Discussion

In contrast to recent claims that there are few field-based and quantitative studies of the shielding function of mangroves against wind-induced or tsunami waves (Danielsen *et al.*, 2006) this bibliometric study shows that there have been numerous such reports. However, the fact that high-profile journals failed to pick up this research may be a factor in the world-wide publicity that this important ecosystem function has received. It is a feature of high-profile journals to report almost exclusively about scientific break-through studies and to compete for its publication with all consequences associated (*e.g.* Hwang, 2006), while disregarding many other studies that are equally fundamental or innovative and that may hold enormous indirect benefits to natural habitats and to the people living in association with these habitats. Unfortunately, mangrove forests have only become an “appealing topic in frontier science” after the tsunami struck, not before. The sad conclusion is that whereas mangrove forests have long been one of the most threatened ecosystems world-wide (Farnsworth & Ellison, 1997; Alongi, 2002; FAO, 2003; Duke et al., 2007), and whereas they have a wide array of ecosystem functions and services ranging from fish and other food sources to physical protection of the coastal zone, a major tsunami with hundred thousands of deaths and millions of displaced victims in 12 countries were necessary in order to raise mangrove-associated research to a publication level that is of *immediate interest to researchers in a broad range of other disciplines* or that is not *too narrowly focused on a particular geographic area*.

Long before the tsunami disaster, Sri Lankan researchers reported that scientific research outputs in scientific journals with a low or with no Impact Factor were considered less relevant by governmental agencies than research published in high profile journals. This is in line with the world-wide publicity that high profile journal publications receive, which is in part a consequence of the press releases by the journals themselves. Also media agencies focus primarily on press releases by high profile journals rather than on scientific output by a wide range of journals. This vicious circle of mutual reinforcement between media and high-profile journals is of global nature and benefits only the papers that indeed get published in these journals. The lack of high-profile publications devoted to mangrove ecosystems has likely contributed to the lack of realisation of the benefits of mangroves world-wide. As a parallel we highlight the important globally recognized status of the Amazon forest, and the appearance of no less than 89 publications associated to this ecosystem in *Science* or *Nature* between 1998 and 2005 (see Web of Science®). This has not entirely saved the Amazon forest from being deforested, but we maintain that it has helped or at least it is has raised a world-wide public concern. Instead of being similarly valued and protected, mangrove forests have been historically depicted as a breeding site for malaria, as a horrific area with dangerous wild animals (crocodiles, snakes,…), and as a purposeless forest (*e.g.* Von Rosenberg, 1867; Murphy, 1899). In the past century, numerous forms of mangrove destruction occurred, of which conversion to shrimp farms or tourist resorts, and over-exploitation are probably the most important ones (Farnsworth & Ellison, 1997; Alongi, 2002; Dahdouh-Guebas, 2006). Apart from the loss of physical protection, this has resulted into disastrous consequences for local and global fish supplies (Barbier, 2000; Naylor *et al.*, 2000), the worst effect of which is probably yet to come.

The best suggestion to the problem described above is that high-profile interdisciplinary journals should adopt no focus on certain topics within the disciplines they cover, and should look past scientific break-through and business-driven media attention when evaluating research papers. Future research should focus on the complexity of mangrove formations and their surroundings and all publication outlets should participate in reporting the results that will be highly relevant for nature, environment, science, economy, and subsistence populations.

Framework for future research on the protection function of mangroves

The precautionary principle dictates that we should carefully manage natural ecosystems because of their assumed functions, but the necessity for in-depth research is now announced. We generally assume that mangroves can mitigate the damage in landward settlements by absorbing the destructive impact of incoming waves, and many references were found that are in favour of this theory. However, this so-called evidence has never been proven or unravelled, which forms a shortcoming in fundamental scientific research on vegetation dynamics and sediment dynamics in mangroves. Particularly the typology (vegetational and geomorphological settings), species composition, and the dynamics (static or dynamic) of mangroves can vary considerably between mangrove forests and so can the degree to which they can protect a coastline. We propose that these are investigated in-depth in future research on the level of the organism, the vegetation assemblage and the ecosystem (Fig. 4). The research framework below is not associated to frameworks needed in general mangrove conservation or rehabilitation of tsunami-affected areas (*cf.* Adger *et al.*, 2005; Barbier, 2006).

