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マングローブ林減少による植物資源ミックスの変容 —ミャンマー・エーヤワディーデルタの事例から—

大野勝弘¹⁾・鈴木邦雄¹⁾

Dynamics of Plant Resource Mix Affected by Mangrove Forest Decline -A Case Study in the Ayeyarwady Delta, Myanmar-

Katsuhiko Ono¹⁾, Kunio Suzuki¹⁾

Abstract: Dynamics of plant resources utilization from mangrove forests and home gardens were examined in Ashe Mayari village located on a beach ridge in a coast of the Ayeyarwady Delta, Myanmar. An inventory of useful mangrove and useful non-mangrove plants was compiled based on a literature review and our field survey. And, resource mixes of different functional categories among mangrove plants, non-mangrove plants and other non-plants in the past and present were determined by interviewing with two groups of stakeholders, home garden owners and landless peoples. The plant resources were classified into four groups based on the differences of resource mixes and past mangrove utilization between stakeholders. Two of them have the similar resource mix patterns for both stakeholders, and a portion of its utilization was 1) extremely higher and 2) lower, in comparison with non-mangroves. The patterns of others were different, and a portion of its utilization for the landless was 3) extremely higher, and 4) similar or slightly higher, compared to non-mangroves. Mangrove forests provide a source of housing materials and firewood as a long-term basis for their daily lives. In contrast, home garden is a source of medicine and edible stuff for maintaining their bodies. Because mangrove plants have helped household economies of vulnerable landless people, current decline of mangrove forests have changed their traditional life style, degraded material quality of life, and increased expenditures. On the contrary, home gardens work as the substitution of mangrove forests. Therefore the home garden owners have adapted to decline of mangrove forests by utilizing their garden and high economic resources.

Keywords: home gardens, mangroves, Myanmar, plant resources, stakeholders

緒 言

エーヤワディーデルタの海岸帯にはかつて広大なマングローブ林が存在しており、地域の人々は、マングローブ林産物の恩恵を長期にわたり受けてきた (Ohn, 1992)。しかし、1960年代以降、域外向けの薪炭材利用を目的とした過剰伐採と水田等への土地利用転換によって、マングローブ林の劣化が進み、必要とする資源をマングローブ林から保続・安定的に採集するのは困難となっている (尚後, 1995; Maung Maung Than & Ono, 2005)。

当地におけるマングローブ林の植物資源研究のこれまでの主要なテーマは、次の二つにまとめられる。

第一に、「マングローブ林減少とその原因究明」である。これまでに、マングローブ林の分布と消失場所の調査、材積量算定などが行われ、森林の減少速度や用材の移出入などの実態が把握されてきた (Ohn, 1992; Tin Maung Kyi, 1992; JICA, 2005)。しかし、「人間によるマングローブ林への影響」を解明する研究に比べ、「マングローブ林減少が引き起こした人々の生活変容」を明らかにする研究は少ない。マングローブ林の減少が、地域の人々の生活に困難

をもたらしたとする一般的な議論は多いが、「資源の変化」の「人々の生活文化への影響」に関する具体的な検証がされていない。

第二に、「マングローブ植物資源の役割の解明」である。マングローブ林の構成種と有用種が調査され、資源再生の意義がまとめられている (Ohn, 1992; Tin Maung Kyi, 1992; Win Maung, 1999; Forest Department, 2002; JICA, 2005)。しかし、当地ではマングローブ林の植物と同時に、ホームガーデンの非マングローブ植物も生活文化の中で多彩に用いられており (大野・鈴木, 2004)、複合的な植物の利用体系の中でマングローブ植物資源が果たしてきた役割を明らかにする必要がある。本論文では、こうした、「複数の供給源または資源群から、生態環境と社会経済環境の制約のもと、適応的もしくは戦略的に選択され、最適化された資源の組み合わせ」に注目し、「資源ミックス」と定義して論を展開する。

さらに、村落内部には、植物資源に関する複数の利害関係者が併存しており、「特定資源に対する競合や差異 (佐藤, 2002)」が存在する。また、土地所有や資源の利用権にも相違があるなど、資源ミックス研究においては村落内

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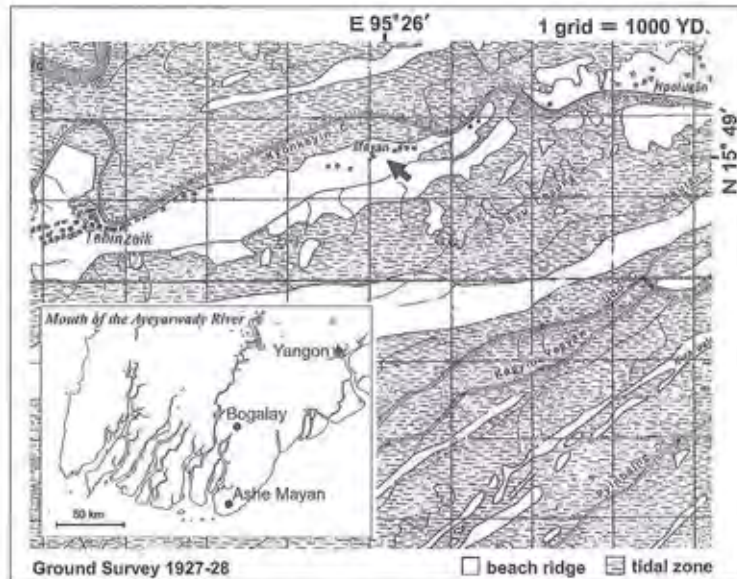


Fig. 1. Map of survey site in Ashe Mayan village, Ayeyarwady Delta.

の重層性も重要となる。

本研究の目的は、村落の人々にとってのマングロブ林およびマングロブ植物の性格と役割を、ホームガーデンの非マングロブ植物を含めた資源ミックスのなかで位置づけることである。そのために、当該地域における資源的利用価値を把握するため、マングロブ植物資源および非マングロブ植物資源のインベントリーを作成し、有用種の用途と種数を明らかにする。次に、マングロブ林の減少による植物資源利用の変容を、利害関係者を区別して明らかにする

研究方法

1. 調査地の概要

Ashe Mayan 村は、1902 年の森林法ですでに集落域とされており、商業地域から遠隔であることから、今日まで長期にわたり生活、文化および生計の多くを、集落内と近傍の植物資源に依拠してきたと考えられることから調査地に選定された。近傍の街 Bogalay までは小型の貨客船で数時間を要し、首都 Yangon まではさらに貨客船で 10 時間流路を遡上する必要がある。

同村は、エーヤワディーデルタの海岸帯（高谷, 1985）に位置する（Fig. 1）。熱帯モンスーン気候区に属し、月平均気温の変動が少なく、年平均気温は約 26°C で、11 月から 4 月の乾季と、5 月から 10 月の雨季に季節が分かれる。

調査地の水文環境を特徴付けているのは、海岸線から内陸に約 20 km にわたって存在する浜堤列である。浜堤上の「陸域」と、浜堤間の「水域」および汽水が及ぶ「潮間帯」の 3 要素の組み合わせが、列の直交方向に数百 m から数 km の幅で繰り返し出現し、海岸帯における地生態的な基準単位としてとらえられる。生物・生態系としては、

浜堤上部の非マングロブ植物からなる植生の生態系と、広大な潮間帯に広がるマングロブ林生態系が、それぞれに対応して存在している。Ashe Mayan 村は、二つの感潮水路に挟まれた浜堤上にあり、家屋は浜堤最上部の道に沿って約 3 km に渡り散在する。家屋と潮間帯の間を埋めるようにホームガーデンが広がり、集落に隣接する潮間帯上部のマングロブ林は水田に、下部はニッパヤシ植林地に転換された場所が多い。

就業構造は、全 110 世帯のうち約半数の土地持ち世帯が、稲作やホームガーデンでのココナツ (*Cocos nucifera*)、ピートルナツ (*Areca catechu*)、ニッパヤシ (*Nypa fruticans*) プランテーションでの屋根葺材の生産を行う。所有地が狭地か土地を持たない世帯は、漁労や村内の賃金労働などで生計を営む (Table 1)。

2. 調査と研究の方法

2003 年から 2005 年にわたり実施したインタビューと参与観察によって、1) マングロブ植物と非マングロブ植物の資源インベントリー作成、および、2) 双方の植物群および非植物の資源ミックスとその時間動態の把握を利害関係者別に行った。被面接者にはキー・インフォーマントとして、古くから受け継がれてきた「植物資源の採集、加工、利用の智慧」が豊富だと考えられる村人 13 名を選んだ。選定に際しては、マングロブ林が豊かであった 1960 年代以前から居住していたか、転入出があっても当時 Ashe Mayan 村に住んでいたこと、および周辺の森林で生業活動を行っていたことなどを考慮した。次に、キー・インフォーマントから、適宜 3 名ないし 4 名からなるグループを構成し、グループインタビューを行った。インタビュー中は、個々の被面接者に発言機会を確保し参加

Table 1 Outline of Ashe Mayan village

Nature datum	Information
Establishment	Before late 19th century
Distance to the nearest town	ca.22 km to Bogalay town, Bogalay township, Pyapon district, Ayeyarwady division
Population/Household	ca.680/ca.110
Ethnic group	Bamar
Public facility	One primary school, one store and two stalls (no monastery)
Subsistence	Rice cultivation: 23%* (avg.: 5 acre**/household) Home garden: 18% (avg.: 2 to 2.5 acre/household) Fish, shrimp and crab catching: 14% Nipa plantation: 5% (avg.: 15 acre*/household) Others: 53% (Small business, permanent or casual labors)
Land ownership	Over 50 households are landless
Home garden products	Coconut, betel nut, betel leaf etc.
Live stock	Duck, chicken, pig, cattle, water buffalo, etc.

*%: Household base, **1 acre = 0.4 ha

Table 2 Functional category of plant resource utilization

	Functional category	Usage
Material resources	Construction	structure and floor material of buildings
	Craft	tool, furniture, non-structure material of buildings, fencing material
	Tying	string, cord, cordage, fishnet
	Roof & Wall	thatch, partition and walling
Non-material resources	Fuel	firewood, charcoal
	Edible	foodstuff, beverage, spice, cooking oil
	Medical & Poison	remedial, preventative drug, poison, rejectant, medical care, detergent, tannin, psychoactive drug and taste material
	Others	decoration, cosmetic, ceremonial and magic, entertainment, game, dye, food-curing, fertilizer, etc.

を促すとともに、被面接者間で相互確認と合意形成がなされた情報を記録した。

対象種

当地のマングローブ林の植物を掲載した「Plants in Myanmar Mangroves (Win Maung, 1999)」の88種をマングローブ植物、その他の種を非マングローブ植物として扱った。マングローブ植物の対象種は、植生調査をもとに周辺のマングローブ林に分布しない種を除き、顔出しながら未掲載の *Stenochlaena palustris* を加えた77種とした。したがって、「必ずしもマングローブ構成種とは言えない非マングローブ種 (中村・中須賀, 1998)」が含まれている。非マングローブ植物の対象種は、ホームガーデンと、これに隣接する耕作地周辺で、植生調査とフロラ調査を実施し、樹高60 cm以上の植物を対象として決定した。

植物資源インベントリーの作成

インタビューにより、対象種の自給的な利用の有無を確認した。また、「利用した」もしくは「利用する」とされた有用種について、樹体の部位ごとに採集、加工および利用の方法を質問し記録した。この際、資源の品質の高低や村人の嗜好性の大小、非植物資源の代替品利用がある場合その情報を記録した。なお、他の地域での見聞や、伝聞から得た知識に基づく回答は除外した。インタビューは、

マングローブ植物については、2003年9月と2004年9月に、非マングローブ植物については、2004年9月と2005年3月および9月に、双方の植物群とも延べ約17時間/4日間実施した。

インタビューの結果を、「マングローブ植物資源」と「非マングローブ植物資源」の二つのインベントリーにまとめた。その際資源の用途は、Phillips & Gentry (1993) の広義分類を基礎に、燃料、建材、工芸材、結束材、屋根葺・張壁材、食用、薬毒用とその他に区分した (Table 2)。

植物資源、非植物資源の選択と利用割合

ホームガーデンを所有する「土地持ち村民」(以下同)と、所有しない「土地無し村民」(以下同)の二つの利害関係者を対照とし、過去および現在のマングローブ植物資源、非マングローブ植物資源、および非植物資源の利用割合を調査した。また、主に利用されたおよび利用する具体的な資源と、その獲得方法を記録した。「過去」とは、マングローブ林の減少が進んだ1960年代以前をさす。

含まれる要素が多様な用途区分については、幾つかの下位の用途区分に分けてインタビューした。具体的には、「工芸材」から「家具」、「食用」から「副食」、「薬毒用」から「医薬」と「毒・忌避剤」を分けている。「副食」用途においては、自給的資源としての「マングローブ植物資源」と「非マングローブ植物資源」の対比が研究の主眼で

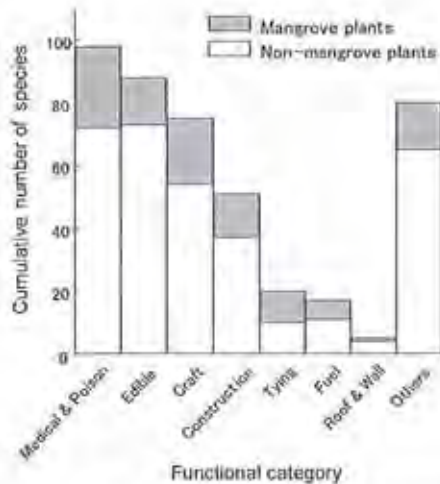


Fig. 2. Cumulative number of useful plant species for eight functional categories.

あるため、「購入する農作物」の利用は除外した。

資源の利用割合は利用頻度の割合とし、その定量化は、「10回中何回利用」、「10個中何個利用」、「10箇所中何箇所利用」など、用途に応じた問答により行った。3つの資源の利用割合を「資源ミックス」とし、過去における、利害関係者間の資源ミックスの同異と、マングローブ植物資源の利用割合により資源を類型化した。

なお、正確には同国では全ての土地は国家が所有し、「私有地」は法的に存在しないが、本論文では「土地と産出物の一定の私的利用」が法的に認められている場合、「土地を所有する」と表現した。

インタビューは、2005年9月に延べ約10時間/3日間実施した。

結 果

1. 植物資源インベントリー

ホームガーデン等における植生調査とフロラ調査から、142種類の非マングローブ植物を区別し121種を同定した。このうち科レベルまで判別された129種の非マングローブ植物に、マングローブ植物77種を合わせた、206種を対象としてインタビューを行った。

その結果、マングローブ植物50種と、非マングローブ植物124種を合わせた174種が、過去に利用されていた、もしくは現在利用されている有用種であった。Fig. 2に8つの用途別の有用種数を示した。用途別の有用種数を合算した延べ有用種数は、マングローブ植物が108種、非マングローブ植物が326種で、1有用種あたりの平均用途数はそれぞれ2.16と2.63であった。マングローブ植物、非マングローブ植物とも、薬毒用、食用、工芸材、建材などに利用されるものが多く、特に薬毒用と食用の非マングロー

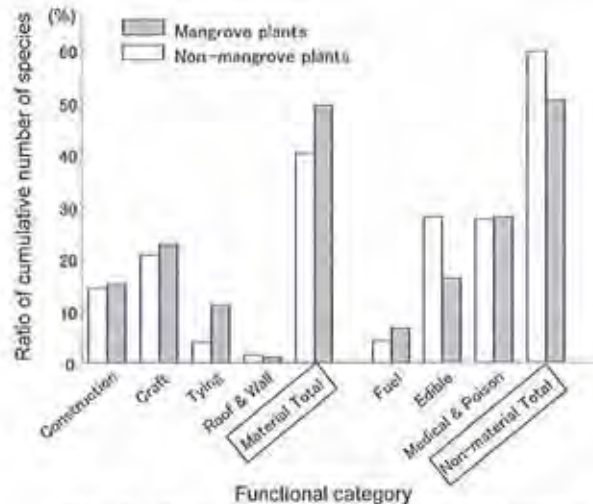


Fig. 3. Ratio of cumulative number of species for functional categories. Ratio to the total cumulative number of species in each functional category are shown. The category of others in fig. 2 is excluded from the calculation.

ブ植物が多かった。

Fig. 3に、マングローブ植物と非マングローブ植物について、それぞれの延べ有用種数に対する用途別の種数の比率を示した。本論文では建材、工芸材、結束材、屋根葺・張壁材用途など、物質的な文化を構成する(Cotton, 1996)資源を「材料資源」とし、燃料、食用、薬毒用途の資源を「非材料資源」として、各用途の合計比率を同掲した。マングローブ植物の材料資源の比率は、延べ有用種数の50%で、非マングローブ植物における40%に比べて高かった。材料資源のうち、特にマングローブ植物の結束材の延べ有用種数に対する比率は、非マングローブ植物の約3倍であった。反対に、食用の非マングローブ植物の種数比率は28%と、マングローブ植物の16%に比べて高かった。

2. 資源の類型化と資源ミックスの動態

1) 資源の類型化

Fig. 4に、用途別の資源ミックスの動態を二つの利害関係者ごとに示す。

過去における資源ミックスを、利害関係者間で比較すると、燃料、建材、屋根葺・張壁材、結束材、医薬の用途においては両者の差異が無かった。このうち、燃料、建材、屋根葺・張壁材においては、過去圧倒的にマングローブ植物が利用されていた。一方、医薬における非マングローブ植物の利用割合は、土地持ち村民ではマングローブ植物の1.5倍、土地無し村民では2倍以上であった。また、毒・忌避剤、家具、結束材、副食の用途においては、利害関係者間の資源ミックスに差異があり、土地無し村民のマングローブ植物の利用割合が土地持ち村民の1.5倍から4倍であった。

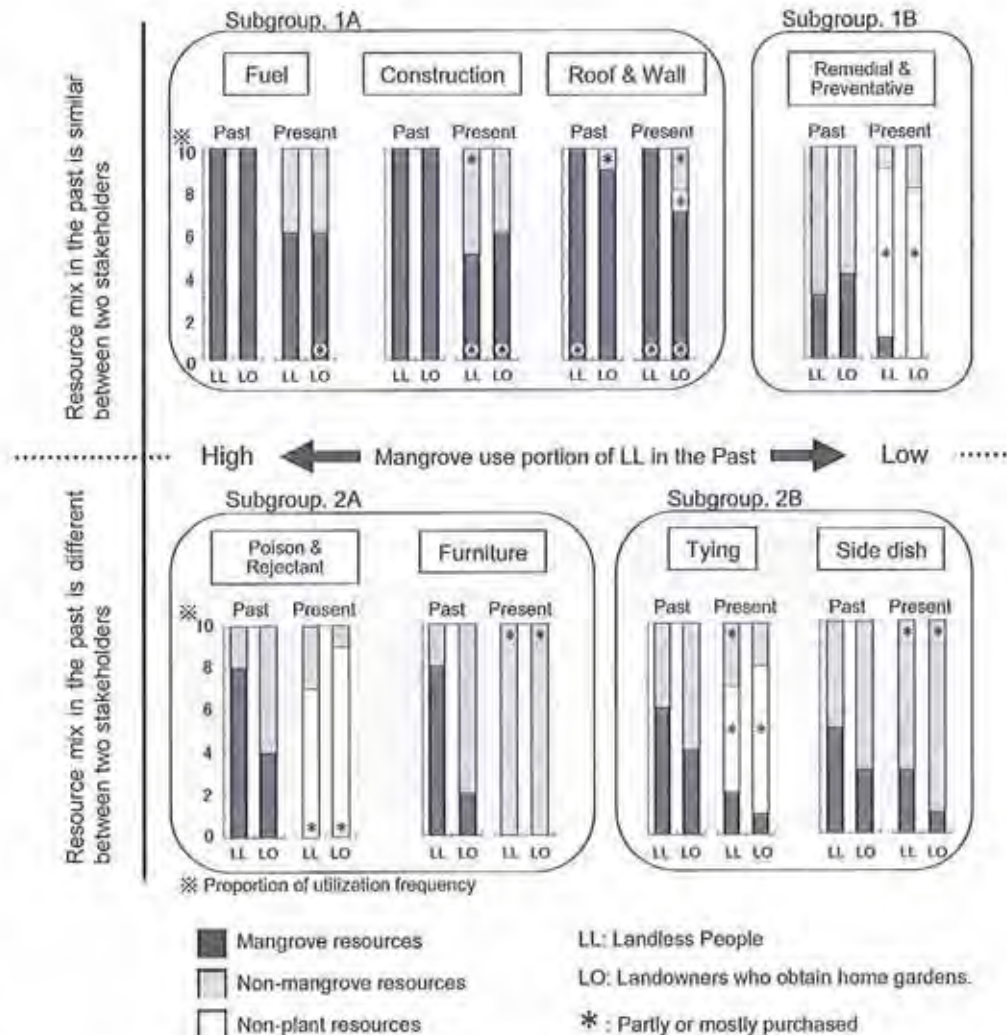


Fig. 4. The dynamics of plant resource mixes for two stakeholder groups.

