



A bibliometrical review on pre- and post-tsunami assumptions and facts about mangroves and other coastal vegetation as protective buffers

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Abstract. Using the Web of Science® database (Institute of Science Information – ISI, Philadelphia, PA, USA) we analysed pre- (1972-2004) and post-tsunami (2005) clues about the protective buffer offered by mangroves and other coastal vegetation in peer-reviewed ISI-rated scientific literature. Apart from providing a literature review on the above topic, this study reveals that papers dealing with or suggesting the protective function of mangroves have been well represented in scientific literature since the 1970s. However, high-profile journals and their associated media engine tremendously failed to pick up the importance of the scientific findings related to mangrove ecosystems. Apparently, the tsunami strike of 26 December 2004 raised the status of mangrove research overnight, and to a level that was of *immediate interest to researchers in a broad range of other disciplines*, and thus fit for high-profile journals. However, the database showed a highly significant inverse relationship between the impact factor of the journals in which post-tsunami mangrove papers were published and the pre-tsunami mangrove expertise of the authors. While suggesting that the above trend is worrying, we present a research framework that should receive much more attention in research in the future by many journals of low and high impact factor. In the light of mangroves and protection against a wide range of water-related impacts - not only tsunamis but also cyclones, sea-level rise, daily tidal action and heavy El-Niño rains - it should be investigated which type of mangrove formation or coast-geomorphological settings has which effect. Root type, vegetation structure and species composition are categories with a lot of variation within, and may be considered in parallel with for instance a lagoon

setting with a fringing forest. Detangling the effect of such complexity under various water-related impacts will allow fully exploring and understanding the power of mangroves and other coastal vegetation as protective buffers. These priorities in fundamental research should be considered in parallel with research and policy measures on the conservation and restoration of mangroves, taking into account links with the socio-economic reality of local communities.

Keywords : mangrove, bibliometry, Web of Science®, Mangrove Action Project, Impact Factor, tsunami, defence, barrier, protection, cyclone, hurricane, storm, ecosystem function, ecosystem service, future research directions.

1 Introduction

Tropical coasts face a dual problem : on one hand the population density is very high, and on the other hand a series of negative anthropogenic and natural impact cumulate in the coastal zone, such as water pollution, harbour and tourism-related development, consequences of cyclones or heavy rains, and tsunamis. Although a tsunami is limited in time and space, there are a number of local coast-geomorphological and climatological conditions and/or changes, or human factors that strengthen the impact of a tsunami. In the tropics, the natural systems that are often affected first by these phenomena are coral reefs, mangroves, seagrass beds, sand banks, dunes and other coastal vegetation. Mangrove forests generally occur in intertidal areas along tropical and subtropical coasts and stabilise the coastlines. They do not only function as 'living dykes', but also fulfil a protective role for coastlines that in turn form a physical buffer. The ecological importance of these forests is reflected by their function as breeding, spawning, hatching and nursing grounds for young development stages of fish and shellfish. The mangrove ecosystem also serves as a production unit of wood and are therefore of local and global socio-economic importance (Baran, 1999; Barbier & Cox, 2002; Barbier, 2003). Apart from the increasing anthropogenic pressure on these ecosystems (*e.g.* by over-exploitation of mangrove wood, conversion for aquaculture, agriculture and oil spills) (Farnsworth and Ellison, 1997; Duke *et al.*, 1997), also chronic impacts can leave traces that can be reinforced by global climate change. This global climate change, together with an increase in average temperatures and a rising sea level (incl. changes in sedimentation, soil texture, and origin of sediment, etc.), can result in an increase in the intensity of heavy storms (IPCC, 2001).

The tsunami event and international articles

On 26 December 2004 the world was shaken by one of the largest natural disasters in recent history; a seabed earthquake in the Indian Ocean caused an enormous ocean surge that hit the coasts of Sri Lanka, India, Thailand and Indonesia among others. With a measure of 9.0 on the Richter scale and a length of approximately 900 km along the megathrust rupture of the subduction zone between the India- and Burma plates, the earthquake was the strongest of the past 40 years (Bhattacharjee, 2005) and caused millions of homeless and hundred thousands of deadly casualties amongst the coastal people. The shift of the plates resulted in a 'killer-tsunami' that damaged

many coastal settlements, but also the adjacent coastal ecosystems have severely suffered from the violence of nature.