Vegetational typology and species composition cover a wide range of differences that are rarely considered. Different species imply different complexes of above-ground pneumatophores (*i.e.* aerial roots) : prop or stilt roots, pencil roots, peg roots, knee roots, plank roots and buttress roots (Fig. 4). Some species or some specimens within the species have well-developed roots, others may have no clear above-ground roots depending on environmental conditions (*e.g.* *Heritiera* spp.). It is assumed that this variety of roots lead to different degrees of protection against chronic or acute water-related events and disasters. The same is valid for the general physiognomy of a tree (particularly the stem and to a lesser degree the canopy), which is environment-dependent. Apart from the above aspects of the individual organism, similar physiognomic aspects can be described on a vegetation assemblage level, such as species composition, density, basal area, etc. (Fig. 4). These elements, which constitute the vegetation structure, can be structured as zones, partial zones or mosaic vegetation patches and the functionality of such vegetational types should be investigated in detail. Different mixes of species are indeed assumed to be a factor in degree of coastal protection, and so are the historic changes or vegetation structure dynamics that occur on the level of floristics and vegetation assemblages (*cf.* Dahdouh-Guebas & Koedam, 2002). The causes of such change may have a natural component, or it may be anthropogenic, either directly or indirectly. On one hand, areas deteriorated by human activities or previous natural hazards may be even less functional in coastal protection. One example is provided by the effect termed 'cryptic ecological degradation' (Dahdouh-Guebas *et al.*, 2005b), which was found to be a factor in protection against the tsunami (Dahdouh-Guebas *i.e.*, 2005c). On the other hand, the above anthropogenic or natural impacts or stochastic events may increase the complexity of a forest and therefore the protection function (*cf.* Duke, 2001). Which of these contrasting views is correct in the light of physical protection is also subject to in-depth research.

The third level on which the research framework should focus is on the ecosystem level, which has been subdivided in a window on mangrove community and one on geomorphology. This level is in part overlapping and in part cross-cutting the above individual and assemblage levels. Mangrove community types, as defined by Lugo & Snedaker (1974), include the following forest types : overwash, fringe, riverine, basin, hammock and scrub forest. Geomorphological settings include the river-dominated, the tide-dominated, the wave-dominated barrier lagoon, the composite river and wave dominated and the drowned bedrock valley setting defined by Thom (1984). It also includes the above-water elevation of the landscape and the underwater topography of the continental shelf.

From the above research framework levels it becomes clear that there is no typical level of protection by mangroves, but a wide range of different settings in a multi-dimensional space that need in-depth investigation instead.

Finding *in situ* examples of tsunami-struck areas or villages with comparable settings (*i.e.* equidistant from the sea, similar continental shelf, similar elevation, similar infrastructure and settlements) but with the difference that one is protected by a well-developed mangrove and one is open to the sea, is virtually impossible and counter-advised in view of scientific correctness (*cf.* Dahdouh-Guebas & Koedam, 2006). Rather than finding such test-examples, country-wide or regional assessments should be carried out, and future *de novo* research should focus on modelling the different types of settings in tanks. So far only one publication exists that directly investigates the effect by mangroves on wind-induced wave action (Massel *et al.*, 1999), and it is limited to combined effects of drag caused by mangrove roots and trunks and bottom friction. The latter paper, which is in fact at the level of the tree (*cf.* research framework above), is exemplary for the type of research that is needed, but then with a complexity different magnitudes larger. As indicated in the introduction, also the characteristic waves or currents, and the characteristic sediment transport/erosion pattern of water-related impacts (cyclones, sea-level rise, daily tidal action, and heavy El-Niño rains) are criteria that must be distinguished in this type of study (*cf.* Wolanski, 1992, 1995; Mazda *et al.*, 1995; Furukawa & Wolanski, 1996; Furukawa *et al.*, 1997; Mazda *et al.*, 1997a, 1997b; Ridd *et al.*, 1998; Mazda *et al.*, 1999, 2002, 2005). Also the effect of floating debris (*cf.* Stieglitz & Ridd, 2001; Krauss *et al.*, 2005) on currents and waves may be a factor in such investigations.

