Resilience Thinking Applied to The Mangroves of Indonesia

A Look at the General Resilience of Indonesia's Mangrove Forests, as Socio-Ecological Systems with Reference to Potential Thresholds.

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This report was produced with the financial support of the Organismo Autónomo Parques Nacionales (OAPN) of the Ministry of Environment of Spain, under the project "Rehabilitating Coastal Ecosystems in a Post Tsunami Context: Consolidation Phase". The views expressed in this publication do not necessarily reflect those of OAPN, Ministry of Environment or IUCN.

Citation: Brown, Benjamn (2007). "Resilience Thinking Applied to the Mangroves of Indonesia." IUCN & Mangrove Action Project; Yogyakarta, INDONESIA

Photography: front cover: Ben Brown - Simeulue Island - Aceh; back cover: Ben Brown, Jaring Halus, North Sumatera all other photos by Ben Brown, with exception of pp. 19 (Ratna Fadillah, North Sulawesi); 24 (Jajang Sonjaya, Segara Anakan, Java); 39 (Melissa Bentivoglio, Simeulue Island, Aceh); 42 (Miswadi and Lukmanul Hakim, Bengkalis Island, Riau).

Written by: Ben Brown w/ extensive direct quotes from "Resilience Thinking"
Layout by: Ben Brown
Editors: R.R. Lewis, Adrian Coen, Paul Hooper
Printed by:
Available from: Ecosystems and Livelihoods Group, Asia
The World Conservation Union - IUCN
4/1 Adams Avenue,
Colombo 4,
Sri Lanka
Tel: ++ 9411-2559634/5
Fax: ++ 9411-2559637
Website http://www.iucn.org

also available at
http://mangroveactionproject.org

Composition: of the Paper: The cover is printed on Aconda 300 gsm which contains 40% recycled fibre and 60% virgin wood fibre of which at least 50% is FSC certified.
The content is printed on Normaset Puro 90 mgs which is 100% virgin wood fibre of which at least 30% is FSC certified.

Printed with vegetable oil-based inks.

Resilience Thinking Applied to Mangroves

By Ben Brown
Mangrove Action Project - Indonesia

Adapted and with extensive quotes from
"Resilience Thinking"
by Brian Walker and David Salt

IUCN - The World Conservation Union

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Rehabilitating Coastal Ecosystems in a Post Tsunami Context: Consolidation Phase

This project was developed to address the long-term threats to mangroves in tsunami-affected countries, and to restore, rehabilitate and conserve these vital ecosystems. Funding is being provided by the Organismo Autónomo Parques Nacionales (OAPN), Ministry of Environment of Spain. Between September 2005 and December 2006, OAPN made available a grant to assist with mangrove rehabilitation in tsunami-affected areas of Sri Lanka and Thailand. OAPN provided a second grant, running between January and December 2007, to consolidate and share the lessons learned in the course of carrying out mangrove rehabilitation during the first phase of the project. This consolidation phase focuses on using the knowledge gained while carrying out the first phase for awareness-raising and capacity building for those involved with mangrove restoration, particularly Protected Area managers. This phase aims to share information and learning with additional sites and groups in Sri Lanka and Thailand, the countries participating in the first phase of the project, as well as to extend learning with another tsunami-affected country, Indonesia.

MANGROVE MAP ACTION PROJECT

Mangrove Action Project

The Mangrove Action Project is dedicated to reversing the degradation and loss of mangrove forest ecosystems worldwide. MAP's main goal is to promote the rights of traditional and indigenous coastal peoples, including fishers and farmers, to sustainably manage their coastal environs. Through its global network and offices in the U.S. (International Office), Thailand (Asia Regional Office), Indonesia, and Latin America, MAP is stimulating the exchange of ideas and information on the conservation and restoration of mangrove forests, while promoting sustainable utilization of mangroves by rural coastal communities.

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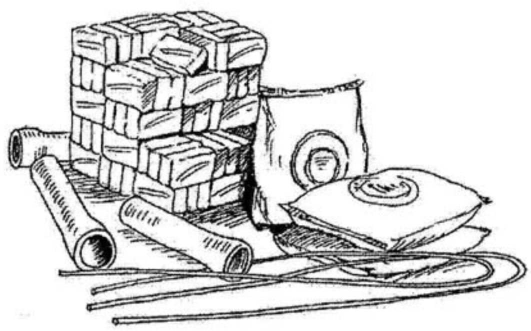
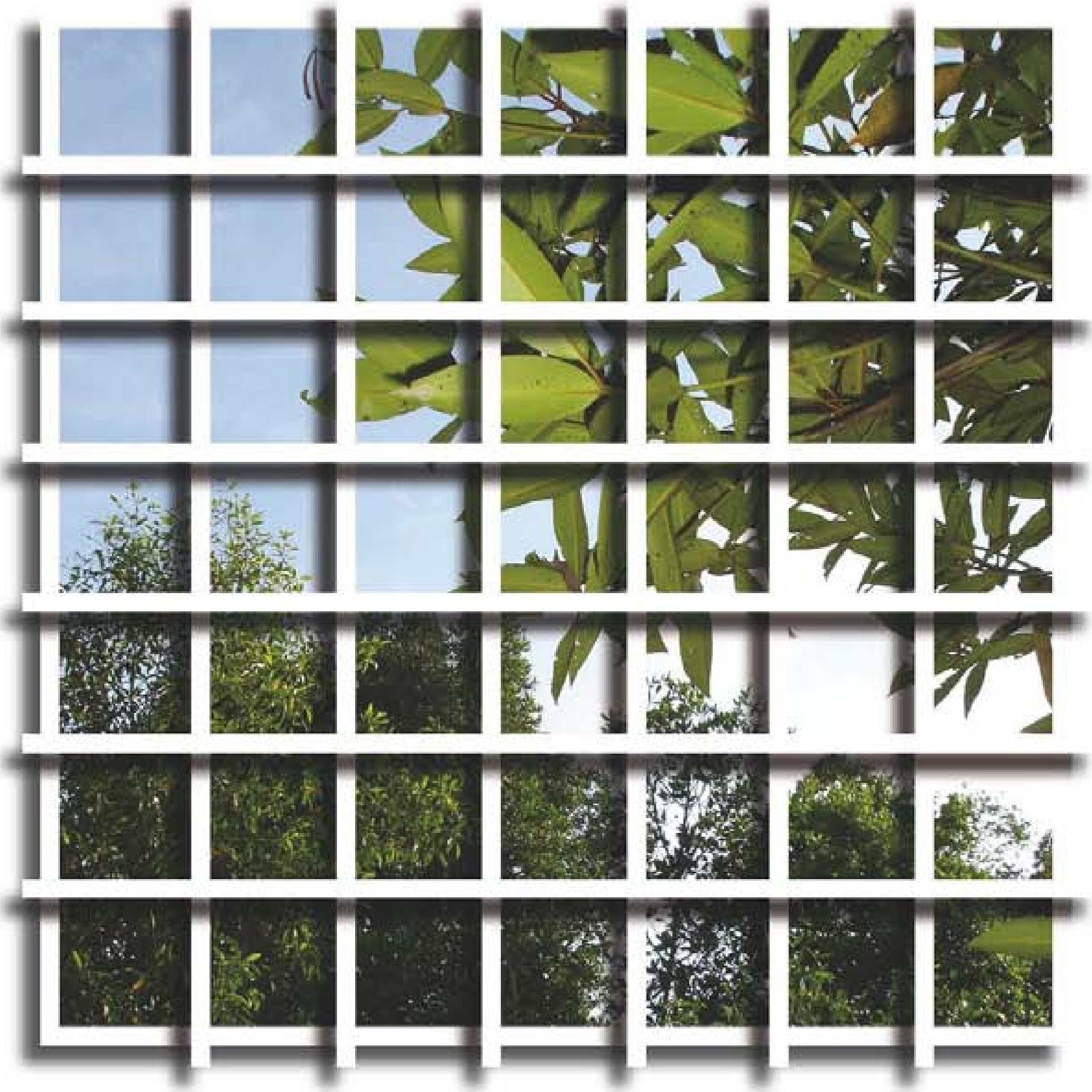




ACKNOWLEDGEMENT
Mangrove Action Project and MAP - Indonesia would like to thank IUCN and other supporters for the opportunity and freedom to create media we deem essential to forward the cause of mangrove conservation.

To the authors of "Resilience Thinking," and to readers, we would like to apologize for omissions and inconsistencies in this paper. Learning about resilience and linking resilience to mangroves is a work in progress. If parts of this paper ring true, or are able to shed light on a new way to look at mangroves, we are grateful.

MAP-Indonesia, 2007

FOREWARD

One year after the 2006 Yogyakarta Earthquake, I found myself poking around a friend's house in Bantul, one of the regions most devastated by the quake. Approximately 200 of the 250 houses in his village were either destroyed or properly damaged. Most of the houses, one year after the fact, had been rebuilt, do to the fund-raising prowess of an ex-pat who runs Yogyakarta's largest handicraft export business, and has resided in the same village for nearly a decade. Before this substantial aid found its way to the village, truck-loads of community volunteers had already come pouring down from the Central Javanese highlands, laden with bamboo and free or cheap labor, to help in reconstruction.

I had not yet heard much of the term resilience, but seemingly, social systems in Yogyakarta (local community, government, non-government, and international) were by and large up to the task of rebuilding, at least to a greater extent than the 2004 tsunami disaster in Aceh. At any rate, this is not a paper on the resilience of disaster stricken communities, but my introduction to resilience thinking came during this time period. While at my friend's house, I came across an unassuming looking paper-back with the succinct title "Resilience Thinking." What immediately caught my eye, was the photograph on the cover depicting a solitary, four-leaved mangrove seedling (*Ceriops tagal*), poking up from an uplifted coral head. By chance, I had just returned a week before from a mangrove restoration assessment on Simeulue Island, Aceh (see case study #2), from 6 sites which had undergone tectonic uplift of around 1 meter. I had in my, literally one hundred of my own photos identical to the one gracing the cover of "Resilience Thinking." I borrowed the book, read it cover to cover, made eight copies, and now am re-borrowing (haven given away all eight copies) the book as a reference for this writing.

Resilience thinking is really nothing new (the description of the adaptive cycle in "Resilience Thinking" mirrors the ancient Chinese cycle of the five elements), but the authors, David Salt and Brian Walker, have mapped out the theory behind resilience thinking in such a way that it resonates with readers. It certainly resonated with me, at once framing my past decade of work in SE Asia in the realm of community based mangrove management, conservation and restoration, as well as providing a frame-work for future management actions.

In the first chapter, the authors express their hope that readers will start asking questions about the systems with which they work. This challenge came at a time when the IUCN had contracted us at Mangrove Action Project – Indonesia, to produce media on mangroves for larger-scale distribution. The series of recently produced publications also includes a technical paper and poster on Ecological Mangrove Restoration, an Indonesian adaptation/translation of Post-Disaster Rapid Coastal Assessment techniques, as well as a compilation of Indonesian case studies on community involvement in policy making for mangrove conservation.

IUCN has already produced a working paper on resilience, entitled "Managing Mangroves for Resilience to Climate Change," which is drawn from in this paper. "Resilience Thinking on Mangroves" differs from this previous work in that adheres closely to the paradigm for resilience described in "Resilience Thinking" and goes beyond the impacts of climate change on resilience, looking at the general resilience of mangroves as a socio-ecological system. As a very serious disclaimer, this paper is really not much more than the rambunctious musings on a subject new to this mangrover. On top of that, scientifically speaking I am not a true mangrover, perhaps more of an associate of mangroves. The best that can be said for myself and the staff of Mangrove Action Project in Indonesia, is that we are very close to the fisher-folk with whom we work, and we probably have a better understanding of rural coastal community dynamics in Indonesia than most. This writing on resilience does not focus as much on community involvement as it should, with the exceptions of the case studies. Local community involvement in mangrove management is of course an essential part of building resilience into the system as a social-ecological whole. That being said, much has been written recently on community involvement in forestry management, while little has been written linking forestry management to resilience. In future editions, we will need to expand upon building resilient social communities.

In the meantime, what we are attempting with this paper, is the application of a wonderful way of thinking (resilience), to a system very dear to us (mangroves). Our hope is that at least a few readers will take up the challenge to learn more about resilience thinking and to apply it to current mangrove management efforts in their own regions. Friends at the Resilience Alliance have made it easy for us. They have set down their theory in "Resilience Thinking," and have provided us with a pair of workbooks with which to undertake resilience assessments; one for the practitioner, the other for the scientist. These valuable resources can be downloaded from the resources section of the Resilience Alliance's website (www.resalliance.org)

Thanks to the authors of "Resilience Thinking" for throwing down the gauntlet, and to IUCN for giving us the chance to accept the challenge of applying resilience thinking to mangroves. And our sincere apologies for the many short-comings of this trial effort.

Ben Brown
Director, Mangrove Action Project - Indonesia
October 31, 2007

Part 1:
Introduction to Resilience Thinking

This paper, intends to present the precepts of "Resilience Thinking" as they relate to mangrove management in Indonesia. The paper's only real design, is to provide mangrove managers with basic information on resilience, so that they may begin to think of mangrove forests under their jurisdiction as socio-ecological systems and begin to perceive management actions based on their ability to maintain or increase the resilience of the mangrove forest.. Before going into the specifics of resilience and mangroves, we need a basic understanding of the concept of resilience as described by David Salt and Brian Walker, authors of "Resilience Thinking." As opposed to paraphrasing the authors (and misconstruing their connotations), many of the key concepts on resilience are taking verbatim from the book "Resilience Thinking" and the Resilience Alliance website, not with the intent to plagiarize, but because so many mangrove managers in Indonesia will not be able to access the original, and also so that translation from English to Indonesia takes place with as little distortion as possible. Again, the main emphasis of this paper is to make a new mode of thinking accessible managers who have limited access to written materials.

WHAT IS RESILIENCE? (from www.resalliance.org)

Ecosystem resilience is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes. A resilient ecosystem can withstand shocks and rebuild itself when necessary. Resilience in social systems has the added capacity of humans to anticipate and plan for the future. Humans are part of the natural world. We depend on ecological systems for our survival and we continuously impact the ecosystems in which we live from the local to global scale. Resilience is a property of these linked social-ecological systems (SES). "Resilience" as applied to ecosystems, or to integrated systems of people and the natural environment, has three defining characteristics:

- The amount of change the system can undergo and still retain the same controls on function and structure
- The degree to which the system is capable of self-organization
- The ability to build and increase the capacity for learning and adaptation

CATASTROPHIC SHIFTS IN ECOSYSTEMS

The amount of resilience a system possesses relates to the magnitude of disturbance required to fundamentally disrupt the system causing a dramatic shift to another state of the system, controlled by a different set of processes. Reduced resilience increases the vulnerability of a system to smaller disturbances that it could previously cope with. Even in the absence of disturbance, gradually changing conditions, e.g., sedimentation, sea-level rise, habitat fragmentation, etc., can surpass threshold levels, triggering an abrupt system response. When resilience is lost or significantly decreased, a system is at high risk of shifting into a qualitatively different state. The new state of the system may be undesirable, as in the case of a mature mangrove forest that becomes a pock-marked terrain full of *Acrostichum* fern or or an abandoned shrimp pond complex. Restoring a system to it's previous state can be complex, expensive, and sometimes even impossible. Research suggests that to restore some systems to their previous state requires a return to environmental conditions well before the point of collapse (for more on restoration of mangrove systems, refer to papers on Ecological Mangrove Restoration at www.mangroverestoration.org and www.mangroveactionproject.org).

HOW IS RESILIENCE LOST?

The resilience of a mangrove forest as a complex social-ecological systems depends largely on underlying, slowly changing variables; such as climate, land use, water balance, human values and policies. Resilience can be degraded by a large variety of factors including:

- loss of biodiversity
- toxic pollution
- inflexible, closed institutions
- perverse subsidies that encourage unsustainable use of resources
- a focus on production and increased efficiencies of a specific part of the mangrove system

HOW IS RESILIENCE ENHANCED?

Mangrove forests are inherently resilient, but just as their capacity to cope with disturbance can be degraded, so can it be enhanced. One key to resilience in social-ecological systems is diversity. Biodiversity plays a crucial role by providing functional redundancy. This means that more than one species can fill an important ecological role when other species may be absent or unable to fulfill such a role. As an example from the mangroves; different mangrove species occur at various substrate heights or levels of tidal inundation. A change in substrate height (due to sedimentation or an earthquake causing tectonic uplift) would lift previously existing mangroves out of the tidal zone, and create new areas appropriate for mangrove colonization. A resilient forest, would have enough different types of mangroves, including colonizers, to vegetate uplifted areas and maintain the basic functions of a mangrove forest.

Avicennia marina (left) and *Sonneratia alba* (right) are two common members of the seaward fringe, with small propagules that readily colonize the coast after mild disturbance. Redundancy in functional roles is one way that the resilience of a system is increased, as more than one species is available to adjust to shocks and disturbances.

Similarly, when the management of a resource is shared by a diverse group of stakeholders (e.g., local resource users, research scientists, community members with traditional knowledge, government representatives, etc.), decision-making is better informed and more options exist for testing policies. Active adaptive management, whereby management actions are designed as experiments, encourages learning and novelty, thus increasing resilience in social-ecological systems.

THE STATUS OF MANGROVES

Before we begin to apply our understanding of resilience specifically to mangrove ecosystems, we will briefly define mangrove ecosystems and take a general look at the status of mangroves around the world. Later in the paper we will look at factors determining distribution and health of mangrove ecosystems that may proove to be key variables in determining the resilience of mangroves.

The word mangrove indicates both a type of tree or shrub and also the forest type which grows along tidal mudflats and along shallow water coastal areas; extending inland along rivers, streams and their tributaries where the water is generally brackish. The mangrove ecosystem is dominated by mangrove trees as the primary producer interacting with associated aquatic fauna, social and physical factors of the coastal environment (Melana et. al, 2000)

The mangrove flora consists of 48 true mangroves as well as associated species belonging to 36 families (Tomlinson, 1986) In terms of distribution globally, 40 of the true mangroves exist in the Eastern Hemisphere while only 8 exist in the Western Hemisphere. At least 38 species of true mangroves exist in Indonesia. True mangroves grow in the mangrove environment while associated species may grow on other habitat types such as the beach forest and lowland areas. The mangrove fauna is made up of shore birds, some species of mammals (monkeys, bats, etc.), reptiles, mollusks, crustaceans, polychaetes, fishes and insects.

With regard to the status of mangroves around the world, the prognosis is not good. High population pressure in coastal areas has led to the conversion of mangroves for short to mid-term economic development; including conversion to aquaculture, oil palm plantations, and rice and salt production. The results of the most recent survey and trend analyses conducted by the FAO/UNEP indicate that total mangrove area worldwide had fallen below 15 million hectares as of 2000, down from 19.8 million ha in 1980. The world has thus lost 5 million hectares of mangroves in the twenty years period between 1980 and 2000, or 25 percent of mangrove coverage found in 1980. (FAO - *Status and Trends In Mangrove Area Extent Worldwide*). Mangrove destruction in Indonesia may be as high as 50% in the same time period, falling from a historical total of 4.3 million hectares to around 2.4 million hectares by 1990 (Giesen, 1993)

Typical desolation associated with development of shimp ponds in Indonesia. This 40 hectare pond complex, near Belawan port, North Sumatera was abandoned after 2 years of operation. There was no attempted reparation to hydrology, or restoration at this site.