利害関係者間における二種類の植物資源ミックスの同異と、マングローブ植物資源の利用割合の高低から、資源は4つのグループに区分できた。

Group 1. 過去、利害関係者に関わらず、資源ミックスは同様

Subgroup 1A. 過去、マングローブ植物の利用割合が極めて高い……燃料、建材、屋根葺・張壁材

Subgroup 1B. 過去、マングローブ植物の利用割合が低い……医薬

Group 2. 過去、利害関係者により、資源ミックスが異なる

Subgroup 2A. 過去、土地無し村民のマングローブ植物の利用割合が非常に高い……毒・忌避剤、家具

Subgroup 2B. 過去、土地無し村民の両資源の利用割合が同程度か、マングローブ植物の利用割合がやや高い……結束材、副食

2) 資源の獲得と利用実態の変容

現在、マングローブ植物の利用割合は、土地無し村民が屋根葺・張壁材に用いる場合を除き、利害関係者によらず全ての用途において低下し、毒・忌避剤と家具材には利用されなくなった (Fig. 4)。Table 3に、主要な資源として例示されたマングローブ植物資源、非マングローブ植物資源および非植物資源と、その獲得方法を示した。

1A: 燃料、建材、屋根葺・張壁材

利害関係者に関わらず燃料には、これまで非マングローブ植物はほとんど用いられず、*Heritiera fomes*、*Cynometra ramiflora* など、高木のマングローブ植物の枝条が採集されていた。マングローブ植物は依然として主な燃料であるが、資源の種類と獲得方法は利害関係者間で異なった。すなわち、土地無し村民は低質な *Brownlowia tersa* などを採集し、土地持ち村民は良質とされる *Ceriops decandra* の根を購入していた。また、両者ともホームガーデンの落枝や

Table 3 Specific description of resource mixes and their acquisition method (a) and (b) is for landless people and landowners, respectively.

(a)

		LANDLESS PEOPLE								
Functional category	Time	Mangrove plant resources			Non-mangrove plant resources			Non-plant resources		
		Botanical name	PP*	AM**	Botanical name	PP*	AM**	Resource name	AM**	
Fuel	Past	<i>Heritiera fomes</i>	G	G						
		<i>Cynometra ramiflora</i>	G	G						
		<i>Ceriops decandra</i>	G	G						
	Present	<i>Brownlowia teresa</i>	G	G	<i>Dipterocarpus alatus</i>	G	G			
		<i>Hibiscus tiliaceus</i>	G	G	<i>Cocos nuciferae</i>	B,C	G			
					<i>Melastoma malabathricum</i>	G	G			
				<i>Syzygium oblatum</i>	G	G				
Construction	Past	<i>Bruguiera spp.</i> ⁽¹⁾	G	G						
		<i>Heritiera fomes</i>	G	G						
		<i>Xylocarpus moluccensis</i>	G	G						
	Present	<i>Phoenix paludosa</i>	G	B	<i>Areca catechu</i>	G	B			
					<i>Cocos nuciferae</i>	G	B			
					<i>Dipterocarpus alatus</i>	G	B			
Roof & Wall	Past	<i>Nypa fruticans</i>	C	B						
	Present	<i>Nypa fruticans</i>	C	B						
Remedial & Preventative	Past	<i>Clerodendrum inerme</i>	C	G	<i>Embllica officinalis</i>	B,C	G			
		<i>Merope angulata</i>	B,C,G	G	<i>Tamarindus indica</i>	B,E,H	G			
		<i>Acrostichum aureum</i>	F,G	G	<i>Cassia alata</i>	A	G			
		<i>Caesalpinia bonduc</i>	B	G	<i>Tinospora cordifolia</i>	F,G	G			
		<i>Mussaenda macrophylla</i>	G	G	<i>Cassia fistula</i>	B,D,E,F	G			
					<i>Piper betle</i>	C	G			
					<i>Eupatorium cannabinum</i>	C,G,H	G			
					<i>Eupatorium odoratum</i>	C	G			
					<i>Premna integrifolia</i>	G	G			
					<i>Ludisia discolor</i>	F,H	G			
		Present	<i>Merope angulata</i>	B,C,G	G	<i>Piper betle</i>	C	G	Balm	B
						<i>Embllica officinalis</i>	B,C	G	Antibiotic	B
					<i>Eupatorium odoratum</i>	G	G	Multi-vitamin	B	
								Quinine	B	
								Stomach drugs	B	
	Poison & Rejectant	Past	<i>Sapum indicum</i>	B	G	<i>Derris elliptica</i>	A	G		
			<i>Amoora cucullata</i>	B	G	<i>Cocos nuciferae</i>	B	G		
Present					<i>Derris elliptica</i>	A	G	Fish poison	B	
					<i>Cocos nuciferae</i>	B	G			
Furniture	Past	<i>Xylocarpus moluccensis</i>	G	G	<i>Lagerstroemia speciosa</i>	G	G ²			
		<i>Xylocarpus granatum</i>	G	G						
	Present				<i>Dipterocarpus alatus</i>	G	B			
					<i>Artocarpus heterophyllus</i>	G	B			
					<i>Cocos nuciferae</i>	G	B			
Tying	Past	<i>Stenochlaena palustris</i>	G	G	<i>Spatholobus listeri</i>	G	G			
		<i>Flagellaria indica</i>	G	G	<i>Dendrocalamus brandisii</i>	G	G			
		<i>Hibiscus tiliaceus</i>	G	G	<i>Calamus viminalis</i>	G	G			
	Present	<i>Hibiscus tiliaceus</i>	G	G	<i>Dendrocalamus brandisii</i>	G	B,G	Plastic tape	B	
		<i>Flagellaria indica</i>	G	G	<i>Calamus viminalis</i>	G	B			
		<i>Stenochlaena palustris</i>	G	G						
Side dish	Past	<i>Phoenix paludosa</i>	G	G	<i>Amomum corynostachyum</i>	B,C	G			
		<i>Caesalpinia bonduc</i>	B,C	G	<i>Archidendron jiringa</i>	B,C	G			
		<i>Sarcobolus carinatus</i>	B	G	Kybaung	C	G			
		<i>Sonneratia caseolaris</i>	B,G	G	Tree fruits	B	G			
		<i>Sonneratia apetala</i>	B,G	G	<i>Salacia chinensis</i>	B	G			
		<i>Cayratia trifolia</i>	B,C	G						
		<i>Mussaenda macrophylla</i>	G	G						
		Present	<i>Phoenix paludosa</i>	G	G	<i>Amomum corynostachyum</i>	B,C	B,G		
	<i>Cayratia trifolia</i>		B,G	G	<i>Archidendron jiringa</i>	B,C	B,G			
	<i>Sarcobolus carinatus</i>		B	G	<i>Dendrocalamus sp.</i>	G	B,G			
	<i>Sonneratia caseolaris</i>		B,G	G	<i>Oxytenanthera albociliata</i>	G	G			
	<i>Sonneratia apetala</i>		B,G	G	Kybaung	C	G			
					Tree fruits	B	G			

(b)

		LANDOWNERS							
Functional category	Time	Mangrove plant resources			Non-mangrove plant resources			Non-plant resources	
		Botanical name	PP*	AM**	Botanical name	PP*	AM**	Resource name	AM**
Fuel	Past	<i>Heritiera fomes</i>	G	G	<i>Microcos paniculata</i>	G	G		
		<i>Cynometra ramiflora</i>	G	G					
		<i>Ceriops decandra</i>	G	G					
	Present	<i>Ceriops decandra</i>	F	B	<i>Dipterocarpus alatus</i>	G	G		
		<i>Hibiscus tiliaceus</i>	G	G	<i>Cocos nuciferae</i> (Rice husk)	B,C	G		
Construction	Past	<i>Bruguiera</i> spp. ^①	G	G					
		<i>Heritiera fomes</i>	G	G					
		<i>Xylocarpus moluccensis</i>	G	G					
	Present	<i>Avicennia officinalis</i>	G	B	<i>Cocos nuciferae</i>	G	G		
		<i>Kandelia candel</i>	G	B	<i>Dipterocarpus alatus</i>	G	G,B		
Roof & Wall	Past	<i>Nypa fruticans</i>	C	G	<i>Melocanna baccifera</i>	G	B		
	Present	<i>Nypa fruticans</i>	C	G	<i>Melocanna baccifera</i>	G	B,G	Zinc sheet	B
		<i>Avicennia officinalis</i>	G	B					
Remedial & Preventative	Past	<i>Glerodendrum inerme</i>	C	G	<i>Emblica officinalis</i>	B,C	G		
		<i>Merope angulata</i>	B,C,G	G	<i>Tamarindus indica</i>	B,E,H	G		
		<i>Acrostichum aureum</i>	F,G	G	<i>Cassia alata</i>	A	G		
		<i>Caesalpinia bonduc</i>	B	G	<i>Tinospora cordifolia</i>	F,G	G		
		<i>Mussaenda macrophylla</i>	G	G	<i>Cassia fistula</i>	B,D,E,F	G		
					<i>Piper betle</i>	C	G		
					<i>Eupatorium cannabinum</i>	C,G,H	G		
					<i>Eupatorium odoratum</i>	C	G		
					<i>Prenina integrifolia</i>	G	G		
		Present	<i>Merope angulata</i>	B,C,G	G	<i>Piper betle</i>	C	G	Balm
					<i>Emblica officinalis</i>	B,C	G	Antibiotic	B
								Multi-vitamin	B
								Quinine	B
								Stomach drugs	B
	Poison & Rejectant	Past	<i>Sapium indicum</i>	B	G	<i>Derris elliptica</i>	A	G	
<i>Anoera cucullata</i>			B	G	<i>Cocos nuciferae</i>	B	G		
Present					<i>Cocos nuciferae</i>	B	G	DDT	B
								Agrichemical	B
							Pyrethrum coil	B	
Furniture	Past	<i>Xylocarpus moluccensis</i>	G	G	<i>Lagerstroemia speciosa</i>	G	G		
		<i>Xylocarpus granatum</i>	G	G					
	Present				<i>Dipterocarpus alatus</i>	G	G		
					<i>Artocarpus heterophyllus</i>	G	B,G		
					<i>Lagerstroemia speciosa</i>	G	B		
Tying	Past	<i>Hibiscus tiliaceus</i>	G	G	<i>Spatholobus listeri</i>	G	G		
		<i>Flagellaria indica</i>	G	G	<i>Dendrocalamus brandisii</i>	G	G		
		<i>Stenochlaena palustris</i>	G	G					
	Present	<i>Hibiscus tiliaceus</i>	G	G	<i>Cocos nuciferae</i>	B	B	Plastic tape	B
					<i>Dendrocalamus brandisii</i>	G	G		
Side dish	Past	<i>Phoenix paludosa</i>	G	G	<i>Amomum corynostachyum</i>	B,C	G		
		<i>Caesalpinia bonduc</i>	B,C	G	<i>Archidendron jiringa</i>	B,C	G		
		<i>Sarcobolus carinatus</i>	B	G	Kybaung	C	G		
		<i>Sonneratia caseolaris</i>	B,G	G	Tree fruits	B	G		
		<i>Sonneratia apetala</i>	B,G	G					
	Present	<i>Phoenix paludosa</i>	G	G	<i>Amomum corynostachyum</i>	B,C	B,G		
		<i>Caesalpinia bonduc</i>	B,C	G	<i>Archidendron jiringa</i>	B,C	B,G		
		<i>Sarcobolus carinatus</i>	B	G	<i>Dendrocalamus sp.</i>	G	B,G		
		<i>Sonneratia caseolaris</i>	B,G	G	<i>Oxytenanthera albociliata</i>	G	G		
		<i>Sonneratia apetala</i>	B,G	G	Kybaung	C	G		
			Tree fruits	B	G				

The shaded portion shows the resource group of the most frequent use among three resources groups.

Even though frequency of use was low, the resources expressed by interviewees are indicated in the table.

*: Part of the plant—A: whole plant, B: seeds, nuts or fruits, C: leaves, D: saps, E: bark, F: roots, tubers, bulbs or rhizomes, G: pith, shoots or stems, H: flowers

**: Acquisition method—B: buying, G: gathering for free

① *Bruguiera gymnorrhiza* or *Bruguiera sexangula*. ② Illegal cutting in reserved forests.

Cocos nucifera の中果皮などの非マングローブ植物を副次的に利用するが、土地無し村民はより多種類の植物を採集していた。

建材においても、過去利害関係者に関わらず *Bruguiera* spp. や *H. fomes* など、幹が通直な高木のマングローブ植物が採集されていた。現在土地無し村民は、廉価であるが強度と耐久性に劣る *Phoenix paludosa* などのマングローブ植物と *Areca catechu* などの非マングローブ植物を購入していた。一方土地持ち村民は、やや良質の *Avicennia officinalis* などのマングローブ植物を購入するか、自所に生育する *Dipterocarpus alatus* などの非マングローブ植物を採集していた。

屋根葺・張壁材には、過去、現在とも利害関係者に関わらず圧倒的にマングローブ植物の *Nypa fruticans* が用いられており、土地無し村民は購入、土地持ち村民は採集をしていた。

1B: 医薬

利害関係者に関わらず、過去非マングローブ植物が主に用いられ、主要な資源の数も他の用途と比べ多かった。また、植物体の複数の部位が資源となる植物が多かった。現在は、二つの利害関係者ともに市販薬の利用割合が最も高かった。土地無し村民は、割合は低いものの、現在でも低木のマングローブ植物の *Merope angulata* を採集・利用していた。

2A: 毒・忌避剤, 家具

過去土地無し村民は、マングローブ植物である *Sapium indicum* の果実を採集し、果皮を魚毒として頻用していたが、現在では希少となったため、魚毒を用いず漁労を行うか、市販の薬品を利用していた。一方、土地持ち村民は漁労をほとんど行わないが、過去まれに非マングローブ植物の *Derris elliptica* を魚毒とし、現在農薬を水田やホームガーデンに用いていた。

家具用材として最も高品質の資源は、高木の非マングローブ植物 *Lagerstroemia speciosa* であるが、過去土地無し村民は、主にマングローブ植物の *Xylocarpus moluccensis* や *X. granatum* を採集・利用していた。現在ではマングローブ植物をまったく利用せず、*D. alatus* や *Artocarpus heterophyllus*、*C. nucifera* など、非マングローブ植物の二級品を購入していた。一方、過去土地持ち村民は、ホームガーデンから *L. speciosa* を採集していたが、現在これを購入し、採集や購入する他の非マングローブ植物を併用していた。

2B: 結束材, 副食

過去土地無し村民は、結束材につる性の *Flagellaria indica* や *Stenochlaena palustris* などの強靱性の高いマングローブ植物を主に用い、*Spatholobus listeri* や *Dendrocalamus brandisii* などの非マングローブ植物を副次的に利用していた。

一方、土地持ち村民も同様の植物を用いていたが、非マングローブ植物の利用割合の方が高かった。現在両者ともに、プラスチック製品を中心とした非植物資源の利用割合が最も高いが、土地無し村民のマングローブ植物の利用割合は土地持ち村民の2倍で、これまでと同様の植物が採集されていた。

土地無し村民は、かつて副食にマングローブ植物と非マングローブ植物を同程度に、土地持ち村民は、非マングローブ植物を主に採集・利用していた。主要なマングローブ植物資源の数は、土地持ち村民より土地無し村民の方が多かった。現在両者ともに、マングローブ植物の利用割合は低下し、主に非マングローブの購入や採集を行っていた。主要な非マングローブ植物資源の数は、両者とも過去に比べ現在の方が多かった。

考 察

1. 植物資源と資源供給地の基本的性格

過去における資源ミックスは、マングローブ林が減少する以前の、伝統的な資源の選択・利用状態を表している。資源の用途のうち、グループ1の燃料、建材、屋根葺・張壁材、結束材、医薬においては、利害関係者による資源ミックスの差異は無かった (Fig. 4)。したがって、これらの用途の資源ミックスは、村人にとっての資源の基本的性格を反映している。そこで、植物資源のインベントリー (Fig. 2, Fig. 3, Table 3) と、グループ1の過去の資源ミックス (Fig. 4) から、植物資源および資源供給地としての「マングローブ林」と「ホームガーデン」の基本的な性格と役割を考察する。

非マングローブ植物の有用種は対象とした129種中124種で、その数はマングローブ植物の有用種に比べ2倍以上であり、1有用種あたりの平均用途数もマングローブ植物を上回っていた (Fig. 3)。同様な生態環境にあるベンガルデルタのホームガーデンでは125種の植物資源が、1有用種あたり平均2.5の用途を持つ (吉野・安藤, 1999)。Ashe Mayan 村の非マングローブ植物の有用種数は、これと非常に近似し、平均用途数も2.63とほぼ同等であった。吉野・安藤 (1999) の事例では、区分した用途の数が本研究より多く、土壌保護などの間接的利用を含めるなど方法が相違し、有用種の多用途性を直接比較するのは困難である。しかしながら、エーヤワディーデルタの村人は、ベンガルデルタと同様に様々な植物の特質を把握し、多重的利用の体系を作り上げており、ホームガーデンは生活との結びつきの深い多様な資源の供給地であると言える。

伝統的な社会では、住居、道具、日用品などの物質文化において、野生および栽培植物は必須のものである (Cotton, 1996)。南米やアフリカの伝統社会における植物資源インベントリーでは、このような材料資源の数が、全ての植物の用途数の半数を超えている (Phillips & Gentry, 1993; Medley, 1993; Milliken et al., 1992)。本研究

では、マングローブ植物の材料資源の種数比率は50%と非マングローブ植物より高く、特に結束材においてその差は顕著であった (Fig. 3)。結束材は、日用品や農具・漁具などの製作のほか、住居やフェンスなど構造物にも多用される。また、過去、利害関係者に関わらず、燃料および建材、屋根葺・張壁材などの住居建築資材としてのマングローブ植物の利用割合が極めて高く、現在でも非マングローブ植物を上回っていた (Fig. 4)。マングローブ植物の利用は家屋の柱・梁などの構造材や、棚・棧、壁面・床面など、ほとんどの部材に観察される。したがって、村人にとってマングローブ林は、日常生活の長期的基盤である「住」に関わる材料資源と「食」に関わる燃料の供給地としての基本的性格を持っている。

一方、非マングローブ植物の中では、食用と薬用の有用種が特に多かった (Fig. 2)。また、食用の非マングローブ植物の用途別種数比率は、マングローブに比べて際立って高かった (Fig. 3)。さらに、医薬における非マングローブ植物資源の利用割合は、過去において、ホームガーデンの所有・非所有に関わらず極めて高く (Fig. 4)、主要な資源の数も最大であった (Table 3-a, 3-b)。したがって、ホームガーデンは、村人が「生物としての肉体を維持するための資源 (小林, 1994)」の供給地としての基本的性格を持っている。

2. 村落内の重層性と資源供給地の役割

Ashe Mayan 村では、利害関係者の間で、生業構造、購買力、資源の利用権などの属性が異なる。土地持ち村民の主な生業は、樹木作物の生産を中心としたホームガーデンの経営である。隣接する潮間帯の土地を所有する場合が多く、ニッパヤシの栽培も行う。購買力は比較的高く、所有地に生育する植物資源全般を利用する権利を有している。一方、土地無し村民は、小規模な漁労やカニ採りと賃金労働農業を複合的に営み、購買力は比較的低い。親戚などのホームガーデン内の一角に小さな家屋を建てて住み、土地に生育する植物資源は、地権者の了解のもと利用するか、金銭や労働などの対価により入手しなければならない。

また、利害関係者間の属性の違いは、両者のマングローブ林へのアクセス頻度に差異を生じさせている。土地無し村民は、燃料材やカニの採捕などのため、アクセス頻度が高い。一方土地持ち村民は、燃料材の採集を土地無し村民に行かせ、かつ多様な資源をホームガーデンから得られることから、アクセス頻度は低い。

過去、土地無し村民は伝統的な漁労の魚毒や家具材に、無償のマングローブ植物資源を利用していた (Table 3-a)。一方、土地持ち村民は漁労を生業とせず、家具材には自所の高品質な非マングローブ植物資源が得られた (Table 3-b)。したがって、2A の資源における利害関係者間の資源ミックスの差異 (Fig. 4) は、両者の属性の違いにより生じたと言える。マングローブ林は、社会・経済的に脆弱な土地無し村民の生業を支え、生計を安定・維持さ

せる役割を果たしていた。

結束材は簡単な植物体の加工で得られるため、通常、利用する場所で採集される。その結果、マングローブ林へのアクセス頻度が高い土地無し村民は、過去マングローブ植物資源を頻用していた。また、野生の食用資源の多くは非常食・救荒食であり、食生活への寄与は少ない (Cotton, 1996) が、土地無し村民はマングローブの食用資源を採集する機会が多かった。したがって、2B の資源における両者の資源ミックスの差異 (Fig. 4) は、マングローブ林へのアクセス頻度の差により生じていたと言える。土地無し村民が示した、副食となる主要なマングローブ植物資源の数が、土地持ち村民より多かった (Table 3-a, 3-b) のも、同じ理由によると考えられる。ただし、土地無し村民のマングローブ植物の利用割合が、2A においてほど高くなかった (Fig. 4) のは、彼らも地権者の了解のもと 2B の資源をホームガーデンから採集できたからだと解釈できる。

農漁具の維持に用いる強靱性の高いマングローブ植物の結束材は、土地無し村民の生業活動に役割を果たしていた。また、付随的に採集する食用資源であっても、マングローブ植物資源の無償性は、購買力の低い土地無し村民の生計維持に寄与していたと言える。長期間継承されてきた日常生活空間外での生物資源の採集には、生活の変化と潤いの選択肢としての社会・文化的な重要性がある (松井, 1998; 2004)。マングローブ植物の食用資源利用には、このような意味もあると推察され、今後の研究課題の一つである。

3. 資源利用の変容と利害関係者への影響

マングローブ植物の燃料、建材、家具材の減少に対して土地無し村民は、利用するマングローブ植物の変更と多様化、および非マングローブ植物への依存割合の増加により対応している (Table 3-a, Fig. 4)。低質なマングローブ植物の燃料への変更による薪量の増加と、多様な非マングローブ植物の採集のため、採集時間と労力が増加している。建材と家具材に用いる資源の質が低下し、家屋の小型化と耐久性の低下、および家財の質の低下を招いている。建材と家具材は全て有償となり、家計負担の増加を引き起こしている。一方、土地持ち村民も、燃料を他のマングローブ植物に変更したが、資源の質は高く獲得は購入によっている。また全てをマングローブ植物に依存していた建材は、一部が自所の非マングローブ植物に代替された (Fig. 4, Table 3-b)。利害関係者間のこのような対応の差異は、両者の購買力と、代替資源の利用権の有無により生じている。マングローブ林の減少による燃料、建材、家具材の減少は、経済力が弱くホームガーデンを持たない土地無し村民の、労働や生活に負の変化を招いている。