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Table 1. Publications in the Web of Science® database (ISI) that relate 'mangrove' with one or more keywords below *sensu lato*. Note that the interest lies in the power of mangroves to protect the coastal zone; *e.g.* papers on 'protection' are not about 'protection *of* the mangrove' but about 'protection *by* the mangrove' (coastal protection, shoreline protection), or papers on 'hurricane' are not on 'hurricane impact *on* the mangrove' but about the 'impact reduced *by* mangroves'. The 54 publications do not differentiate between news items, short communications, full research papers, etc. Although multiple keywords may be applicable to a specific paper, the references listed are listed only once (under the prime keyword).

<table>
<tr><th>Keyword 'tsunami'</th><th>Keyword 'function'</th><th>Keyword 'protection'</th></tr>
<tr><td>Bryant et al. (1992)
Dahdouh-Guebas et al. (2005)
Danielsen et al. (2005)
Kathiresan & Rajendran (2005)
Liu et al. (2005)
Martinez (1995)
Ramachandran et al. (2005)
Williams (2005)</td><td rowspan="3">Farnsworth (1998)
Field et al. (1998)
Gilbert & Janssen (1998)
Iftekhar & Islam (2004)
Kaly & Jones (1998)
Lee (1999)
Moberg & Rönnbäck (2003)
Rönnbäck (1999)
Ruitenbeek (1994)
Twilley et al. (2005)</td><td rowspan="9">Alongi (2002)
Bacon & Alleng (1992)
Badola & Hussain (2005)
Barbier (1993)
Barbosa et al. (2001)
Clüsener-Godt (2002)
Ewel et al. (1998)
Field (1998)
Field (1999)
Halide et al. (2004)
Hester et al. (2005)
Klein et al. (2001)
Mimura & Nunn (1998)
Oo (2002)
Saenger & Siddiqi (1993)
Sathirathai & Barbier (2001)
Wong (2003)</td></tr>
<tr><th>Keyword 'service'</th></tr>
<tr><td rowspan="7">Boyer & Polasky (2004)
Chee (2004)
Abuodha & Kairo (2001)
Ewel (2001)
Martinez-Alier (2001)
Kaplowitz (2001a)
Kaplowitz (2001b)
Rönnbäck & Primavera (2000)
Yap (2000)
Arrow et al. (2000)
Ron & Padilla (1999)
Primavera (1997)
Primavera (1995)</td></tr>
<tr><th>Keyword 'defence' or 'defense'</th></tr>
<tr><td>Pearce (1996)
Pearce (1999)
Nicholls et al. (1999)
Tri et al. (1998)</td></tr>
<tr><th>Keyword 'cyclone' or 'hurricane' or 'storm'</th></tr>
<tr><td>Bandyopadhyay (1997)
Blasco et al. (1992)</td></tr>
<tr><th>Keyword 'barrier'</th></tr>
<tr><td>Anthony (2004)</td></tr>
</table>

Table 2. Pre-tsunami mangrove expertise expressed as number of papers on mangroves listed in the Web of Science® database (ISI) for all authors of post-tsunami mangrove publications (in alphabetical order). News items or introductory editorial matter were excluded from the search in

order to focus on research output (research papers, review papers, essays, short communications). See text for description of database filtering and its limitations. First authors are printed in bold.

Author post-tsunami mangrove paper on the impact of the tsunami (2005)	Number of general pre-tsunami mangrove papers (1972-2004)	Journal of post-tsunami paper
Anitha S.	0	*Current Science*
Balamurugan V.	0	*Current Science*
Bosire J.O.	3	*Current Biology*
Burgess N.D.	0	*Science*
Dahdouh-Guebas F.	15	*Current Biology*
Danielsen F.	2	*Science*
Dharanirajan K.	0	*Current Science*
Di Nitto D.	0	*Current Biology*
Divien M.I.P.	0	*Current Science*
Fernando H.	0	*Science*
Fritz H.	0	*Science*
Goff J.	0	*Science*
Hansen L.B.	0	*Science*
Higman B.	0	*Science*
Hiraishi T.	0	*Science*
Hussain I.S.	0	*Current Science*
Jaffe B.E.	0	*Science*
Jayatissa L.P.	2	*Current Biology*
Karunagaran V.M.	0	*Science*
Kathiresan K.	39	*Estuarine, Coastal and Shelf Science*
Koedam N.	22	*Current Biology*
Liu P.L.-F.	0	*Science*
Lo Seen D.	0	*Current Biology*
Lynett P.	0	*Science*
Morton R.	0	*Science*
Olwig M.F.	0	*Science*
Parish F.	0	*Science*
Quarto A.	0	*Science*
Rajendran N.	10	*Estuarine, Coastal and Shelf Science*
Ramachandran S.	1	*Current Science*
Rasmussen M.S.	0	*Science*
Selvam V.	8	*Science*
Sørensen M.K.	0	*Science*
Suryadiputra N.	0	*Science*
Synolakis C.	0	*Science*
Udayaraj A.	0	*Current Science*
Vel A.S.	0	*Current Science*
Vendhan K.E.	0	*Current Science*