Although the press – both the general and the scientific press writers such as Science, CNNworld, Newsweek, Courrier International, BioNieuws, etc. – has well highlighted the role of mangroves with respect to this tsunami, we have to acknowledge that hard scientific evidence is missing for both historic and recent ocean surges. The event of 26 December 2004 has received global attention and in various press releases the ‘protective role’ of mangrove ecosystems and the damage inflicted by the tsunami was highlighted. However, most reports were of very local nature and/or anecdotic (Danielsen *et al.*, 2005; Liu *et al.*, 2005), while others over-interpreted or minimalised the role of mangroves (Overdorf & Unmacht, 2005). Both types of reports were criticised because of caveats or because they failed view the facts, results or assumptions against well-documented and published papers (Dahdouh-Guebas *et al.*, 2005c; Kathiresan & Rajendran, 2005; Dahdouh-Guebas & Koedam, 2006).

In the Web of Science® database, the only two analytical peer-reviewed publications based on medium to large scale investigations were conducted by Dahdouh-Guebas *et al.* (2005c), who focused on 24 mangrove lagoons in a coastal stretch of hundreds of kilometres along the Sri Lankan coast, and by Kathiresan & Rajendran (2005), who investigated 18 fishermen hamlets in a coastal stretch of about 25 km in India. Kathiresan & Rajendran (2005) investigated human death and loss of wealth in coastal villages in function of distance and elevation with respect to the sea, and in function of the type and area of coastal vegetation shielding the villages. Although the scientific basis of these results has been criticised by Kerr *et al.* (2006), who in turn has been criticised by Vermaat & Thampanya (2006), the anecdotal value of the paper by Kathiresan & Rajendran (2006) remains valid. Dahdouh-Guebas *et al.* (2005c) focused on tsunami damage inflicted on mangroves in function of pre-tsunami status of the forests and in function of cryptic ecological degradation (*cf.* Dahdouh-Guebas *et al.*, 2005b). However, despite all above papers, from a critical scientific point of view the question of mangroves have functioned as a buffer (or if they still function as such today) remains unanswered. Even more essential than this question is the thought that mangroves can function as a physical buffer, while protecting other coastal areas that in turn function also as a buffer (Nico Koedam, pers. comm.). Apparently, this has also never been investigated.

In addition, the approach and the findings that could result from an investigation that addresses the above questions in a planned scientific fashion, would not only be applicable within the framework of mangrove forests and tsunami protection, but particularly within the framework of mangroves and protection against a wide range of water-related impacts, among which cyclones, sea-level rise, daily tidal action, and heavy El-Niño rains (*cf.* Badola & Hussain, 2005). Although each of these impacts is characterised by typical waves or currents, and a characteristic sediment transport/erosion pattern, it remains almost certain that the mangrove as an ecosystem can form a positive physical buffer and that it can mitigate the impact of the above phenomena (Badola & Hussain, 2005; Dahdouh-Guebas *et al.*, 2005c).

Objectives

This paper is a first step into an in-depth investigation of the tsunami-event, and has as first objective to review the assumptions and the facts about mangroves and other coastal vegetation as protective buffers from scientific literature. Rather than the simple compilation and presentation of a references list of peer-reviewed papers and information therein, this paper is brought as a bibliometrical analysis of that review. The aim of this bibliometrical analysis is to get insight on what science underlies the hypothesis of vegetation (with a large emphasis on mangroves) as a coastal defence, and on which was the publication venue. The latter is important as a measure of amount of wide publicity given to the results (*i.e.* not only within academic circles but also to the broad public), as this significantly varies with journal and with impact factor (see below). The second objective is to outline a number of problems related to international and multidisciplinary rehabilitation of tsunami-struck areas. And the final objective is to provide a research framework, or at least a number of ideas to learn from what happened, and to view the tsunami disaster area as a natural experiment and natural laboratory. The paper therefore aims at researchers of coastal vegetation, scientific journal editors interested in bibliometry, and national and international institutes and institutions concerned about coastal protection.