医薬および結束材において、利害関係者に関わらず非植物資源の利用割合が最も高いのは、購入可能となった工業製品を選択しているためである (Fig. 4, Table 3-a, 3-b)。

また、土地無し村民によるマングローブ植物の利用割合が土地持ち村民より高いのは、無償性や生業への高い適合性を持つ種が存在するためだと言える。一方、毒・忌避剤において非植物資源の利用割合が最も高くなった理由は、利害関係者により異なる。土地持ち村民の場合は、農薬の利用を積極的に選択したことが理由である。一方、生業選択が限られる土地無し村民の場合は、マングローブ林の減少による伝統漁業の消極的な変更による。

副食における利害関係者双方の資源ミックスの変化は、マングローブ林訪問頻度の低下と、果実や葡などのホームガーデンの資源の種類増加 (Table 3-a, 3-b) によると解釈できる。しかし、土地無し村民のマングローブ植物の利用割合は依然土地持ち村民より高く、資源の無償性は現在でも生計維持に意味を持つと言える。

建材や家具材における、資源の減少に対する土地持ち村民の対応は、ホームガーデンの持つマングローブ林に対する資源供給の上での代替機能を示している。彼らの生活の質に劣化が見られないのは、ホームガーデンの代替機能と経済力により、マングローブ林の減少に順応しているためである。

まとめ

- 2003年から2005年にわたり、ミャンマーのエーヤワディーデルタ海岸帯の浜堤上にある Ashe Mayan 村で、マングローブ林とホームガーデンの植物資源利用とその変化に関する調査を行った。マングローブ植物資源と非マングローブ植物資源のインベントリーの作成、過去および現在のマングローブ植物、非マングローブ植物、非植物の資源ミックスを、ホームガーデンの所有・非所有という利害関係者別のインタビューにより把握した。
- 有用種として、マングローブ植物 50 種と、非マングローブ植物 124 種がインベントリーされた。用途別の有用種数を合算した「延べ有用種数」は、前者が 108 種、後者が 326 種で、特に薬毒用と食用の非マングローブ植物が多かった。非マングローブ植物の 1 有用種あたりの平均用途数は 2.63 と、多重的な利用が確認された。
- マングローブ林減少以前の、利害関係者間の資源ミックスの同異とマングローブ植物の利用割合の高低から、植物資源は次の 4 つのグループに区分された。利害関係者に関わらず、マングローブ植物の利用割合が、1) 極めて高かった燃料材、建材、屋根葺・張壁材、2) 低かった医薬、土地無し村民によるマングローブ植物の利用割合が、3) 非常に高かった毒・忌避剤、家具、4) やや高かった、もしくは二種類の植物資源の利用割合が同程度だった結束材、副食。
- マングローブ林の基本的性格は、日常生活の長期的基盤となる住居や燃料の、ホームガーデンは人の肉體維持のための医薬や食料の供給地であった。マングローブ植物の魚毒や結束材は土地無し村民の生業の維持に、家具材や建材、副食材は家計の維持に貢献してきた。
- マングローブ林の減少により、土地無し村民は、生活の質の低下と家計負担の増大、生活様式の変更を余儀なくされた。一方土地持ち村民は、自所の非マングローブ植物資源と経済力を活用し、マングローブ林減少に順応している。
- 今後マングローブ林の減少が進んだ場合、社会・経済的に脆弱な土地無し村民の生活に、さらなる負の変化が起きると考えられる。

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Quantitative and Qualitative Evaluation on Stored Carbons of Mangrove Ecosystems in Chumphon, Thailand

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Abstract: Abundant carbon content and a high carbon accumulation rate were quantitative characteristics of the mangrove mud layer, which was formed by the development of mangrove forests. As a qualitative characteristics, humic acids extracted and determined from mangrove ecosystems showed that mangrove had a relatively high amount of aliphatic component, while deltaic sediments underlying the mangrove mud layer showed a lower content of aliphatic and a higher content of carboxylic component. Humic acid components of the mangrove mud layer resemble to those of paddy soils, ascribed to soil formation with the influence of water. Stored carbons of mangrove ecosystems were not yet progressed in humification. However, aliphatic rich mangrove soils are susceptible to carbon decomposition due to its long chain structure. Land use changes that may cause dehydration should be avoided from the viewpoints of sustaining a certain level of carbon level in mangrove ecosystem.

Keywords: mangrove soils, ¹⁴C dating, carbon accumulation rate, humic acids

Introduction

Mangrove's role as carbon sink has been well documented and reported in the last few decades (Woodroffe et al. 1989; Fujimoto and Miyagi 1993; Matsui 1998, Matsui and Yamatani 2000) because their implication attracted much attention by growing concerns on global warming problems.

Tropical coastal region of the biosphere are the most biogeochemically active regions and represent potentially important sinks of carbon in the biosphere (Twilley et al. 1992). In the previous study, we estimated total stocks of sediment carbon considering stratigraphy of underlying mangrove forest (Matsui and Yamatani 2000). It was then revealed that 1,208 tC ha⁻¹ of carbon were stored to the basement rock at 8.5 m depth. And a significant portion of total carbon was stored in the mangrove mud layer that was formed by the development of mangrove forests. A capacity of storing carbon in the mangrove mud layer was significantly high if comparing to two other sub-layers (shell-dominated sand- and mud layer), which are deltaic sediments formed by terrestrial deposits supplied on the different time of sea-level change.

By adding the results of radiocarbon dating to those carbon stocks, sedimentation rate of each layer can be given to better understand the contribution of mangroves in carbon dynamics of coastal ecosystem. It also gives insights into understanding the time of mangrove development at the study region.

While quantitative aspects of organic carbon in mangroves were studied intensively, qualitative aspects

have not been quite investigated due partly to the difficulty of fractionation of organic matter (=humic) substances. Soil humus is formed immediately after fresh plant debris incorporated into the soil and metabolized by microorganisms. It plays roles not only as nutrient source for plants and microorganisms, but also as a slow-acting fertilizer due to its high cation exchange capacity. The quantity and quality of humic component are determined by environmental factors like soil temperature, soil moisture regime, vegetation type and clay contents. Moreover, humic component is positioned in dynamic equilibrium, whose components determined on the balance between input of fresh organic matter and output through humification. Composition of humic acids could indicate environmental condition under which humic acids were formed and source of organic matter from where humic acids derive. Thus studying of humic acid may provide another insight to understanding about how carbon stored by the influence of mangrove and also about the fate of organic matter accumulated by forests.

Adsorption chromatography using nonionic macroporous resin Amberlite XAD-8 made possible to separate into 4 different components which are 1) aromatic rings with short aliphatic substituents and many carboxyl groups, 2) phenolic groups, 3) relatively long aliphatic chains and 4) aromatic rings with long aliphatic substituents (Yonebayashi and Hattori 1990). With this developed separation technique, we attempted to clarify humic components of mangrove soils for understanding qualitative aspects of mangrove organic matter.

As described in the above, this study has the objectives

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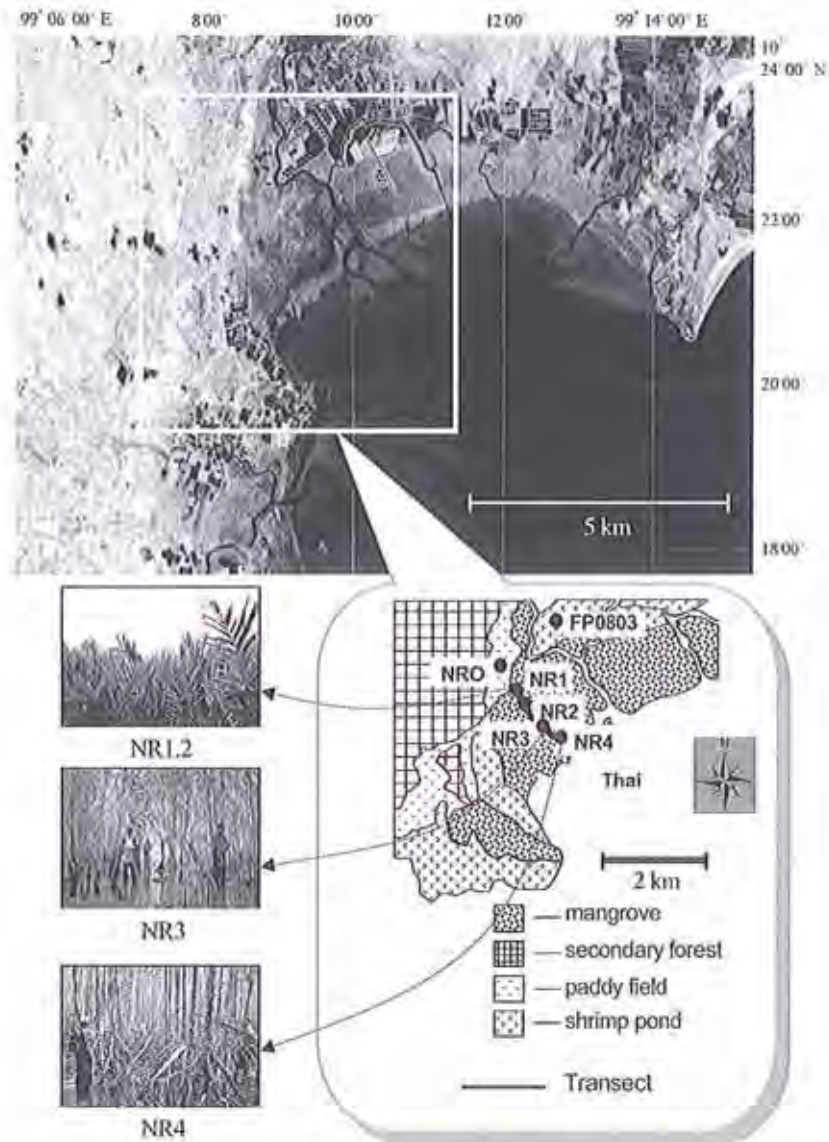


Fig. 1. Locations of sampling sites

1) to understand quantitatively carbon stocks in mangroves from the viewpoints of space and time, 2) to clarify characteristics of mangrove humic acids comparing to those of other ecosystem, and 3) to consider proper carbon management in tropical coastal ecosystem judging from qualitative and quantitative characteristics of mangrove carbons.

Materials and methods

1. Study site

The transect across different mangrove zones was made in Tungka Bay, Chumphon, Thailand (Matsui and Yamatani 2000). 4 sampling points (NR1-NR4) were established in mangrove areas along the transect, and

2 point (NR0, FP0803) were made in paddy field, and in abandoned shrimp pond, respectively (Fig. 1). Study site was affected by anthropogenic activity, especially by shrimp aquaculture. There were some traces of human activity even in the midst of mangrove forests (NR3, NR4). In NR1, NR2 located nearby the village, conversion from natural mangrove ecosystem is significant. In which a high frequency of cutting trees from 1980's made changes into *Acrostichum* spp. dominated field.

Relative dominance of mangrove species was measured in each sampling point. In the plot of 10 x 10 m, diameter and tree height of each specie were determined after the species identification.

Table 1 Information on the samples for radiocarbon dating analysis

Site	Layer	Code no.	Depth*	Type of sample	Pre-treatment
NR1	Mangrove mud	Beta-150281	105-115	organic sediment	acid washes
NR2	Mangrove mud	Beta-147659	100-104	organic sediment	acid washes
	Shell dominated Mud	Beta-147660 Beta-147661	400-404 530-540	organic sediment shell	acid washes acid etch
NR3	Mangrove mud	Beta-150282	105-112	organic sediment	acid washes
	Shell dominated Mud	Beta-150283 Beta-150284	385-393 535-542	organic sediment organic sediment	acid washes acid etch
	Mangrove mud	Beta-147663	174-176	shell	acid etch
NR4	Shell dominated Mud	Beta-147665 Beta-150285	387 700-710	shell organic sediment	acid etch acid washes

*Depth where the sample was taken

2. Methods

2.1 Soil sampling and measuring soil properties

Soil samples were collected by Soil Check Simplification Consortium (SCSC). SCSC is the boring machine equipped with engine, developed for collecting undisturbed soil samples from the deeper depths. Three phase distribution, bulk density were determined from undisturbed soils removed by 100cc stainless cylinder. EC was measured from 0.5 ml of pore water diluted 20 times by adding distilled water with TOA Electronics, Conductivity meter TOA CM305. Total carbon and nitrogen were measured by combustion method at 800 °C using a Sumitomo-Kagaku sumigraph NC-800-13N.

2.2 Determination of radiocarbon dating and sedimentation rate

Table 1 shows sample information for ¹⁴C dating referring the depth of sample collection and determination method.

For the radiocarbon dating, two different types of samples were used. One is shell, which was pre-treated by acid etch, then measured by AMS (Accelerator Mass Spectrometry) method. Shell is likely to be ideal sample since it is autochthonous fossil showing more accurate time of sedimentation wherein shell is buried. Not large amount of shell were obtained in the sampling, however radiocarbon dating was possible since AMS method requires just a few grams of sample. Another is organic sediment, pre-treated by acid wash, measured by radiometric-standard method, which is standard method being widely used in radiocarbon dating.

Sedimentation rate was calculated from the results of radiocarbon dating for the mangrove mud layers previously identified by stratigraphic survey. For which samples were collected just above the boundary of each layer in order to know the starting time of each layer formation (Fig. 2).

2.3 Humic acid determination

Humic acids were determined from the samples of the mangrove mud layer (NR2, NR3, NR4 0-5), the shell dominated layer (NR4 305-310) and the mud layer (NR4 490-495), and from paddy field (NR0) and abandoned shrimp pond (FP0803).

Followed to fractionation method of Yonebayashi and Hattori (1990), humic components were separated as follows. Amberlite XAD-8 resin was pulverized and the 50-200µm range was isolated. The sieved particles were washed with ethanol, acetonitrile, again with ethanol, and packed into a column (20cm × 1.8cm i.d.) which was conditioned with 0.1 M sodium hydroxide followed by the universal buffer taken to pH 3 with sodium hydroxide. Humic acid was dissolved in 0.1 M NaOH and treated with Amberlite IR-120 resin to make the H⁺-saturated form. Five mg of humic acid dissolved in 2 ml of aqueous solution was loaded onto the column packed with XAD-8 resin. A pH-gradient solution was prepared by titrating 200 ml of 0.02 M universal buffer, contained in an air-tight flask, with 0.1 M NaOH using a peristaltic pump, and passed through at a flow rate of 1.5 ml min⁻¹. The pH of the column effluent was measured with a pH electrode. A water-ethanol gradient was generated by mixing 200 ml of distilled water, contained in an air-tight flask, with ethanol using a peristaltic pump. Elution was at a flow rate of 1.5 ml min⁻¹. The elution profile was determined by measuring the optical density at 400 nm after the effluent was alkalinized above pH 12 by addition of 10 M NaOH. Stepwise elution was run with universal buffer solutions adjusted to pH 7 and pH 11, distilled water, and 50 % ethanol. The elution profile was determined in the same way as for the pH gradient chromatography. Each effluent was precipitated with sulfuric acid and dissolved in 0.1 M NaOH. Since the humic fraction eluted at pH 7 was not precipitated by acidification, it was adsorbed on a small XAD-8 column at pH 3 and eluted with the NaOH solution. Each of the four eluates was dialyzed against distilled water and freeze dried.

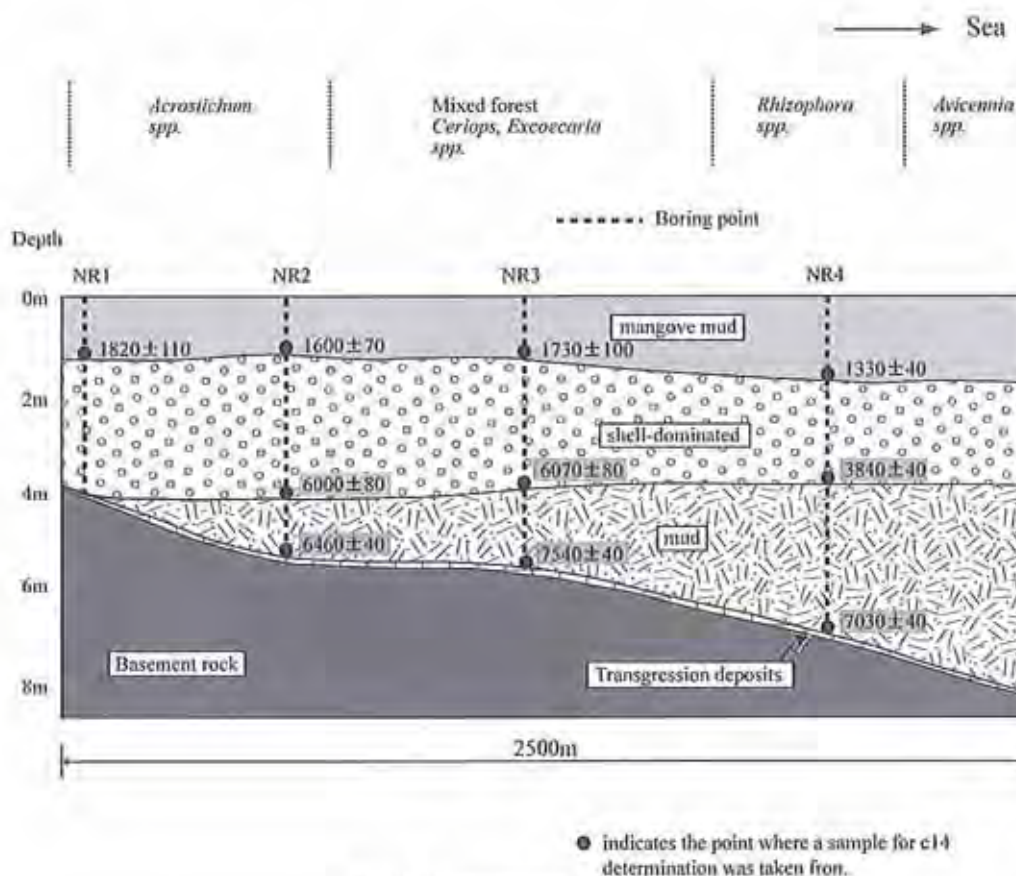


Fig. 2. Stratigraphy of the studied soils

Table 2 General characteristics of the studied soils

	Soil depth (cm)	Three phase distribution (%)			Bulk density (g/ml)	Root debris ¹⁾ (%)	EC (dS/m)	Total-C (%)	Total-N (%)	CN ratio
		Air	Liquid	Solid						
FP 0803	0~5	8.4	36.4	55.2	1.44	0.29	0.48	0.52	0.04	14.7
NR0	0~5	44.4	14.6	41.0	1.12	0.28	3.49	0.38	0.02	16.0
NR1	0~5	18.8	58.2	23.0	0.56	0.76	37.5	9.64	0.62	15.6
NR2	0~5	16.9	69.7	13.4	0.29	0.98	40.0	14.2	0.87	16.3
NR3	0~5	11.1	65.2	23.7	0.58	2.17	45.0	3.41	0.18	18.9
NR4	0~5	15.4	64.6	20.0	0.48	1.16	39.4	4.84	0.22	22.1
NR4	305~310	9.0	46.2	44.9	1.21	0.03	48.4	0.79	0.02	33.0
NR4	490~495	4.4	48.4	47.2	1.25	-	52.6	1.13	0.02	51.2

¹⁾ - (minus) indicates no root debris was collected.

Results

1. Vegetation characteristics in the sampling points

In the each sampling point, mangrove species composition was determined. For arboreal composition, *Excoecaria agallocha* occupied 100% in NR1, NR2. The total D2H of NR1, NR2 were 3.9 and 22.9, respectively. For forest floor vegetation in NR1, NR2, >90% was occupied by *Acrostichum spp.* In NR3, relative dominance was *Excoecaria agallocha* 69.7%, *Ceriops tagal* 30.3% with total D2H of 263.7 and 114.9, respectively. *Rhizophora apiculata*,

Rhizophora mucronata were present in NR4 with a relative dominance of 90%, 10%, and with total D2H of 421.5 and 46.8.

In NR1, NR2, *Acrostichum spp.* were notably extended in the area. *Acrostichum spp.* normally distribute in small area, however distribution in this area had more than a few ha which is quite unusual (personal communication with Prof. Dr. Suzuki, Yokohama National Univ.)

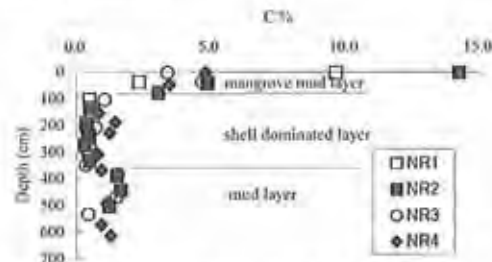
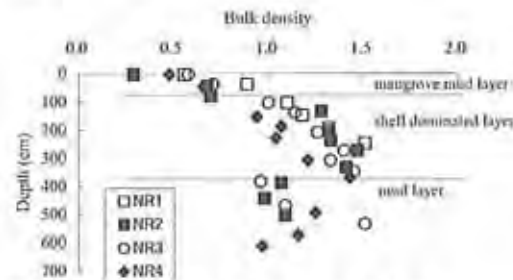
2. General characteristics of soil properties

Non-mangrove soils were characterized by a low

Table 3 Results of radiocarbon dating analysis

Site	Layer	Depth ^a	Measured ¹⁴ C age (yr BP)	δ ¹³ C (‰)	Conventional ¹⁴ C age (yr BP)	Sedimentation rate (mm/yr)
NR1	Mangrove mud	105-115	1820±110	-25.00	1820±110	0.60
NR2	Mangrove mud	100-104	1610±70	-25.70	1600±70	0.63
	Shell dominated Mud	400-404	6020±80	-25.90	6000±80	
NR3	Mud	530-540	6070±40	-1.40	6460±40	0.62
	Mangrove mud	105-112	1730±100	-24.40	1730±100	
	Shell dominated	385-393	6080±80	-25.90	6070±80	
NR4	Mud	535-542	7530±40	-24.20	7540±40	1.32
	Mangrove mud	174-176	1020±40	-5.80	1330±40	
	Shell dominated	387	3400±40	1.80	3840±40	
	Mud	700-710	7050±40	-26.20	7030±40	

^a Depth where the sample was taken

**Fig. 3.** Changes of C% in the depth**Fig. 4.** Changes of bulk density in the depth

EC value (Table 2). However, abandoned shrimp pond (FP0803) showed even lower EC, indicating that salts were washed away after the abandonment of shrimp pond. The studied abandoned shrimp pond was located away from tidal influence. Therefore, precipitation may have lowered salinity without additional salt input from seawater after the abandonment in 1980's.