Table 3. Number of general pre-tsunami mangrove papers listed in the Web of Science® database (ISI) for journals of post-tsunami mangrove publications (in alphabetical order). See text for description of database filtering and its limitations.

Journal post-tsunami mangrove paper on the impact of the tsunami (2005)	Impact Factor (2004)	Number of pre-tsunami mangrove papers (1972-2004)
Current Biology	11.901	0
Current Science	0.688	37
Estuarine, Coastal and Shelf Science	1.058	130
Science	31.853	1*

- This paper focused on the remains of a dinosaur in mangrove deposits and not on the mangrove *sensu stricto*.

Figure captions

Figure 1. Relationship between the pre-tsunami mangrove expertise of the authors of a post-tsunami mangrove paper (each represented by a dot), and the Impact Factor of the journal in which this post-tsunami paper was published. The grey dashed line indicates the expected trend, and the grey dashed circles the locations of outliers to the underlying trend. Studies that followed the expected trend and that were outliers to the underlying trend (the single grey dot, corresponding to Ramachandran *et al.*, 2005) were omitted from the correlation and regression analysis of the underlying trend (solid black line).

Figure 2. Number of pre- and post-tsunami mangrove papers (as recorded in the Web of Science® database) dealing with how well mangroves could or did withstand the impact of ocean surges, published between 1972 and 2005. The data also contain the six papers on non-mangrove coastal vegetation and coast-morphological settings that could have the same protective effect, which does not significantly influence the statistical analysis (see text). There is a significantly increasing trend in number of papers (Acker, 1972; Bruder *et al.*, 1975; Pool *et al.*, 1977; Branch & Grindley, 1979; Pannier, 1979; Lescure *et al.*, 1980; Lindén & Jernelöv, 1980; Lugo, 1980; Semeniuk, 1980; Wolanski *et al.*, 1980; Ferdon, 1981; Buckley, 1982; De Lacerda & Hay, 1982; Naidoo & Raiman, 1982; Woodroffe, 1982; Plaziat *et al.*, 1983; Woodroffe, 1983; Lakshmanan, 1984; Sherrod & McMillan, 1985; Singh *et al.*, 1986; Mildenhall & Brown, 1987; Rutzler & Feller, 1987; Sing *et al.*, 1987; Vannucci, 1988; Aleem, 1990; Amadi, 1990; Choong *et al.*, 1990; Ibrahim & Hashim, 1990; Bacon & Alleng, 1992; Blasco *et al.*, 1992; Bryant *et al.*, 1992; Barbier, 1993; Saenger & Siddiqi, 1993; Ruitenbeek, 1994; Delaney & Devoy, 1995; Martinez, 1995; Primavera, 1995; Pearce, 1996; Bandyopadhyay, 1997; Bryant *et al.*, 1997; Bryant & Price, 1997; Primavera, 1997; Ewel *et al.*, 1998; Farnsworth, 1998; Field, 1998; Field *et al.*, 1998a; Gilbert & Janssen, 1998; Hindson *et al.*, 1998; Kaly & Jones, 1998; Mimura & Nunn, 1998; Tri *et al.*, 1998; Field, 1999; Lee, 1999; Nicholls *et al.*, 1999; Pearce, 1999; Ron & Padilla, 1999; Rönnbäck, 1999; Arrow *et al.*, 2000; Rönnbäck & Primavera, 2000; Yap, 2000; Abuodha & Kairo, 2001; Barbosa *et al.*, 2001; Ewel, 2001; Kaplowitz, 2001a; Kaplowitz, 2001b; Klein *et al.*, 2001; Martinez-Alier, 2001; Sathirathai & Barbier, 2001; Alongi, 2002; Clüsener-Godt, 2002; Oo, 2002; Young & Bryant, 1992; Moberg & Rönnbäck, 2003; Wong, 2003; Anthony, 2004; Boyer & Polasky, 2004; Chee, 2004; Halide *et al.*, 2004; Iftekhar & Islam, 2004; Tuttle *et al.*, 2004; Badola & Hussain, 2005; Dahdouh-Guebas *et al.*, 2005; Danielsen *et al.*, 2005; Hester *et al.*, 2005; Kathiresan & Rajendran, 2005; Liu *et al.*, 2005; Ramachandran *et al.*, 2005; Twilley *et al.*, 2005; Williams, 2005).

