sequestration and nutrient cycling.

Keyword index

Author index

NOTES



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