We want to highlight that all discussions about natural barriers against water-related phenomena such as the tsunami should be viewed in the light of what can be done, and not in the light of what cannot be done or what is useless. For example, tsunami impacts of apocalyptic magnitudes such as the ones described in Hills & Mader (1997) or Bryant & Nott (2001) overrule the objective of the present paper. *In situ* post-tsunami research on how natural barriers withstood the tsunami in areas where the tsunami reached apocalyptic dimensions (*e.g.* Banda Aceh) will inevitably lead to a rejection of the hypothesis that healthy coastal environments reduced tsunami damage (*e.g.* coral reefs in Baird *et al.*, 2005). Such a conclusion is evident and pre-empted when focusing solely on a region where the tsunami was apocalyptic in nature, but it would be a grave error to generalize this. In addition, a lack of local and/or scientific knowledge and descriptions of the pre-tsunami status of potential barriers in study sites badly affected by the tsunami, will make any findings on the inability of natural coastal barriers to mitigate a tsunami impact questionable (maybe the barriers were unable to fulfil their function because of chronic human impact, but could have helped if left in healthy status). Likewise, terrestrial environments without such barriers and that were weakly affected, will make results on the ability of terrestrial environments to mitigate a tsunami impact equally questionable if pre-tsunami status is undocumented (maybe barriers mitigated the tsunami impact but were subsequently washed away).

Material & Methods

International databases

One of the pillars of this bibliometric research is the Web of Science® (Institute of Science Information – ISI, Philadelphia, PA, USA). Web of Science® consists of five databases : Science Citation Index Expanded™, Social Sciences Citation Index®, Arts & Humanities Citation Index®, Index Chemicus®, and Current Chemical Reactions®. The first three of these databases, on which we focused, fully cover peer-reviewed publications from more than 8,750 journals in all sciences (Agriculture, biology and environmental sciences; Physical, chemical and earth sciences; Engineering, computing and technology; Life sciences; Clinical medicine; Arts and humanities;

Social and behavioural sciences), and it indexes individually selected, relevant items from over 10,000 of the world's leading scientific and technical journals. Web of Science® covers a period of 33 years (1972-2005, with occasional references published before 1972), and is updated weekly. Its limitations are that it only covers journals with an Impact Factor (which is also calculated by ISI), and not the numerous peer-reviewed journals without an Impact Factor. Without going into the details of the use and abuse of these databases or the Impact Factors (see Amin & Mabe, 2001), its use is in itself not expected to be biased for the following reasons. First, a majority of researchers who build up a scientific publication record through peer-reviewed papers do not deliberately target those journals without an Impact Factor. In reality, researchers publish in both rated and non-rated journals. Second, the ISI databases are unfortunately the only existing international databases to carry out decadal retrospective bibliometric research on specific research areas, co-authorship patterns and so forth (Dahdouh-Guebas *et al.*, 2003). There are no other international multidisciplinary databases that are organised, structured and updated on such a regular basis and that go back so far in time.

We also highlight that we are aware of numerous publications in the category of 'grey literature' or in the category of 'non-ISI-rated scientific literature'. We are also aware of a number of scholarly or popular books on mangrove forests (Tomlinson, 1986; Field, 1995; Field, 1996; Stafford-Deitsch, 1996; Spalding *et al.*, 1997; Hogarth, 1999; De Lacerda, 2002; Saenger, 2002), as well as of reports published by global organisations such as Food and Agricultural Organisation (FAO), United Nations Environment Programme (UNEP) or United Nations Educational, Scientific and Cultural Organisation (UNESCO). There are also electronic discussion lists or newsletters, among which the Mangrove Research Discussion List (ran by M. Van Keulen and hosted at Murdoch University, Perth, Australia; URL : <http://lists.murdoch.edu.au/mailman/listinfo/mangrove>) and the Mangrove Action Project News (ran by A. Quarto at Mangrove Action Project, Port Angeles, Washington, USA; URL : <http://www.earthisland.org/map/>). However, since no structured database similar to Web of Science® was available, and reaching completeness in this category is therefore virtually impossible, this category was dropped altogether. Pre-empting the results from this study in this methodological section, we emphasize that the above is not a shortcoming of the research. In fact, any addition of grey or non-ISI-rated literature is reinforcing the 'conservative' results presented in this review paper. This was explicitly the case for the archive of the Mangrove Action Project News.