Surface soils in the mangrove areas showed a relatively high content of organic matter comparing to non-mangrove areas such as abandoned shrimp pond (FP0803) and paddy field (NR0) (Table 2, Fig. 3). This fact would indicate a comparatively high organic matter productivity of mangrove ecosystem. In *Acrostichum* area (NR2), total carbon showed a highest value, 14.2 %. Since the other *Acrostichum* area (NR1) also had a high total carbon content, it is plausible that *Acrostichum* area is capable to produce a high organic matter. Low carbon content in abandoned shrimp pond (FP0803) where it was mangrove

before 1980's may indicate that a decline of carbon content was caused by land use change. As a large part of mangrove was converted into shrimp pond in the study area, a significant amount of carbon was certainly lost from coastal ecosystem.

CN ratio of topsoil tends to decrease seawards from NR1 to NR4 (Table 2), and from the upper layer (NR1 0-5) to lower layer (NR4 490-495). Since biological activity generally lowers CN ratio, this tendency indicates higher biological activity in inland zone and in the surface layer.

In general, sub-layers (the shell dominated layer, the mud layer) were more compacted comparing to the mangrove mud layer as shown in a relatively high percentage of bulk density and solid phase (Table 2, Fig. 4). In the sub-layers, the mud layer was less compacted as was shown by bulk density (Fig. 4). This fact might be related with higher carbon content of the mud layer (Fig.

Table 4 Carbon stocks (tC ha⁻¹) and carbon accumulation rate (tC ha⁻¹ year⁻¹)

Layer	NR1		NR2		NR3		NR4	
	Stocks	Accum.rate	Stocks	Accum.rate	Stocks	Accum.rate	Stocks	Accum.rate
Mangrove mud	370	0.21	440	0.35	373	0.22	553	0.50
Shell dominated			245	0.12	305	0.11	332	0.27
Mud			104	0.14	109	0.10	162	0.15

3). Carbon content was higher and bulk density was lower in the mud layer comparing to the shell dominated layer (Fig. 3).

3. Radiocarbon dating

The mud layer started to form around 6460 - 7030 ¹⁴C B.P as were shown in the radiocarbon dating of the mud layer bottom (NR2, 6462; NR3, 7540; NR4, 7030 ¹⁴C B.P.) (Table 3), the mud layer formed. As Fujimoto et al. (1999) reported the first regression occurred before 7200 year B.P in the Southwestern coast of Thailand, the mud layer could be formed during the transgression period.

The organic-rich mangrove mud layer has started to deposit around 1330 - 1820 years B.P. These quite resembled with the reported times in the Southwestern coast of Thailand (Fujimoto et al. 1999). Sedimentation rates of the mangrove mud layer were quite similar except for one of NR4 (Table 3). The higher sedimentation rate at NR4 in *Rhizophora spp.* is supposedly due to the location since NR4 situated most seaward.

If comparing carbon dating results among the different locations in the mangrove mud layer, sedimentation is likely to start earlier in inland than offshore. This would agree to the belief that mangrove ecosystem is developing into the direction of offshore. Moreover, quite different carbon accumulation rate of topsoil among the locations shall reflect different forest productivity depending on mangrove species (Table 4).

Carbon accumulation rate was relatively high in the mangrove mud layer and the highest in the zone of *Rhizophora spp.* (Table 4). Since the formation of the mangrove mud layer was greatly affected by mangrove forests, its vigor productivity contributed to higher carbon accumulation rate comparing to underlying sub-layers (the shell dominated layer and the mud layer).

4. Characteristics of humic acids

The distribution of humic acid components was illustrated in a three-axial diagram (Fig. 5). In order to compare mangrove humic acids with ones of other ecosystems, the data was cited from the study conducted by Yonebayashi (1992). From the viewpoints of humic substances distribution, topsoils of NR0, NR1, NR3 and

NR4, which belong to the mangrove mud layer, were grouped into the same group. Carboxylic content in mangrove humic substances was between paddy soils and volcanic soils, and aliphatic content was relatively high. These facts indicate that humification of mangrove humic substances were not so yet progressed. Mangrove ecosystem is generally influenced by tidal water so that humification is retarded from progressing.

NR2 was notably characterized by a quite high amount of semi-aliphatic and aliphatic component, which resembled to chemical characteristic of sea-bottom or lake-bottom sediments. Highly dominance of *Acrostichum spp.* in NR2 and high organic matter content in surface soils may have influenced to this humic composition, but the exact reason still remained unclear.

In NR4, carboxyl components were higher and aliphatic components were lower in the sub-layers. An increase of carboxyl and a decrease of aliphatic components, are related with structural changes caused by humification process. If dehydration occurs, demethylation proceeds in aliphatic components, increases carboxyl which is resistant component, hence advances humification. Sediments of sub-layers were supposed to be transported from the land, partly incorporated with marine origin deposits. Terrestrial organic matter is susceptible to humification since terrestrial condition is generally drier than aquatic condition. Humic components in the sub-layers therefore were rich in carboxyl components and less in aliphatic components. In an abandoned shrimp pond, FP 0803 where water is stagnant inside the pond, humification did not occur strongly due to its prolonged wet condition.

Aliphatic rich mangrove soils are susceptible to decomposition. Change of land use such as conversion from mangrove to shrimp pond may cause structural changes of mangrove humic components. Specially, aliphatic components are easily broken by microbial activity since it holds a long aliphatic chain in their structure (Yonebayashi 1992). Carbon decomposition will be accelerated by a decrease of moisture regime and by an increase of soil temperature. Therefore, it is worth studying a fate of mangrove organic carbons caused by land use change, with water/soil condition monitoring

from the viewpoints of humic substances,

Acknowledgements

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- 松井 直弘¹⁾・小崎 隆²⁾: タイ国チュンボン県のマングローブ生態系に蓄積した炭素の定量的, 定性的評価
- マングローブとその隣接した生態系の合計8地点から土壌中の腐植酸を抽出し, その特徴を明らかにした. マングローブ泥層は他の層に比べて蓄積炭素量が多く, 脂肪族性の腐植酸が多く含まれていた. 一方, マングローブ泥層下部のデルタ堆積物層では脂肪族性腐植酸が少なく, カルボキシル性腐植酸が多かった. マングローブ泥層が水田土壌に近い腐植酸構成を持っていることから, マングローブ泥層が水の影響を強く受けて生成されたことがわかった. 長期的に水が停滞する地点ではミミモチシダが繁茂しており, 土壌中腐植酸は海底や湖底の堆積物に近似した, 脂肪族性腐植酸に富む腐植酸構造を示した. 脂肪族性腐植酸は長側鎖構造を持っていることで好気的な環境下で分解されやすい特徴を持っている. そのため水分率を低下させ, 土壌を酸化的環境に導く土地利用はマングローブ生態系から多量の炭素を消失させる可能性がある.

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Tidal deformation and inundation characteristics within mangrove swamps

Yoshihiro Mazda¹⁾ and Kentaro Kamiyama²⁾

Abstract: Based on the field measurement of tidal elevation in mangrove areas and estimated astronomical tides in open sea, the tidal deformation in mangrove swamps was formulated quantitatively. Furthermore, considering that the physiology and ecology of biota in mangrove swamps are influenced by the water inundation with tidal periods through many decades, the statistical tidal characteristics in the swamp were analyzed, based on the above formulation.

It was found that the frequency of tidal inundation, tidal inundation duration and exposure duration in mangrove swamps vary seasonally over a wide range, corresponding to the seasonal changes in tidal condition and the mean sea level in the adjacent open sea. And, the field measurement showed that the tidal level in mangrove swamps deforms greatly from that in the adjacent open sea. The magnitude of the deformation was formulated using the parameters, the distance from the creek bank, the water depth at high tide and the vegetation condition. Based on these data analyses, it was shown that the tidal inundation duration needs to be modified significantly from that in a case without deformation. Further, it is noted that the deformation characteristics in mangrove swamps varies considerably between regions and between topographies of swamps.

Keywords: Mangrove, Tidal deformation, Statistics, Inundation duration

1. Introduction

Mangrove ecosystems are established as a result of feedback processes between coastal landform, water flow, atmosphere and biota itself through many decades (Snedaker and Snedaker, 1984; Vannucci, 1989). The total and partial feedback processes between these individual factors are schematically represented in Fig.1. For example, biota such as trees, benthos and algae in mangrove forests receive salt water, nutrients and dissolved oxygen through tidal inundation; in other words, the growth of biota in mangrove forests is stimulated and restricted by tidal inundation. On the other hand, the tidal inundation and flushing are controlled or strongly influenced by the drag and viscous forces of thickly vegetated mangrove trees/roots (Mazda *et al.*, 1997; Mazda *et al.*, 2005) and by the permeability of animal burrows under the ground (Ridd, 1996; Mazda and Ikeda, 2006), which vary with vegetation/population density. Change in density of mangrove trees causes the change in magnitude of tidal inundation. The change in tidal inundation feeds back to the change in density of mangrove trees. However, the physiology and ecology of biota cannot respond instantly to the tidal change, which repeats with a period of one year in a statistical sense, but follow the statistical tidal inundation characteristics gradually through many decades.

Watson (1928) recognized a correlation between tidal inundation and the species zonation of mangroves in

Malaysia. And he developed a zonation model composed of the site elevation and the tidal height. Snedaker (1989; further, personal communication) has also pointed out the importance of the statistical tidal information such as the frequency of tidal inundation, the tidal prism volume, the inundation duration and salinity for the growth of mangrove forests. Lewis (2005) has also recently described the importance of these same factors in controlling mangrove zonation and attempts to restore mangroves. Dr. Otto Dalhaus (personal communication) lasts laboratory examination about the dependence of the growth of mangrove seedlings on the inundation duration and salinity.

However, these relationships have not been quantitatively formulated, resulting in that the Watson's model has not been in practical use. In order to develop their ideas for practical use, at first, the tidal inundation characteristics in mangrove forests should be quantitatively understood.

In this article, we analyze particularly the characteristics of tidal inundation duration in mangrove forests, based on our field measurement in a mangrove forest and statistical features of the tidal elevation in open sea as an input into mangrove forest.

2. Sea level change in open sea as an input into mangrove swamp

2.1 Tidal and seasonal changes in sea level in various regions

Though the tidal water inundating mangrove swamps

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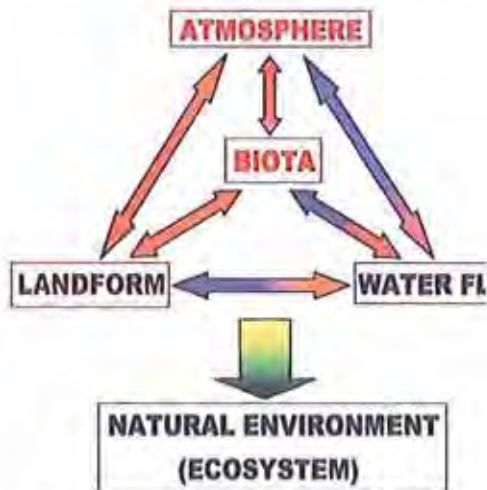


Fig.1. Feedback process in mangrove ecosystem.

from open sea is deformed due to drag and viscous forces of mangrove vegetation and landform or local topography (Mazda *et al.*, 2005), at first we need to understand the original feature of tidal motion in open sea as an input.

Figure 2 shows different tidal conditions in three coastal water areas, the mouth of Aira Gawa, Iriomote Island, southernmost Japan (Fig.2a), the mouth of Chone River, middle Ecuador (Fig.2b), and the offshore area of Can Gio, Vietnam (Fig.2c), adjacent to mangrove swamps, respectively. These time series plots of tidal level are estimations calculated using harmonic tidal constants. The seawater moves with tidal periods vertically as a tidal elevation and horizontally as a tidal current.

Due to astronomical force and latitudinal- topographical conditions the tidal motion has several periods of ca. 24 hours ($K_1=23.93$ hours; $O_1=25.82$ hours; $P_1=24.07$ hours; $Q_1=26.87$ hours; $S_1=24.00$ hours) and ca. 12 hours ($M_2=12.42$ hours; $S_2=12.00$ hours; $N_2=12.66$ hours; $K_2=11.97$ hours). Among these components, K_1 , O_1 , M_2 and S_2 are called the dominant tidal components. Both the amplitude and phase of each tidal component are different between locations of observation sites.

Generally, due to the characteristics of the dominant tidal components, both the high and low tide levels change tide by tide (see Fig.5a), resulting in that the duration of flood phase is different from that of ebb phase, which is called the tidal inequality, furthermore the timing of the high tide shifts by ca. 50 minutes every day (Ippen, 1966). In mangrove areas, it is usual that the tidal flow stagnates at high and low tides, and commences inundation into swamps around at middle of flood tide, as seen in Fig.5b. Though these tidal oscillations are roughly symmetrical between flood and ebb tides in offshore areas, they are

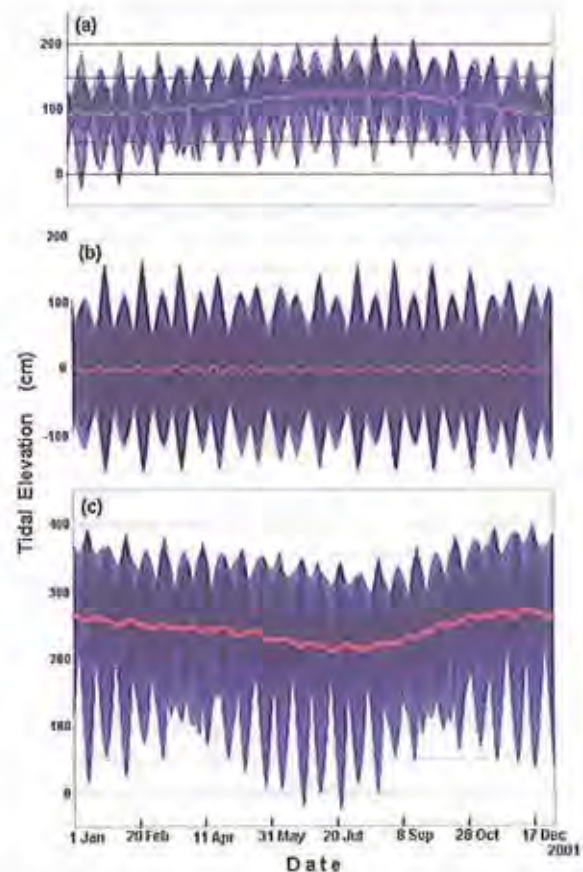


Fig.2. Sea level change and mean sea level (red line) in open sea in 2001.

- (a) The mouth of the Aira Gawa mangrove area, Iriomote Island, southernmost Japan.
- (b) The mouth of Chone River, middle Ecuador.
- (c) The offshore area of Can Gio, Vietnam.

modified asymmetrically in mangrove swamps due to the presence of mangrove vegetation and local topography, as discussed after. Particularly, the modification is great for a time before the bottom substrate dries up at ebb tide, as seen in Fig.5b.

In Figs.2a and 2c the seasonal change in water level, particularly in mean sea level, can be appeared, while it is not obvious in Fig.2b. The seasonal change in mean sea level is caused by water temperature that controls the expansion of water, atmospheric pressure, seasonal wind such as monsoon and river runoff due to rain (Kjerfve, 1990). For example, in Fig.2c at the Can-Gio coast, Vietnam, the range of mean sea level change is ca. 60 cm with the lowest in summer and the highest in winter, while it is negligible at the mouth of Chone River (Fig.2b), middle Ecuador. Kjerfve (1990) has also stated that the semiannual changes in mean sea level can occur

as a result of runoff events or variability in the wide scale ocean circulation. We can see, further, the semiannual change in tidal range, which is particularly salient in Fig.2c. Thus, it is noted that some mangrove swamps may continue to dry through a few months, and their ecosystems depend strongly on these seasonal changes.

Due to astronomical forces, which form the change in new moon to full moon, the tidal range changes fortnightly with spring and neap tides as seen in Fig.2. The volume of water that inundates and is trapped in mangrove swamps changes greatly during this spring-neap cycle (Mazda *et al.*, 1995). The tidal inundation in some innermost parts of mangrove swamps is particularly affected by this cycle. As a result, innermost parts of mangrove swamps may continue to dry through a few days during neap tide. The magnitude of groundwater flux is also greatly different between the spring and neap tides (Mazda and Ikeda, 2006).

2.2 Statistical feature of sea level change

As mentioned above, in water areas there are various water motions horizontally and vertically with different periods. However, given that the movement of celestial bodies causing tidal motion and the atmospheric condition repeat with one year, the sea level behaves statistically with a period of one year, though it has a little dispersion.

For example, Fig.3 shows the statistical information for tidal inundation at a site in a mangrove swamp (Stn. E in Aira Gawa; see Fig.4), based on Fig.2a. Fig.3 was calculated on the assumption that the tide inundates the swamp without deformation from the open sea. The frequency of tidal inundation (f) is defined as the number of inundation times per a month (30 days). The inundation duration (T_I) and the drought duration (T_D) are defined as the average length of time that the site lasts to be submerged and dried up per a month, respectively. It is obviously seen from Fig.3 that these statistical values have wide seasonal variation. The relations between the inundation frequency per a month (f), the inundation duration (T_I) and the drought duration (T_D) are as follows.

$$(T_I + T_D)f = 24(\text{hours}) \times 30(\text{days}) \dots \dots \dots (1)$$

Since the value of f varies with month, the value of $T_I + T_D$ is not constant through months as seen in Fig.3. It is noted that these values depend on the site elevation.

These characteristics should influence the physiology and ecology of biota in the swamp. However, these results should be modified when mangrove trees are thickly

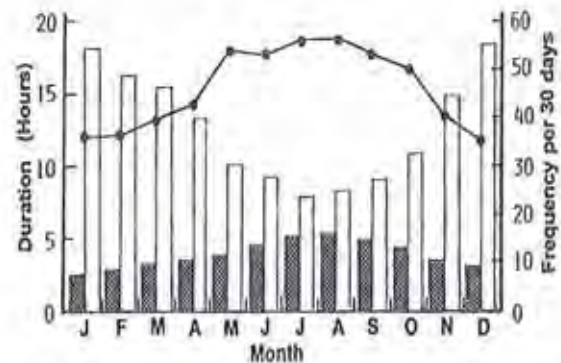


Fig.3. Statistical characteristics of sea level change in the Aira Gawa mangrove forest in a case without tidal deformation. Line graph represents the frequency of tidal inundation per a month (30 days). Bar graphs hatched and without hatching represent the inundation duration and the exposure duration, respectively.

vegetated in the swamp, because the tidal inundation is deformed due to the drag and viscous forces of mangrove trees and roots emerged from the substrate. In order to evaluate the significance of this deformation, the magnitude of this modification is estimated and discussed in the following section, based on our field observation.

3. Tidal measurement in a mangrove swamp

3.1 Study site

Figure 4 shows the observation sites in the Aira Gawa mangrove area on Iriomote Island, southernmost Japan. *Bruguiera gymnorhiza* is the dominant species. In the tidal creek (Stn.A) and the mangrove swamp (Stns.B-E) water level gauges (Pressure memory-type RMD; Rigosha Co. Ltd.) recorded the surface water level at 1-min intervals from 19 to 23 April 2004.

Around these sites the bottom slope in a direction perpendicular to the creek is ca. 2/1000. Detailed local topography and vegetation distribution are described by Kobashi (2001) and Kamiyama (2005).

3.2 Results

Figure 5 shows the water levels measured at Stns.A to E. The sea level in the creek (Stn.A) is the same as that in open sea, except at low water level (Mazda *et al.*, 1995). Particularly, due to a sill at the mouth of the creek the water level at Stn.A in the creek was not able to descend below the sill level (ca.50cm; see Fig.5a). An enlargement of the record on 22 April is shown in Fig.5b. Around high tide the water levels in the swamp (Stns.B-E) changed in accordance with that in the creek (Stn.A), except when the tide is very small (Stn.E at midnight on 22 April).