THE DRIVERS OF UNSUSTAINABLE MANGROVE MANAGEMENT

What lies behind this decline in mangrove coverage? Walker and Salt have us look at three broad underlying reasons:

1. People have no choice but to overuse their resources due to poverty and population density.
2. Intentional depletion of resources due to greed and interest in short-term profits
3. Lack of understanding of how mangrove ecosystems work and how to manage for sustainability.

The first case, where human's have no choice but to over-exploit due to population density and poverty seems difficult to apply to most mangroves. Small rural communities have a general history of excellent stewardship of mangroves, extracting products including timber, but in balance with what the ecosystem can safely provide. Over harvesting of fisheries products directly in the mangroves is also difficult to achieve, due to difficulty in access. Over harvest of fisheries products from mangroves once the fish have moved out to sea is another story. When a population grows, however, does it usually deplete its mangrove resources? It often the case that a relatively few number of exploitative individuals, investors, etc. exploit the mangroves in both rural and industrial settings, rather than overexploitation by a critical mass of individuals.

The second case is quite common in the mangrove world, where a resource is allowed to decline or purposely driven down. A look at the mangrove charcoal industry in Indonesia presents a ready example of this scenario. A relatively small amount of investors are granted permission to utilize the resource (by clear-cutting), who have little or no intention of sustainably harvesting the resource or restoring it once utilized. Likewise, from the government side, there is little enforcement to limit the harvest to permitted areas, and no clear mechanism to ensure post-harvest restoration Government facilitation of forest utilization for short-term economic gains in Indonesia, has led to most rapid and large-scale loss of forests in the history of the world. This holds true for both terrestrial forests and mangroves. Walker and Salt sum this up as "the result of humankind's insatiable desire to produce and consume, leading to willful short-term greed and corruption with no heed for the future."

There is a third driver; however, which is not based on greed and overexploitation. In fact, mangroves are disappearing even in areas where positive intentions, adequate resources and effort are all focused on their sustainable proliferation (refer to case study #4 on the ADB Citanduy river diversion project where literally millions of dollars where spent to prevent mangrove degradation based on faulty ecological principles). In these cases, it is our lack of understanding of a system which leads to the demise of mangroves, at great cost to both environment and society.

All three of the above scenarios are evident in the four case studies provided at the end of this paper, with a greater focus on scenarios two and three. This is in contrast to the case studies from "Resilience Thinking," in which the authors primarily look at the third driver. One reason for this, is that mangrove ecosystems in Indonesia and SE Asia in general are still by and large disappearing due to short-term profit-based greed (scenario #2) whereas in developed nations this is not as much of an issue. With regard to the third scenario; lack of understanding, we delve into some key factors which govern the health and existence of mangroves, even before looking at the case studies. This is done in an effort to provide managers with some direction in terms of thinking about key factors which drive mangrove systems, which are essential to recognize when managing for resilience. Lack of understanding of key environmental requirements of mangroves not only sabotages conservation, but mangrove restoration as well, and is responsible for a large amount of wasted resources in terms of time and money. So although we will focus on scenario's two and three, it remains the intent of this paper to provide managers with a general picture of resilience in mangrove systems.

THE PITFALL OF OPTIMIZATION

Often-times when visiting a mangrove area and speaking with local community members, I am asked the question, “What species of mangrove is the best mangrove?” The question from, their perspective, is mere rhetoric. Coastal villagers across the region, have a preference for *Rhizophora* spp. mangroves. This preference is also entrenched in the minds of nearly everyone who has ever seen a mangrove, from government foresters to surfers of the internet. The image of prop roots hanging down from limbs tens of meters overhead, and spreading out in the muddy substrate provides one reason. The fact that *Rhizophora* wood makes excellent charcoal, and high quality timber another. For fisherfolk, the roots of *Rhizophora* are commonly believed to provide the best type of shelter for intertidal fish/crabs/shellfish and juvenile shrimp. But what about the other forty-odd species of mangroves in the region? Don’t they have their uses too? Is it only the odd mangrover or forestry professor who values a scraggly *Pemphis acidula* as much as a *Rhizophora*?

When replanting mangroves, we inevitably see communities and forestry officials alike adhere to the standard practices of either jabbing *Rhizophora* propagules into the ground, or planting seedlings reared in polybags. These seedlings are more often than not, planted without regard to ecological preferences such as; tidal inundation, substrate type, etc. The ecology of individual mangrove species is known as *autecology.* From understanding the autecology of a whole collection of species from a specific mangrove area, we can learn what is known as the *community ecology* of that area. Unfortunately, across the SE Asian region, autecology and community ecology requirements are seldom taken into consideration in during conservation or restoration efforts.

It is common, when looking at mangrove community ecology, to see clear zones of different mangrove species growing in different areas. This is commonly known as zonation. A classic zonation pattern is shown in Figure 1 below. This figure clearly shows various species of mangroves growing with various tidal preferences. Yet, across the board, the majority of attention in both mangrove management as well as restoration is focused on the mid inter-tidal zone, along with estuarine river banks which are by and large the province of one of three *Rhizophora* species commonly encountered in Indonesia (*R. mucronata, R. apiculata,* and *R. stylosa),*

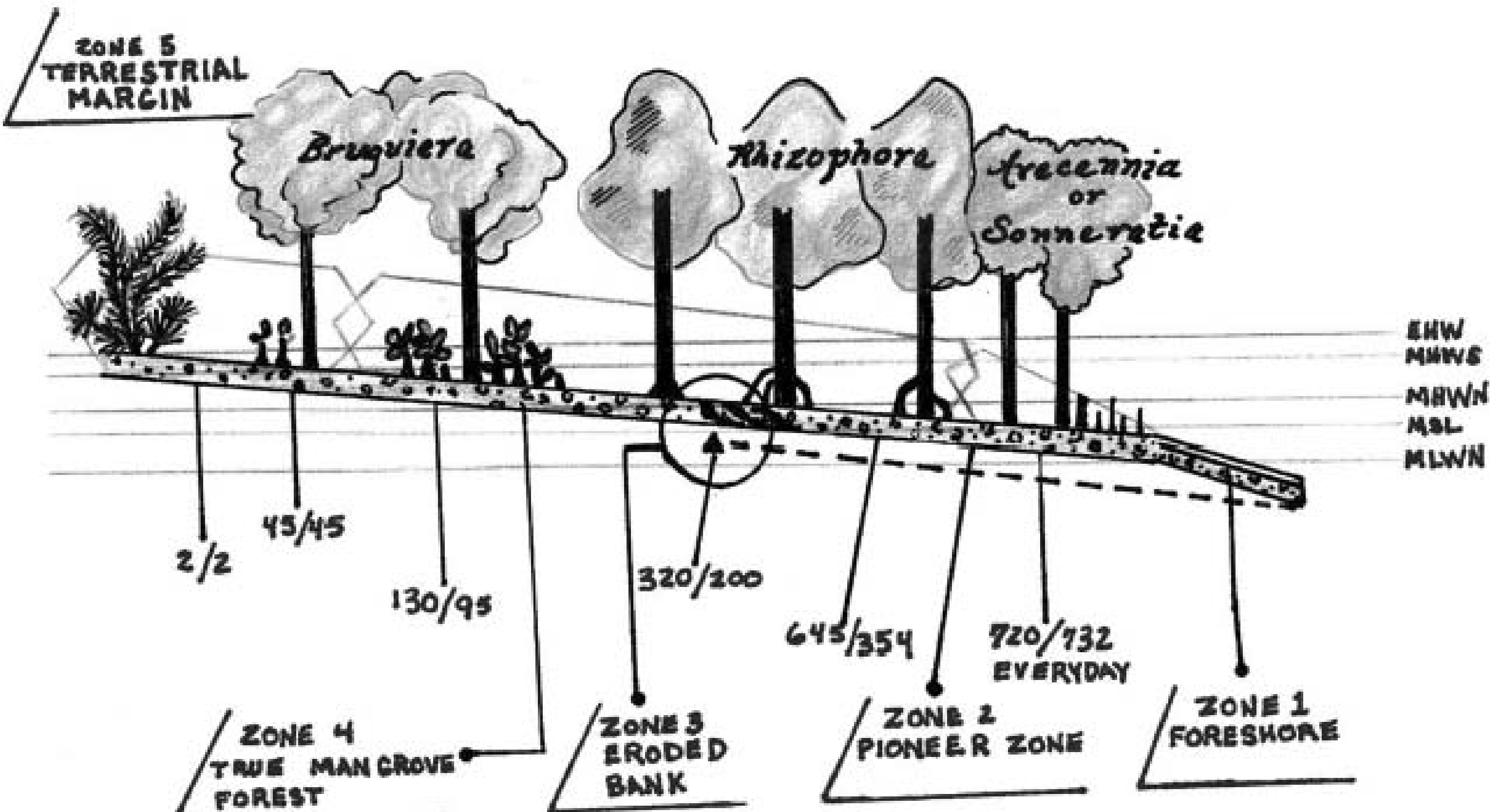


Figure 1. Mangrove zonation related to tidal datums in Sumatra, Indonesia (modified from Whitten et al., 1987)

A look at mangrove legislation in Indonesia reveals a similar bias (see Box 1). National Legislation for mangrove conservation outside of protected areas is based almost entirely on the theoretical conservation of a protective coastal greenbelt.

Box 1: NATIONAL INDONESIAN LAWS FOR MANGROVE PROTECTION (Bengen, 2000)

In 1984, the Ministries of Agriculture and Forestry drafted KB.555/264/Kpts/4/1984 and 082/Kpts-II/1984 which are the first national policies to make mention of a requisite 200 meter mangrove belt along coasts where mangroves naturally occur. This legislation was precedent setting in two ways; it provided a measure of protection for mangroves nation-wide, and also called for inter-agency collaboration in natural resource management.

In 1990, the Department of Forestry released forestry law 507/IV-BPHH/1990, that added a 50-meter mangrove greenbelt along major rivers in mangrove areas, while reinforcing the 200 meter coastal greenbelt.

Greenbelts reared their heads again in Presidential Decree 32, 1990, on Protected Area Management. The law declared that all coastal areas were to be protected from activities which disturb major coastal ecological functions. No specific formula was suggested for determining buffer width, although managers were urged to create protected coastal areas proportional to vastness of the coastal area, with a minimum distance set at 100 meters.

In order to further clarify the extent of mangrove greenbelts, an ecological study determined a formula for calculating coastal greenbelt width. The formula suggests multiplying the average height differential between spring neap and spring ebb tides by 130 times. For example, if the highest high tide in a calender year is 1.7 meters, and the lowest low tide is -0.8 meters, the difference is 2.5 meters. This is multiplied by 130 to result in a 325 meter greenbelt:

$$\text{ex. } 1.7 - (-0.8) = 2.5 \times 130 = 325 \text{ meters}$$

Most SE Asian nations have placed similar emphasis on the protection or establishment coastal greenbelts after the December 2004 Indian Ocean tsunami. Managing for an such a margin of coastal protection is a clear case of optimization. Law-makers, scientists and managers are looking for a magic number, the minimum breadth of mangrove forest coverage necessary to maintain specific ecosystem services, such as storm protection, while allowing the area behind the greenbelt to be converted to other uses (most commonly shrimp aquaculture, charcoal production, and recently oil palm plantation for bio-fuel, but also other forms of development including agricultural, residential and port development etc). Coastal greenbelts provide a clear-cut case of wanting to have one's cake and eat it too. Suggested figures for coastal greenbelt breadth of 200 meters, completely ignore the potential importance of the terrestrial edge of a mangrove forest. Application of the formula suggested in Box 1, (130 x mean tidal range), denies the ecological significance of the back mangrove. Can we really do away with the back mangrove without any effect on the seaward zones of mangroves? Without impact to fisheries production? Protective services? Water treatment? What happens to the resilience of the mangrove forest when we remove that back layer of mangrove? What happens to the terrestrial zone behind the mangrove? As we will see in case study number three from Bengkalis, Riau, destruction of the back mangrove poses a range of potential negative impacts, both environmental and economic. These impacts are not limited to the mangrove area but also to terrestrial systems such as agro-ecosystems, and coconut plantations as is the case in case study #3.

To begin an assessment of mangrove resilience, it will be necessary to determine the bounds of your system of focus. Here is where managers will have the chance to go beyond the limits of coastal greenbelt conservation, and determine the true bounds of the mangrove system. Even the most rudimentary of definitions of a mangrove, point to the inadequacy of managing for green-belt protection alone. "A mangrove is a forest existing within the inter-tidal zone and adjacent communities." (Tomlinson, 1986) A mangrove forest is an ecosystem invariably defined by its water relationships (flux between amounts of salt and fresh water). Mangroves, thus, require a balance of inputs from both land and sea. Management for the protection of a coastal greenbelt alone, exhibits a bias in favor of seaward mangroves, and denies the importance of water balance to the functioning of a mangrove ecosystem. In some cases, a coastal greenbelt will exhibit resilience, but in most cases, a resilient mangrove forest will include the entire range of mangroves from terrestrial edge to seaward edge, and will require unimpeded supplies of water both from land and sea.

Over the course of this paper, we will look at the key environmental factors, including (water balance), which determine the extent of mangrove distribution and ecological functions. We will next consider whether or not these factors can be thought of in terms of resilience. Are these key environmental factors in danger of being altered themselves and pushing a mangrove forest over a threshold into another type of system (regime)? Are these key environmental factors susceptible to human-caused change? We will also look at common stresses to mangrove ecosystems to help us further define these key variables. But first, back to the question of optimization.

Nature does not work based on optimization principles. So why are we managing mangrove ecosystems for optimization? Why are our laws for mangrove protection at the highest levels of political organization solely based on optimization? The Matang forest in Malaysia is the self-proclaimed "best managed mangrove ecosystem in the world." If we look at the system in terms of resilience, we might be able to challenge that statement? Have there been sacrifices made in order to achieve a maximum sustained yield of timber for charcoal? How resilient a socio-ecological system are the mangroves of Matang? One walk through a restored are of the Matang forest, and anyone familiar with mangroves notices a significant lack of benthic macroinvertebrates. Have decades of spraying with herbicides (to control *Acrostichum* colonization after clear-cutting and promote re-growth of *Rhizophora* trees) altered the bio-chemistry of the substrate? Has the preference of Matang's managers for *Rhizophora apiculata* resulted in an overall reduction in resilience to the mangrove forest? Although the Matang forest has been managed for charcoal production for nearly a century, we will see that it still may be susceptible to a sudden shock. The system is currently in the foreloop of the *adaptive cycle* (discussed in Part III of this paper), but the onset of a backloop in nature is both sudden and potentially devastating. This paper is not intended to criticize specific management cases, but rather to begin to apply the framework of resilience to mangrove management. This is in order for us to begin to ask the right set of questions which can lead to truly sustainable mangrove management with a focus on maintaining the resilience of mangrove systems.

> An optimization approach aims to get a system into some particular "optimal state," and then hold it there. That state, it is believed, will deliver maximum sustained benefit [be it timber or production of wild prawns, protection from storms or water-water treatment]. To achieve this outcome, management builds models that generally assume (among other unrecognized assumptions) that changes will be incremental and linear. These models mostly ignore the implications of what might be happening at other scales. Optimization does not work as a best-practice model, because this is not how the world works. The systems we live in and depend on [including mangrove systems] are configured by extreme events, not average conditions."
> (Walker and Salt, 2006)

Tectonic uplift of mangroves after a major earthquake, cutting off of tidal flows to a mangrove area after the construction of a break-wall, and lowering pH in the substrate due to increased amounts of acid sulfates in soil after to clear-cutting all challenge the resilience of a mangrove ecosystem.

> The linkages between scales and sectors/actors (agriculture, industry, conservation, energy, forestry, etc.) often drive changes in the particular system that is being managed....Optimization does not match the way our societies value things either. It promotes the simplification of values to a few quantifiable and marketable ones, [such as charcoal production] and demotes the importance of unquantifiable and unmarketed values," (ibid)

In the case of mangroves, these "unquantifiable and unmarketed values" are known as ecosystem services and are listed in the first column of Table 1, along with products that can be sustainably derived from mangroves. Note that forestry and fisheries products can be sustainably derived from a mangrove system, but require effective management. We will come to see, that effective, sustainable management can not ignore the principles of resilience which we are exploring in this paper. The second column in Table 1 lists types of mangrove utilization which require conversion/destruction of the system as "elimination uses."

Table 1 - Mangrove Goods and Services

Potentially Sustainable Uses	Elimination Uses
Fisheries products	Agriculture (rice fields)
Food	Aquaculture (shrimp ponds)
Medicine	Salt ponds
Honey	Plantations (palm, sugar)
Alcohol (fuel)	Mining
Riverbank protection	Industrial development
Flood runoff engineering	Urban development
Shoreline protection	Ports
Prevent salt water intrusion	Airports
Recreation (eco-tourism)	Waste assimilation
Education	Road Development
Construction timber	Pasture and grazing lands
Wood chips	
Paper	
Charcoal	
Firewood	
Tannins	

Source: The Ecology of the Indonesian Seas Volume VIII

Whether we realize it or not, we depend on ecosystem services for our survival and way of life. We also value what can be called "leaving a legacy." We want our grandchildren to see a healthy coral reef, to know what a live tiger looks like stalking a prey, to paddle a kayak along a tidal creek while gazing at a colony of fruit bats.

> Optimization, however, distorts this. It reduces time horizons to a couple of decades – the limit of the time horizon for most commercial investments [only an average of 2 years for shrimp aquaculture in Indonesia - source]. Values that do not have property rights or are publicly owned are not marketed, do not generate wealth, and gain little support, even if they involve critical ecosystem services. (Walker and Salt, 1986)

This above statement encapsulates the precise case with mangroves. People do not understand just how crucial mangroves are to the health of the coastal region and the quality of life of coastal communities. Only recently are researchers beginning to quantify the economic value of these environmental goods and services (Table 2). It is still the dominant paradigm that policy makers, especially in developing nations, will often place the short-term economic good of the few, over the good of the many.