Figure 3. Individual and annual average Impact Factor of pre- and post-tsunami mangrove papers (as recorded in the Web of Science® database) published between 1972 and 2005 (on a logarithmic scale). The

data also contains the six papers on non-mangrove coastal vegetation and coast-morphological settings that could have the same protective effect, which does not significantly influence the statistical analysis (see text). There is a clearly identifiable increase in the average Impact Factor following the tsunami disaster (2005 *versus* any of the previous years). The papers involved are the same referenced in figure 2.

Figure 4. Graphical representation of a research framework for the in depth study of the potential of mangroves to act as protective barriers on the level of the organism, the vegetation assemblage and the ecosystem. We refer to the text and to the original references indicated for detailed explanations.

Figure1.

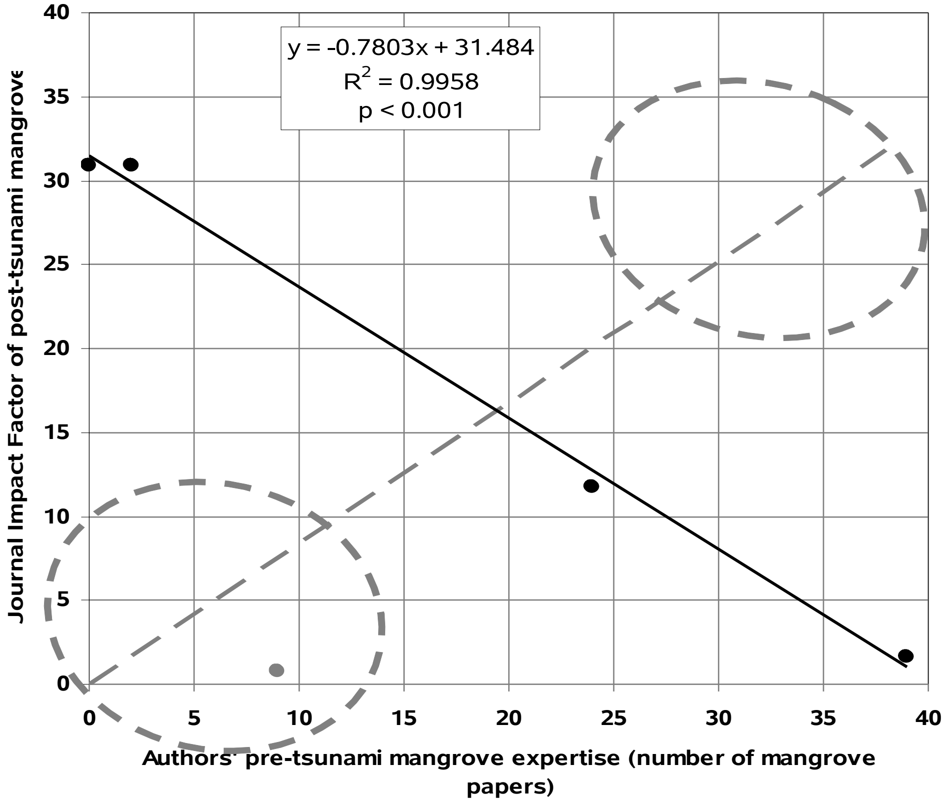


Figure2.