Search protocols

The Web of Science® database was searched for the period between 1 January 1972 and 1 January 2006, which contained 31,109,001 publication records. We first filtered the database on the condition that the term 'mangrove' appeared in title, abstract or keyword fields (author keywords as well as extra database keywords). Papers on mangroves for which this condition was not true were therefore not retrieved, which may be considered a bias. However, the number of papers on a particular topic that does not list this topic in the title, in the keywords or in the abstract is negligible (*cf.* Dahdouh-Guebas *et al.*, 2003). In addition, the only way to overcome such a bias would be to actively read the full text of all 31.1 million papers, which is impracticable. The first conditional query of the full Web of Science® database generated a list of 3,878 publications. Within this list we extracted those papers that complied with the second condition that any of the following keywords appeared in title, abstract and keyword fields : 'tsunami',

'defence', 'barrier', 'protection', 'storm', 'cyclone', 'hurricane', 'function' and 'service', all keywords that may highlight the ability of mangroves to function as a protective barrier against water-related phenomena such as cyclones, tsunamis, El-Niño events, and heavy rains. For each of these papers the abstract was read to ascertain that this emphasis was present to a minimal degree. For the keyword 'service' the entire paper was read to ascertain the same, since the reading of the abstract mostly generated inconclusive results. Whenever the above-mentioned emphasis was lacking in a paper it was omitted from further analysis. Note that papers with only a focus on these keywords (second condition) and without emphasis on mangroves (first condition) are not included in the quantitative analysis, e.g. the paper by Bryant *et al.* (1992) on the effect of palaeotsunamis on coastal areas of Australia was not included as it has no focus on mangroves. Likewise, many papers on the effect of sea-level rise *on* mangroves and not on the protection of the coast *by* mangroves were not selected (Woodroffe, 1990; Woodroffe *et al.*, 1995; Woodroffe, 1999). However, some relevant studies amongst them were used in the discussion qualitatively.

In addition to the references resulting from the above protocol, all papers published between 1972 and 1991 ($n = 787$) were re-analysed, as the database does not list keywords or abstracts for this period. This means that the above automated protocol for this period could only be based on title information. By manual reading and interpreting the title context 28 additional papers were withheld, a majority of which were general ecological papers.

For the sake of completeness with respect to other coastal settings and vegetations that may have been reported as a protective barrier against tsunamis, we searched the original Web of Science® database (1 January 1972 and 1 January 2006) for the combination of the term 'tsunami' and each of the following terms : 'continental shelf', 'coral', 'dune', 'sand', 'sediment', 'soil' and 'vegetation'. This generated 264 extra papers, to which we applied the second condition as described above.

Finally, we highlight one more limitation to the use of the Web of Science® database. First, there may be a delay of several months before publication of a paper in a journal, and its appearance in the Web of Science® database. Some papers published in 2005 (most likely those published at the end of 2005) will have appeared after 1 January 2006. We have deliberately not investigated articles published at later stages (2006-present) in order to be able to discuss the immediacy of publication on a topic such as the tsunami disaster.

Results

Below we refer to papers on mangroves that were published before the tsunami hit (1972 to 2004), hereafter called 'pre-tsunami mangrove papers', and papers published after the disaster (2005), hereafter called 'post-tsunami mangrove papers'. Both types specifically refer to papers dealing with how well mangroves could or did withstand the impact of ocean surges (tsunami, cyclone). We also refer to general pre-tsunami mangrove papers of authors as a measure for their expertise on mangroves prior to the tsunami disaster. Note that the term 'pre-tsunami' refers to the time of publishing of general mangrove papers and not to papers on the tsunami-related topics.

According to the Web of Science® database 54 papers were published between 1972 and 2005 that highlighted the ability of mangroves to function as a buffer between land and sea (Table 1). In addition, there are six papers that link protection by coastal settings (such as shallow bays, sand

banks, form of the continental shelf) or by coastal vegetation other than mangroves (e.g. sand dune vegetation) to tsunami impact *sensu lato* (Young & Bryant, 1992; Delaney & Devoy, 1995; Bryant & Price, 1997; Bryant *et al.*, 1997; Hindson *et al.*, 1998; Tuttle *et al.*, 2004).