Table 2 - Economic Value of Mangrove Goods and Services

Fisheries Products	3400
Non-Timber Forest Products	870
Recreation (Eco-tourism)	500
Storm Protection	1700
Wastewater Treatment & Other Environmental Services	6840
TOTAL	13,310

Costanza et. Al. (1997), Ronnback (1999)

Managing for optimization, in fact, works against sustainability and resilience in the long run. When you strive to maximize the production or presence of one or a few elements of a complex system, you become more vulnerable to shocks and disturbances. In the case of a mangrove forest entirely consisting of a single *Rhizophora* species, a single shock such as change in tidal inundation or a pest outbreak could very well destroy the entire system. From the profile diagram in Figure 1 we see that *Rhizophora apiculata* in this Sumatran system prefers between 200-320 inundation events per year. What happens when all other species are depleted, to concentrate on growth of *Rhizophora* for "sustainable" charcoal production against the background of sea level rise? *Rhizophora* mangroves will soon be inundated much more frequently than their ecological preference. In the extreme case they will be submerged twice a day, everyday of the year (730 inundation events). This increased level of inundation is more suitable to various *Sonneratia* or *Avicennia* species, but these species may have been reduced or even taken out of the system by managers. The resilience of the forest as a whole has been decreased. A disturbance (in the form of increased inundation events) has stressed the system with a resultant decrease of all environmental goods and services provide by a normal, functioning mangrove forest.

That damaged mangroves provide fewer goods and services than functioning mangrove ecosystems is nothing new. Nor is the fact that mangroves are undervalued ecosystems suffering from both poor management and a low level of protection. Above we have set the stage to better understand the relationship between resilience and the socio-ecological systems that are mangroves. Recognizing that current management practices based on optimization are bound for failure, is the first step in moving toward a healthier view of mangrove management based on resilience.

Ecological Mangrove Restoration, Tiwoho Village, North Sulawesi

Part 2:
Key Variables Determining Mangrove Health

Now it is time to take a closer look specifically at the ecology of mangrove ecosystems, and begin to highlight the environmental factors that describe a mangrove ecosystem. Some of these factors may be considered as key environmental factors useful in determining levels of resilience of various mangrove forests. Although there are many factors essential to mangrove systems, there are a few key variables, to any social-ecological system that drive that system. These key variables are often-times slow moving, but changes in these key factors can push a system closer to, and eventually over a threshold. Once a threshold has been crossed, it is very difficult to facilitate a return to the previous system. Although it may only take an incremental change in variables to push the system across a threshold, an equivalent push in the opposite direction is usually not enough to drive the system back over the threshold into its original state.

A system's resilience is a measurement of how far the system is away from a potential threshold. The key to maintaining a system in its proper state, is to understand where the thresholds are in your system and to manage the key variables you have identified so as to keep your system as far away from a threshold as possible. If this is unclear now, hopefully it will become more clear by the end of this paper. We also suggest reading "Resilience Thinking," and posibly downloading the assessment workbooks offered in the resources section of www.resalliance.org, in order to perform a resilience assessment in your own management area.

ENVIRONMENTAL REQUIREMENTS (Potential Key Slow Variables)
The following section is adapted from Ecology of Indonesian Seas (Tomascik et al, 1997).

Chapman (1977) identified seven key environmental factors, that to a large extent, determine the distribution of mangroves, namely: 1) temperature, 2) protected coastlines, 3) currents, 4) substrate type, 5) shallow shores, 6) salt water and 7) tidal range. Here we will add an eighth category, tidal creeks, as not only an important requirement to keep mangrove forests functioning, but as a key formative factor. These eight environmental requirements will be briefly discussed in terms of resilience, specifically with regard to Indonesia, in order to highlight areas which need to be researched further, with thought given to determining key factors which may be responsible for pushing a mangrove ecosystem toward a threshold.

1) Temperature

Air and water temperature most likely play a minimal role in mangrove distribution in Indonesia which is fully situated within the tropics. With regards to resilience we expect a North/South migration of mangroves to higher latitudes due to global warming. This is discussed in greater detail in the IUCN Paper "Managing Mangroves for Resilience to Climate Change." Mangroves are accustomed to temperature shocks. Anyone who has waded through tide pools in Indonesia knows of the potential thermal variation as shallow water stagnates and heats up during low tide, cooling as deep ocean waters replenish the mangrove during high tide. Cold upwelling waters, especially in Eastern Indonesia provide much variation to water temperatures in coastal mangroves. Humans have a great capacity to cause drastic environmental change, including thermal pollution, and while we might be tempted to overlook temperature as a key variable, there exists the potential to thermally push a mangrove across a threshold.

2) Protected Coastlines

Although mangroves typically are found along low energy coastlines, there can be great seasonal variation in wave and current energy at various sites in Indonesia. Much of the Indonesian Archipelago is influenced by a strong monsoonal climate with seasonal shifts in wind and wave direction. Most coastlines in the archipelago are therefore sheltered, at least during part of the year, which may provide sufficient time for mangrove seedlings to become established. Even coastlines, seemingly protected from high open ocean wave energy, have seasons of high waves, such as the East coast of the Riau Archipelago in Sumatera or the North Coast of Sulawesi. Wave energy is usually high during the "angin barat" (west wind) season, related to monsoons. This allows for increased dispersal of some mangrove seedlings, but presents difficulty in establishment. One case of humans overcoming nature and establishing mangroves in a high energy system has taken place in Sinjai, South Sulawesi. Here, fishing communities have planted 400 hectares of Rhizophora apiculata for production of poles in an area where few if any mangroves previously grew. Planting during the onset of the calm season perhaps provided these mangrove seedlings with the head start needed to get past a critical phase of protection. Mature mangroves are now firmly established in the entire area.

In terms of resilience, humans certainly play a role in exposing coastlines. Increasing wave energy is predicted to occur due to increasingly erratic weather and storm activity as a result of global warming. Destruction of coastal mangroves also may transform a previously protected coastline into a shoreline no longer suitable for mangrove growth. This can occur due to loss of fine sediment, deepening of substrate, greater exposure to waves and currents, accumulation of sand etc. Although a presidential decree on conservation of coastal green-belts is in place, it has proven inadequate in terms of maintaining needed resilience of coastal mangrove ecosystems.

Mangroves along this high energy shore on the West coast of Bengkalis Island, Riau, succomb annually to seasonal currents (left). Nonetheless, propagules are able to establish themselves during the calm season.

Three species of mangrove propagules (*Avicennia marina, Brugueira parviflora and Xylocarpus granatum*) have taken root on the remains of one of their ancerstors, toppled by ocean currents over the past decade (right). A solid substrate seems to provide the ideal nursery for mangrove establishment.

3) Currents

Oceanic currents have been noted as essential for mangrove dispersal, and thus a major factor in mangrove biogeography. Strong long-shore currents are not necessarily detrimental to mangrove growth, and in some cases we see excellent seedling establishment even in areas of high current. In terms of resilience global warming is again predicted to play a role in changing oceanic currents. A change in oceanic currents also ties into potential thermal changes, both of which could impact mangrove resilience.

4) Substrate Type

The majority of mangroves are associated with mud and muddy, fluvial deposits. Mangroves do, however, exist on hard substrates; including pure calcareous substrates, on sand underneath coral rubble, and on harder sandy/muds. A significant increase in sediments, from landward run-off can push a mangrove forest over a threshold, as is evidenced in the Segara Anakan Lagoon of Central Java (*case study* #4). In 1984, the surface area of the lagoon measured 2906 hectares, and has been reduced to 1575 hectares by 1994 with perhaps under 600 hectares of surface area remaining today, due to erosion on mainland Java caused by deforestation and poor agricultural practices. Substrate type, volume, and resultantly substrate height at any given site is determined by a variety of geomorphologic factors. These factors, and thus the substrate itself, are under constant flux. Nonetheless, excessive sedimentation from landward erosion, or lack of sediment recruitment due to development of break walls/shoreline armoring provide two clear cases where thought needs to be given to management of substrate as a key variable influencing resilience.

5) Shallow Shelf

Chapman points out that extensive mangrove forests are invariably associated with shallow and gently sloping shelves that extend long distances offshore. These conditions occur off the larger islands in Indonesia (with larger river systems) such as Kalimantan, Sumatera, Sulawesi and Papua. With regard to management for resilience, shelf slope is the result of geomorphologic processes, and little influenced by human activity. Perhaps the most likely scenario that takes into account shallow shelves and could result in reduced resilience of the mangrove is sea level rise. Given predicted levels and rates of sea level rise, mangrove forests will invariably migrate inland through their offspring, or die-off. The presence of a shallow sloping shelf for retreat will increase the success of inland migration. Thus, areas where a shallow shelf exists provide greater resilience to mangrove forests. In unpopulated areas like Papua, mangroves may be unhindered in their migration inland over the generations. In areas with higher human populations, such as southern Sumatera and southern Sulawesi, there will be numerous cases of competing land uses acting as a social barrier to inland mangrove migration. This scenario provides us with the reminder that a system's resilience is dependent upon both social and ecological factors.

6) Salt Water

Mangroves are halophytes (both facultative and obligate) meaning they are tolerant to salt and in some cases seem to require it (*Rhizophora*). Mangroves have a competitive advantage over other plant species due to this salt tolerance. Along major rivers, we see a change in mangrove community structure as we proceed upstream, from *Rhizophora apiculata, R. stylosa* and *Avicennia* spp. dominated systems continuing upstream to paired associations of *R. mucronata —Bruguiera* spp.; *Sonneratia caseolaris —Nypa fruticans*; and finally *Heritiera littoralis —Oncosperma tigillarium* forests in salinities of 0-10 parts per thousand (ppt.). Again, predicted sea level rise will result in an increase in seawater penetration both inland and upstream. Resilience comes into the picture as we look at how people will deal with increased events of salinization. Case study #3 from Bengkalis Island looks in greater detail at this issue.

7) Tides and Tidal range

Tides are not a direct physiological requirement of mangroves (take lagoon mangroves as an example) but they are essential for most mangroves. Tides also play an important role in the ecological functioning of the system, since tidal currents are the primary means by which nutrients and organic matter are transported into, through, and out of the mangrove system. In some cases, human blockages of normal tidal functioning will certainly shift a mangrove ecosystem over its threshold.

Hydrological variables such as tidal depth, tidal duration, frequency of tidal inundation, and frequency of tidal flooding will prove to be the most essential variable determining the extent of natural mangrove plant communities and their resilience. Many a mangrove restoration site has been witnessed, where failure to imitate natural hydrological conditions of a nearby functioning mangrove forest has resulted in failure of the restoration effort. Excessive flooding, poor drainage, lack of water and other stresses result from un-natural changes in tidal inundation. These factors are investigated in greater depth in MAP's manual "Five Step to Successful Ecological Mangrove Restoration." (available for dowload at www.mangroveactionproject.org)

According to Chapman, the greater the tidal range, the greater the vertical range available for mangrove communities. However, local topography (land elevation and shelf slope) play an important role as well. Most extensive mangrove development occurs on shallow, gently sloping shorelines and flat alluvial planes. Wide tidal range is; however, not necessary, since mangroves occur even under micro tidal conditions (19 cm, Kakaban Lagoon). (Tomascik and Mah, 1994) In both South Sumatera and Bintuni Bay, Papua, mangroves penetrate inland up to 30 km, yet the maximum tidal amplitude (1/2 the tidal range) in South Sumatera is 1.75 m while it is 5.6 m in Bintuni (tidal range of 11.2 m). These luxuriant mangrove ecosystems have in common a vast alluvial plane just above the mean high tide mark (a promising region for future retreat during sea level rise). Human influence of the actual tidal range is not a likely issue. However, determining the extent of the intertidal zone, adjusted for global warming, based on tidal ranges is an activity that should be carried out by mangrove managers for each region. Projecting "inland" mangrove migration as a result of sea level rise, will prove integral to managing for mangrove resilience into the future.

8) Tidal Creeks

Although not listed by Chapman, R.R. Lewis, MAP's Senior Science Advisor has this to say about the importance of tidal creeks.

> I have never seen, or read about a healthy mangrove system that did not have a tidal creek network. I consider them an essential natural feature, in particular for ingress and egress of mobile fauna, particularly fish and larger invertebrates (crabs, shrimp). Changes in flow patterns [human caused or natural] can change the scouring mechanisms that keep tidal creeks open, and thus allow closure due to silting and eventual overgrowth by mangroves. This further reduces the tidal prism and thus tidal exchange, and eventually leads to the large die-off of mangroves from either hypersalinity, or excessive flooding by heavy rains that cannot drain from the system.
>
> Blockage of tidal creeks or inadequate design of culverts or closure of culverts due to fouling are one of the most common causes of mangrove die-offs worldwide.
>
> Which comes first [the mangrove or the creek]? Look at a tidal delta mudflat. First the creeks, then further deposition, then mangroves colonize, but only on higher ground, which limits tidal cover and flows and channelizes the creeks further."

Tidal Creeks provide refuge for mangrove fauna during low tide, and facilitate the exchange of sea and fresh water. Tidal creeks can be considered the veins and arteries of a mangrove ecosystem, without which, a mangrove will be subject to dessication.

DISTURBANCE & STRESSES TO MANGROVES

Disturbance*:* Actions, functions, or events that influence or maintain the structure, composition, or function of the components of ecosystems.

Natural disturbances in mangrove systems can be such things as seismic uplift, fire, disease, or hurricanes. Human caused disturbances include conversion (to aquaculture, agriculture, settlements etc), excessive logging for charcoal production or timber, changes in hydrology etc. Disturbances in economic systems related to mangroves include subsidies for aquaculture development, bans on charcoal production from mangroves in neighboring nation increasing demand, discovery of oil on site etc. Disturbances can be characterized in many ways—by their frequency, duration, severity, or predictability, to name just a few.

Stress:

(1) The conditions resulting from any environmental change that disturbs the normal functioning of a system to such an extent that its chances for continued existence are reduced.

(2) The result or consequent state of a physical, chemical, or social stimulus on a system;

Above we looked at key environmental requisites to mangroves, in order to help us identify which factors may be vulnerable to losing resilience. We called these slow moving variables. Following is a look at factors that are known to stress mangroves and or stress mangrove re-establishment after a disturbance (Talbot, 2001). These may be considered as slow moving variables as well, and in some cases overlap with the above listed environmental requisites.

WHAT ARE SOME KEY STRESSES TO MANGROVES?

1) Water Balance

Changes in water flows, both originating from terrestrial systems as well as tidal waters may result in death of trees, sickness, stunted growth, and failure to reproduce. Mangroves that are cut-off from the sea by roads, dykes, or dam construction will soon die. Mangroves cut off from terrestrial water sources by roads, earth bunds, dams, or channels associated with fish ponds, which change water courses, will dry out will kill or damage mangroves as well; as salt concentrations increase, killing species with low tolerance to salinity.

Likewise, mangroves experiencing excessive freshwater flows for an unusually long period of time can be negatively affected. Degradation of the upper watershed results in decreased rainwater absorption (decreasing the replenishment of aquifers) and increased run-off. This in turn leads to increased variance of freshwater flow from the terrestrial system into the mangrove. Flows will be higher in the rainy season due to exacerbated run-off, and lower in the dry season as aquifers are unable to deliver water during the end of the dry season. Both situations are deleterious to mangrove growth, as prolonged high flows can waterlog the mangroves, while prolonged freshwater drought leads to desiccation, stress and death.

Extreme run-off events, from deforested lands also exacerbates erosion. Soils, eroded from the uplands, may clog tidal creeks essential for proper mangrove functioning. The total amount of water flowing through a cross section of a river or creek both from terrestrial fresh water sources, as well as tidal waters, is known as the *tidal prism*. Maintenance of the tidal prism, is critical to keep tidal creeks vibrant and in turn, mangroves in-tact. Excessive siltation of tidal creeks, leads to a decrease in the tidal prism and may lead to permanent closure of the tidal creeks. As this occurs, mangroves from the creek-side invade the creek, exacerbating the problem of closure.

In summary, a healthy riparian greenbelt and overall forested upper watershed is essential to mangrove growth and development, providing balanced fresh water and sediment inputs.

2) Excessive Silting

Silting and sediment flow increases where there is deforestation, poor agricultural practice, road building, aquaculture development or urban development. Siltation primarily occurs during heavy rain events and monsoons, particularly when forest clearing increases the amount and speed of water flowing off the hillsides. Too much sediment can cover the aerial roots of mangrove species, or alter the water balance in a mangrove forest. Sediment may also cause a decrease in the tidal prism in rivers running through the mangrove, resulting in the closing of tidal creeks and the degradation of the forest.

Reinforced by looking at points 1 (water balance) and 2 (sediment), is the need to link mangrove management with the management of the upper watershed, at various social and political levels.

Dredging of excessive sediment was a case of too little, too late in the Segara Anakan Lagoon (see case study #4). This ADB project failed to address the root causes of the issue of upland erosion. This case goes to show that once a threshold has been crossed, it is difficult, if not impossible to cross back.

3) Acid Sulphate Soil

Mangrove soils often become extremely acidic when waterlogged sediments which are high in sulphides (from bacterial decay of past leaf litter, silt with organic material from leaves, wood, plankton and seaweeds) are exposed to the air or water with a high oxygen content. This is the frequent result of conversion of mangroves to shrimp aquaculture and resultant abandonment or clear cutting without adequate reforestation. The resulting acid-sulphate soils can stress or kill not only mangroves but animals in nearby waterways. Low pH in the substrate may also cause the leaching of heavy metals from the soil into the waterway.

4) Pollution

Oil spills and industrial pollutants as well as chemical fertilizers, pesticides and piscidies used in industrial shrimp farming can be damaging to mangroves.

As an example we can look at the Niger Delta, home to the third largest contiguous mangrove forest in the world. Once rich in biodiversity and teeming with marine life, the area is now being rapidly degraded by petroleum production. In Nigeria, oil is found in relatively small fragmented pockets at the Niger Delta. The wells from several fields supply a single flow station through a network of pipelines. Major pipelines then transport the oil to refineries or to shipping terminals and are complemented by tank farms and pumping stations along the way. This infrastructure in itself occupies and traverses the land. The leaked oil permeates the coastal waters and streams, coating the exposed, air breathing roots of the mangroves, making it difficult, if not impossible, for the plants' breathing lenticels to perform their essential functions, thus in effect slowly suffocating the mangroves. Vast tracts of mangrove forests are adversely affected by oil pollution and related developments. (Article based on information from: "Court Declares Gas Flaring Illegal In Nigeria!", November 14, 2005, ERA Nigeria, http://www.eraction.org)

Spills from an oil refinery located adjacent to the Segara Anakan Lagoon (case study #4) affect mangrove fauna.

5) Natural Impacts

Natural stresses like drought, freshwater flooding, erosion/shoreline abrasion, lightning strikes, fire, and insect damage can damage or kill mangroves. Case Study #3 from, Bengkalis Island, goes on to dispel the myth that mangroves prevent shoreline erosion; as strong currents, wave action and perhaps sea level rise are continuously toppling coastal mangroves and encroaching on inland villages and farms. The tsunami of December, 2004, caused vast mangrove damage in many areas, also depicting that while mangroves may protect coastlines form normal wave action and storms, mangroves too can be damaged by extreme waves and currents.

Tectonic subsidence and uplift, as discussed in case study #2 from Simeulue Island, Aceh, have elevated mangroves entirely out of the inter-tidal zone. In this picture, mangroves experiencing uplift are both drying out and being outcompeted by terrestrial vegetation (right)

It will be important, in determining how to manage mangroves for resilience, to understand both; a) key environmental factors and b) stresses to mangroves as presented previously. The factors from both of theses lists will need to be analyzed, and augmented in order for mangers to begin to develop a list of potential key factors which may push a mangrove forest over a threshold into a less desirable regime or state.