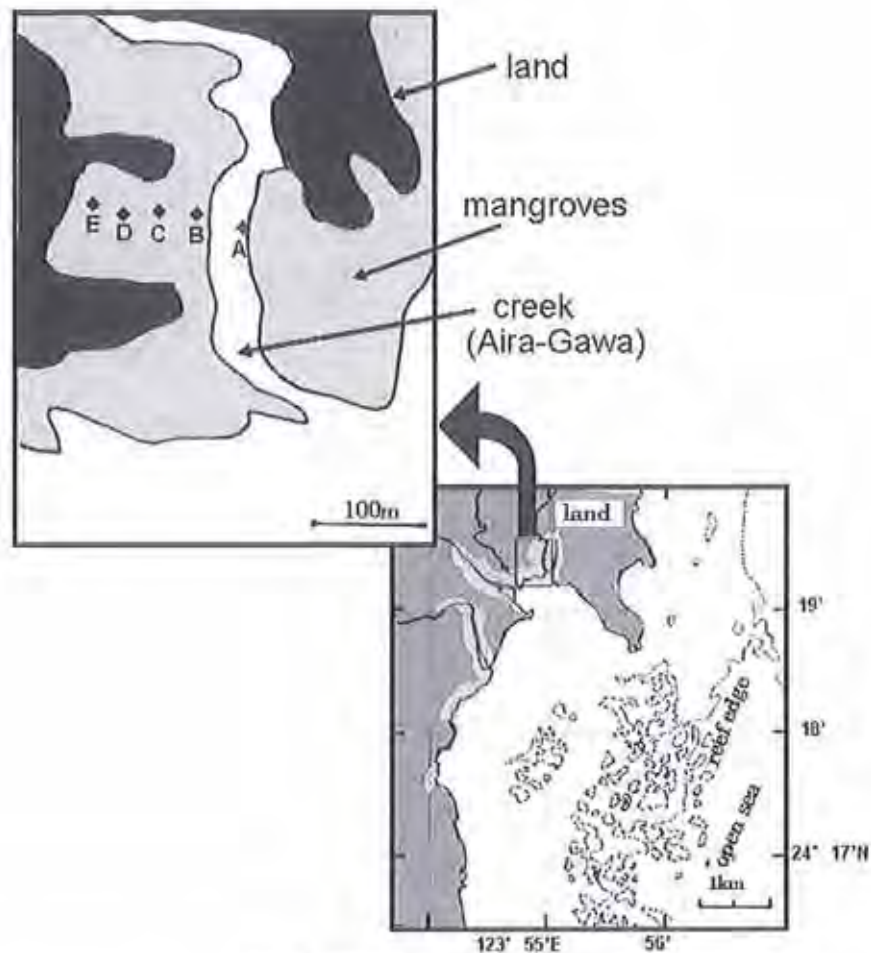


Fig.4. Map of observation sites, Stns.A-E

However, at the beginning of tidal inundation ($S1$ in Fig.5b) and for a time before the swamp surface was exposed ($S2$ in Fig.5b), the water levels in the swamp diverged from that in the creek. It is noted that according to this deformation the inundation duration increases a few hours, while the hatched area $S1$ is negligible compared to that of $S2$. After the water level fell below the soil surface, the descent speed of the groundwater level slowed and was approximately constant until the subsequent flood tide covered the swamp (Mazda and Ikeda, 2006).

4. Data analyses and discussion

4.1 Quantification of tidal level deformation in mangrove swamps

At the beginning of tidal inundation and for a time before the swamp surface was exposed, the water level in the swamp diverged from that in the creek or open sea. This deformation of tidal level in the swamp from that in

the creek ($S1$ and $S2$ hatched in Fig.5b) is caused mainly by the drag and viscous forces of submerged mangrove vegetation. Here we define a value $S=S2-S1$. As the value S means the net deformation toward the tide in open sea, we call hereafter this value S as the deformation fraction.

The relationship between the deformation fraction (S) and the water depth at high tide (H in Fig.5b) at each site is shown in Fig.6a. Obvious relationships can be seen between S and H in each site (Stns.B-E). The larger the tide, the deeper the tidal water inundates the recesses of the swamp. Drag and viscous forces due to mangrove trees and roots increase with inundation area, resulting in the conspicuous deformation. As the value of S should converge to 0 for the value of H going to 0, regression lines through the origin are shown in Fig.6a as a first-order estimation, which is represented as follows.

$$S = aH \dots\dots(2)$$

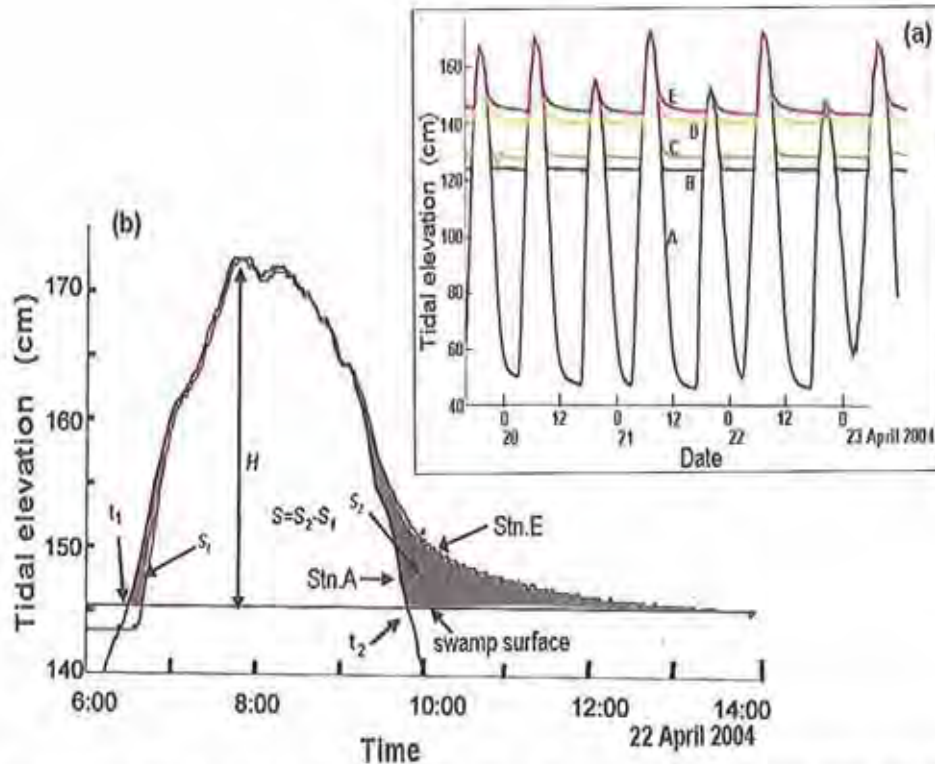


Fig.5. Time series plots of tidal level (a) during the period from 19 to 23 April 2004, and (b) the enlargement on 22 April. In Fig.5b, the definition of the deformation fraction (S) is represented as S_2-S_1 .

where α is the gradient of the regression line, which is varies with sites. The relationship between the gradient (α) of the regression line and the distance of the site from the bank of the creek (L) is shown in Fig.6b. An obvious linear relationship can be seen between L and α , which is represented as follows.

$$\alpha = \beta L \dots \dots \dots (3)$$

Where β is the coefficient of proportionality. In Eq.(3) the distance from the creek bank (L) can be replaced by the elevation of the soil surface at the site. Substituting Eq.(3) to Eq.(2),

$$S = \beta H L \dots \dots \dots (4)$$

In conclusion, the deformation fraction or the deformation of tidal level in mangrove swamps depends on both the distance from the creek bank and the water depth at high tide (or the tidal range). Further, it is suspected that the magnitude of β varies with the condition of mangrove vegetation such as mangrove species and the vegetation density.

4.2 Definition of the equivalent correction time of the inundation duration

As mentioned previously, the physiology and ecology of biota in mangrove swamps are influenced by the statistical factors such as the frequency of tidal inundation, the inundation duration and the water depth due to tidal inundation. If the deformation fraction (S) influences significantly the physiology and ecology of biota, the statistical values estimated in Fig.3 has to be corrected.

In areas such as mangrove swamps that reiterate water inundation and exposure with tidal period, it is suspected that the physiology of biota is exposed to more or less stress or is encouraged at a given water depth, i.e. the threshold depth. The intensity of the influence, i.e. the amount of stress, depends on form of biota which is under consideration. For example, mangrove trees are stressed at high water depth, while the physiology of small mud crabs living near the soil surface is influenced even at shallow depth such as a few cm. Once the target biota is selected, the magnitude of the threshold depth can be decided. In this paper this threshold depth shall be called the ecological control depth (HE). For example, the magnitude of HE for mud crabs is determined by the

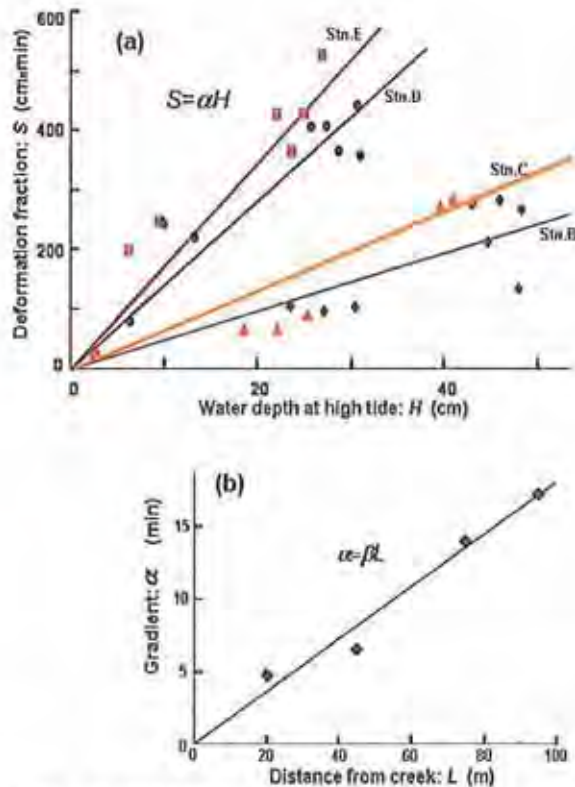


Fig.6. (a) Relationship between the deformation fraction S and the water depth at high tide at each site H , and (b) the relationship between the gradient α of the regression line in (a) and the distance of sites from the creek bank L .

water depth that mud crabs cannot survive at over a long period of time, which may be a few cm. However, the water depth larger or smaller than HE also influences the physiology of the target biota with different weight. Applying the idea of the ecological control depth (HE) to the deformation fraction (S), we discuss the correction of the inundation duration shown in Fig.3, as follows.

Considering that, as seen in Fig.5b, the water depth shallows gradually during a period of the deformation, furthermore the deformation fraction (S) has dimensions of the product of the depth and the time, we replace S as follows.

$$S = H_e T_e \dots \dots (5)$$

Eq.(5) means that the deformation fraction (S), which is formed by the water depth gradually shallowing with time, is equivalently transformed into a situation that the ecological control depth (HE) continues with constant value during a period of TE . Since the water depths deeper and shallower than HE also influence weightedly

the physiology of the objective biota, TE can be called the equivalent correction time of the inundation duration for the target biota. Substituting Eq.(5) into Eq.(4),

$$T_e = \beta \frac{HL}{H_e} \dots \dots (6)$$

Once the target biota is selected (or HE is decided) at a given site (or L is decided), the magnitude of TE can be calculated corresponding each high tide (H), based on Eq.(6).

4.3 Correction of the inundation duration by the equivalent correction time

As mentioned previously, tidal condition changes seasonally, though it has a period of one year in statistical sense. It is difficult to measure the tidal level in mangrove swamps continuously during one year, because the hydraulic and hydrologic conditions in mangrove swamps are severe for tide gauges to measure through the long term. Here we discuss the seasonal characteristics of inundation duration, based on modifying the inundation duration shown in Fig.3, which is calculated from the data available for adjacent open ocean waters.

First, once the site (L) is selected, the inundation duration in a case without deformation from the open sea (TO ; $t_2 - t_1$ shown in Fig.5b) for each tide in a year is calculated in the same manner as calculated in Fig.3. Next, if the ecological control depth (HE) is selected, the correction time (TE) is calculated from Eq.(5) for each tide (H) in a year. Last, the corrected inundation duration ($TC = TO + TE$) is averaged during each month. Figure 7a shows examples for $HE = 3\text{cm}$, 5cm , 10cm and 15cm at Stn.E ($L = 96\text{m}$).

In the figure the inundation duration in a case without deformation from the open sea is referred. Further, the rate of TC to TO at each site is also added in Fig.7a. The ecological control depth $HE = 3\text{cm}$ or 5cm may correspond to the height of mud crabs. And $HE = 15\text{cm}$ may correspond to the height of aerial roots of *Bruguiera* sp. (Mazda *et al.*, 1997). It is noted that the magnitude of correction is not negligible particularly for small biota. For example, the correction up to 170% is needed for $HE = 3\text{cm}$. Further, the magnitude of correction, i.e. the increasing rate, is not constant through a year, but varies seasonally.

4.4 Regional change in tidal inundation

As shown in Fig.2, tidal condition is very different from region to region. Thus, the tidal inundation characteristics are suspected to be also different from region to region. Figures 7b and 7c exemplify the corrected inundation

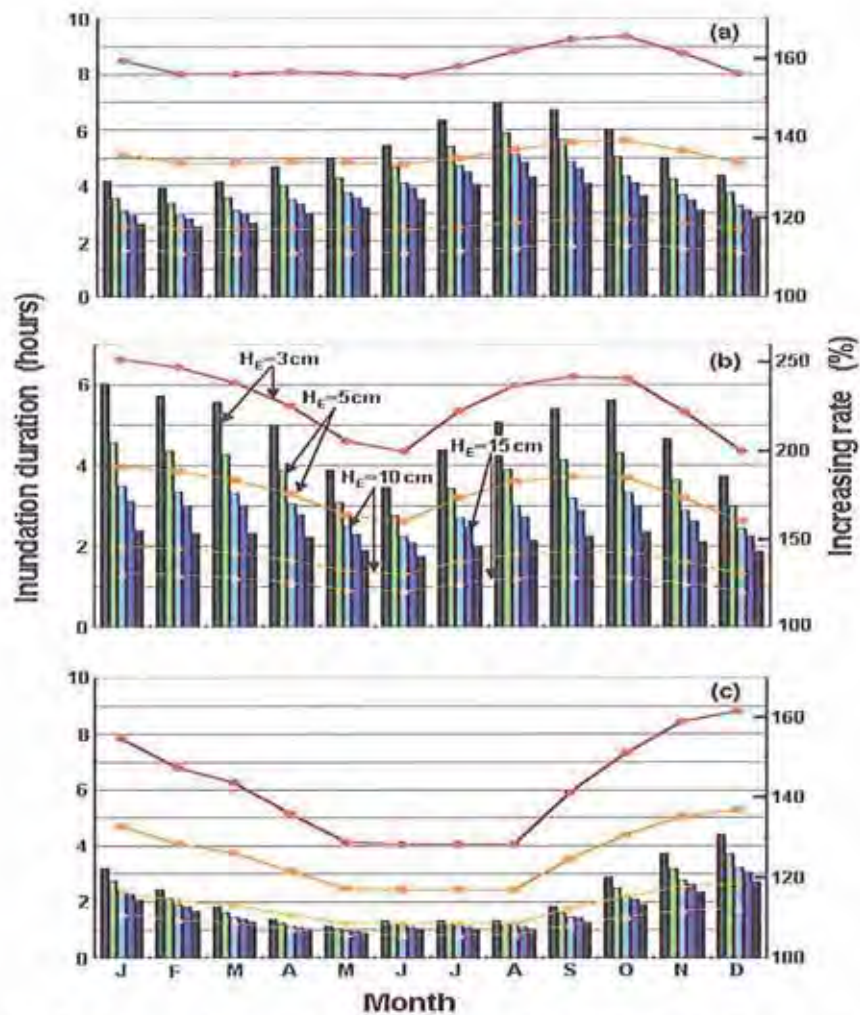


Fig.7. Seasonal changes in inundation duration (a) at $L=96\text{m}$ in the Aira Gawa, (b) at $L=200\text{m}$ in the Chone River and (c) at $L=125\text{m}$ in the Can Gio mangrove forests. Bar graphs represent the inundation duration for the cases without deformation, $H_E=3\text{cm}$, 5cm , 10cm and 15cm , in order from the right side for each month, respectively. Line graphs represent the increasing rate of inundation duration of $H_E=3\text{cm}$, 5cm , 10cm and 15cm toward the case without deformation, in order from the bottom, respectively.

durations for various tidal conditions at $L=200\text{m}$ in Chone River and at $L=125\text{m}$ in Can Gio, respectively shown in Fig.2, but with the same value of β as that in Aira Gawa. As the magnitude of β varies with region, local topography of mangrove areas and vegetation condition, these results shown in Figs.7b and 7c are only model illustration, which emphasize the difference due to tidal condition. It is noticed that in Fig.7b the correction increases up to 240%. In Fig.7c both the inundation duration and the increasing rate change greatly through a year, as reasonably understood from the seasonal changes in tidal condition

and the mean sea level (see Fig.2c). Also in Fig.7b the seasonal changes are remarkable, notwithstanding that in Fig.2b the seasonal change is not obvious, especially in the mean sea level. It should be noted that the seasonal change in Fig.7b is caused by the seasonal change in tidal range.

Fig.7: Seasonal changes in inundation duration (a) at $L=96\text{m}$ in the Aira Gawa, (b) at $L=200\text{m}$ in the Chone River and (c) at $L=125\text{m}$ in the Can Gio mangrove forests. Bar graphs represent the inundation duration for the cases without deformation, $H_E=3\text{cm}$, 5cm , 10cm and 15cm ,

in order from the right side for each month, respectively. Line graphs represent the increasing rate of inundation duration of $HE=3\text{cm}$, 5cm , 10cm and 15cm toward the case without deformation, in order from the bottom, respectively.

4.5 Change in ecosystem through feedback processes

Mangrove ecosystems change very gradually and establish stabilized situation through feedback processes between coastal landform, water flow, atmosphere and biota itself (Fig.1) over many decades. Mazda *et al.* (1999) introduced the idea of transitional process that artificially-deforested mangrove colonies stabilize through the feedback system, based on their numerical model. Mazda *et al.* (2002) have pointed out that the transition of mangrove environment in the above mentioned Can Gio, Vietnam, which was caused by the artificial deforestation and the following reforestation, lasts during 80 years. When mangrove areas are artificially deforested or reforested, the quantitative result obtained in this paper cannot be adopted directly. It should be noted that the observational results shown in Fig.5 represent the situation stabilized after many decades through the above feedback processes. As mentioned previously, Dr. Otto Dalhaus and his collaborators are directly examining in their laboratory how the physiology of mangrove seedlings is influenced by the inundation duration, as same as salinity. Their study and our present results will help the quantitative development of Watson's inundation class model and Snedaker's idea mentioned previously, as basic findings.

5. Conclusion and remarks

The statistical tidal condition in mangrove swamps such as the frequency of tidal inundation, the inundation duration and the water depth due to tidal inundation, which influence the physiology and ecology of biota in mangrove swamps, has not been understood quantitatively. In this article, we analyzed particularly the characteristics of the tidal inundation duration, based on our field measurement in the Aira Gawa mangrove area in Iriomote Island, Japan and statistical features of the tidal elevation in open sea as an input of tidal inundation into the mangrove swamp.

It was noted that all of the frequency of tidal inundation, the tidal inundation duration and the exposure duration in the mangrove swamp varies over a wide range, corresponding to the seasonal change in tidal condition and the mean sea level in the open sea. It was shown that as tidal condition is very different from region to region,

their tidal inundation characteristics are also different.

It was found that the tidal level in the mangrove swamp deforms greatly from that in the adjacent open sea. The magnitude of the deformation was formulated quantitatively with parameters, the distance from the creek bank, the depth at high tide and the vegetation condition near the soil surface. Based on this formulation and the ecological control depth, which is defined as the depth influencing the physiology and ecology of each sort of biota, the tidal inundation duration was corrected. Compared with the inundation duration in a case without deformation from the open sea, the magnitude of correction varied with the ecological control depth and seasonally.

As Snedaker has pointed out, the frequency of tidal inundation, the tidal prism volume (or the tidal inundation height) and the inundation duration are suspected to be important factors that influence the physiology and ecology of biota in mangrove swamps. Based on the consideration that the intensity of the influence is different between sorts of biota, we introduced a simple parameter, i.e. the ecological control depth as mentioned above. The significance of this parameter need to be discussed in detail, in collaboration with ecologists in this area.

In this paper we focused on the inundation duration. We acknowledge that other factors are important too, viz, the frequency of tidal inundation and the tidal inundation height. When the tide is very small, the water level at high tide in mangrove swamps cannot reach that in open sea because of drag and viscous forces due to mangrove roots particularly strong near the soil surface (Mazda *et al.*, 1999). For example, as seen in midnight on 22 April (Fig.5a), when the water depth at high tide is ca. 5cm , the water level is ca. 2cm lower than that at open sea. Accordingly, the above two statistical factors, i.e. the frequency of tidal inundation and the water depth due to tidal inundation also need to be modified from Fig.3.

In order to preserve and utilize the mangrove ecosystems, the feedback processes between coastal landform, water flow, atmosphere and biota itself through many decades must be studied quantitatively. Our present results were obtained in a steady state, in which the ecosystem was established through feedback processes during many decades. Based on these findings, the transitional processes, in which these factors are feeding back each other, should be studied.

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***Kandelia candel* and '*Kandelia obovata*': ecotypes, varieties or different species?**Gordon S. Maxwell¹⁾

Abstract: Recently there has been an attempt to subdivide *Kandelia candel*, a long established Rhizophoracean mangrove species, into two species: the existing *Kandelia candel* and '*Kandelia obovata*' described as a 'new mangrove species from Eastern Asia'. While many in mangrove science will welcome additions to biodiversity, especially at the higher plant level of taxonomy, this paper sounds a cautionary note as it critically examines the taxonomic and ecological basis for the attempted creation of *Kandelia obovata*. Special attention is given to ecophysiological adaptations within various populations of *Kandelia candel* such as cold tolerance and to a number of morphological and anatomical leaf and flower attributes which can be found throughout the biogeographic range of this species. Comparisons are made with another well known, widely dispersed and cold tolerant species, *Avicennia marina*, to illustrate the important taxonomic point that polytypicity in terms of subspecies within species is the norm rather than the exception. The paper concludes by strongly contending that *Kandelia candel*, at present, consists of two ecotypes which may be indicative of subspeciation within the existing gene-pool of *Kandelia candel*. Thus the 'new' *Kandelia* species, '*Kandelia obovata*' is at the very least premature and should be looked upon as no more than an ecotype with, perhaps, subspecific potentialities.