There were five post-tsunami mangrove articles with in total 38 authors (Table 2). However, 29 of them (76%) had no pre-tsunami mangrove publication record, 4 of them had three papers or less, and only 5 of them had a considerable pre-tsunami mangrove publication record (8 papers or more). A similar degree of opportunism was true for some of the journals in which the post-tsunami mangrove papers were published (Table 3): while expecting a positive correlation, the relationship between the Impact Factor of these journals and the pre-tsunami mangrove expertise of the authors was negative (Figure 1). When omitting expected patterns from the relationship, *i.e.* authors with a lot of expertise who publish in journals with high Impact Factors, and authors with little expertise who publish in journals with low Impact Factors – this corresponds to a single study – the worrying underlying trend became even more clear : the higher the profile of the journal, the lower the pre-tsunami mangrove expertise of the authors who published a post-tsunami paper in it (Figure 1). The journal with the highest Impact Factor in this list (*Science*) published even two post-tsunami mangrove contributions, as well as a set of disaster-related viewpoint papers by experts (e.g. Adger *et al.*, 2005; Allenby & Fink, 2005; Linnerooth-Bayer *et al.*, 2005; Mills, 2005), but just a single “mangrove” publication in the 30 years preceding the tsunami (Smith *et al.*, 2001). The latter paper focused on the remains of a dinosaur in mangrove deposits rather than on the mangrove itself, and was therefore excluded from further analysis. We do highlight that a recent paper on the macro-ecology of mangroves (Ellison, 2002) reported 4 papers published in *Science*, *Nature*, or *Proceedings of the National Academy of Sciences of the USA* in the period 1945-1972, but we were not able to obtain particulars about the reference to these papers.

Bibliometric retrospection over the past 33 years reveals that papers relating the mangrove ecosystem to shoreline protection have always existed and have significantly increased in number throughout the time period considered (Figure 2)¹. However, the individual and average annual Impact Factor of the journals in which such papers get published have increased unmistakably since the tsunami disaster. Prior to 2005, however, one can only track 3 papers in *Nature* on mangroves. One of these is on the original topic of the distribution of ancient mangrove forests (Woodroffe *et al.*, 1985). The remaining two papers were on the adverse effect of aquaculture on fish supplies (Naylor *et al.*, 2000), and on the beneficial effect of mangroves on fish assemblages (Mumby *et al.*, 2004), topics that have been recurrently dealt by many authors (e.g. Folke & Kautsky, 1989, 1992; Primavera, 1997; Baran & Hambrey, 1998; Barbier & Strand, 1998; Boyd & Clay, 1998; Baran, 1999; Folke *et al.*, 1998; Dewalt *et al.*, 1996). There is no other record of papers on mangroves, let alone on its ability to function as a natural dyke, in high-profile journals².

As indicated in the methodology, any addition from grey literature to the above results reinforces them. The archive of the Mangrove Action Project News was in line with the trend observed for the Web of Science® database, *i.e.* highlights of the protective functions is recurrent over time, and boomed after the tsunami disaster.

¹ Inclusion of the six papers on non-mangrove coastal vegetation or coast-morphological settings that could fulfil the same protective function does not significantly alter the results or their further statistical analyses.

² The term ‘high-profile’ is based on the journals that cover a wide variety of topics in ecology and have an impact factor superior to 10.

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 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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References have been subdivided as 'references in text' and 'References only in tables or figures, as part of the bibliometric analysis'.

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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).