Homework For the Mangrove Manager

- Document the critical disturbances and stresses affecting your mangrove system.
  What are the frequency and impact of disturbances? What are the impacts of stresses?
- Report which of these disturbances have been changing in magnitude or frequency.
- Identify potential novel disturbances and stresses that could affect your focal system in the future.
- Develop a list of disturbances and stresses that are potentially threatening.

Filling out the following table, may be of use to a manager as well;

Disturbance	Pulse or Press?	Frequencies of occurrence (if pulse)?	Does the system have time to recover between occurrences (if pulse)?
Change over the past few years or decades? (none, little, less frequent, more intense, etc.)	Magnitude of impact (minor to severe)	Variable or component of the system most affected? (e.g., substrate, hydrology, charcoal markets etc.)	

STATES & CUES IN MANGROVE SYSTEMS

Several definitions will be useful for this section:

Stable State: A system with stability. Stability being the ability of a system to return to an equilibrium state after a temporary disturbance. The more rapidly it returns, and with the least fluctuation, the more stable it is.

Alternate State: Identified by a shift in dominant organisms or system structure and a change in the processes that reinforce a particular state.

Feedback: A signal within a system that loops back to control the system. In natural systems feedback can help to maintain stability in a system (negative feedback) or it can speed up processes and change within the system (positive feedback).

Cue: A signal within a system that indicates the relative health of the system. Monitoring for cues can help us determine when a system is approaching a threshold.

STABLE STATES IN MANGROVES

What does a normal mangrove forest look like? There are many possible answers, as a variety of conditions (climatic, hydrologic, biological, geophysical and geomorphologic) determine mangrove type. Understanding a stable-state mangrove forest is essential in order to be able to make judgments on resilience, to be able to identify stresses and disturbances when they occur, and to steer the system away from possible thresholds.

The three most common classification schemes used to describe mangroves are based on structural attributes of mangroves (Specht 1970), physiographic characteristics (Lugo and Sneadeker 1974) and coastal geomorphology (Thom, 1982, Hutchings and Saenger, 1987). These papers describe six coastal environments (alluvial plains, tidal plains, barriers and lagoons, alluvial plains with barriers, drowned bedrock valleys and coral coasts) in which mangroves are commonly found. They provide us with insight as to what a mangrove community might look like physically, in a stable state. Descriptions of these geomorphologic classifications were taken from "Ecology of Indonesian Seas" Volume II, pages 939-942. Later on in this paper we will take a look at specific tidal inundation classes described for the Segara Anakan Lagoon, of Central Java, as part of the Case Study #2 on Segara Anakan, described by DeHaan in 1931.

The complexity and structure of mangrove forests in Indonesia, varies from place to place, depending on coastal physiography and tidal dynamics. Along the straight coastal areas, mangrove forests can be relatively narrow (e.g., 25-50 meters) while in river deltas and along coastal flood plains where rivers and sea currents bring large volumes of allochthinous (external) material, such as mud and sand, mangroves can grow rapidly and spread out widely along the coastline. In general, zonation patterns for mangrove forests are determined by: local topography; tidal amplitude, duration and frequency; substrate stability; sediment composition; water and soil salinity; and exposure to waves and currents (Tomascik, 1997). Mangrove zonation can also be influenced by anthropogenic (human-caused) change.

Based on all of these factors, we can classify the mangroves of modern-day Indonesia into *five groups*. (ibid)

Five (5) Mangrove Community Types in Indonesia

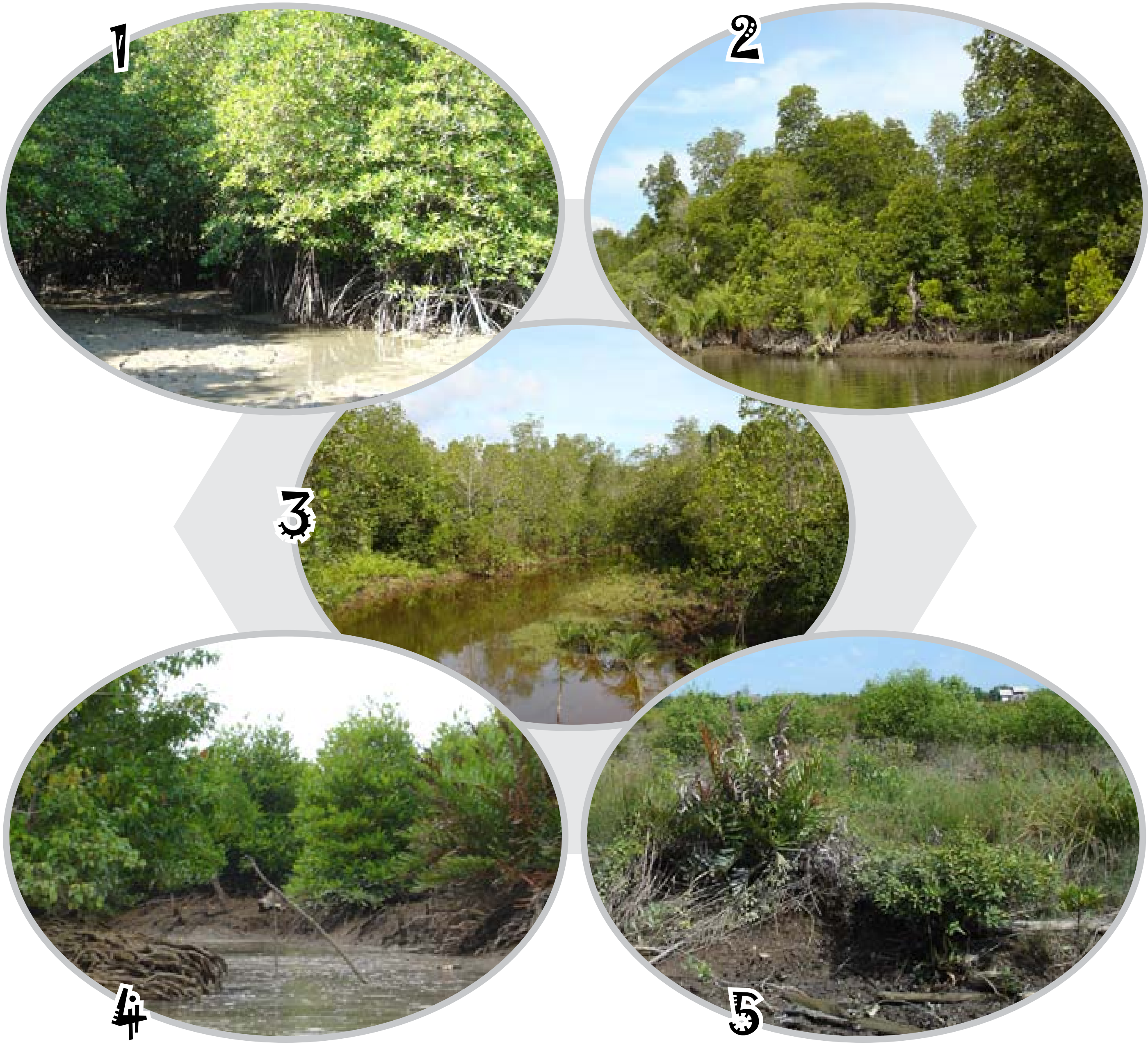
1) Rhizophoraceae Communities: In these communities, *Rhizophora* spp., and *Bruguiera* spp. are the dominant mangrove units, with *Xylocarpus* spp. and *Ceriops* spp. being subdominant on higher ground.

2) Complex Mangrove Communities: These are mixed communities consisting predominantly of *Avicennia* spp., *Rhizophora* spp., *Bruguiera* spp., *Ceriops* spp. and *Xylocarpus* spp. Occasionally, *Nypa fruticans* and undergrowth of *Scyphiphora* spp., *Brownlowia* spp. and *Acrostichum* spp. are intermingled within the mangrove forests to varying degrees, depending on fresh water input and degree of water-logging. Mixed mangrove communities often extend long distances inland (e.g., 30 km in South Sumatra) and are often characteristic of coastal areas influenced by large river systems. In general, undergrowth is very limited in undisturbed mangrove forests, however, thick undergrowth consisting of *Scyphiphora* spp., *Brownlowia* spp. and *Acrostichum* spp. is very common in mangrove areas degraded by various human activities (e.g. logging, conversion, etc.)

3) Transitional Communities I: These communities form the transition from seawater-dominated systems to freshwater communities, and consist primarily of *Sonneratia—Oncosperma* and *Nypa—Acanthus* associations. Further inland (i.e., higher ground), or upriver, transitional communities may consist of paired associations of E*xcoecaria, Acrostichum* and *Brownlowia*. These associations are often found bordering some of the larger rivers and are under strong freshwater influence.

4) Transitional Communities II: These communities form the transition to upland vegetation. *Exoecaria* forests are found generally on ripe soils, and are associated with *Lumnitzera—Scyphiphora* and *Nypa—Heritiera*, often with dense *Brownlowia—Acrostichum* undergrowth. In Indonesia, these associations are frequently found on the outer, landward fringes of both basin and coastal mangrove types.

5) Cleared Mangrove Areas: Vast clear-cut areas may be eventually recolonized by a secondary growth of sparse *Avicennia* scrub or *Exoecaria* regrowth. Mangrove species frequently invading clear-cut areas are invasions consisting of *Acrostichum* spp., *Pluchea* spp., and some *Lumnitzera* spp. Extensive growths of *Acrostichum* ferns are very common on the landward side of clear-cut mangrove forests, and are often seen as a serious problem for management, since they can prevent re-colonization by more economically important tree species (e.g., *Rhizophora* spp., *Bruguiera* spp., *Avicennia* spp., *Sonneratia* spp. and *Xylocarpus* spp.) In some cases, where disturbance has occurred, an *Acrostichum* dominated system may be considered a regime change, as it replaces a once specious mangrove forest, inhibiting natural restoration. But where natural *Acrostichum* stands exist at the mangrove/terrestrial interface, we should try to understand their ecological importance to the system. They are there for a reason and likely play a role in the resilience of the mangrove as a whole that has not yet been uncovered.



The above classification helps us to understand what a stable mangrove forest might look like for a typical area in Indonesia Again, there is much variation, and site managers are encouraged to understand their own local system in greater detail. Setting up a monitoring program and collecting baseline data is recommended in your quest to understand what a natural, stable-state mangrove system looks like in your region. A methodology for preparing a participatory biodiversity study is being prepared by Gordon Claridge and Ahmad Baehaqie, which provides an excellent opportunity to involve local communities in monitoring and management. Interviews with community elders to understand the state of the mangrove forest before human caused disturbance is another useful activity. So is participatory mapping. A search on the internet, or at university libraries for old botanical, biological or ecological surveys may be of use. Getting your hands on older remote sensing images (aerial photos, satellite photos) can be very useful, but these images are hard to track down in Indonesia.

Given that much of Indonesia's mangroves have undergone change, especially due to human caused disturbance, it will be important to recognize if your mangrove system has been altered. A look at potential alternate states for Indonesia's mangroves is provided below.

Potential alternate ecological states in mangroves; (Tomascik, 1997)

- Hyper-saline barren mud flat
- Stagnant pond
- Disused shrimp pond
- Less productive mangrove
- Barren area with compacted soil surfaces
- Barren area with changed water flow
- Pock-marked and dominated by *Acrostichum* scrub
- Salt tolerant grass area
- Monoculture (differing from a monospecific stand in that monocultures are not natural occurences)

Case study #4 from Segara Anakan, depicts a regime change from specious mangrove forest to a patchwork of freshwater wetlands, mud flats, disused shrimp ponds etc. In some cases, regime changes are not less desirable states to humans, but as is the case with Segara Anakan, local communities will need to develop new livelihoods other than fishing to cope with drastic ecological change.

Redundancy: Although zonation into regionalized monospecific stands in mangroves is commonplace, Indonesian mangrove ecosytems (whole forests) exhibit a high level of species diversity. Managing specifically for "biodiversity" may seem like another form of optimization, but in general, increased biodiversity leads to a higher amount of resilience, as it increases what is known as redundancy. Redundancy in mangroves means that more than one species of plant or animal will fill the same functional role. Therefore, the loss of or stress to a single species is less disruptive to the mangrove ecosystem as a whole. An example of this can be seen in Simeulue Island, Aceh (case study #2). After the most recent tectonic uplift event, pioneer species are coming back to colonize hard substratum on uplifted coral reefs. This would usually be the role of *Avicennia marina*, a common colonizer that is conspicuously absent from the Simeulue flora in most locations. The functional role of colonizer, however, is being filled by several species including *Sonneratia alba* and *Pemphis acidula*. Although we are speaking here in terms of ecology, redundancy exists in the social arena as well; where multiple stakeholders/actors, involved in mangrove forest management allow for a more resilient management system than one single or very few stakeholders.

This area has become dominated by *Acrostichum ilicifolium* scrub after clear-cutting for charcoal production Bengkalis Island, Riau

CUES & FEEDBACKS

One key, in discussing resilience, will be to recognize, before a state change takes place, when a system is moving toward a threshold. A manager will need to look for cues within the mangrove ecosystem, that all is not well. The following is a list of problems that can occur if the rate of tree harvest outpaces the rate of re-establishment of seedlings & regrowth, or if the mangroves are totally removed. This list can provide us a with a good starting point to deriving a more complete list of potential cues that tell us when we are nearing a threshold.

Damage to Mangroves as Cues to Decreased Resiliency (Talbot, 2001)

- Loss of prawn and fish habitat.
- Loss of prawn and fish nursery areas.
- Loss of crab fisheries.
- Loss of benthic macro-invertebrate community.
- Loss of traditional medicines, direct food source, fuel-wood and timber for communities.
- Increased erosion of the mangrove area and the land behind the mangroves with coastal damage.
- Intrusion of salt water into farming land following this erosion.
- Loss of sediment filtering and trapping by mangroves, resulting in more sediment flowing on to seagrass beds and coral reefs.
- Exposure of acid sulphate soils and acid leaching.
- Loss of mature trees that provide propagules.
- Loss of biodiversity of plants and associated animals.
- Fire in areas where mangroves die or dry out.
- Gaps in the canopy cause higher death rates of newly settled young trees through increased light and evaporation.

Processing of mangrove propagules for food has become a recent focus of non-timber forest product development in Indonesia. Aside from providing nutrition to coastal villagers, the added income provides a direct, short-term economic incentive for fisherfolk to become involved in mangrove conservation. Here, members of a womens cooperative are processing *Avicennia* fruits to make flour used in baking cakes (Balikpapan, East Kalimantan).

Drying out of mangrove area due to blockage of fresh water inflow, Naga Lawan, North Sumatera

Part 3: **Resilience Thinking Models**

We have brought up the subject of regime changes and thresholds several times during this paper, and will now take the opportunity to expound upon these concepts. Walker and Salt provide us with two visual models to help think about resilience; the *Ball-in- the-Basin-model,* which directly relates to regimes and thresholds, and the metaphor of the *Adaptive Cycle*. We will briefly take a look at these two models before going into the case studies, to allow the reader the best opportunity to take a look at the case studies with an eye for picking key concepts of resilience out of the stories.

WHAT IS A THRESHOLD? (from www.resalliance.org)
A threshold is defined here as a point between alternate regimes in ecological or social-ecological systems. When a threshold along a controlling variable in a system is passed, the nature and extent of feedbacks change, such that there is a change in the direction in which the system moves. A shift occurs when internal processes of the system (rates of seedling establishment, mortality, growth, consumption, decomposition, etc.) have changed such that the variables that define the state of the system begin to change in a different direction, towards a different attractor. In some cases, crossing the threshold brings about a sudden, large and dramatic change in the responding variables, whilst in other cases the response in the state variables is continuous and more gradual.

BALL-IN-A-BASIN MODEL (Walker et al, 2004)
It is helpful, in understanding how a system approaches thresholds to use the following Ball-in-a-Basin visual model.

Within a basin (where the system has essentially the same structure and function, and the same kinds of feedbacks) the ball tends to roll to the bottom. We call this the system's equilibrium state. In nature, the system is never really in a constant state (the ball is never at rest at the bottom) but moving about the system. Nonetheless, the system maintains its integrity. For example a mangrove ecosystem may continue as a *complex mangrove community* (Mangrove Communtiy Type #2, pg. 26), although the relative abundance of various mangrove species may change.

The shape of the basin also changes as external conditions change, for instance amount of sediment deposited (see Figure 4). The ball changes position and the basin changes shape. From a resilience perspective the question is how much change can occur in the basin and in the system (ball's) trajectory without the system (ball) leaving the basin?

Beyond some limit (the edge of the basin), there is a change in the feedbacks that drive the system's dynamics and the system tends toward a different equilibrium. The system in this new basin has a different structure and function. It is a different social-ecological system. The system is said to have crossed a threshold into a new basin of attraction – a new regime. Instead of a complex mangrove community we may end up with an *Acrostichum* dominated landscape. This new regime may be stable, but it may also be less desirable. It should be noted, that it can be very difficult to return from a new regime into the original one. In the following scenario, for instance, it may be more difficult to restore the mangrove forest than simply planting trees, restoring hydrology or dredging excess sediment.

Figure 3 : The System as a Ball-in-the-Basin Model
The ball is the state of the social-ecological system; in this case the mangrove forest, fisherfolk, government, and other stakeholders who both benefit from and manage the system. The basin in which it is moving is the set of states which have the same kinds of functions and feedbacks, resulting in the ball moving towards to equilibrium. The dotted line is a threshold separating alternate basins. (*For the time being, ignore the variables; Pr, R and L*)

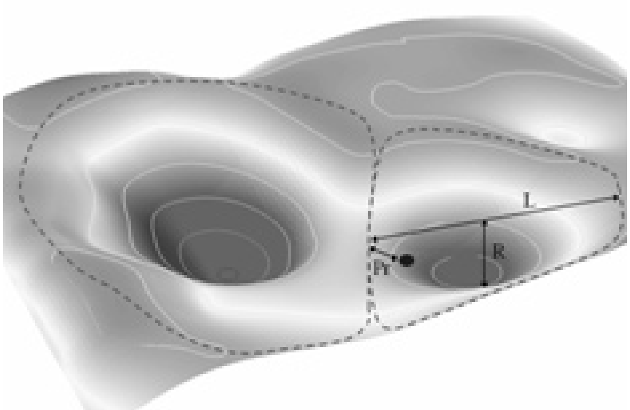
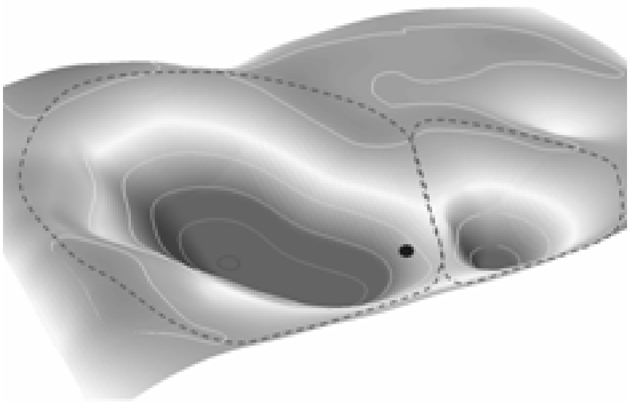


Figure 4: The Basin Changes Shape
This is the same system from Figure 3. The state of the system (position of the ball) has not changed, but as conditions change, so too does the shape of the basin and the behavior of the system.