Keywords: *Kandelia candel*, *Kandelia obovata*, *Avicennia marina*, intraspecific variation, ecotypes, subspecies, gene-pools, reproductive isolation.

Introduction

This paper reviews what is and is not known about the taxonomy, ecology and ecobiogeography of *Kandelia candel* (L.) Druce, long regarded as a monotypic species within the Rhizophoraceae (Yamashiro, 1961; Wang *et al.*, 1964; Nakasuga *et al.*, 1974; Chapman, 1976; Ho, 1980; Nakamura, 1982; Hu *et al.*, 1986; Tomlinson, 1986; Chen *et al.*, 1988; Maxwell, 1993 and Chang, 1997).

In recent years the field of mangrove genetics has gained a new spark of activity which should be welcomed. On close examination of the resultant publications in mangrove genetics and biodiversity, it can be seen that these studies appear to be based on a relatively small percentage of the total genome available within the species populations studied. This situation is also the case with the widely dispersed (Chapman 1975; Tomlinson, 1986; Urasaki *et al.*, 1986; Maxwell 1993, 1995; Chiang *et al.*, 2001 and Chiou-Rony Shew *et al.*, 2003) and rather understudied mangrove, *Kandelia candel* (Aksonkoae *et al.* 1992, Maxwell, 1993, 1995, Maxwell *et al.*, 1997). In areas where *Kandelia candel* is a relatively conspicuous member of the mangrove community, this species features more strongly in the literature, e.g. in Japan, China and Hong Kong. Japanese botanists and ecologists have a long history of *Kandelia* studies (as evidenced in my recent inspection of the impressive collection of *K. candel* herbarium material held at Tokyo National Science

Museum, covering the period 1896 – 1970; TNS 2000). Perhaps one of the neatest and core studies being that of Yamashiro (1961) on propagule dispersal, a theme picked up again by Nishihira & Urasaki (1983) and Urasaki *et al.* (1986). In China, *Kandelia candel* features in ecological studies which often relate to economic utilization of mangroves but also include observations on cold tolerance and ecotypicizing e.g. Lin & Fu (2000). Likewise, in Hong Kong where mangrove science has recently become a more popular topic for research, *Kandelia candel* has been long recognized as a conspicuous species within the eight or nine true mangroves which occur here (e.g. see reviews by Hodgkiss, 1986 and Maxwell, 1993). In Japan, China and Hong Kong, one of the outstanding attributes of *K. candel* which has gained the attention of botanical scientists, is cold tolerance (Maxwell, 1995; Maxwell *et al.*, 1997). While this point has interested Japanese scientists (e.g. Sakai, 1974; Nakamura, 1982; Nakagoshi & Nehira, 1986) for decades, it has typically escaped the attention of many others and the idea that the only mangrove species to exhibit cold tolerance is *Avicennia marina* is still widespread in the literature (e.g. Duke *et al.* 1998 and Kathiresan & Bingham, 2001). Happily, Saenger (2002) citing Maxwell (1995) may help to correct this false impression.

The attribute of cold or chill tolerance has very important biogeographic implications. It is surprising therefore to find *Kandelia candel* as being totally ignored

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in reviews of global mangrove spatial issues (e.g. Farnsworth, 1998) and responses to environmental change & stress (e.g. Kathiresan & Bingham 2001). This may reflect at least in part, the tendency to pay little attention to what is perceived to be 'regional' literature rather than 'international' literature: a trend which is unfortunate in modern ecological writing. The publishing trend, encouraged by universities seduced by so called 'impact factor' thinking about scientific literature, works against what is perceived as locally and regionally relevant publishing and publications. Consequently, some important ideas are ignored by writers attracted to so-called 'high impact', 'international journals' (Maxwell, 1998).

My objectives in this paper are to discuss many important issues which, in my earnest assessment, should be fully addressed *before* biologists (of all disciplines and sub-disciplines) accept the taxonomic validity of *Kandelia obovata*, as a new species. My paper aims to show that, at present, it is far more acceptable to give due recognition to at least the ecotypes within the *K. candel* species population and, at most, the possible subspecies or varieties of *K. candel*.

The paper begins with some important general biological and taxonomic issues and then moves on to more specific aspects of some recent trends in mangrove thinking in genetics and evolution. My paper attempts to evaluate these trends and presents a conclusion that *K. candel* is yet another example, like *Avicennia marina* (Tomlinson, 1986; Everett, 1994) and *Excoecaria agallocha* (Parani *et al.*, 1997) of strong ecotypicity and genetic polymorphism within the mangrove flora. In style, the paper in its present form and organization is designed as a 'lecture on paper'.

1. The species concept and polytypicity

The concept of reproductive isolation or genetically isolated gene pools is still, I believe, a core component of the species definition. Likewise, the concept of gene pool as the sum total of all genes in an interbreeding population remains essential in population genetics (Thain & Hickman, 2000). It is possible that within biology, zoologists are perhaps more strongly attracted to the core concept of reproductive isolation in defining a biological species. The nomenclature of the Iriomote cat is an excellent case in point here! There are those, too, who feel that because it may be hard to define a species; to list the necessary properties for this biological taxon, that we should be relaxed and flexible about the 109 process of species taxonomy. Yet, as Thain & Hickman (2000)

argue, we still need to define a species in philosophical terms even if this is not always so easy. The word species is not equivalent to element or compound in scientific status. Nevertheless, despite this lack of precision, we in biology should not create new species too easily, especially if the core evidence for reproductive isolation is lacking. As Thain and Hickmott (2000) remind us, most species probably comprise two or more subspecies or races and are said to be polytypic. *Bos domestica* consists of 6-8 major breeds each with numerous morphologies and biochemical differences but are still one species. Likewise, with *Canis familiaris* (the domestic dog).

Finally, who, in anthropological circles, would welcome a proliferation of new species designations for the very polytypic species, *Homo sapiens*? There would even be justified resistance to the use of subspecies with respect to *H. sapiens*.

2. Some sources of uncertainty in mangrove taxonomy

2.1 Hybridization

As Duke (1992) pointed out, many problems still exist with mangrove taxonomy and many of these are based on hybridization between species (Kathiresan & Bingham, 2001). Let it be emphasized here too, that this idea is not new and has been noted by mangrove field botanists before Duke (1992) or Kathiresan and Bingham (2001), e.g. by Nakamura (1982) who wisely remarked that it can be difficult to always easily distinguish *Rhizophora mucronata* in Thailand from (*R. stylosa* in Japan. Nakamura pointed out that a careful examination of the style may be necessary. *R. stylosa* typically has a long style). Debate continues on the number of species. Tomlinson (1986) lists 54 species, while Duke (1992) and Field (1996) accept 69. Sun *et al* (1998) prefer ~ 80 spp. Lin & Fu (2000) settle on 70; Kathiresan & Bingham (2001) 'reconcile' the figures of Tomlinson (1986) and Duke (1992) to get 65 species and finally, Primavera *et al.* (2004) diplomatically embrace the flexible number of "around 70". Who are we to believe? Clearly, more work needs to be done and if *Kandelia obovata* is to be accepted as a valid species, the number will again increase by one 'new' species. Will the new revised number be 55, 70, 71, 66 or 81?

Clearly Duke (1992) was correct in identifying problems and some of these may stem from hybridization. The matter is dynamic and in a state of flux. An excellent example of this flux comes from the dynamic status fluctuation of *Rhizophora annamalayana* from southern India. Kathiresan (1995) described *R. annamalayana* as a 'new' species. But recently Snengor (2002) citing Parani *et*

Table 1 Variation in leaf features in *E.agallocha* and *E.ovalis* from Australia (based on the above paper)

Species (geography)	length	Width	Petiole	Margin	Apex
<i>E.agallocha</i> (NSW)	71.2±10.0	40.7±7.7	14.6±2.9	crenate	Blunt-acute
<i>E.ovalis</i> (WA)	39.3±2.1	25.3±2.5	11.3±1.2	Entire	Blunt

al. (1997) who used some genomic DNA analysis, argued that this 'new' *Rhizophora* species was (only) a sterile F₁ hybrid of *R. mucronata* and *R. apiculata*.

In similar studies, *R. lamarckii* was viewed as the hybrid between *R. apiculata* and *R. stylosa* (Tomlinson *et al.*, 1979). As Nakamura (1982) showed, some careful field work with actual populations can help botanists to avoid making mistakes or conducting incomplete studies.

Saenger (2002) wisely concludes, I believe, that although hybrids are also known within the species associated with *Sonneratia*, *Xylocarpus* and *Lumnitzera* as well as *Rhizophora*, this hybridization should be taken to indicate that the genetic isolation between species of these genera are not complete. And, let it be emphasized, these mangrove genera are of outstanding importance within global mangrove flora. Thus, I contend, we should adopt a conservative approach when contemplating 'new' species within mangrove genera, including *Kandelia*.

2.2 Molecular or microgenetic variations

In recent years, a new field of ecology has caught the imagination of a number of workers; it is *molecular ecology* and molecular genetics a source of many tools within this field. Molecular genetic techniques are helping to shed new light on ancestry and evolutionary connection of mangrove species (Saenger, 2002). I will now examine some case studies in molecular genetics of mangroves and show that, although interesting, these innovative contributions rarely prove the existence of new species.

2.2.1 Use of *Internal transcribed spaces* (ITS) region of *ribosomal genes* (Maguire & Saenger, 2000) with *Excoecaria* spp.

This work was done with geographically isolated populations of *Excoecaria* from New South Wales, Western Australia and Queensland and showed that the various *Excoecaria* species, *E. agallocha* (E. Aus, i.e. New South Wales) and *E. ovalis* (from W. Australia) were genetically uniform within species but differed from each other consistently. Leaf morphology especially length, width, petiole, margin and apex also varied (Table 1).

E.ovalis has only recently been elevated to species status on the basis of morphological (Wightman, 1989) and DNA (Maguire & Saenger 2000) data.

But, I ask, two questions here:

(1) How much of the total genome was represented by the ITS regions of ribosomal genes? and

(2) Were reproductive compatibility (cross-fertilization) tests done on these two 'species' of *Excoecaria*?

If they are not genetically isolated, then is *E.ovalis* really a separate species from *E.agallocha*?

Is *E.ovalis* a subspecies of *E.agallocha* i.e., *E.agallocha* var. *ovalis*?

2.2.2 Chemotypicity i.e. 'chemotypes' in *Rhizophora mangle* and *Avicennia germinans*

Kathiresan & Bringham (2001) cite the work on *Rhizophora mangle* from Puerto Rico which indicated the existence of 'distinct chemotypes' within this American *Rhizophora* species (Corredor *et al.*, 1995). On close study of the original paper by the Corredor group, it is clear that work is restricted to albino mutants, which in nature have a chance of short term survival largely due to vivipary. I report similar observations with *Avicennia marina* var. *resinifera* in New Zealand. Here they were not albinos but rather, yellow mutants, clearly deficient in chlorophylls (Maxwell, 1971). They lasted as long as the food store in fleshy cotyledons; clearly they were not part of a future gene pool.

While these 'pigment Fingerprints of chlorophyll deficient mutants' are interesting, they are simply mutants. The term, chemotype, does in my view hint at a status closer to that of ecotype. The term ecotype implies much more than mutation around several different loci, as was the case with these *Rhizophora mangle* heterozygotes. I feel, therefore, that the term chemotype conveys far more taxonomic meaning than it should and contend that the use of this term in the context of an account of genetic variation within mangroves is misleading.

2.2.3 'Ecotypic diversity' in cuticular waxes of mangroves at 'the bioclimatic extreme'

Again Kathiresan & Bingham (2001) discuss foliar leaf waxes as evidence of genetic variation within mangroves. I accept that this is an example of such variation but do not accept the implication, conveyed in the above title to the paper by Dodd *et al.* (1999), that this can be interpreted as subspeciation or even ecotypicity in action.

In addition, while the mangrove species that can occupy 'one of the direst habitats in the world', *Avicennia marina*, is at a bioclimatic extreme, it is not at 'the bioclimatic extreme'. There are other such bioclimatic extremes including the northern limit of *Kandelia candel*, in Japan and the southern limit of *Avicennia marina*, at Ohiwa in New Zealand.

These developments in cuticular wax hydrocarbons (C33 & C31 long chain compounds) reported by Dodd et al (1999) are excellent examples in my view, of the inherent ecological plasticity that typifies *Avicennia marina*. They are not examples of evolution of new varieties or subspeciation.

2.2.4 Isozyme studies in *Kandelia candel* populations

Studies by Sun et al. (1998) using isozyme electrophoresis on flower buds or youngest leaf buds of *K. candel* from 13 isolated microgeographic populations within the territory of Hong Kong, revealed little genetic variation among these populations. The actual percentage of total *K. candel* genotype (gene load) studied was very small e.g. heterozygosities observed and expected were calculated only for two common polymorphic allozyme loci.

The significance of these studies seems to point to conservative gene flow in *Kandelia candel*, a property which may be linked to its so far incompletely studied mating system. As indicated earlier by Baba et al (1989) isozyme genotype analysis could be an effective tool in mangrove species studies but care is needed and questions such as seasonal change of isozyme phenotype patterns should also be studied.

2.2.5 *Kandelia candel* genetics in East Asian populations of this species.

Using nucleotide variation of chloroplast and mitochondrial DNA extracts from *K. candel* in Japanese islands, Taiwan, mainland China, East Malaysia and southern Thailand, Chiang et al. (2001) found significant gene allele differences in cp-DNA & mt-DNA in the northern and southern reaches of the South China Sea, but these differences did not lead these workers to proposed even a new subspecies and certainly not a new species form these *Kandelia candel* populations. They did show however, that some long-range seedling dispersal was evident. This finding tends to support the idea that *K. candel* produces propagules, some of which retain buoyancy for months, are capable of distant phytogeographic dispersals (Maxwell, 1993; Maxwell, 2002a).

2.2.6 Inconsistent elevations of mangrove species to species status

This point is potentially huge; a paper or lecture in itself. In addition to the examples mentioned above, there are many others of which the following illustrate important aspects of the nature of these inconsistent treatments:

- (a) *Heritiera littoralis* and *H. fomes*
- (b) *Acrostichum aureum* ecomorphs
- (c) *Avicennia marina* subspecies, and
- (d) *Kandelia candel* vs. *K. obovata*

Each example will be addressed in turn.

2.2.6.1 *Heritiera littoralis* and *H. fomes*

Accounts of these two species of mangroves within the Sterculiaceae by Saenger (2002), Das et al. (2001) and Tomlinson (1986) give overlapping but not identical assessments of the validity of these two species of mangrove *Heritiera*. Other botanists too, point to variations with *H. littoralis* populations especially in leaf morphology (e.g. Aksonkone et al., 1992). The recent work by Das et al. (2001) using random amplified polymorphic DNA (RAPD) studies of *H. littoralis* and *H. fomes* has shown that the two species are closely related with a high level of intraspecific polymorphism. Tomlinson (1986) highlights the differences in fruit morphology as the key to specific subdivision in these two species: *H. littoralis* having a smooth fruit with 'a rudderlike crest' but lacking the transverse, circular ridge while *H. fomes* has a knobby fruit with a ventral ridge and a transverse circular ridge. It is possible too, according to Tomlinson (1986) that the ability or otherwise to produce pneumatophores (*H. fomes* can, but *H. littoralis* can't) may also separate these two species. In my assessment, more field work needs to be done and some close attention give to the core question of interfertility testing: are these two species of *Heritiera* completely isolated genetically?

2.2.6.2 *Acrostichum aureum* ecomorphs

Ecomorphs or perhaps more genetically fixed growth forms have been reported within this species of mangrove fern (Medina et al., 1990). The work by the Medina team was done in Puerto Rico and their findings together with those of Lloyd and Buckley (1986) and Watson's (1928) observation in Malaysia point towards ecotypic differentiation, especially with respect to salt tolerance within *A. aureum* populations. This aspect of ecotypicity and the colourmorphs noted by Tomlinson (1986) i.e. S.E. Asian *A. aureum* young fronds having a characteristic crimson colour which is lacking in New

Table 2 Mean measurements with standard error and ranges (in parenthesis below mean of numeric morphological attributes in populations of *Kandelia candel* from Brunei, Hong Kong and Thailand. Attributes 1-5 and 7-8 in cm; attributes 9 and 10 in g. (Ranges in brackets)

Attribute	<i>K. candel</i> populations				
	Brunei	Hong Kong		Thailand	
	Tutong R.	Chek Keng	(MaiPo)DeepBay	La-Un	
(a)	Leaf				
1	Length L	11.8±0.124 (10.00-15.00)	6.69±0.11	9.11±0.131 (7.6-13.6)	15.00±0.11
2	Width W	3.48±0.032 (2.8-4.2)	2.80±0.06	3.9±0.064 (2.9-5.5)	6.23±0.06
3	Petiole length	1.01±0.04	0.71±0.01	1.20±0.016	1.29±0.03 (0.8-1.5)
4	L/W	3.41±0.44 (2.61-5.07)	2.40±0.039 (1.97-3.02)	2.45±0.024 (2.06-3.01)	2.63±0.02
5	L x W	20.65±0.332 (12.76-39.00)	9.56±0.341 (2.97-13.80)	17.89±0.570 (11.4-37.4)	50.61±0.692 (33.8-65.36)
6	General form	oblong-elliptic with some marginal curling	oblong-elliptic	oblong-elliptic	Broadly oblong-elliptic
(b)	Propagule				
7	Length	31.05±0.30 (18.9-39.5)	19.32±0.236 (10.9-27.0)	22.10±0.291 (14.8-27.95)	46.89±0.602 (40.2-53.6)
8	Width	0.95±0.006 (0.7-1.09)	1.09±0.114 (0.7-1.5)	1.30±0.009 (0.99-1.49)	1.32±0.012 (1.12-1.42)
9	Wet weight	15.67±0.399 (8.22-20.77)	9.83±0.265 (5.17-15.64)	14.72±0.288 (5.75-21.09)	34.37±1.193 (22.15-47.85)
10	Dry weight	6.76±0.13 (3.8-10.0)	3.26±0.251 (1.96-5.57)	7.19±0.168 (3.99-10.63)	12.87±1.465 (8.41-13.40)

(Adapted from Maxwell, 1995) (Means were subject to one-day ANOVA and post-test Bonferroni corrections. In all cases, except petiole length & width between Mai Po and La-Un the differences were significant (P=0.001 level))

World representative of this species.

Despite these differences and the all important ecophysiological difference in gametophyte tolerance of salinity that exists within various *A. aureum* ecotypes, there has been no serious attempt to date to subdivide *A. aureum* even into subspecies.

2.2.6.3 *Avicennia marina* subspecies

Varieties or subspecies within the worlds most widely dispersed and ecologically versatile mangrove, *Avicennia marina*, have been acknowledged and accepted as useful taxonomic categories for decades. Tomlinson (1986) address this taxonomic variation and cautions that morphological distinctions may not be clear cut. He nevertheless highlights some of the most distinctive features which do give at least some of these subspecies a

stamp of uniqueness. Likewise, Aksornkone *et al.* (1992) draw strong attention to the varieties within this species. In my extensive work on and with *A. marina* populations from the geographic southern limit in New Zealand (38 ° South at Ohiwa) throughout East and S.E. Asia, I have seen consistent differences especially between *A. marina* var. *resinifera* (NZ subspecies) and those of Hong Kong, Thailand and North Borneo (Brunei) (Maxwell 1971, 1993). Those from Thailand and Brunei fit the *A. marina* var. *marina* designations, while those of Hong Kong being dwarf with small stature, small leaves and small fruits strongly resemble those of Iriomote Island, Okinawa Prefecture, Japan. (Maxwell per obs, 2005). Despite true tropical condition in Iriomote and the absence of chill shock that is a feature of a Hong Kong winter (Maxwell, 1993, 1995, 2002,b) *A. marina* here assumes a consistent

Table 3 *K. obovata* vs. *K. candel* (Vietnam work, extracted from Nguyen 2004 in Hong 2004 pages 163-173).

Feature	<i>K. obovata</i> (<i>K.o.</i>)	<i>K. candel</i> (<i>K.c.</i>)
1. stigma	3-lobed (more-closed)	3-lobed (more open)
2. cotyledons	More concave	More pointed
3. Propagule length	Shorter than <i>K.c.</i>	Longer than <i>K.o.</i>
	(no figures were given)	
4. Propagule cortex parenchyma	Smaller air spaces between cells	Larger air spaces between cells
	(no measurements were given)	

Table 4. Gene mutations and their taxonomic impacts in mangrove evolution (Adapted from Kathiresan and Bingham (2001) based on Saenger (1998))

# of gene mutations	Status/taxonomic or evolutionary impact
1-2	Minor biochemical differences e.g. albino mutants
5-10	Some change at the physiological level e.g. cold tolerance?
>10	Morphological variations e.g. leaf form
>100	Taxonomic change e.g. new subspecies, species

squat, sprawling growth form which is in stark contrast to the more erect trunk based architecture of non *Avicennia* mangrove species on Iriomote. It is possible that we have a new subspecies here. *A. marina* var. *iriomotensis*?

The acceptance of subspecies within the diverse *A. marina* species populations seems well established and was formalized again by Everett (1994) according to Saenger (2002).

While a comprehensive account of subspeciation within *A. marina* is possible, it is well beyond the scope of this paper. The central point, I wish to emphasise in the context of this paper on *Kandelia candel* vs. *K. obovata*, is that the acceptance of 5-7 subspecies within *A. marina* while not applying similar taxonomic thinking to *Kandelia candel* is inconsistent and unacceptable.