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

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 | <i>Current Science</i> |
| Balamurugan V. | 0 | <i>Current Science</i> |
| Bosire J.O. | 3 | <i>Current Biology</i> |
| Burgess N.D. | 0 | <i>Science</i> |
| Dahdouh-Guebas F. | 15 | <i>Current Biology</i> |
| Danielsen F. | 2 | <i>Science</i> |
| Dharanirajan K. | 0 | <i>Current Science</i> |
| Di Nitto D. | 0 | <i>Current Biology</i> |
| Divien M.I.P. | 0 | <i>Current Science</i> |
| Fernando H. | 0 | <i>Science</i> |
| Fritz H. | 0 | <i>Science</i> |
| Goff J. | 0 | <i>Science</i> |
| Hansen L.B. | 0 | <i>Science</i> |
| Higman B. | 0 | <i>Science</i> |
| Hiraishi T. | 0 | <i>Science</i> |
| Hussain I.S. | 0 | <i>Current Science</i> |
| Jaffe B.E. | 0 | <i>Science</i> |
| Jayatissa L.P. | 2 | <i>Current Biology</i> |
| Karunagaran V.M. | 0 | <i>Science</i> |
| Kathiresan K. | 39 | <i>Estuarine, Coastal and Shelf Science</i> |
| Koedam N. | 22 | <i>Current Biology</i> |
| Liu P.L.-F. | 0 | <i>Science</i> |
| Lo Seen D. | 0 | <i>Current Biology</i> |
| Lynett P. | 0 | <i>Science</i> |
| Morton R. | 0 | <i>Science</i> |
| Olwig M.F. | 0 | <i>Science</i> |
| Parish F. | 0 | <i>Science</i> |
| Quarto A. | 0 | <i>Science</i> |
| Rajendran N. | 10 | <i>Estuarine, Coastal and Shelf Science</i> |
| Ramachandran S. | 1 | <i>Current Science</i> |
| Rasmussen M.S. | 0 | <i>Science</i> |
| Selvam V. | 8 | <i>Science</i> |
| Sørensen M.K. | 0 | <i>Science</i> |
| Suryadiputra N. | 0 | <i>Science</i> |
| Synolakis C. | 0 | <i>Science</i> |
| Udayaraj A. | 0 | <i>Current Science</i> |
| Vel A.S. | 0 | <i>Current Science</i> |
| Vendhan K.E. | 0 | <i>Current Science</i> |

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) |
|---|----------------------|---|
| <i>Current Biology</i> | 11.901 | 0 |
| <i>Current Science</i> | 0.688 | 37 |
| <i>Estuarine, Coastal and Shelf Science</i> | 1.058 | 130 |
| <i>Science</i> | 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.

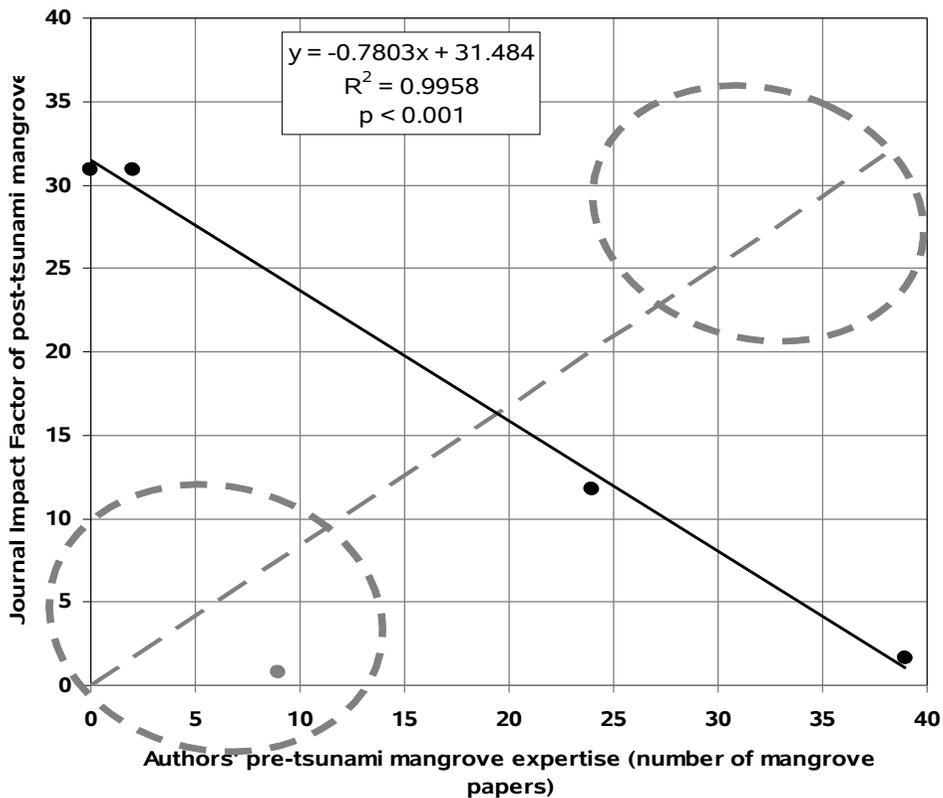


Figure2.