It is not just the state of the system (the position of the ball) in relation to the threshold that is important. If conditions cause the basin to get smaller, resilience declines, and the potential of the system to cross into a different basin of attraction becomes easier. It takes a progressively smaller disturbance to nudge the system over the threshold.

A good example of a system crossing a threshold can be found in case study # 4 from the Segara Anakan Lagoon. In this case, excessive sedimentation from upland erosion on mainland Java has caused the lagoon to fill with sediment. For a while, mangrove species tolerant to higher substrate elevations colonized and established themselves on newly accreted lands; but this process could not go on indefinitely. Eventually a dredging project was implemented, at great cost, but was unable to maintain the integrity of the lagoon system. Over time, the lagoon volume and surface area have been drastically reduced, and mangroves now exist only on the largest channels, connected directly to the South Java Sea.

Key Points on Thresholds (Walker and Salt, 2006)

- Though social-ecological systems are affected by many variables, they are usually driven by only a handful of key controlling (often slow moving) variables.
- Along each of these key variables are thresholds; as the system moves beyond a threshold it behaves in a different way, often with undesirable and unforeseen surprises.
- Once a threshold has been crossed it is usually difficult (in some cases impossible) to cross back.
- A system's resilience can be measured by its distance from these thresholds. The closer you are to a threshold, the less it takes to be pushed over.
- Sustainability is all about knowing if and where thresholds exist and having the capacity to manage the system in relation to these thresholds.

ADAPTIVE CYCLE (from www.resalliance.org)
The model of the adaptive cycle was derived from the comparative study of the dynamics of ecosystems. It is meant to be a tool for thought. It focuses attention upon processes of destruction and reorganization, which are often neglected in favor of growth and conservation. Including these processes provides a more complete view of system dynamics that links together system organization, resilience, and dynamics.

Traditionally, ecology has focused on the concept of succession that describes the transition from a time when exploitation (i.e., the rapid colonization of recently disturbed areas) is emphasized to a time when conservation (i.e., the slow accumulation and storage of energy and material) is emphasized. Our current understanding of ecological dynamics however indicates that two additional functions - release and reorganization - are needed.

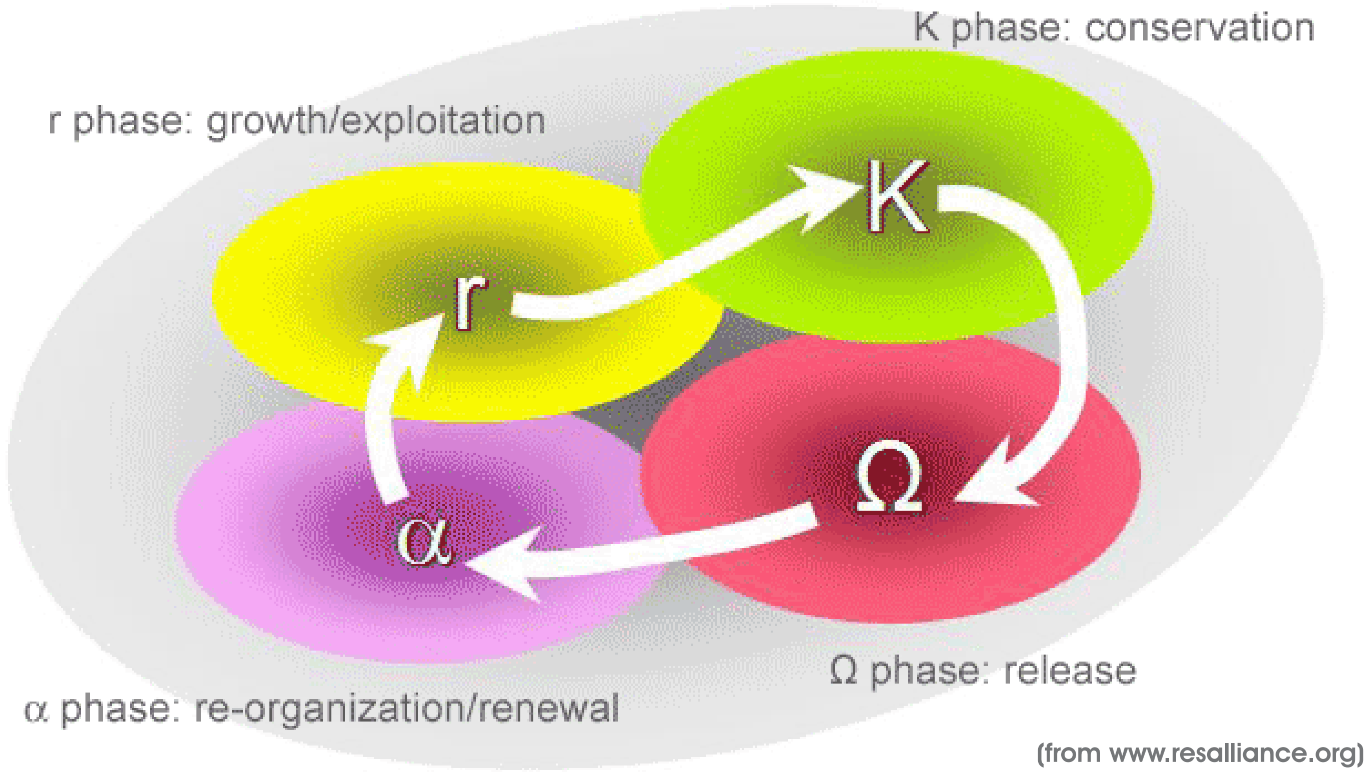
An adaptive cycle that alternates between long periods of aggregation and transformation of resources and shorter periods that create opportunities for innovation, is proposed as a fundamental unit for understanding complex systems from cells to ecosystems to societies. The basis for this thought actually comes from the ancient Chinese cycle of the five elemental energies (Teeguarden, 1984)

For ecosystem and social-ecological system dynamics that can be represented by an adaptive cycle, *four* distinct phases have been identified:

1. Growth or exploitation (r)
2. Conservation (K)
3. Collapse or release (omega - Ω)
4. Reorganization (alpha - α)

The adaptive cycle exhibits two major phases (or transitions). The first, often referred to as the *foreloop*, from r to K, is the slow, incremental phase of growth and accumulation. The second, referred to as the *backloop*, from Omega to Alpha, is the rapid phase of reorganization leading to renewal. One major problem with scientific research on mangroves, is that most of it takes place during the foreloop, the slow phase of growth and accumulation. With so much damage taking place to mangroves in so short a time, there is a dire need for greater understanding mangrove systems during the backloop. Greater information on the backloop phase may help managers guide the process of reorganization and renewal. All of the case studies at the end of this paper, have experienced recent and quite substantial backloops phases.

Figure 5: The Adaptive Cycle



LIFE DURING THE FORELOOP

During the slow sequence from exploitation to conservation, connectedness and stability increase and a capital of nutrients and biomass (in ecosystems) is slowly accumulated and sequestered. Competitive processes lead to a few species becoming dominant, with diversity retained in residual pockets preserved in a patchy landscape. This is frequently evidenced in mangroves, where large monospecific stands or paired associations of species are dominant, with much of the floral diversity occurring at the terrestrial margin.

Most of the time, mangrove forests as a social-ecological system, are changing along the growth to conservation phases (foreloop) pictured above. In this phase, growth and development take place in small increments, life is predictable and resources get locked up in doing things in an increasingly efficient manner. Optimization for immediate benefits may work well in these two phases of the foreloop. (Walker, 2006) An example from the mangrovesmight be the well managed harvesting larger *Rhizophora* mangroves for charcoal production. As long as the hydrology of the area is unchanged, and as long as some propagules are left and made available for either natural revegetation or planting, the forest may continue to produce consistent biomass for carbonization. From the social side, perhaps only a few small businesses and a single local government agency are in charge of operating and regulating the industry. As long as biomass production is both quick and consistent, life is *good*.

REORGANIZATION DURING THE BACKLOOP

Inevitably, however, the conservation phase will end. The longer the conservation phase persists, the smaller the shock needed to end it and initiate a release phase in which linkages are broken and natural, social and economic capital leaks out of the system. The system then reorganizes itself. In this backloop phase, optimization does not work. (Walker, 2006) A shock may come in the form of increased market demand. A ban on mangrove charcoal production in Thailand, leads to increased demand in Sumatera. Regeneration of *Rhizophora* mangroves alone does not meet the new market demand. Charcoal producers, are forced to harvest various species of mangroves, including root balls to provide biomass for their kilns and keep supply at a constant. Changes in hydrology take place, and propagules to regenerate the forest become scarce. Lack of regulation during the growth phase, has resulted in the incapacity of local actors to conserve or restore the resource. In short time, an area which was once a productive, has turned into a barren mud flat, colonized by species of little or no economic value. The way back to an "optimal" mangrove system is no longer easy or incremental. Even planting of *Rhizophora* propagules obtained from elsewhere will not work as the region's hydrology has been altered. Because managers were not thinking in terms of maintaining the resilience of the mangrove forest, they have lost the resource nearly overnight. This scenario has played itself out countless times in Sumatera and Kalimantan over the past two decades.

ADAPTIVE CAPACITY

Previous sections have paid more attention to ecological aspects of mangroves than social aspects. First we will briefly discuss adaptive capacity with some brief examples from Indonesia. Then in the next Part 4 we take a look at four management case studies, while keeping in mind the state of social-ecological resilience in each case, as well as where these systems are in terms of approaching thresholds.

Adaptive capacity in ecological systems is related to genetic diversity, biological diversity, and the heterogeneity of landscape mosaics (Carpenter et al. 2001a, Peterson et al. 1998, Bengtsson et al. 2002).

In social systems, the existence of institutions and networks that learn and store knowledge and experience, create flexibility in problem solving and balance power among interest groups play an important role in adaptive capacity (Scheffer et al. 2000, Berkes et al. 2002). With regards to Indonesia's mangrove forests, we are just now experiencing the formation of meaningful networks of stakeholders coming together for the conservation of mangroves. Case study #3 from Bengkalis Island, Riau is one such case; where coastal communities, government, academics and NGO's are sincerely and actively working together for the mutual benefit of mangrove forests and the communities that live amongst them.

While there has been positive movement involving rural coastal communities in policy making[1] and forestry management over the past decade, community involvement in mangrove forest management in Indonesia, although discussed much amongst NGO's, is still far from commonplace. A policy and legal framework supportive of rural fisher folks' agendas will not just happen. The allocation of critical resources by governments will not be directed to poor fishing communities without a strong amount of pressure exerted by the marginalized communities themselves. This is where coalition and network building among fisher folk organizations and community-based NGOs will make a difference. There is a need for strong advocacy where forging strategic alliances within the ranks of fisherfolk organizations play a crucial role. Only with true community participation, will we achieve social resilience in the realm of mangrove management.

At a higher level of political organization (a higher scale), Provincial forums have been formed under the Department of Fisheries for more effective coastal management. These multi-stakeholder forums (known as Konsortium Mitra Bahari or Coastal Partners Forum), exist now in 15 Provinces, and bring together oceanic sciences faculties from universities, provincial government offices (Planning Dept., Fisheries and Forestry Depts.), non-governmental organizations and related industries. The South Sulawesi Coastal Partners Forum is interested in partnering with Mangrove Action Project and CUSO-Indonesia on a large-scale mangrove restoration program and sustainable livelihood development program, targeting 2500 ha of disused shrimp ponds in four districts. The coordination of so many high profile partners is challenging, but provides the political power necessary to engage in far-reaching initiatives.

Systems with high adaptive capacity are able to re-configure themselves without significant declines in crucial functions both ecological (primary productivity, hydrological cycles), and social (enforcement of mangrove policy, economic prosperity). Consequences of a decreased resilience (and therefore adaptive capacity) is a loss of opportunity, the inability of the system to withstand stress and disturbance, and constrained options during periods of re-organization and renewal. When a non-resilient social-ecological system does finally emerge from such a period of change, it may be moving along an undesirable trajectory.

Resilience Is Key To Enhancing Adaptive Capacity

Are there elements that sustain adaptive capacity of social-ecological systems in a world that is constantly changing? Addressing how people respond to periods of change and how society reorganizes following change, is the most neglected and the least understood aspect in conventional resource management and science (Gunderson and Holling 2002). Folke et al. (2002) identify and expand on four critical factors that interact across temporal and spatial scales and that seem to be required for dealing with natural resource dynamics during periods of change and reorganization:

- Learning to live with change and uncertainty;
- Nurturing diversity for resilience;
- Combining different types of knowledge for learning; and
- Creating opportunity for self-organization towards social-ecological sustainability.

1 MAP, with support from IUCN has just published a compilation of case studies on community involvement in mangrove policy making and collaborative management. This manual "Sudi Kasus di Bidang Perancangan Kebijakan dan Pengelolaan Hutan Bakau Berbasis Masyarakat" is currently available in Bahasa Indonesia only from www.mangroveactionproject.org

Collecting Acanthus ilicifolius leaves to make herbal tea
Amaiteng Village, Simeulue - Aceh

Part 4: Case Studies

Looking for Resilience in Indonesia's Mangroves

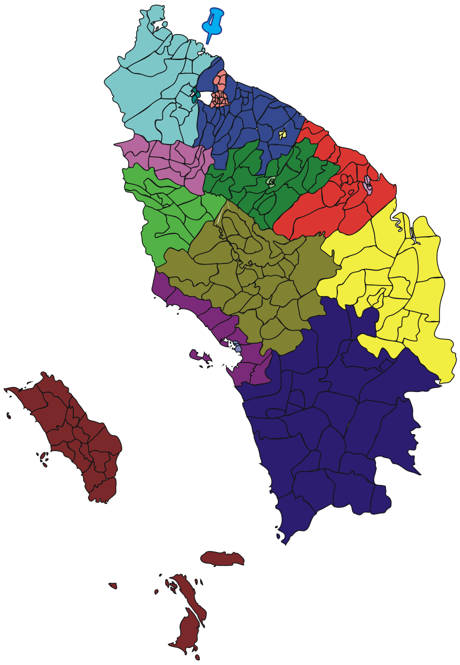
Before delving into the case studies, let us return to our initial definition of resilience. "Resilience is the capacity of a system (composed of both social and ecological aspects) to absorb change and disturbances, and still retain its basic structure and function – its identity. Resilience thinking is about envisaging a system in relation to thresholds. Is it approaching a threshold beyond which it will be in a new regime? What forces – economic, social and environmental are driving the system towards this threshold?" (Walker and Salt, 2006)

"One of the central ideas of resilience thinking is that social-ecological systems have multiple regimes (stable states) that are separated by thresholds" (ibid)

In presenting the following four case studies, please keep in mind that it is not our intent, nor indeed are we yet capable of, presenting them as complete assessments of resilience. Long study of historical data, coupled with current surveys and analysis are needed to prepare a valid case study of the resilience of each system. The authors of "Resilience Thinking" have provided us with a pair of workbooks (one for practitioners and a second for scientists) as tools in order to begin to assess the resilience of our mangroves. These workbooks can be downloaded from the resources section of www.resalliance.org. MAP-Indonesia is planning on using these tools for the first case study, from SE Langkat Wildlife Sanctuary in North Sumatera.

Let us now look at the following four scenarios using our lenses tinted by resilience thinking. As you read through these case studies, test to see if you can pick out key slow moving variables, stresses and disturbances, signs of adaptive capacity. Are these systems are at risk of crossing a threshold or have they already crossed a threshold into a new regime? Do these systems seem resilient to you from an ecological standpoint? From a social perspective? Also try and look for similarities and differences between the systems described in the case studies and the mangrove forest that you are concerned with. Keep in mind, that developing a network for sharing of information on how to overcome issues of mutual concern is in and of itself a resilience building activity. Perhaps the actors involved in the following case studies will be able to offer you some advice based on their own experiences. Contact information for stakeholders from the various case studies are provided at the end of each case study.

Case Study # 1 - South East Langkat Wildlife Sanctuary
North Sumatera Province



The 9000 hectare SE Langkat Wildlife Sanctuary is a mangrove ecosystem at the mouth of the Wampu River in North Sumatera. Mangroves have been illegally logged here to meet the demand of the export charcoal market for over two decades. The sanctuary is managed by the provincial office of the National Agency for Natural Resource Conservation (BKSDA I). Up until 2006, only three agency staff were tasked with management and enforcement over this 9000 hectare area. Local communities, by law, were not allowed access to the sanctuary for any type of activity, be it fishing, logging, collection of medicinal plants, reforestation or protection.

Over the years, selective logging of the main trunks of *Rhizophora apiculata* (the preferred mangrove species for charcoal making in the region) has given way to clear-felling of nearly all significant woody mangrove biomass, including root-balls. The digging up of root-balls leaves behind an uneven, pock-marked substrate. Raised and disturbed, the substrate is further built up by burrowing crabs and the mud lobster (*Thalassina anomala*) and eventually colonized by *Acrostichum* fern, which effectively prevents new replacement mangrove seedlings from re-vegetating the area. A reduction in mature trees leads to an overall reduction in propagules for natural recruitment, a reduction of plant biomass, and a resultant decrease of faunal populations (crabs, shrimp, fish etc.) Shrimp ponds also began popping up in the wildlife sanctuary. This development was permitted by various local government officers, without actual authority over the sanctuary. Most of these shrimp ponds have since been abandoned, on average within two years of their establishment. The value of the resulting, stunted mangrove ecosystem, both in terms of economics and ecological services, had been greatly diminished.

In terms of social and ecological resilience, the wildlife sanctuary was in trouble. Although still able to regenerate naturally, trees were seldom given a chance to grow into maturity, and there were already signs of hydrological change, from diking and channelizing for shrimp ponds development as well as an increase in the presence of mud-lobster mounds, and areas dominated by of *Acanthus ilicifolius* and *Acrostichum aureum*.

The village of Jaring Halus rests just outside the border of the sanctuary, sitting atop stilts above the mouth of the Wampu River. Historical village boundaries included about 2000 hectares of mangrove forest which now is situated inside of the wildlife sanctuary. Establishment of the sanctuary had effectively denied traditional claims to the mangroves and their resources. The community was left with a 33 hectare mangrove forest, located immediately behind their village, which has been managed sustainably since the establishment of the village in the early 20th century. Today, this village forest represents the healthiest, most biodiverse, biomass-laden mangrove forest in the district. Traditional law allows for cutting of mangroves for ceremonial firewood and timber, but with a high level of village control; requiring permission from the traditional spiritual leader and a stipulation that five trees be planted for every one tree felled.