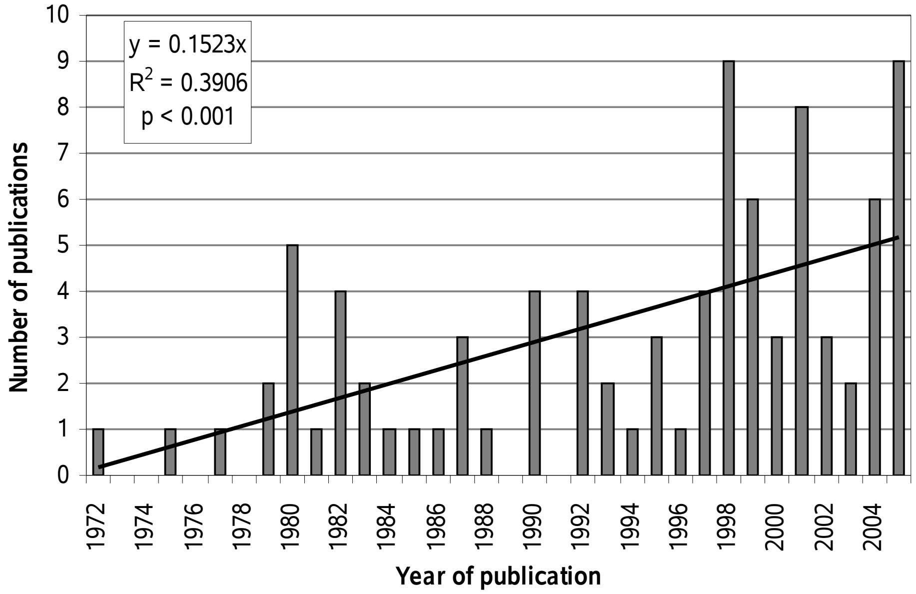


Figure3.