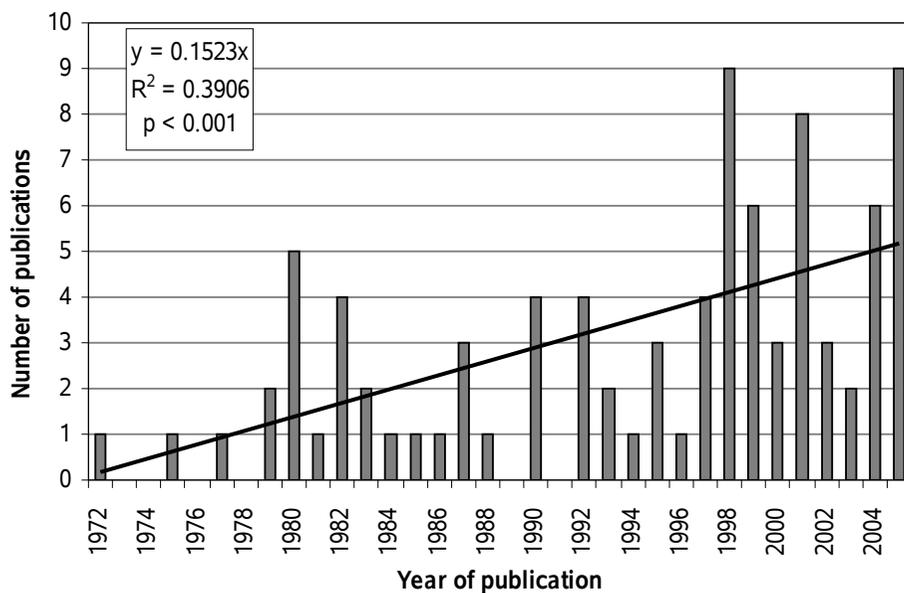


Figure3.

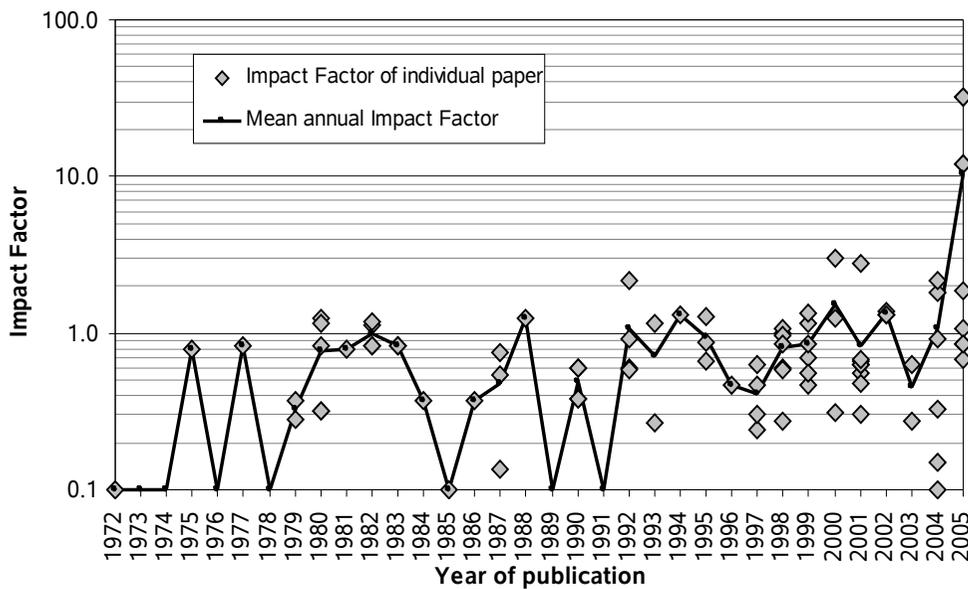


Figure4.