Mangrove Action Project came to the region in 2003 after being introduced to the community at an “In the Hands of the Fisherfolk” workshop several districts to the East. MAP had received financial support to demonstrate Ecological Mangrove Restoration (EMR) in the region, and was scouting abandoned shrimp ponds with local communities from the JALA (North Sumatran Fisherfolk Advocacy Network) network. A group called IPANJAR (Youth Fishermen’s Alliance of Jaring Halus) had worked with JALA for several years in North Sumatera, and provided MAP with a three-hectare abandoned shrimp pond complex suitable for demonstration EMR. During the planning phase of the project, IPANJAR toured MAP through the decimated wildlife sanctuary. IPANJAR members relayed that 6 years prior, they had planted mangroves in the sanctuary in partnership with BKSDA I, but were disappointed that these restored areas were already being illegally logged for charcoal, without adequate protection by BKSDA. The community themselves did not have the legal right to enforce the strict no-take regulations of the sanctuary, and were disenfranchised regarding future opportunities to be involved in mangrove restoration or conservation.

It needs to be said, that around 2005, illegal logging in the region had temporarily ceased. The Minister of Forestry himself hails from the Langkat District, and had enacted a severe crackdown on all forms of illegal logging. No one is sure how long this crack-down will last. It is generally felt that increased enforcement is merely politically motivated, and as such provides only a short-term solution to illegal logging in the region. As of 2005, there had been no significant involvement of local communities in mangrove conservation, or capacity building amongst sanctuary managers or local law enforcement.

It was decided that what was needed in the area, more than a demonstration of successful mangrove restoration, was a collaborative agreement, granting local villagers the right to both sustainably utilize and actively conserve a portion of the mangrove sanctuary. IPANJAR and MAP, together with support from USAID Environmental Service Program, approached BKSDA I armed with a PowerPoint presentation and local testimony. Pictures of the 33 hectare forest, which the village had successfully stewarded for generations spoke louder than words, and after a single field visit, along and a few participatory mapping activities, 500 hectares of the 9000 hectare SE Langkat Wildlife Sanctuary was designated as a collaborative management area. Collaborative management was made possible by a national law drafted in 2004, allowing for community involvement in the management of wildlife sanctuaries and protected forests.

Up until the writing of this paper, the SE Langkat case is the only case in Indonesia where this law has been taken advantage of by local stakeholders in a mangrove area. Over the next 10 years, a management plan will be formulated and implemented, including the development of better mechanisms for enforcement. One such mechanism is the establishment of traditional fish weirs on several of the tidal creeks which flow through the management area. It is expected that operation of the fish weirs will increase community presence in the forest as well as augment local livelihoods, without damaging the ecology of the mangrove forest.

Mangroves restoration (both by planting and natural revegetation), a participatory biodiversity survey and continued monitoring of biodiveristy and mangrove restoration plots are all currently being implemented. Nonetheless, stakeholders still have a long way to go to assure lasting protection of the area, and not all stakeholders are optimistic. For one thing, funds for continued, active conservation as scarce. Government budgets have yet to be significantly allocated to this santuary management, NGO's live grant to grant, and local fisherfolk are more apt to volunteer time than financial resources. Strongly tying conservation to local livelihoods is one solution, but the need for the government to allocate an appropriate budget to stay involved in management is still unanswered. Although the leader of BKSDA I is a strong proponent of the collaboration, government officials are often transferred, and not all of the lower-ranking officers of BKSDA I are in favor of collaborative management. Some, were likely involved in protecting illegal loggers during the two decades when they ran rampant in the sanctuary. In terms of ecological resilience, the mangroves seem to be are recovering well to unregulated cutting; yet in terms of social resilience, although social systems are stronger than they have been for several decades, there are still many challenges to be faced.

For more information contact;

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Jl. Pasar Baru No. 30 Padang Bulan, Medan, 20156
djatiwhadi@yahoo.com

USAID Environmental Services Program – It. M. Khairul Rizal
Spatial Planner/GIS Specialist
khairul_rizal@dai.com

IPANJAR Youth Fishing Cooperative of Jaring Halus Village - Rustam & Basri
SEROJA women's non-timber forest products cooperative – Masiah
Send sms text messages to: 081370739902

Mangrove Action Project – Indonesia, Ben Brown
<seagrassroots@gmail.com>

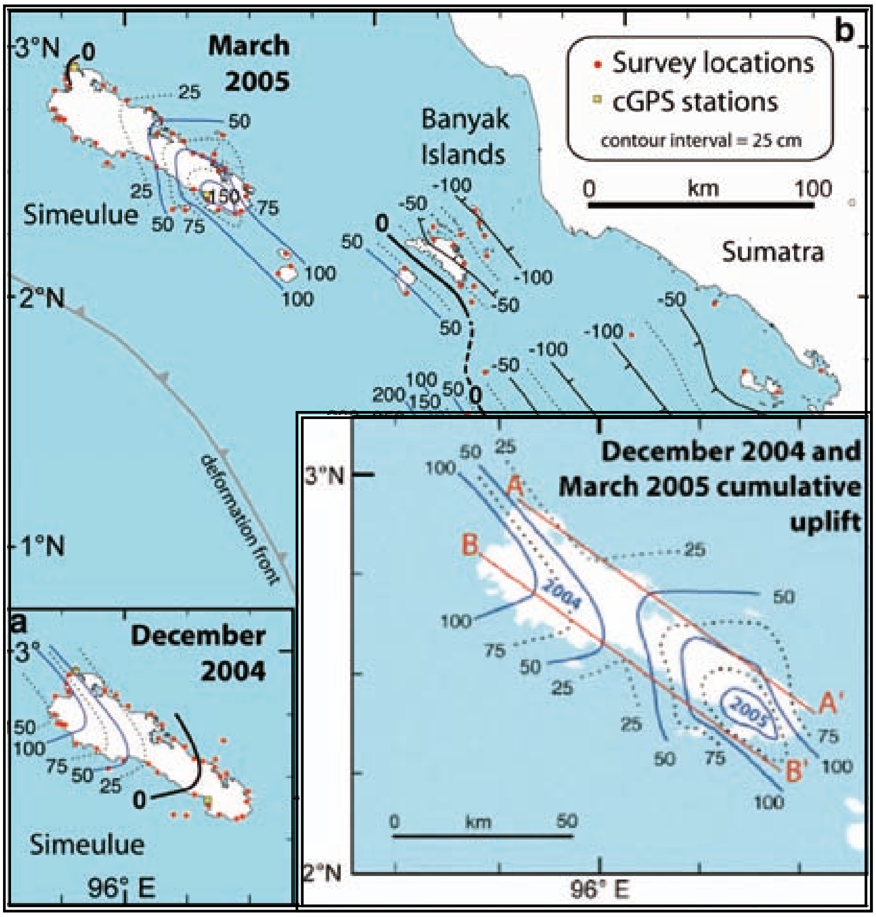
Case Study #2 - Simeulue Island, Aceh Province

The December 26, 2004 earthquake epicentered off the coast of Aceh, which resulted in the tsunami that devastated coastal areas throughout the Indian Ocean region, also resulted in drastic tectonic change on Simeulue Island. By and large, the western part of the island experienced uplift of between 25-150 cm while points along the eastern edge of island experienced submergence. (Briggs et. al, 2007)

Mangroves in uplifted areas fared better than mangroves which experienced submergence, where significant and immediate mortality was observed. Submerged mangroves will die quite readily as above ground components of root systems are no longer able to ventilate underground roots to enable respiration. The submerged roots, no longer able to respire, can not adequately expel waste CO_2, circulate methane (CH_4) absorbed from the sediment, or resist Sulfur which is a by-product of anaerobic respiration in the substrate and which toxifies the root hairs. Lenticels, (pores through which the mangrove breathes) on the trunk of the tree alone, at a certain level of submergence, can not effectively supply the roots with the oxygen they need to respire. On the other hand, mangroves which found themselves suddenly risen above the tidal zone, did not die-off immediately, but exhibited stress, and over a period of several months were out-competed by terrestrial species including many mangrove associates. Signs of stress included shedding of leaves, drying out, increased size of lenticels, and failure to produce propagules.

The subsequent earthquake of March 2005 (centered between Nias and Simeulue Islands), effectively uplifted the eastern part of the island which had been submerged as a result of the 2004 earthquake. The maps below show gradients of uplift from each separate earthquake, along with cumulative uplift contours for the entire island. Submergence on Simeulue Island, after the March earthquake, was no longer an issue. The island as a whole experienced uplift, but to varying degrees in various places.

Figure 6: Seismic Uplift on Simeulue (PhD. Kerry Sieh, 2007)



Uplift of course, not only affected mangroves, but other tropical marine ecosystems such as seagrass beds, tidal mudflats, coral reefs and their associated fauna. Fisherfolk from the entire island have noted significant decreases in coastal fisheries due to destruction of these habitats, and are desperate to restore what they can of fisheries habitats for livelihood security. Overall uplift in the East and West was quite significant, while uplift in the central part of the island was less dramatic, evidenced by the healthier condition of mangroves. In the East and West, most mangroves were lifted completely out of the tidal range. This brought them into direct competition with terrestrial plants and mangrove associates. Over a two-year period, some of these mangroves have ceased production of propagules (mangrove fruits, seeds and seedlings dispersed by water, both tidal and riverine), due to stress and competition. Where mangroves which exist above the reach of the high tide and are still producing propagules, the propagules fall onto dry land, unavailable for dispersal by tides and ocean currents.

Exceptions are mangroves that were not lifted completely out of the tidal range (predominantly mangroves which formerly grew at the lowermost edge of the previous tidal range), or mangroves growing along tidal creeks and rivers. Such mangroves are still able to produce and disperse propagules, with resultant natural regeneration of mangroves. The mangroves are in essence "migrating" seaward, and establishing themselves in newly uplifted land. These uplifted lands consist of former seagrass beds, coral reefs and tidal mudflats. Natural mangrove establishment and growth in these disturbed ecosystems is dependent on a variety of factors; including proximity to sources of propagules, substrate type, and strength of waves and currents along the coast.

In central Simeulue, primarily in the Teluk Dalam region, mangrove uplift was low, on the order of 40-65 cm. (Briggs et al, 2006) More mangroves are surviving and producing propagules in this region, and there is a higher incidence of natural regeneration. This region will become an important source of propagules to assist regeneration of mangroves in the eastern and western parts of the island. Humans are helping, by collecting propagules and distributing them in target restoration areas during rising high tides, after having practiced this method in a recent Ecological Mangrove Restoration workshop.

In coming to understand the key to recovery for the mangroves of Simeulue, it will be important to also understand that what has taken place as the result of tectonic uplift, is part of a recurring cycle of uplift and subsidence that has played itself out over the centuries in the region. Mangroves, over the next several decades, will migrate outward, re-establishing themselves within their limits in the tidal range. As the island subsides, mangroves will return inland vis-à-vis natural recruitment of seedlings. This time around, the rate of subsidence will be exacerbated by sea-level rise, the much feared by-product of global warming. This "adjusted" rate of subsidence has been calculated by Dr. Kerry Sieh of California Technological Institute and can be made available to local natural resource managers. Understanding these long-term, cyclical processes is a pre-requisite to creating an appropriate spatial plan for the future, that includes room for mangrove migrations (seaward and back) over the next century.

Humans; however, are impatient beings. Thinking in terms of 100-150 year time scales is not our strong point. Undoubtedly, humans will begin to develop lands along the newly uplifted coast, developing coconut plantations, housing, resorts, etc. In order for future inland mangrove migration to take place, parts of this coast will need to be set aside as a buffer zone. Local community and government alike have stated that mangroves are important to them. The government set a ban on all mangrove cutting after the recent tsunami. But lack of understanding of long-term cycles, and political realities that development usually wins out over conservation in the region will come into play.

The mangroves of Simeulue are exhibiting a high degree of ecological resilience. Migrating out where possible and establishing themselves on available substrates, including mud, corral rubble and sand. In terms of social resilience, by and large the communities of Simeulue have taken good care of their mangroves, but without actual conservation intent. Mangrove forests for the most part were healthy before the tectonic disturbances of 2004-2005, sustainably harvested for timber in some areas, but valued more for their role as fisheries habitat (fish, crabs and prawns). The exceptions to this rule took place near to the city center of Sinabang where mangroves had been clear-cut in the 1980s and 1990s to fuel a coconut oil processing plant. It is common in Indonesia, for rural fisherfolk communities to co-exist with healthy mangrove forests. Yet, even though traditional management practices may be sound, community based natural resource management lacks legitimacy. We learned earlier in this paper that mangrove forests should be seen as a social-ecological system. In order to maintain their integrity through disturbances, mangroves will require both ecological as well as sociological resilience. In this day and age, passive or even traditional management alone does not provide the level of social resilience needed to keep mangrove forest alive and in tact. At any given time, in most parts of Indonesia, mangroves are susceptible to disruptive forces (be they earthquakes or investors). Most mangroves are by law, state-owned forestsm, making them extremely vulnerable to political whimsy and development or conversion for short-term economic interests.

So although the communities of Simeulue have taken good care of most of their mangroves over the past century, the mangroves are at risk of development by outside forces. Simeulue's remoteness and political conflict in Aceh are chiefly responsible for safe-keeping Simeulue's mangroves from development over the past decades. But as is evidenced by the current conversion of a large tract of rainforest to oil palm plantation in central Simeulue, the island is now in the cross-hairs of outside investors. Local political will for forest conservation is weak and community involvement in forest management is not yet on the government's radar.

Building Social Resilience - Participants from eight villages on Simeulue Island attended a five day "In the Hands of the Fisherfolk" workshop on community based mangrove conservation and restoration. Pictured here, participants are learning about the individual species ecology of 12 different types of mangroves in order to proceed with ecological mangrove restoration. Previous restoration attempts met with failure due to inadequate knowledge of appropriate methods.

The future of mangroves on Simeulue, depends on an understanding of resilience, and putting management plans and practices into place that maintain the resilience of mangroves, rather than plans that optimize short-term human utilization of the coastal zone. Already we are seeing this "optimization" mind-set take hold. What are the best species of mangroves for fisheries habitat? What are the best trees to plant along recently uplifted lands? If mangroves don't make money, can they be replaced with something that will? Human's are eager to change nature to suit their own short-term purposes. History teaches us over and over, that our manipulation of the environment will come back to haunt us in the end. Let us hope that the communities of Simeulue are able to recognize their plight, and that if they really want mangroves around for the future, they act now to make it possible.

Summary of major points:

- Uplift of mangroves resulted in direct competition between mangroves and terrestrial plants including mangrove associates.
- Most areas on the island are propagule limited due to; a) stressed mangroves which have ceased to produce propagules and, b) successfully produced propagules are falling above the tidal range, and thus unavailable for dispersal by tides and currents.
- Out-migration of mangroves is taking place where propagules are available for distribution. Various species of mangroves are establishing themselves even on seemingly undesirable substrates (coral and coral rubble).
- Humans are starting to assist natural revegetation by hand-dispersal of propagules, collected from regions still producing propagules (Teluk Dalam) as well as mainland North Sumatera and Aceh.
- Humans need to be cognizant of long-term cycles, and plan for the outward and eventually back migration of mangroves.
- Social systems in Simeulue are not well networked, mangrove restoration efforts and government cutting bans alone will not secure the future of mangroves in the region.

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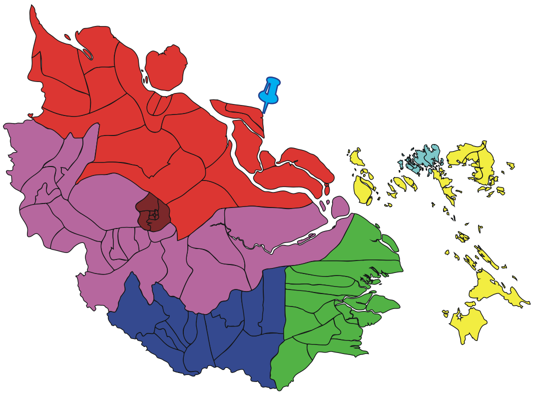
Case Study #3 - Bengkalis Island, Riau Province



Legal and illegal logging for industrial charcoal production had decimated mangrove forests along the Jangkang and Kembung Rivers for two decades, much akin to the case study from SE Langkat Wildlife Sanctuary. Local stakeholders and communities had not given much thought to mangrove protection in the 1980's and early 1990's. Local fisherfolk, however, have long been organized, having been involved in a decades-old battle (literally) with fishing boats from neighboring islands over use of fishing equipment. Local fleets from the Northeast coast of Bengkalis Island have adhered to use of long-line equipment throughout the decades, while outsiders fish the waters around Bengkalis with gill nets and purse seines. Their quarry, the Four Finger Threadfin (Locally: Kurau; Latin: *Eleutheronema tetradactylum*), a food-fish highly valued in Singapore and Malaysia. Local resistance to use of nets, and adherence to long-lining demonstrate both conservation awareness as well as capacity for organization, two keys to social resilience.

Awareness regarding the importance of mangroves came piece-mail, and much later. Awareness grew as islanders came to realize that the sea was reclaiming their land. The Northeast coast of the island is susceptible to severe coastal erosion. Elders recall that currents along the coast in the "North Wind Season" were always strong, and mangrove growth minimal along shorelines away from the influence of the river mouths. Nonetheless, *Avicennia marina* was able to establish itself in dense patches over time, as the propagules are quick to take root and seemingly had taken advantage of the calmer waters during the annual season when wave energy is low and ocean currents less strong.

In the 1970's and 1980's, indigenous people gathered shellfish from the pneutmatophores (air-breathing roots) of the *Avicennia* trees by direct cutting (amputation) of the pneumatophore. This practice, it is said, led to tree mortality (one of the few cases this mangrover has heard of involving intentional destruction of a mangrove resource by indigenous people). Over subsequent years, waves and currents during the North wind season eroded the unprotected coast. *Avicennia* found it hard to re-establish itself as substrate depths were lowered due to this coastal abrasion. Locals also surmised that increased beach debris during this period (a by-product of the charcoal industry) rendered the substrate difficult to colonize (much as coral has a difficult time establishing itself on rubble-fields).

In the 1990's, one individual community member took on the role of planting mangroves along the coast in the tens of thousands to fight erosion. In some areas his reforestation efforts succeeded, while in others, even mature mangroves were and are to this day falling into the sea during the high wave season. Villagers were worried about the safety of their agricultural crops, settlements and mangrove forests. Several villages are currently at risk of falling victim to erosion in the next 5 years.

All the while that awareness of the importance of coastal mangroves increased in the minds of local fisher-folk, mangroves in the mid-intertidal and along the terrestrial edge were being disturbed. By 2003, 158 charcoal kilns were operating on the island, responsible for the clearing of 640 hectares of mangroves per year. (MAP - State of Mangroves of Bengkalis Atlas, 2003) At this time, the only mangrove species that were harvested were *Rhizophora apiculata* (for carbonization into charcoal) and Xylocarpus granatum (used to fire the kilns). Even without active replanting, the forest usually recovered from this type of logging, relatively undisruptive to the substrate and not usually ruinous to hydrology. As nearby propagule sources were still abundant, most forests recovered naturally. By 2003, however, the practice of selective logging had changed. Nearly all forms of woody mangrove biomass, including root balls were dug up for charcoal production. This disrupted the resilience of the mangrove forest in at least two important ways.