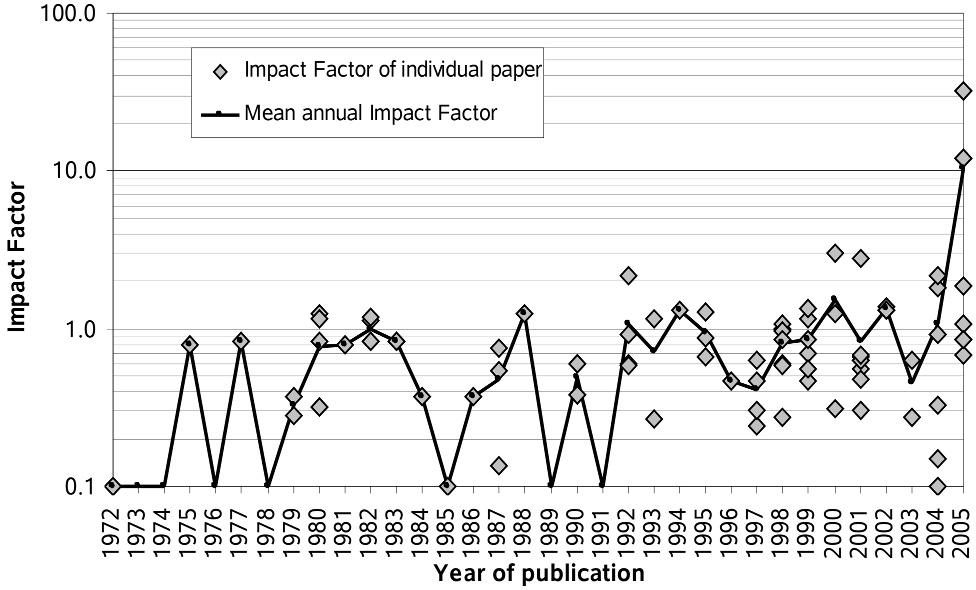
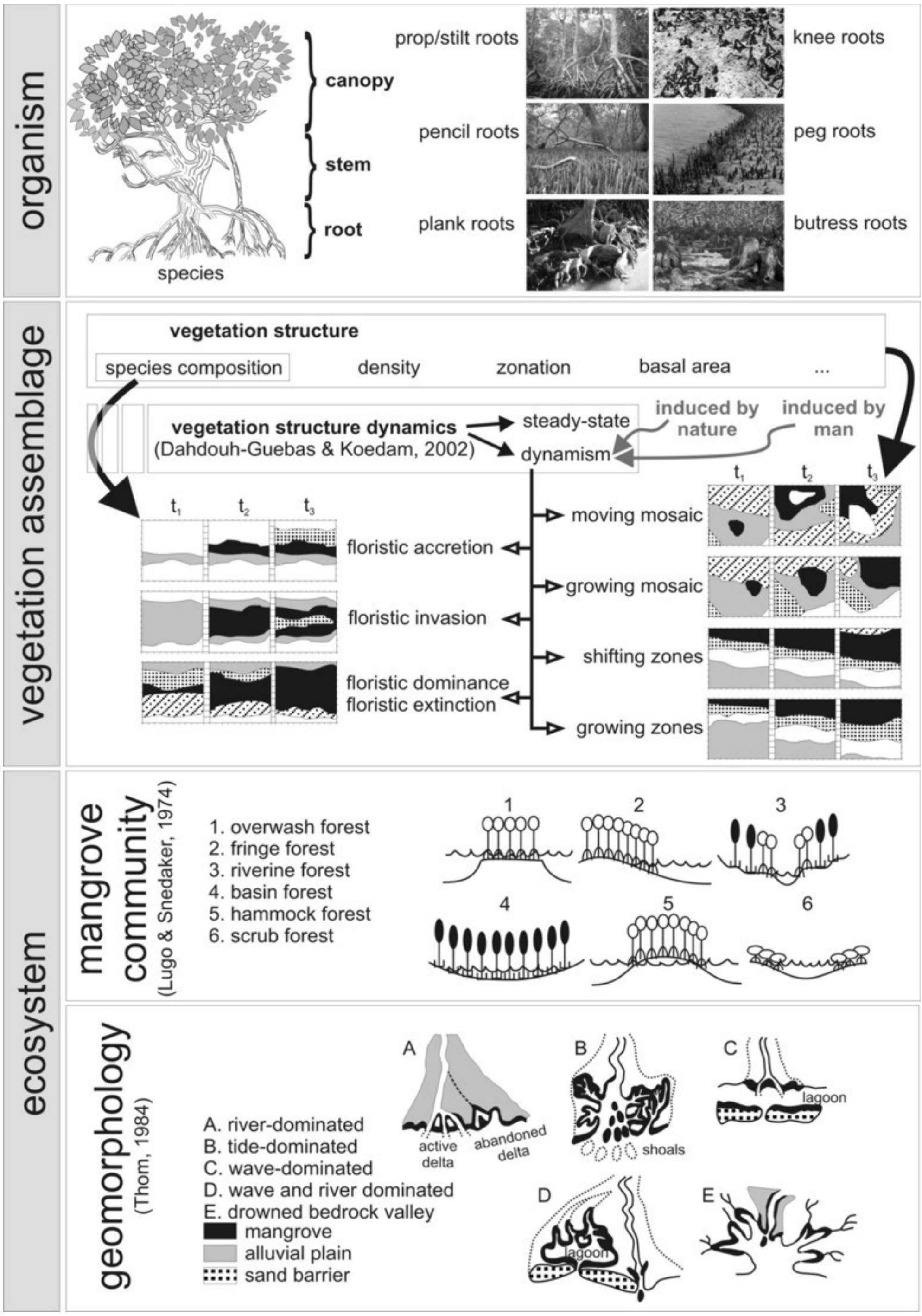


Figure4.


organism
canopy
stem
root
species
prop/stilt roots
knee roots
pencil roots
peg roots
plank roots
butress roots
vegetation assemblage
vegetation structure
species composition
density
zonation
basal area
...
vegetation structure dynamics
(Dahdouh-Guebas & Koedam, 2002)
steady-state
dynamism
induced by nature
induced by man
floristic accretion
floristic invasion
floristic dominance
floristic extinction
moving mosaic
growing mosaic
shifting zones
growing zones
ecosystem
mangrove community
(Lugo & Snedaker, 1974)
1. overwash forest
2. fringe forest
3. riverine forest
4. basin forest
5. hammock forest
6. scrub forest
geomorphology
(Thom, 1984)
A. river-dominated
B. tide-dominated
C. wave-dominated
D. wave and river dominated
E. drowned bedrock valley
mangrove
alluvial plain
sand barrier
active delta
abandoned delta
shoals
lagoon