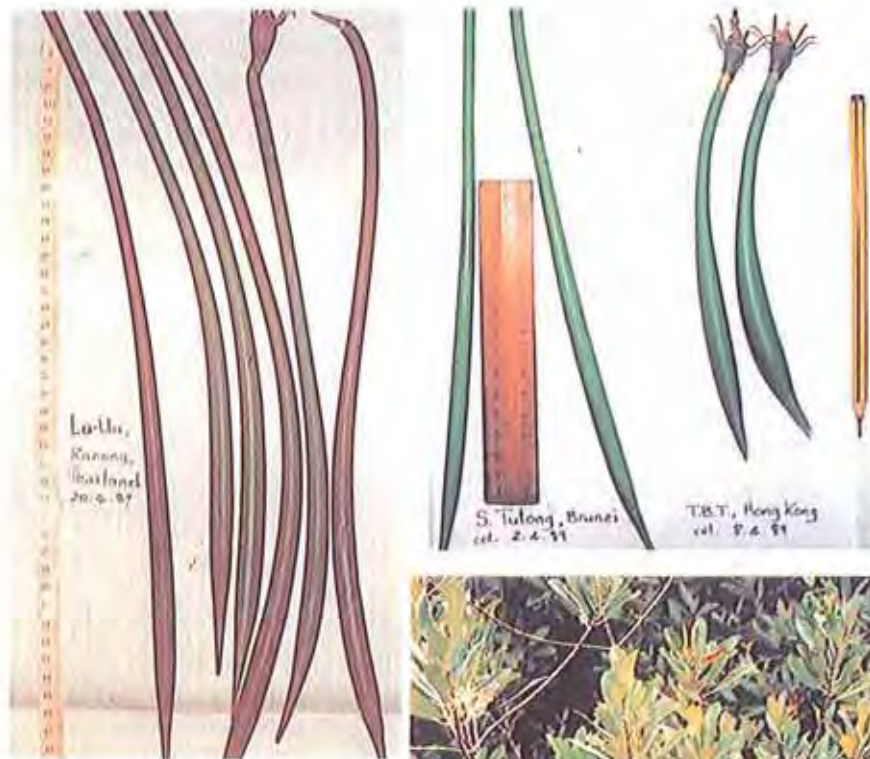
2.2.6.4 *Kandelia candel* vs *K. obovata*

My work on ecogeographic variation within *Kandelia candel* population was the first, as far as I know, to report distinct ecotypes within this widely dispersed species (Maxwell, 1993; 1995).

These ecotypes are perhaps most readily seen in propagule morphology, a diagnostic attribute highlighted by Aksornkoac *et al.* (1992). (Photo 1) Other attributes included leaf morphology and interestingly, physiological differences in cold tolerance. Table 2 presents a summary of this study on ecotypicity (Maxwell, 1995). The work of Chiou Rong *et al.* (2003) builds on this data. Again there is an emphasis on what I would describe as interesting but minor, mostly non-reproductive characters. Examples

included, as one would expect, leaf shape, stipule length, sepal colour and size, petal and style size all of which strongly overlap. The main difference lies in hypocotyl length; with *K. candel* having 20-40cm long hypocotyls while those of '*K. obovata*' were smaller, at 15-23cm in length. No tests of statistical significance of the differences addressed were given in the Chiou Rong *et al.* (2003) paper announcing *K. obovata* as 'a new mangrove species'. Indeed, caution should be exercised even with these apparently strong propagule differences as shown by Maxwell (1995) (See Table 2 and photo 1). In a follow up study within Hong Kong Maxwell and Chope (1995) confirmed that propagule length can vary and be statistically significant, even within geographically isolated Hong Kong populations; these variations seemed to be ecological with perhaps hints of genetic isolation. Again we found the trend evident in Table 2, that morphological factors such as leaf and propagule size can vary markedly from site to site (e.g. Chek Keng vs. Mai Po within Hong Kong). It is noteworthy that the Mai Po *K. candel* growth attributes are similar to tropical Bruncian and Thai populations in several respects while those from Chek Keng are rather different in most respects (Table 2). The outstanding differences between Mai Po and Chek Keng are ecological: the Mai Po environment is characterized by soft, deep estuarine mud and lower salinities (~20ppt) while that of Chek Keng has a stony substratum with limited mud and high, salinities (~30ppt).

These studies tend to be in concert with those of Sun *et al.* (1998) and Chiang *et al.* (2001), mentioned above.



Kandelia candel

รังกะแท้



Photo 1. *Kandelia candel* by Aksornkoae et al. (1992).

Interestingly too, my recent inspection of the substantial collection of *Kandelia candel* herbarium material held at National Science Museum (TNS) illustrates such

variation (TNS, 2006). The sample pool provided by the TNS spans the East China Sea region throughout the Japanese islands and Taiwan, representing a wide range of

climate extremes and habitats. A systemic documentation of this TNS *Kandelia candel* resource is the subject of a future paper.

There was no intention to propose the formation of a new species, *K. obovata* based on ecotypes. Indeed, my work with transplantation, where seedlings of *Kandelia candel* ecotypes from Brunei and Thailand were grown to maturity in the same habitat at Hong Kong alongside local (Hong Kong) ecotypes indicated that they retained much in common. This was especially evident after a setting in phase of about five years, as the tropical transplants adjusted to the Hong Kong environment. All displayed some degree but not identical chill tolerance. Although there was more initial die back and mortality from cold ($\sim 4^{\circ}\text{C}$ for 2-3 nights) with the tropical (Thai & Brunei) saplings than those from Hong Kong, representations of all ecotypes survived Hong Kong winters.

Furthermore and of paramount importance in my view, is the fact that today, some 15 years after the Hong Kong transplant field experiment was initiated, this group of three ecotypes are interfertile: there is no overt evidence of genetic or reproductive isolation! (Maxwell, pers obs 2004). This viewpoint appears to stand in contrast to the treatment of *Kandelia candel* populations in Vietnam as given by Nguyen (2004). Here some relatively minor morphological and anatomical differences with *Kandelia candel* populations are used to support the notion of two species; *Kandelia candel* and *K. obovata*. Table 3 presents a summary of this Vietnam work.

Chiou Rong *et al.* (2003) also present data on chromosome number which suggests that *Kandelia candel* has a $2n$ chromosome number of 38 (Das *et al.* 1995) while '*K. obovata*' has 36 (Yoshioka *et al.*, 1984). This could be deemed important as Nguyen (2004) contends. However, the retention of ecotypic interfertility as mentioned above (2.2.7.4) within the three ecotypes of *Kandelia candel* (Maxwell, 1995) tends to cast a shadow of uncertainty over these chromosome numerical differences and moreover, if they do exist, their importance as isolation mechanisms. It will wise too, to consider and determine just how many gene mutations are needed before we can justify a taxonomic change at the species level. Kathiresan and Bingham (2001) who cite Saenger (1998) estimate more than 100 (Table 4). The work of Chiou Rong *et al.* (2003) and similar studies does not address this question nor the co-lateral issues of individual gene importance within the total genome, polygenic inheritance and nature and status of genes controlling genetic compatibility. Interestingly, the advocates of *K. obovata* as a 'new' species seem to ignore both the core

criterion of ecotypic interfertility (genetic compatibility) and such related considerations as numbers of mutations required for speciation in *Kandelia candel*.

3. How strong is the evidence used to justify subdividing *K. obovata* form *K. candel*:

Clearly, there are differences within this widely dispersed East Asiatic mangrove species known as *Kandelia candel*.

These differences are mostly minor morphological in nature. Both *K. candel* and the proposed *K. obovata* display cold tolerance. This propensity was also evident in the three ecotypes of *K. candel* investigated in transplant field experiments by Maxwell (1995). The differences in cold tolerance between the tropical (Brunei & Thai), *K. candel* ecotypes and the Hong Kong ecotype were strongest only within the first 5 years of the field trial and, today, are not so obvious.

Minor differences in leaf and inflorescences do exist with *K. candel* ecotypes. The same pattern is also displayed by the varieties of *Avicennia marina*. Excellent examples come from *A. marina* var. *resinifera* which has a more compact inflorescence than *A. marina* var. *marina*; larger leaves, a more acute apex, larger fruits, different buoyancy properties in the propagule and considerable cold tolerance not found in the more tropical subspecies. Recent work by Ge *et al.* (1999) using material from New Zealand, Hong Kong, China and Thai populations of *A. marina* has confirmed genetic divergence at the isozyme and chlorophyll-DNA levels. There is however, no suggestion of proposing new species for all these *A. marina* varieties or subspecies!

During my recent (Sept-November, 2006) field work on Iriomote island, Okinawa Prefecture (Japan), I was able to examine two growth forms of *Kandelia candel* which co-exist in the same habitat (Urauchi River mouth zone). The growth forms are distinct: one is a compact, squat, sprawling bonsai-like shrub with limited vertical trunk development; the other is a tree form. The possibility of some genetic basis exists (Baba, pers. Comm., TBRC, Univ. of Ryukyus) and these alternative growth forms of *K. candel* from Iriomote will be the subject of another paper. Field observations of this nature should be exhaustively studied to determine the ecological, climatic (e.g. typhoon patterns) and genetic (if any) basis of such biological variation. These recent observations tend to deepen my belief in ecotypicity and ecological plasticity within the gene pools of species such as *Kandelia candel* and *Avicennia marina*.

4. Conclusion

I conclude by strongly advocating that the so called 'new' species *Kandelia obovata* be reviewed and re-designated as either an ecotype or, at most, a subspecies of *Kandelia candel*: perhaps, *K. candel* var. *obovata*. The other *Kandelia candel* populations could perhaps retain the original name and be known as *K. candel* var. *candel* or *K. candel* var. *macrocotyla*, a reference to the longer cotyledons! To date, in my assessment of biodiversity within the various populations of *Kandelia candel*, the evidence presently available indicates that it is more appropriate to use ecotypes rather than such subspecies designations.

Finally, I wish to reemphasise the importance of interfertility in species definition. At present, there is no evidence that the so called 'new' species of *Kandelia*, *K. obovata*, is genetically isolated from or reproductively incompatible with the long established, polytypic species of *Kandelia candel*. Long may *K. candel* endure!

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マングローブ前面群落構成種の個体群構造と相対成長関係

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Population Structure and Allometric Relationships of Seaward Mangrove Species, Thong Nian bay, Southeastern Thailand

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Abstract: We investigated the population structure of seaward mangrove species, *Avicennia alba*, *A. marina*, *Sonneratia alba* and *Rhizophora apiculata* between September 2004 and September 2005 in Thong Nian bay, Khanom, Southeastern Thailand. Mortality rate of *A. alba* and *S. alba* was higher than the other species. Although the rate of gain in basal area of *A. alba* (3.47%), *A. marina* (3.99%) and *S. alba* (3.07%) did not differ, the rate of loss in basal area of *A. alba* was the highest (2.03%). However, the changes in frequency distribution for stem diameter did not differ significantly between September 2004 and September 2005. Height and diameter relationships of the species were regressed by expanded allometric equation, and maximum attainable height of *S. alba* and *A. alba* was greater than that of *A. marina*. In the study site, it is considered that *S. alba* and *A. alba* regenerate first, and *A. marina* regenerate as follows.

Keywords: *Avicennia*, expanded allometry, pioneer species, population structure, *Sonneratia*

はじめに

樹木の樹高と直径の相対成長関係を明らかにすることにより、個体群の発達段階や群落の遷移過程を推察する研究が多く行われてきた (e.g. 中須賀 1979, O'Brien *et al.* 1995, 石原・持田 1999)。特に拡張相対成長式は、遷移系列や様々な環境傾度上における各樹種の相対的な序列を推察できるため (e.g. 依田 1971, Ogawa & Kira 1977)、立地環境の違いと最大樹高や樹高と直径の相対成長関係に関する研究 (三木ほか 2003, Tateno & Takeda 2003, Tomita *et al.* 2005) や、林冠木および下層木の樹高と直径の相対成長関係についての研究 (Aiba & Kohyama 1996, Thomas 1996) などに用いられてきた。

タイの河川の河口部では、汀線に沿って *Avicennia alba* と *Sonneratia alba* を標徴種とする *Sonneratia alba*-*Avicennium albae* (宮脇ほか 1985) や *S. alba*-*A. alba* 群落 (中村ほか 1985, Mochida *et al.* 1999) が前面群落を形成している。同様に前面群落を形成する種として *A. marina* があげられる (宮脇ほか 1985, Duke 1992, 馬場・北村 1999)。これら *A. alba*, *S. alba* と *A. marina* は先駆種であることが知られており (Tomlinson 1986, Aksornkoae *et al.* 1992)、河口部付近の干潟や砂州などの新しく形成された堆積地に定着する (Aksornkoae *et al.* 1992, 宮城ほか 2003)、ところが 3 種ともに先駆種とされるものの、*Sonneratia* 属や *A. alba* の実生はギャップなどに多く生育する (緒方ほか 2005) 一方、*A. marina* は林冠下の暗環境で

も生育可能である (Walters 2005) ことから、遷移系列上の各種の序列は大きく異なると考えられる。また、タイにおける *A. alba* と *S. alba* が優占する林分構造は、中須賀 (1990) などにより報告されている一方、*A. marina* を含む林分構造については、オマーン (三木ほか 2003)、ニュージーランド (Osunkoya & Creese 1997) や日本 (中須賀 1979) などで見られるのみで、タイにおける報告例はほとんどない。

そこで本研究では、*A. alba*, *S. alba*, *A. marina* が共存する前面群落において、その林分構造を明らかにすることを目的として調査を行った。具体的には、出現種の個体群構造および、樹高と直径の相対成長関係を拡張相対成長式で回帰した結果から、前面群落に出現する種の遷移系列上の序列と調査群落の遷移段階をそれぞれ推察した。

調査地および調査方法

タイのマレー半島中央部の東側に位置し、タイ湾に面するナコン・シ・タマラート県カノムのトン・ニアン湾 (9° 18' 14.0" N, 99° 48' 3.4" E) で調査を行った (Fig. 1)。タイ湾では干潮と満潮がほぼ 1 日に 1 回の頻度で起こり、それぞれの水位の差は 1~2m である (Spalding *et al.* 1997)。泥質土壌の干潟を形成しているトン・ニアン湾には、陸域からの土砂供給が見込めない干潟が立地となるタイグランドラットタイプ (宮城 1991, 1992, 宮城ほか 2003) の

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マングローブ林が発達している。ナコン・シ・タマラート県における2003年の平均気温は27.3°C、年間降水量は2831.6mmである(National Statistical Office Ministry of Information and Communication Technology 2005)。

2004年9月にマングローブ林の汀線側の前縁部を基線として50m×50m(0.25ha)のプロットを設置した。プロット内の樹高1.5m以上の幹を対象に毎木調査を行い、種名・樹高・地上高1.3mの位置における胸高周囲長(Girth at Breast Height: GBH)を記録した。ただし、*Rhizophora apiculata*は支柱根が発達しているため、地上高で最上位に位置する支柱根の上部0.3m地点の周囲長を計測した。加えて、2005年9月にGBHの再計測と幹の消長を記録した。

計測したGBHから胸高直径(Diameter at Breast Height: DBH)と胸高断面積(Basal area: BA)を算出し各解析に用いた。2004年9月における種間の胸高直径階級分布の違いを、Kolmogorov-Smirnov検定を用いて解析した。有意性の判断には、多重性による第1種の過誤を避けるためにBonferroniの補正後の有意水準($\alpha^* = 0.05/6 = 0.0083$)を用いた。各種の2004年9月から2005年9月までの1年間の胸高直径階級分布の変化を、Kolmogorov-Smirnov検定を用いてそれぞれ解析を行った。解析には統計解析ソフトSPSS(SPSS Inc. 2005)を使用した。また、2004年から2005年の一年間のBAの変化を明らかにするために、次式を用いて出現種のBAの増加率と減少率をそれぞれ算出した(Kanno *et al.* 2001)。

$$\text{BAの増加率} = BA_1 / BA_0 \quad (1)$$

$$\text{BAの減少率} = BA_0 / BA_1 \quad (2)$$

ここで BA_1 は2004年に計測したBAの合計値である。 BA_0 は2004年から2005年にかけて増加した分のBAの合計であり、 BA_2 は枯死もしくは減少した分のBAの合計である。

また、2005年3月に、地上高0.3mの位置における周囲長の計測を個体ごとに行い、直径(Diameter at 0.3m height: $D_{0.3}$)を求めた。さらに、各種の直径と樹高の相対成長関係を明らかにするために拡張相対成長式(Ogawa & Kira 1977)を用いて回帰を行った。

$$1/H = 1/(A \cdot D^2) + 1/H_{max} \quad (3)$$

ここで D は各個体の直径である。ただし、*R. apiculata*は萌芽幹を持たないためDBHを用い、複数の萌芽幹を出すその他の種については $D_{0.3}$ を用いて、それぞれ回帰した。変数 A 、 h 、 H_{max} は各種に固有の変数であり、 A は個体密度に対応した値、 h は相対成長係数、 H_{max} は各種の最大樹高の推定値である(依田 1971, Aiba & Kohyama 1996)。

結 果

本調査地では、*A. alba*、*A. marina*、*S. alba*の3種に加えて*R. apiculata*が確認され、各種の幹数とBAは大きく異なった(Table 1)。2004年の幹数は合計469本であり、各



Fig. 1. Location of study site in Thong Nian bay, Khanom, Southeastern Thailand.

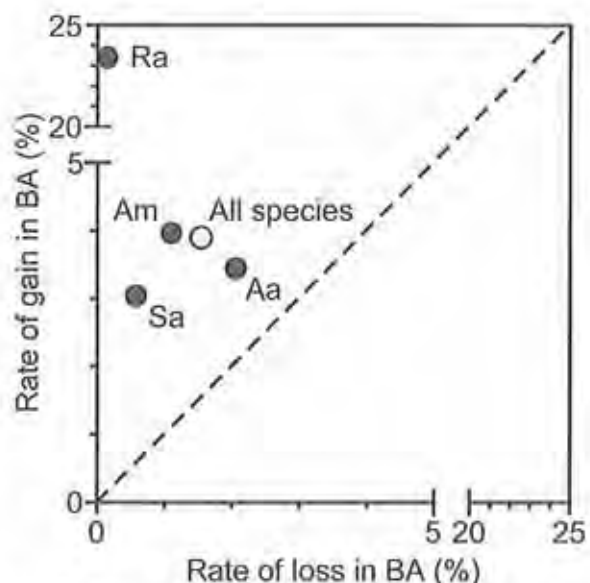


Fig. 2. Relationships between rate of gain and loss of basal area for each and all species. See Table 1 for species abbreviations.

種で25~258本と大きくばらついた(Table 1)。*A. marina*の相対出現幹数が55.01%と最も高く、次いで*A. alba*が30.28%と高かった。また、*R. apiculata*は9.38%、*S. alba*は5.33%であった。2004年から2005年までの合計幹数の減少率は6.18%であり、すべての種で幹数が減少した。種ごとの幹数の減少率は、*A. alba*が9.86%と最も高く、次いで*S. alba*が8.00%、*A. marina*が4.65%であった。*R. apiculata*は2.27%と減少率が最も低かった。

2004年のBAの合計は18.74m²/haであり、各種で

Table 1 Changes in the number of stems and basal area of the species (height > 1.5m) in the study site (0.25ha).

Species	Abbreviation	Density (number of stems / 0.25ha)			Basal Area (m ² / ha)			Relative change (%)		
		2004	2005	Mortality rate (%)	2004	2005	Gain	Loss	Total	
<i>Avicennia alba</i>	Aa	142	128	9.86	10.84	10.99	3.47	2.03	1.44	
<i>Avicennia marina</i>	Am	258	246	4.65	4.19	4.31	3.99	1.07	2.92	
<i>Sonneratia alba</i>	Sa	25	23	8.00	3.33	3.42	3.07	0.55	2.52	
<i>Rhizophora apiculata</i>	Ra	44	43	2.27	0.38	0.47	23.50	0.12	23.38	
Total		469	440	6.18	18.74	19.19	3.92	1.51	2.41	

Table 2 Changes in the frequency distribution of diameter at breast height in the study site (0.25ha). Values show the number of stems in September 2004. Values in parenthesis show the number of stems in September 2005.

Species	DBH class (cm)						
	-5	5-10	10-15	15-20	20-25	25-30	30-35
<i>Avicennia alba</i>	50 (37)	17 (18)	21 (18)	18 (19)	13 (12)	19 (19)	4 (5)
<i>Avicennia marina</i>	143 (129)	73 (74)	30 (30)	9 (10)	3 (3)		
<i>Sonneratia alba</i>	3 (1)	4 (4)	3 (3)	4 (4)	3 (3)	4 (4)	4 (4)
<i>Rhizophora apiculata</i>	32 (28)	10 (13)	1 (1)	1 (1)			
Total	228 (195)	104 (109)	55 (52)	32 (34)	19 (18)	23 (23)	8 (9)

Table 3 Sample sizes, parameters for the expanded allometric equation and the coefficients of determination for each species.