1) Irresponsible logging left behind a pock-marked surface, with deep holes next to high mounds. The mounds quickly were built up even higher by mud lobsters, and in many cases colonized by the mangrove fern, *Acrostichum aureum*. The holes retained water, and were generally too low for mangrove establishment and survival. Mangroves require proper drainage. Left standing in water for extended periods of time they will undergo stress and may die.

2) Clear-felling of all species and size classes of trees reduced propagule availability and natural regeneration. A decrease in biodiversity, and resultant decline in redundancy, will result in decreased resilience.

During the period when the charcoal industry was harvesting only *R. apiculata* and *X. granatum*, another form of mangrove destruction was underway, albeit un-intended. Coconut plantations, owned by local Malay communities, were tended directly behind the terrestrial interface with the mangroves. During the 1990's coconut farmers had become increasingly concerned with salt-water intrusion to their plantations. Gradual sea level rise, and also disturbance to the mangrove buffer (both coastal and inner mangroves as described earlier) were the likely causes. The farmers' "solution" was to construct a 22 kilometer long bund separating the back mangal from their coconut plantations. In practice, however, the bund did not exclude salt water. Anyone who has seen a dirt, dike wall in a mangrove first hand will attest to the presence of countless crab holes which render the dike permeable to water. In fact, the presence of the dikes may have exacerbated the problem of salinization, as they effectively blocked fresh water surface flows into the mangrove area, vital to the health of the forest. As mangrove forests were further degraded, their ability to buffer salt-water inflow further reduced, and inland salinty increased. Communities at this time began to look for help in restoring their mangroves.

In 2003, MAP-Indonesia, Yayasan Lakasana Samudera and local fisherfolk worked together to create an atlas on the state of the mangroves of Bengkalis Island. The atlas contained administrative maps, land cover types, satellites, as well as the positions of charcoal concessions and shrimp ponds. The atlas also contained a map suggesting three sites for development of community based mangrove management. Two of these three sites were the Jangkang and Kembung Rivers deltas. The atlas was used to garner government support for the designation of community management areas. In 2004, facilitators from Yayasan Laksana Samudera worked in partnership with the ADB Co-Fish project to delineate 10 collaborative management areas ranging in size from between 11-65 hectares, totaling 300 hectares. Ten community groups were formed and granted stewardship rights over the areas by the Kabupaten (Regency or County) government.

MAP-Indonesia, in partnership with YLS, have since worked with 4 of the 10 community groups on ecological mangrove restoration projects, based on restoring natural water flows (both fresh and tidal) to their stewardship areas, and razing *Acrostichum* mounds, to encourage natural revegetation. The community groups are also engaged in the direct planting of seedlings in some areas. MAP will continue to work with all ten community stewardship groups in order to completely restore the entire 300 hectare area. New groups are eager to partner after having witnessed the success of mangrove restoration efforts from neighboring sites. Sustainable livelihood development projects are also being run to stimulate economic activity while the mangroves recover. In 2007, the Kabupaten government passed a law, banning charcoal production across the entire island. From this case study, we can see the improvement of both social and ecological resilience, after a period of ecological devastation and public apathy regarding mangroves.

Razing and burning *Acrostichum* mounds (top) by the Belukap community steward group, and six months after hydrological restoration mixed with plantings (bottom).

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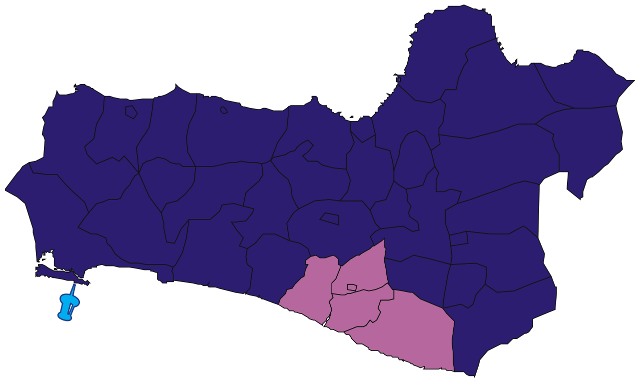
Case Study #4 - Segara Anakan Lagoon, Central Java Province



"Perhaps the most intensively studied mangrove forest in Indonesia is that of the Segara Anakan Lagoon (*Lit*: Little Ocean) on the south coast of Central Java near the port city of Cilacap. The lagoon was once described as a large, shallow sea bay with two connections to the open sea, one at the southern end of a sandy barrier island and the other to the west of the rocky island of Nusa Kambangan (entirely under the jurisdiction of the Indonesian penitentiary system). Fresh water and silt enter the bay via the Citanduy, Cibeureum and Kawunganten Rivers and several smaller streams. Historical mangrove coverage of the lagoon measured 21,750 hectares (12,610 ha tidally affected) dissected by a network of tidal creeks, marshes and mudflats. Current mangrove coverage, and indeed the size of the lagoon itself has been drastically reduced, due to sedimentation caused by excessive soil erosion from mainland Java. Because of long study, the Segara Anakan Lagoon may provide the world with one of the best case studies of a mangrove lagoon ecosystem which has moved over a threshold into a new regime.

Segara Anakan was the subject of early botanical and ecological studies (ex. DeHaan, 1931) and more recently multidisciplinary research programs; including an ecological study performed by Bogor Agricultural University (1980), and a multi-disciplinary study by the Asia Pacific Study Center of the University of Gadjah Mada (1999-2002). The Bogor team recorded 26 mangrove species based on quantitative sampling, confirmed later by the Gadjah Mada team during participatory sampling with the community. Both teams also measured various ecological attributes including associated flora and fauna, geomorphology, and rates of sedimentation. The Gadjah Mada team also consisted of social scientists (an economist, anthropologist, archaeologist, etc.), and developed an in-depth view of social-ecological interactions in the mangrove. The Gadjah Mada team prioritized use of participatory action research methods in the hopes of a) developing action research and problems solving skills amongst local communities, and b) increasing future dialogues between community members and outside researchers to position lagoon inhabitants as interactive subjects, and not objects of research studies.

One of the earlier ecological studies, described by DeHaan from 1931, takes place before major human influences on lagoon ecology, and will provide us with a baseline for comparison to the modern-day situation of the lagoon. Drastic ecological change has taken place, and this type of opportunity for comparison based on long years of study is invaluable in better understanding the resilience of mangrove communities.

DeHaan based his work on tidal inundation classes, developed 3 years earlier by Watson on the mangroves of Port Klang, Malaysia. It is important to remember that tidal inundation classes are not universal, and that local environmental factors such as rainfall, runoff, substrate type, coastal topography etc., will modify mangrove distribution and create new associations. It is also important to keep in mind that although we use the term stable state to describe mangrove resilience, a mangrove ecosystem is constantly undergoing natural change. Changing, while staying in the same basin of attraction was mentioned earlier during the discussion of the ball-in-the-basin model.

What has occurred in the Segara Anakan lagoon, is sometimes described as succession, likening sedimentation to the common successional example of a deep oligotrophic lake filling up due to nutrient loading and turning eutrophic. Succession in mangroves is a concept which is not clearly understood.

> The idea of mangroves representing a successional stage in the development of some climax terrestrial community is strongly embedded in the ecological literature and comes from the analogy of a fresh-water "hydrosere" leading from open lake to terrestrial system....The chief deficiency [of this theory] seems to be lack of direct demonstration of real successional process in time (rather than imaginary ones in space). (Tomlinson, 1986)

To appease proponents of successional mangrove theory, we can at best liken the Segara Anakan case to one of cultural eutrophication, where humans have sped-up what is a naturally occurring process. As far as this case study is concerned, we will look at the filling up of Segara Anakan lagoon from a perspective of resilience; that the system crossed a threshold due to environmental and human factors and is now operating as a new regime. To achieve this, let us first go back and consider the previous, stable state, of the Segara Anakan Lagoon, as described by DeHaan from 1931.

Inundation Classes for Zonation of Mangroves in Segara Anakan Lagoon.

Class 1) Outer Zone: Salinity varies from 10 to 30 parts per thousand (ppt). Inundation two times per day up to 20 days per month; substrate consisting of new soft mud colonized by *Avicennia* spp., and *Sonneratia* spp. Substrate consisting of hard and compact sediments (siliciclastics [sand, silt and clay] and carbonates) frequently colonized by *Rhizophora* spp.

Class 2) Middle Zone A: Salinity varies from 10-30 ppt. Seawater inundation occurs about 10-19 days/month. Most common species *Bruguiera gymnorrhiza*.

Class 3) Middle Zone B: Salinity varies from 10-30 ppt. Seawater inundation occurs about 9 days/month or less. Most common species are *Xylocarpus granatum* and *Heritiera littoralis*.

Class 4) Inner Zone: Salinity ranges from 10-30 ppt. with inundation frequency down to only a few days each year. Dominant species are *Bruguiera* spp., *Scyphiphora hydrophyllacea* and *Lumnitzera* spp.

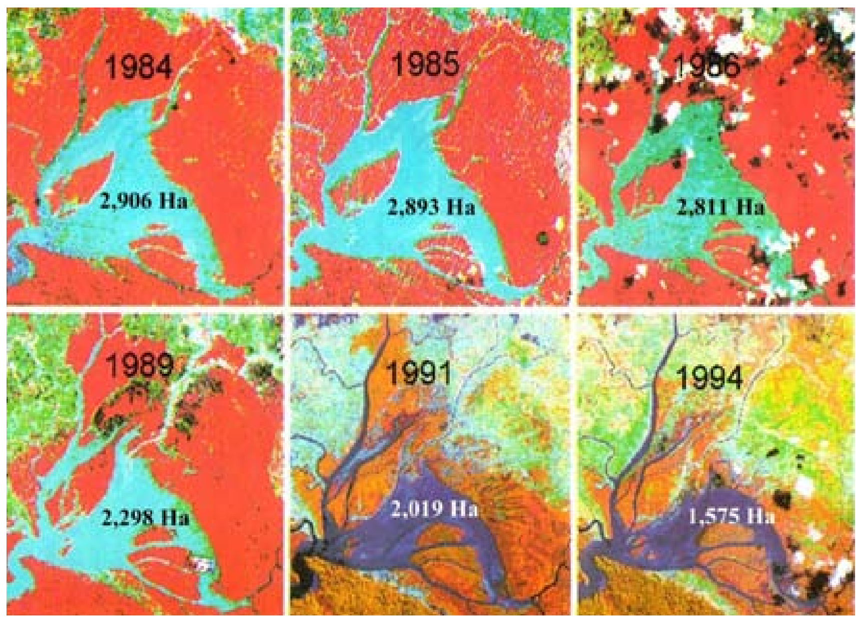
Class 5) Transitional Zone A: This is a transitional zone leading to freshwater swamps, with a small tidal influence. Salinity is 0 ppt, indicating a dominant freshwater environment. This transition zone is frequently dominated by species belonging to genera *Cerbera manghas* and *Oncosperma* spp.

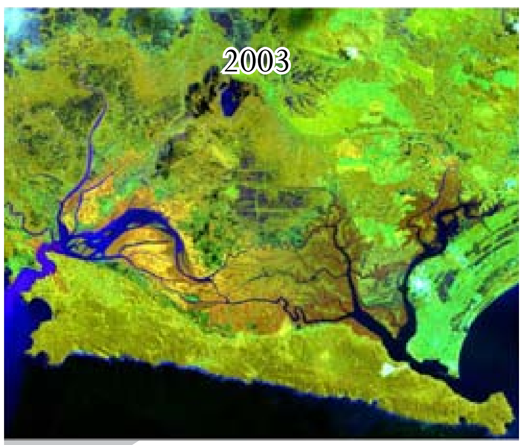
Class 6) Transitional Zone B: Similar to Class 5, but located on higher ground and thus much drier. Salinity is 0 ppt, but affected by water only during the rainy season. Dominant mangrove species *Cerbera manghas* and *Oncosperma* spp.

The team from Bogor, mentioned above, built upon these inundation classes by looking at the ways that tidal levels, soil types, drainage patterns and currents, give rise to dominance of one or two typical and distinct types of mangroves. They defined four types of monospecific stands and seven typical paired mangrove associations in the lagoon, ascribing these types relative dominances (available in "Ecology of the Indonesian Seas" pp. 948-952). We do not, for the time being and for the purposes of discussing the loss of resilience of Segara Anakan's mangroves, need to look at the results of these studies. It is enough to say that these studies and others, provide us with suitable baseline data for the original state of the lagoon.

In comes the disturbance. The mangrove forest together with the estuary and lagoon of Segara Anakan covers an area of about 24,000 hectares. The estuary has experienced heavy silting, due to poor management of upper watersheds on mainland Java. A sedimentation study from 1980 reported 4.5 million tons of sediment deposited in the estuary from the Citanduy river alone (one of four major rivers flowing into the lagoon). It was estimated that if this rate of sedimentation remained constant (it has in fact increased), the lagoon would be entirely filled by 2010, and most mangroves areas would be replaced by other ecosystem types. Shrinkage of lagoon surface area from 2906 hectares in 1984 to 1575 hectares in 1995 is vividly portrayed by Figure 7, depicting the drastic ecological change that has taken place. The 2003 satellite photo shows that nearly the entire lagoon has been filled in, perhaps 500-600 hectares of surface area remaining. Indeed, by 2010, the lagoon may be completely filled.

Figure 7: The Sedimentation of Segara Anakan Lagoon





Segara Anakan lagoon has shrunk in surface area from nearly 3000 ha. in 1984 to perhaps less than 600 ha. present day. A regime change has taken place, as lagoon and mangrove are replaced by freshwater marsh, and scrub forest

This heavy silting not only creates a lot of newly formed land (known as accreted land), but also shoals which change the pattern of tides. Aside from siltation, the mangroves of Segara Anakan have experienced abundant illegal cutting, which has opened gaps in the forest. In 1987 large areas were converted to shrimp ponds, further affecting the biological communities.

The lagoon and the mangrove forests of Segara Anakan, are now, for all intents and purposes, gone. MAP-Indonesia and its partners, realizing the futility of mangrove conservation in the area, are engaged in working with communities to develop alternative livelihoods, and claim newly accreted lands for both sustainable agriculture and wetlands preserves. The emphasis of current development work is to increase awareness and appreciation of lagoon residents towards remaining natural resource, on which their future livelihoods will depend. An Environmental Education program called "Jelajah NUSA" has been created in order to provide youth with a spark of appreciation towards the environment, and the skills and knowledge to make responsible decisions in the future.

Regarding questions of resilience, thresholds and regime shifts, in the case of Segara Anakan, various factors have combined to severely reduce the resilience of the system. Ecologically, the mangroves, for a time, kept up pace with high levels of sedimentation. Pioneering species such as *Avicennia* spp and *Sonneratia* spp. quickly colonized newly accreted lands, while the back mangal slowly gave way to terrestrial species and mangrove associates. These areas in the back mangal were often logged and developed into rice paddies, or aquaculture ponds. The newly accreted lands, once open-access lagoon utilized for fisheries, became state-land. Ecological resilience has since entirely diminished, and the system has crossed a threshold, as will be seen by reading the following articles related to a last-ditch effort to save the lagoon through the implementation of a large-scale dredging project funded by an Asian Development Bank loan.

In terms of social resilience, we can see that Segara Anakan's problems were rooted in larger political and ecological scales. Lagoon management was not, (and still is not) linked with upper watershed management. For decades, since the mid 1980's the problems of cultural sedimentation had been made public by University researchers from both Indonesia and abroad, but managers and law-makers did little to address the issues (poor farming practices on mainland Java) at their roots. The insidious problem of soil loss in the upper watershed also went un-addressed, causing the negative feedback loop of continued conversion of upper watershed forests to farmland. Numerous seminars, studies and articles pointing to the need for immediate erosion control went un-headed, due to government inability to deal with such a large-scale erosion problem on Indonesia's most populated island. With such high populations, change occurs quickly and is difficult to reverse.

The only attempt to remedy the situation was the highly controversial Asian Development Bank dredging and river diversion project presented below. We close this case study with a pair of writings on this project; one written by an aquaculture consultant for the ADB, the other by a pair of Indonesian activists. The presentation of two small articles within a case study has been made to allow the reader to draw their own conclusions about social and ecological resilience. These two articles may prove useful in structuring classroom discussions or role playing exercises on resilience.

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ARTICLE #1 – Unedited
THE CITANDUY RIVER DIVERSION PROJECT
SOME CRITICAL THOUGHTS
By Susi Pudjiastuti and P. Raja Siregar*

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The Asian Development Bank (ADB) is providing financing to the Government of Indonesia for the Citanduy River Diversion Project. The supposed aim of the Project is to preserve the Segara Anakan Lagoon which has a unique and rich marine eco-system. However, the process by which the project has been formulated and negotiated raises serious questions about the ADB's real motives in supporting and promoting the project.

The Segara Anakan is a large lagoon on the south coast of the island of Java in Indonesia. It is situated on the north side of the Nusa Kambangan island, between Cilacap in Central Java and Pangandaran in West Java. The lagoon is connected to the Indian Ocean via the western outlet and smaller connections such as tidal channels towards Cilacap. Two large rivers: the Citanduy and Cikonde supply the majority of the fresh water to the lagoon. A small amount of fresh water is also supplied by smaller rivers. Since the first mapping of the lagoon in the early 1900s, its surface area has continuously declined. The main reason for this is high levels of upland erosion. The fresh water supplying rivers, carry large amounts of sediment and silt into the lagoon. Other important contributing factors are land reclamation and flood control measures. The Segara Anakan has long been the focus of many studies, proposals and projects involving government agencies, international institutions and consultants. Over the years, a variety of proposals have been made for the future use and management of the Segara Anakan (ECI, page 3).

The latest plans - based on two studies (ECI 1994 and BBV 2000) - will ostensibly save the Segara Anakan from being totally filled with sediment from the contributing rivers by undertaking major engineering interventions. The project is being financed and technically supported by the ADB. This paper shows the problems and inconsistencies contained in the proposed engineering interventions and argues for a major review of the threats that Segara Anakan face

The plan and justification. The two latest studies about the Segara Anakan were done by the ECI in 1994, and as a follow-up by Binnie Black and Veach (BBV) in 2000. Both arrived at the conclusion that the Segara Anakan is filling-up because of the sediment brought in by large rivers. They also conclude that there has to be a dredging program and ultimately, the diversion of the Citanduy and Cikonde rivers. Even in reaching these conclusions, both reports contradict themselves and omit facts recorded in other sources. They also do not properly address many potential problems. The diversion of the Citanduy river is planned for early 2002 without an initial trial program of dredging, which was considered a vital part of the plan. In the ECI plan, the justification for the diversions of the rivers is that the Citanduy and Cikonde carry among them almost 100% of the sediment load that is now deposited in the Segara Anakan. By diverting these rivers a large proportion of this sediment can be deposited in the sea. The economic justification for this course of action consists mainly of three elements: the benefit to off-coast fisheries; a proposed aquaculture project; and improved drainage for agriculture areas surrounding the Segara Anakan. It is argued that if the project is not implemented. these benefits cannot be realized for the following reasons :

- As the Segara Anakan fills in, many marine species which use the mangrove and lagoon area as nurseries will be reduced in numbers and thus negatively affect coastal and Lagoon fisheries . If the lagoon is preserved, fisheries can be kept at the present level and even improved.
- The increased salinity of the Segara Anakan makes a large aquaculture project inside the area feasible.
- Direct diversion of the large rivers will improve drainage and decrease flooding upriver. It has to be noted that the report concludes with the fact that if any one of these three benefits cannot be gained fully, the project loses the economic viability. A special focus of the project seems to be the aquaculture component. The ADB claims that it is supporting the project in order to reduce sedimentation in the Segara Anakan Lagoon and that the Project is categorized as an environmental project. However the Project has a component focused on aquaculture by opening 200 hectares (ha) to shrimp ponds.

The ECI report provided the following timetable of activities: from 1994 to 1999, initial annual dredging were to be performed in the lagoon to restore and preserve the shape and size of the lagoon. After this dredging phase (five years) it was to be determined if the environmental requirements and implications of dredging could be addressed. In 1998 and 1999 the Citanduy diversion was to be constructed, but only after it was proved that the mangrove forests could be managed satisfactorily and the dredging program met all the necessary requirements. After that the Cikonde diversion would be undertaken. After all these inte ventions, the report estimates that salinity will be high enough to start the 200 ha aquaculture project. Up until now, no work has been done on dredging. It ap pears that now work shall start directly on the Citanduy diversion, without the initial dredging stage. There are serious doubts about the positive environmental and economic effects of this project as it is planned and proceeding today. These doubts justify an independent and comprehensive review of the project goals, justifications and implementation means.

Environmental impacts

There is no doubt that the project will have a major environmental impact on the Segara Anakan Lagoon and it's surroundings. There is concern that these changes will lead to the destruction of the lagoon environment as it is today. Many indications of major negative impact can found in the ECI and BBV reports :

1. Nutrients

Other than sediments, the large rivers also contribute freshwater and nutrients to the lagoon. Both freshwater and nutrients are needed for the lagoon to function as it does now. The Citanduy alone carries about 75% of freshwater and nutrients into the Lagoon. The ECI Report mentions on page 9: "It is possible to save the Lagoon from the incessant sedimentation and at the same time to destroy its productivity as it now exists. The irony is that the sediment filling the lagoon is accompanied by the nutrients that make the lagoon so productive. " However, the report also attempts to argue that even without the Citanduy input, the nutrients would be sufficient for the lagoon: "… much of the nutrients requirements of the biotic system of Segara Anakan is stored within the system itself " and that freshwater input " merely contribute readily available nitrogen and phosphorus, currently exceeding requirements" (page 19). The truth of these claims is questionable since even nutrients already in the system will one day be exhausted if no there is no regular resupply! In addition, the report mentions that there is no observation of effects on mangroves that would indicate excess amounts if nutrients available (page 33).

2. Salinity

With both rivers diverted, the salinity in the lagoon will rise considerably. At the moment water in the lagoon can be considered brackish at most times with salinity in most parts of the lagoon at no more than 20 ppt during the wet season, and no more than 10-15 ppt in the dry season (BBV, page 42). After diversion, the salinity will double or even triple in places, rendering the lagoon a seawater area. It may also be that the salinity will rise to even higher levels because of increased water temperatures and subsequent evaporation. The possible negative impacts of this increased salinity on the Lagoon and it's habitants is not directly mentioned in the reports. However there are some notable items mentioned which need further clarification to be able to asses the environmental and economic impacts of increased salinity.

On page 25, the ECI Report mentions interactions of species inside the lagoon. It goes on to say that " for instance, many types of shrimp have evolved optimal growth rates at lower salinity levels at certain stages in their life, making them dependent on the inner creek." This could mean that one of the consequences of the river diversion is that many of the shrimp species now present in the lagoon will not be able to live there any more. This will have negative impacts in both the environmental and economic sense. The report discussed extensively laboratory results which suggest that " late juvenile stages of certain shrimp species cannot tolerate very low salinities, whereas young juveniles demonstrate larger tolerances ." It would be interesting to know if this affects commercially valuable shrimp species as well. Also in the ECI Report (pages 18 and 20), there is mention of growth reduction in the mangroves under high salinity conditions. The types of mangroves that grow well in these conditions will also change, in effect, changing the entire ecosystem of the Lagoon. The BBV Report even mentions tested flow scenarios for a "No mangrove scenario, in case that the mangrove loss around Segara Anakan results in the loss of storage volume that presently exists" (page 20). Further, the ECI Report mentions (page 33) that one of the indirect uses of the Segara Anakan is the prevention of saline water intrusion, by maintaining a fresh water wedge on top of the salt water on the coast. It goes on to say that "increased penetration of saline water… may cause far-reaching socioeconomic and ecological impacts." Of course, increased salinity is a very welcome condition for the proposed aquaculture component. This component seems to be extremely important to the ECI consultants since they mention eight times in their report that without the aquaculture component, the entire project will not be feasible from the perspective of Internal Rates of Return (IRR). The plan is to develop a concentrated site with a maximum of 200 ha of brackish water ponds since a greater area " is judged to have a negative impact on the other functions and services of the lagoon mangrove complex " (page 48). However, to improve the outcome of the economic analysis, this area could be increased by up to 70 percent (page 101). The report also mentions the following: "Aquaculture, especially for tiger shrimp, has failed in other parts of Indonesia. Special skills are needed to manage tiger shrimp ponds. It is planned to provide the necessary resources so that failure is avoided in the Segara Anakan" (page 109). This is very correct! Almost all black tiger shrimp farming in Indonesia has failed because of intensive cultures and subsequent overuse and overstocking have resulted in diseases. Pollution has made many ponds unusable for many years to come! Furthermore, these failed ponds mostly had direct access to the open sea whereas the Segara Anakan ponds will contribute to pollution in the Lagoon and eventually poison themselves. Small shrimp pond projects on the south coast work well if they are managed according to traditional methods, but there is no reason to believe that a large 200 ha site in the Segara Anakan would be operated and managed in an environmentally friendly and sustainable manner! It must also be stressed that the EU is getting extremely strict on medications that are permissible in shrimp farming. Economic sense To evaluate the economic sense of the diversion project, the assum tions guiding the project and providing the economic rationale need to be evaluated.

A big question of concern is the urgency with which the river diversion stage, with its associated costs, is being implemented. Dredging and management requirements mentioned in the ECI Report have not yet been implemented (page 106). In addition. according to estimates in the ECI report, the Lagoon should at the present time already be filled completely. However, the lagoon still exists, even if smaller in size than in 1992. An indication of what is happening comes from the BBV report where it is mentioned that already almost 93 percent of all sediment carried by the rivers flow out to sea, and due to a changed lagoon size and coastal shape this amount of sediment may be increasing. Until an equilibrium state is reached (BBV Report, pages 45 and 1), the actual sediment deposition is 500.000 m3 per year (1999) as opposed to 1.000.000 m3 estimated by ECI in 1994 (BBV, page 7). If in fact it is true that there is an equilibrium stage that has almost been reached at this time, there may be time to think about other measures to protect the lagoon than an expensive engineering intervention. If a reduction in fish catches inside and outside the lagoon is taken as an indication that the lagoon is losing it's productivity as it becomes smaller, it must be pointed out that much greater loss in fisheries productivity can be attributed to the use of destructive fishing gear by lagoon and offshore fishermen. This is described in detail in the 1990 report "Coastal Resources Management Project" by the ASEAN-US Cooperative Program on Marine Sciences (pages, 20, 28).

Another important factor is the rapid destruction of mangrove forests around the lagoon by human activity (ASEAN page 19, ECI Report page 21 and 30). The assumed economic benefits of the project through aquaculture must be related to environmental issues. As it is unlikely that black tiger shrimp farming will be successful in the long term, this should not be counted as a project benefit. In addition, marine farm prices have collapsed following the September 2001 WTO attacks and European Union import restrictions. The ECI Report (page 102) mentions that a 10 percent fall in both farmed and captured fish prices will push the IRR below the required 12 percent. Certainly these prices have fallen much more than 10 percent and are expected to remain low.

In looking at offshore fisheries data, it is questionable to use pre-1980 data of 5.000 tons of shrimp and 15.000 tons of fin-fish catches as a base for calculations (ECI Report, page 53). Since a national trawl ban was implemented in 1980, catches have diminished significantly (ECI Report, page 47) and now average about 7.500 tons of fin-fish and 2.000 tons of shrimp. The use of the pre-1980 data casts doubts on the neutrality of the ECI report in its assessment. Also needed is an evaluation of the effectiveness of much cheaper methods to preserve the lagoon, some of which have fewer long-term impacts on the environment. The ASEAN report mentions only agitation dredging and enhanced flushing as methods to preserve the size of the lagoon (ASEAN, page 44). The BBV report also mentions that the Cikonde diversion alone would already have a large effect an the sediment deposits in the Lagoon, without having to construct the much more expensive and environmentally destructive Citanduy diversion project.

Without doubt, an extremely environmentally friendly alternative would be to spend money on preventing the rivers from carrying such large amounts of silt in the first place, which means an effective upriver erosion control program. The ECI report (page 108) devotes a single paragraph to recommend a feasibility study about upland erosion control, but states this is not feasible basin-wide. But how would they know this without the necessary feasibility study?

Alternatives to consider

The following proposals are made:

• A study must be conducted by an independent and neutral entity, supported and accepted by all parties. Current data should be gathered and an assessment made on all possible solutions to Segara Anakan problem.

• Upland erosion control should be considered seriously, as it not only saves the Segara Anakan Lagoon, but also benefits the entire upland watershed areas of the Citanduy and Cikonde rivers. Financing should be made available for these measures..

• Until the erosion control has had positive effects on the filling of the Segara Anakan Lagoon, maintenance dredging (either conventional or agitation) can be performed to maintain the size of the lagoon, or to even enlarge the lagoon back to a suitable size.

• The encroachment of commercial farming and aquaculture on the mangrove and lagoon areas must be stopped.

• Fisheries in the lagoon must be regulated and destructive fishing gears outlawed. No-catch zones, seasonal restrictions, and minimum net mesh sizes should be considered. This must go hand-in-hand with education measures for the fisher folks and increased marine research of the lagoon and offshore fisheries.

• The lagoon should be designated a nature reserve so that disturbances from human activities are reduced and the nursery function of the lagoon can thrive. Together with Nusa Kambangan, the Segara Anakan could from a unique and valuable nature reserve for the southern Java coast. This would eventually be beneficial to local people and communities as a productive fish and shrimp nursery, bird habitat and refuge, and an attraction for visitors from other places.

There is a serious question why the ADB and the government of Indonesia have chosen to divert the flow of the Citanduy river to reduce sedimentation, instead of considering another option that has proved to be successful, namely forest rehabilitation. Forest rehabilitation in upland areas, which had already been completed up to 50 percent, has significantly reduced sedimentation in Segara Anakan. Despite its success, forest rehabilitation was eventually discontinued because of corruption and mismanagement.

Benefits from the project will not go to the local communities or those living up or downstream from lagoon area. The real beneficiaries of the project will be the consultants, project executors (local and national) government officials, commercial shrimp businessmen, and the ADB itself.

ARTICLE #2 – ADB Cancels Segara Anakan Conservation and Development Project - Another Mangrove Habitat Lost

by Charles Angel, Asian Development Bank Aquaculture Consultant

Segara Anakan, sheltered behind the limestone island of Nusakembangan, lies just west of Cilicap, Central Java. In the past 100 years the area of its open waters has shrunk by more than 90% to a mere 500 ha. Degradation of the watershed of the Citunduy River released millions of cubic meters of sediment into the lagoon. The majority of mangroves were destroyed or degraded by poor forestry management and uncontrolled shrimp pond construction. The fisher folk population increased over the years at the same time fisheries production dropped with the shrinking lagoon. Land scarcity and poverty forced farmers higher and higher onto the steep slopes of the watershed, increasing erosion and runoff into the Citunduy. As the lagoon volume decreased, flooding became more severe. Local inhabitants and conservationists realized that something had to be done to save the unique mangrove habitat of Segara Anakan. After extensive studies, the Asian Development Bank provided a $47 million dollar loan to fund a 5 year rehabilitation project. The cost of the project was justified by the value of the coastal shrimp fishery, which is closely tied to the lagoon. The components of the project were intended to address these problems as well as build local management capacity and foster community participation.

The project started in 1997, but serious delays were encountered in both the river diversion and dredging. The dredging contract had to be re-tendered because of corruption while land speculation drove up the cost of the river diversion. Fishers and resort operators in Pangandaran, to the west of Segara Anakan, fearing sediment from the river diversion would impact their fishery and beaches, began to protest this major component. In spite of extensions, these issues could not be resolved and ADB halted its loan last September.

Soon only the channel between Cilicap and Majingklak will remain open and that may close as well. Fishing is no longer a sustainable occupation and the unique culture of the Segara Anakan inhabitants will disappear as fishers are forced to seek alternative employment or migrate to the offshore fishery. The unique wildlife of both Segara Anakan and Nusakembangan Island will be lost. Some say that dredging and mangrove replanting are sufficient to recover the lagoon, but unfortunately these will not work without the river diversion. So much material has to be dredged, that large areas of the lagoon will be raised above sea level. The increasing severity of flooding and deposition has already elevated much of the former lagoon area beyond high tide.

Authors Note: The ADB project was eventually implemented for a time period of seven years. The majority of the project involved dredging of the lagoon, but could not keep apace of rampant sedimentation. The dredging project itself was plagued with corruption at various levels, and caused social friction amongst communities of the lagoon due to inequitable disbursement of compensation. Neither the river diversion projects nor aquaculture were implemented. The Indonesian government ended up owing the Asian Development Bank ???? in loans, while fisheries production of the lagoon continued to drop. Today, only one species of fish is regularly caught in the lagoon by local fisherfolk, who supplement their need for protein in their diet by eating clams known locally as Totok. An increase in clam populations has been noted by the local community, but health issues surround the consumption of filter feeders from this densely populated lagoon, which is subject to both untreated human sewage as well as occasional pollution events/spills from a nearby petroleum refinery.

MANAGING FOR RESILIENCE

Managing resilience requires identifying and managing the critical thresholds that separate desirable states from undesirable states. Knowing the factors that push a system beyond a threshold may be more important than knowing the threshold per se. Once a threshold has been crossed it may be difficult or even impossible to return to a previous state. Thus it is important to understand what it is that moves a system closer to a threshold both if it is to be avoided but also if transformation of the system is a management objective.

The following steps need to be taken by managers interested in managing for resilience in their systems;

- Consider and possibly identify critical thresholds in your system.
- Determine what factors, including potential disturbances, might be pushing your system closer to critical thresholds.
- Develop a list of system attributes that underpin changes in slowly-changing variables, system drivers that can strongly influence the position of thresholds in the system.
- Devise a plan for further understanding and managing critical thresholds and disturbances in your system.

In setting the bounds of the mangrove system it will also be imperative to identify relevant boundaries related to a specific key issue; then a geographic scope and time horizon of that particular issue can be approximately determined."

Some changes in system state are difficult or impossible to reverse as was the case with case study number four on the Segara Anakan Lagoon. In this case, managing resilience perhaps means thinking about the most desirable stable state that managers and local stakeholders would like to see the system in. Continuing with the case in Segara Anakan, a mangrove lagoon is no longer possible. At best, mangroves will continue to exist along major channels which connect to the South Java Sea. Local communities are interested in developing newly accreted lands into both settlements and farmland. There is also current development of Agroforestry demonstrations at the interface between the former back mangal and the island of Nusa Kambangan. Conservationalists are interested in preserving lush fresh water wetland habitat, breeding ground for many species including the endangered Greater Adjuntant. Management in Java is not easy, where there is such a high demand for space and resources, but management is indeed needed so that the future use of existing resources does not turn out the same as the disaster of the previous mangrove system.

MAP-Indonesia currently runs environmental education programs with school-children from the lagoon, learning about upper watershed, wetlands, mangroves, and agro-ecosystems. The hope is that future generations will have a greater appreciation for their natural resources, and demand to be more closely involved in long terms use and protection.

GLOSSARY OF KEY TERMS

Adaptive Capacity: The capacity of actors in a system to influence resilience. In a social-ecological system, this amounts to the capacity of humans to manage resilience.

Alternate State: Identified by a shift in dominant organisms or system structure and a change in the processes that reinforce a particular state.

Cue: A signal within a system that indicates the relative health of the system. Monitoring for cues can help us determine when a system is approaching a threshold.

Feedbacks:
1 - The secondary effects of a direct effect of one variable on another, they cause a change in the magnitude of that effect. A positive feedback enhances the effect; a negative feedback dampens it.
2 - A signal within a system that loops back to control the system. In natural systems feedback can help to maintain stability in a system (negative feedback) or it can speed up processes and change within the system (positive feedback).

Pneumatophores: Roots of mangrove trees that grown through the surface of the mud. They are used to take air into the underground parts of the mangrove.

Propagule: Water-borne fruits and seeds of mangroves often containing food reserves.

Social-ecological system (SES): An integrated system of ecosystems and human society with reciprocal feedback and interdependence. The concept emphasizes the 'humans-in-nature' perspective."

Stable State: A system with stability. Stability being the ability of a system to return to an equilibrium state after a temporary disturbance. The more rapidly it returns, and with the least fluctuation, the more stable it is.

Regime: A set of states that a system can exist in and still behave in the same way - still maintain the same basic structure and functions.

Regime Shifts: When a social-ecological system crosses a threshold into an alternate regime of that system

Resilience: The ability of a system to absorb shocks, to avoid crossing a threshold into an alternate and possibly irreversible new state, and to regenerate after disturbance.

Riparian: Riverside

Siliciclastics – sand, silt and clay

Thresholds: Levels in underlying controlling variables of the system in which feedbacks to the rest of the system change

Tidal Prism: The change in the volume of water covering an area, such as a wetland, between a low tide and the subsequent high tide.

Variables:

Controlling Variables: Variables in a system (such as amount of tidal inundation) which determines the levels of other variables (like mangrove distribution)

Fast and Slow Variables: Controlling ecological variables often tend to change slowly (sediment type and concentration, age structure of mangrove trees) while controlling social variables may be fast (e.x. trend of oil palm plantation development to meet bio-fuel need) or slow (gradual expansion of rural villages into mangrove areas). Slow variables determine the dynamics of the fast variables that are of interest to managers. The fast biophysical variables are those on which human use of systems is based, and the fast social variables are those involved in current management decisions or policies.

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For more information,
please refer to the Resilience Alliance Website:
www.resalliance.org
Also look in the resources section for workbooks on preparing your own resilience assessment.

Check out the Ecology and Society website to access the electronic journal of the Resilience Alliance:
www.ecologyandsociety.org

For more information on mangroves see MAP's website:
www.mangroveactionproject.org

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