Species	n	A	h	H _{max}	r ²
<i>Avicennia alba</i>	90	0.29	1.63	19.22	0.90***
<i>Avicennia marina</i>	61	0.92	1.28	13.55	0.80***
<i>Sonneratia alba</i>	17	0.07	2.31	17.72	0.92*
<i>Rhizophora apiculata</i>	42	1.68	0.82	186.25	0.86**

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$

0.38m²/ha ~ 10.84m²/ha と大きくばらついた (Table 1). *A. alba* の相対 BA が 57.85% と最も大きな値を示した。次いで *A. marina* の相対 BA が 22.35%, *S. alba* が 17.79% であった。*R. apiculata* の相対 BA が最も低く、2.01% であった。全種の BA の合計値は、2004 年から 2005 年の 1 年間で 2.41% 増加し、*R. apiculata* の BA の増加率が 23.50% と最も高い値を示した (Fig. 2, Table 1)。一方、*A. alba* と *A. marina*、*S. alba* に大きな差はみられなかった。

2004 年 9 月の胸高直径階分布を種間で比較すると、*A. alba* と *S. alba* (Kolmogorov-Smirnov 検定: $p = 0.028$) および *A. marina* と *R. apiculata* ($p = 0.120$) のそれぞれの組み合わせに有意な差はなかった。一方、それ以外の組み合わせには有意差が認められた ($p < 0.0001$)。 *A. marina* と *R. apiculata* がともに逆 J 字形の分布を示したのに対して、*A. alba* と *S. alba* は全ての階級に出現し明瞭な分布のピークが見られなかった。*A. marina* は 55.43% の幹が DBH15cm 未満であり、逆 J 字形の分布を示した。また、最大 DBH

が 24.70cm であった。*A. alba* は 35.21% の幹が DBH15cm 未満の階級に出現した。DBH10cm から 30cm の階級の出現頻度は 9.15% ~ 14.79% を示し、最大 DBH が 34.19cm の幹も出現した。出現個体数は少ないものの、*S. alba* も全ての階級に出現していた。一方、*R. apiculata* は逆 J 字形の分布を示したが、最大 DBH が 15.34cm であった。また、それぞれの種において 2004 年と 2005 年の直径階分布を比較したが、4 種ともに有意差はなかった (Table 2, Kolmogorov-Smirnov 検定: $p = 0.213 \sim 0.968$)。

各種の樹高と直径の関係について拡張相対成長式を用いて回帰した結果、それぞれの変数に種間差が認められた (Fig. 3, Table 3)。変数 H_{max} は、*A. alba* が 19.22m、*S. alba* が 17.72m と高い値を示した。一方、*A. marina* は 13.55m と最も低い値を示した。また、*R. apiculata* は、サイズの大きな個体が欠如しているために直線的になった。変数 h の値は、*S. alba* が 2.31 とどの種よりも大きな値を示し、次いで *A. alba* が 1.63、*A. marina* が 1.28 と続き、

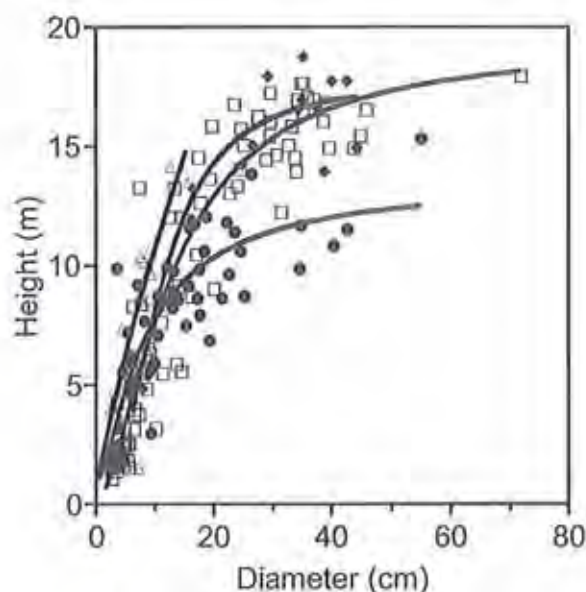


Fig. 3. The height - diameter relationships of each species: (\square) *A. alba*, (\bullet) *A. marina*, (\blacklozenge) *S. alba* and (\triangle) *R. apiculata*. Fitted lines are the expanded allometric equation: $1/H = 1/(A \cdot D^b) + 1/H_{max}$. See Table 3 for the number of species, each parameter for the expanded allometric equation and the coefficients of determination.

R. apiculata が 0.82 と最も低い値を示した。即ち、直径成長に対する樹高成長は *S. alba* が最も大きく、*A. alba*、*A. marina* と続き、*R. apiculata* が最も小さいことが示された。

考 察

本研究では、*A. alba* と *A. marina* が優占する前面群落に出現した種の個体群構造に加えて、各種の樹高と直径の相対成長関係および消長を明らかにすることにより、マングローブ前面群落の形成過程と各種の個体群の発達段階を推察できた。*A. alba* と *S. alba* の個体群は成熟し個体群を維持している段階にあり、その下層で *A. marina* が現在も個体群を拡大していると推察された。また、*R. apiculata* は調査群落に侵入し始めている段階にあると考えられた。

A. alba は、DBH の最も小さな階級に最頻値が認められたものの、他種に比べて大サイズの幹が多く出現し、BA 合計も最も高い値を示した。これは、*A. alba* の個体群は成熟しており、個体群を維持している段階にあることを示唆している。一方、出現幹数と BA の減少率がともに最も高い値を示した。特にサイズの小さなクラスでの減少率が高く、新規に加入する個体によって幹や BA の減少を補償できていないと考えられた。*A. alba* は、河口部などの新しく形成された立地に生育する (Aksornkoae et al. 1992) ことや、*A. alba* の実生は良好な光環境下に多く出現する (緒方ほか 2003) ことから、今後、ギャップ形成などの攪

乱により、実生の生育可能なマイクロサイトが形成されなければ、*A. alba* の個体群が衰退すると推察できる。

S. alba は、DBH の大きな幹が出現しているにもかかわらず、胸高直径階分布に明瞭なピークが見られなかった。さらに、出現幹数もわずかしき減少しておらず、BA についても減少率が増加率よりも低い値を示した。つまり、*S. alba* は、調査群落内において、新規に加入する個体が少ないまま現在の個体群を維持していると考えられる。現地での観察では、種子散布は確認されているものの、当年～数年生の実生はほとんどみられなかった。*S. alba* は、砂州などの新しい堆積地に生育する (Tomlinson 1986, 宮城ほか 2003) ため、現在、泥質土壌が堆積している調査地の立地環境が実生の生育・定着を抑制しているとも考えられる。*S. alba* や *A. alba* が優占する群落では、サイズの大きなギャップが形成され、そのことが *S. alba* と *A. alba* の実生の定着や成長を促進させる (Imai et al. 2006) ことや、成木の根返りや枯死により形成されたギャップでは、表層土壌が流出し立地環境が変化する (Sherman et al. 2000) ことから、*S. alba* も *A. alba* と同様に、ギャップ形成などの攪乱が起きなければ個体群が衰退する可能性がある。

A. alba と同様に、*A. marina* もまた、DBH が 5cm 未満の階級に最頻値が確認された。しかし、幹数の減少率が *A. alba* や *S. alba* と比べて小さく、BA の増加率が大きな値を示したことなどから *A. marina* の個体群は現在も拡大しているといえる。*A. marina* の実生は、林冠下でも成育することが可能であり (Walters 2005)、実生バンクを形成する (Clarke & Allaway 1993) ことが知られている。本調査地の群落は、林冠を構成する *S. alba* と *A. alba* の下層に *A. marina* が侵入し、現在の階層構造を持ったと考えられる。

宮脇ほか (1986) は、*Sonneratia albae-Avicennietum albae* の下層に *R. apiculata* や *R. mucronata* が生育することを報告している。本調査地でも小サイズの *R. apiculata* が群落の下層に生育していた。加えて、幹数の減少率が最も少ないことや、BA の減少がほとんどなく、増加率が高い値を示したことから、本調査地は *R. apiculata* が侵入し始めている段階であると考えられる。また、調査群落の下層に *R. apiculata* の実生が数多く確認されたことから、群落内での優占度が今後上昇していくと考えられる。

拡張相対成長式の相対成長係数 h は、陽樹の場合 1 よりも大きく陰樹の場合はほぼ 1 とみなすことができ、相対成長係数 h が大きいほど直径成長に対する樹高成長が大きくなる (依田 1971)。これまでの研究から先駆種とされる *S. alba*、*A. alba*、*A. marina* (Aksornkoae et al. 1992, 馬場・北村 1999) だが、変数 h の値が最も高い *S. alba* がより先駆的であり、次いで *A. alba*、*A. marina* であると本研究では序列付けることができた。また、*R. apiculata* の変数 h の値は、1 よりも小さかったことから、本調査地においてはより陰樹的と考えられた。つまり、本調査群落は、*S. alba*、*A. alba*、*A. marina*、*R. apiculata* の順で遷移しており、*S. alba* と *A. alba* が群落を形成した後に *A. marina* が侵入す

る段階を経て遷移が進行し、*R. apiculata* の侵入により、さらに遷移が進むと推察される。

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シンポジウム 2004年インド洋大津波災害とマングローブ林

日時：2005年11月5日〔土〕 13:00-16:30
会場：東京農業大学 世田谷キャンパス

シンポジウム開催趣旨：2004年12月26日発生のマグニチュード9のスマトラ沖地震では大津波が襲い、インド洋沿岸諸国に未曾有の物的、人的被害をもたらした。行方不明者をあわせ22万6000人あまりに達している。これまでサイクロンや高潮などの災害とほとんど無縁であった地域であったこともあり、リゾート観光地など壊滅的な物的被害をも生じた。沿岸に発達するマングローブ林や海岸林も様々な被害状況を示し、一大実験場ともなった。私共はこうした沿岸地域のマングローブ林や海岸林がどのように被災し、また耐え、減衰効果を果たしたのかを検証し、今後同様な災害発生時、人的、物的災害を最小限とする方策を探らねばならない。また、今後どのような研究が求められるのかを見定める必要があります。今回のシンポジウムでは被災国の一つタイからの研究者と現地調査にも参加した日本の研究者らとともに議論を深めたい。

課題説明：佐々木 寧 (シンポジウムコーディネーター)
話題提供：

1. インド洋大津波とマングローブ林が果たした役割—タイ国アングマン海沿岸—
東北学院大学文学部 宮城 豊彦
2. インド洋大津波と海岸林が果たした役割—タイ、スリランカ沿岸—
埼玉大学工学部 佐々木 寧
3. 津波に対するマングローブの力学機能
東海大学海洋学部 松田 義弘
4. Coastal Tsunami Damages and Rehabilitation of Thailand
Dr. Sonjai Havanond
5. Physical Effect of Tsunami in Thailand
Dr. Suwit Ongsom



シンポジウム討論と懇親会の様子

The role of coastal vegetation in case of the Indian Ocean tsunami -Coastal area of Thailand and Sri Lanka-

Yasushi Sasaki¹⁾, Samang Homchuen²⁾ and Norio Tanaka¹⁾

Abstract: Based on the field survey of coastal area in Thailand, Sri Lanka and Male in Maldives as wave brakes. It was observed 13 forest types, 14 bush and herbal communities of coastal vegetation. The coastal vegetation in devastated area is mainly *Casuarina equisetifolia* and *Cocos nucifera* in Thailand, in Sri Lanka is *Pandanus odoratissimus* and *Cocos nucifera*. Any trees along the beach, have fallen down very few and have not been lost, except most front line trees and herbal communities remained almost. The coastal vegetation area was observed only limited erosions, on the behinds in the forest sand sedimentation has been observed. By seawater salt, withered vegetation and temporal leaf drops has been observed. And the coastal vegetation has functions as wave breaks so help reduce water speed, changing pathway, and rescue effects such as trap effect, soft-landing effect and escape effect.

Further, coastal vegetation can not repress tsunami itself, that best and most possible disaster prevention under local economical situations is layout of coastal vegetation in tsunami protection, combined mangrove trees.

Keywords: Coastal vegetation, sand hill, trap effect, soft-landing effect, escape effect

1. Introduction

The Indian Ocean tsunami and the Sumatra earthquake have occurred at December, 2004, and countries and peoples around the coastal area have extremely suffered and damaged, which they have never experienced. The disaster made two hundred thousand of people died or lost. Since having a long experience in research activity in Asian countries, we hurriedly organized research group included researchers from Sri Lanka and Thailand, and researched these damages. The survey has been held at 29 points along with West-side coast, about 200 km section between Phuket island and Ranong, Thailand, on January, 2005, and at 19 points, about 250 km section between West coast at the south side from Kolombo and the east coast in Kalmunai, on April, 2005. Also, on January, 2006, held in Male, Maldives.

The survey was focused on "how the seaside forests and Mangrove forest in devastated area are related with reducing damages." Since tsunami becomes larger in sand dune at curved coast geographically, a few Mangrove forests, which are mainly inside of Lagoons in Thailand and Sri Lanka, have directly damaged in tsunami. This paper states about coastal vegetation at sand hill area, which directly damaged in tsunami.

2. The type of coastal vegetation

The types of coastal vegetation in devastated area are mainly *Casuarina equisetifolia* forest and *Cocos nucifera* forest, which is artificial forest. Over 20-meter trees has been observed in the *Casuarina equisetifolia* forest.

Natural vegetations, which are *Terminalia catappa*, *Pandanus odoratissimus* and *Scaevola sercea*, are locally observed; however, there are a few examples which constructs a large coastal vegetation. In addition, the examples which developed herbal coastal vegetation are very few.

On the other hand, the types of vegetation in Sri Lanka are mainly constructed to natural vegetations, which are *Pandanus odoratissimus*, *Cocos nucifera*, or mixture of two. Also herbal coastal vegetation, such as *Ipomoea pes-caprae*, *Spinifex littoreus*, or *Crinum asiaticum* have developed. The other hand, in Maldives with coral beach, *Messerschmidia argentea*, *Calophyllum inophyllum*, *Cardia subcordata*, *Guetarda speciosa* community have developed.

3. Damaged conditions of coastal forest and seashore vegetation

Casuarina equisetifolia and *Cocos nucifera*, which are really tall and no leaves at lower point, had a little damage because of tsunami waves had passed through under the tree. The middle or shorter trees which have

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Fig. 1. Map of the observation sites, Thailand, Sri Lanka and Maldives

Table 1 vegetation types in coastal vegetation of each country

Forest community	Thailand	Sri Lanka	Maldives
<i>Casuarina equisetifolia</i> forest	much	some	some
<i>Cocos nucifera</i> forest	much	much	much
<i>Syzygium gratum</i> community	some	rare	rare
<i>Pandanus odoratissimus</i> community	some	much	some
<i>Terminalia catappa</i> community	some	some	some
<i>Barringtonia asiatica</i> community	rare	some	some
<i>Cerbera odollam</i> community	rare	much	some
<i>Messerschmidia argentea</i> community	rare	rare	some
<i>Cordia subcordata</i> community	rare	rare	some
<i>Calophyllum inophyllum</i> community	rare	rare	some
<i>Guettarda speciosa</i> community	rare	rare	some
<i>Thespesia populnea</i> community	much	some	some
<i>Hibiscus tiliaceus</i> community	much	some	some
Bush and herbal community			
<i>Scaevola taccada</i> community	some	much	much
<i>Calotropis gigantea</i> community	some	much	some
<i>Premna integrifolia</i> community	rare	some	some
<i>Crimon asiaticum</i> community	rare	much	rare
<i>Clerodendron inerme</i> community	some	much	some
<i>Cassine balaie</i> community	much	some	some
<i>Peperomia acida</i> community	rare	rare	some
<i>Acanthus ebracteatus</i> community	some	some	some
<i>Opuntia vulgaris</i> community	rare	much	some
<i>Salvadora-persica</i> community	rare	some	rare
<i>Ipomoea pes-caprae</i> community	some	much	much
<i>Spinifex littoreus</i> community	rare	much	rare
<i>Canavalia lineata</i> community	much	some	some
<i>Sesuvium portulacastrum</i> community	much	some	some



Fig. 2. Only surface sand has eroded by the tsunami at front of sand dune, *Cocos nucifera* forest, in Rekawa Sri Lanka



Fig. 3. Rare case of coconuts trees has been fallen to sea side by backflow of tsunami, In Rekawa, Sri Lanka

leaves even in lower points, such as *Terminalia catappa*, *Pongamia pinnata*, *Pandanus odoratissimus*, *Anacardium occidentale*, have fallen down very little. Fallen vegetation are concentrated on the most front vegetations even in the area, where experienced larger tsunami and greatly damaged. In these cases, fallen trees are mainly in the side road of water flows such as rivers or small waterways, and it results in soil erosion at these roots. The vegetations in Rekawa, Sri Lanka have been fallen backflow of Tsunami, fallen to seaside. However, fallen trees have not been lost from the point by tsunami.



Fig. 4. Rare case of *Casuarina equisetifolia* young trees has been fallen by the tsunami at front of sand dune, but don't flow out in Rekawa, Sri Lanka



Fig. 5. *Alstonia macrophylla* (left) and *Azadirachta indica* (right) has been died by the tsunami in Sri Lanka

4. Rhizomes of trees constructed the coastal vegetation

Regardless of huge tsunami, the coastal vegetation have very few fallen or lost by flown-out. These results points out strength of the tree trunk and the strength of the roots.

5. The damage from salt by flowing seawater

A large amount of seawater has been flowing even deeper inlands by tsunami attack. In the example of Sri Lanka, seawater has reached 1 to several kilometers inland from the coastline. The seawater flowing to inland is considered to influence to groundwater, and its well-water quality has dramatically changed. In addition, many examples of withered vegetation by seawater salt, and temporal leaf drops have been observed. Each species

Table 2 The Tolerance range for salinity

Familie	Sci. name	Thailand	Sri Lanka	Tolerance
Palmae	<i>Cocos nuxifera</i>	+++	+++	○
	<i>Borassus flabellifer</i>	+++	++	×
Casuarinaceae	<i>Casuarina equisetifolia</i>	+++	++	○
Anacardiaceae	<i>Mangifera indica</i>	+++	+++	×
	<i>Anacardium occidentale</i>	+++	+	△
Lecythidaceae	<i>Barringtonia asiatica</i>	++	+++	○
Apocynaceae	<i>Plumeria obtuse</i>	+++	+++	△
	<i>Alstonia macrophylla</i>	++	+++	×
Meliaceae	<i>Azadirachta indica</i>	++	+++	×
Myrtaceae	<i>Psidium guajava</i>	++	++	×
Moraceae	<i>Artocarpus communis, altalis</i>	++	++	△
	<i>Ficus hispida</i>	++	+++	△
	<i>Ficus microcarpa</i>	++	++	○
	<i>Ficus religiosa</i>	+++	+++	○
	<i>Artocarpus heterophylla</i>	++	++	△
Graminae	<i>Bambusa and Dendrocalamus</i>	++	++	○
Apocynaceae	<i>Cobra mangas</i>	+++	+++	○
Guttiferae	<i>Calophyllum inophyllum</i>	+++	++	○
Rutaceae	<i>Limonia acidissa</i>	+	++	○
Malvaceae	<i>Hibiscus tiliaceus (macrophyllus)</i>	+++	+++	○
	<i>Thespesia populnea</i>	++	+++	○
Combretaceae	<i>Terminalia catappa</i>	+++	+++	○
Verbenaceae	<i>Tectonia grandis</i>	+++	++	×
	<i>Premna interfolia</i>	+++	+++	○
Rhizophoraceae	<i>Avicennia marina, alba</i>	+++	+++	○
	<i>Rhizophora apiculata, mucronata</i>	+++	+++	○
Myrtaceae	<i>Eucalyptus camaldulensis</i>	++	++	○
Musaceae	<i>Musa sapientum</i>	+++	+++	○
Leguminosae	<i>Sonchnea saman</i>	+++	+++	○
	<i>Acacia auriculiformis</i>	+	+++	△
	<i>Cassia bakeriana</i>	+	+++	○
	<i>Erythrina indica, stricta, variegata</i>	++	++	○
	<i>Manikara hexandra</i>	+	+++	○
	<i>Zizyphus jujuba</i>	+	+++	○
	<i>Muntingia calabura</i>	+++	++	×
	<i>Bauhinia racemosa</i>	+	++	○

+++ : common ++ : some + : rare ○ : height △ : middle × : low

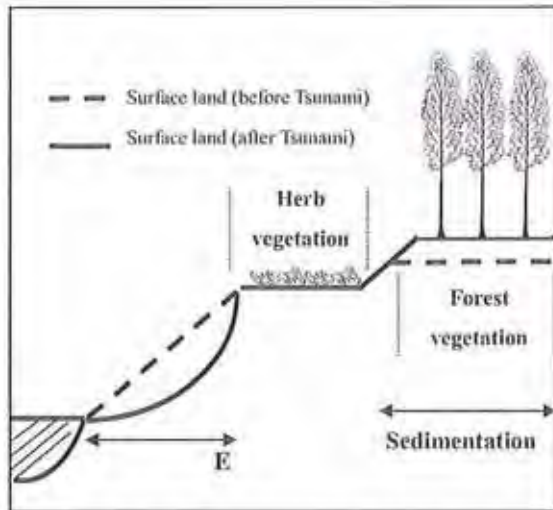


Fig. 6. Erosion and sedimentation of each region on the dune

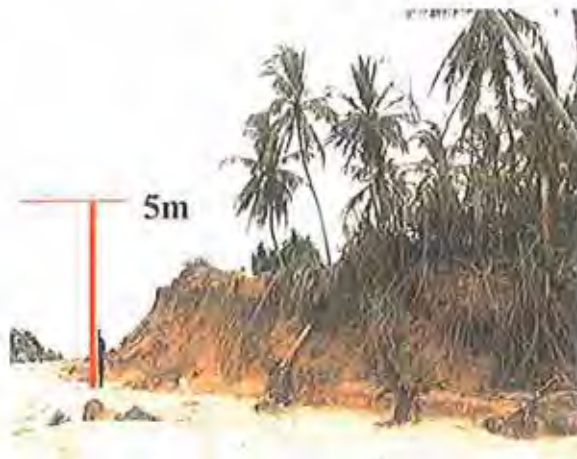


Fig. 7. At the river mouth has been strong eroded by the tsunami wave, in Rekawa, Sri Lanka

damaged differently from them. Especially, many of *Alstonia macrophylla* and *Mangifera indica* have withered.

6. Effects of reducing damages by coastal vegetation.

Many examples of coastal and sand erosions by tsunami have been introduced, and many examples of coastal sandbar lost has been reported.

6-1 Erosion and sedimentation

Erosion, separated Laem Son island in Thailand, has occurred. In Khao Lak, Thailand, over 1 meter erosion has been observed in less vegetated area. In Sri Lanka,



Fig. 8. In the *Casuarina equisetifolia* forest has been deposited sand by the tsunami, in Laem Son, Thailand



Fig. 9. Coastal vegetation can change tsunami way, In this case is *Casuarina equisetifolia* forest, in Laem Son, Thailand.

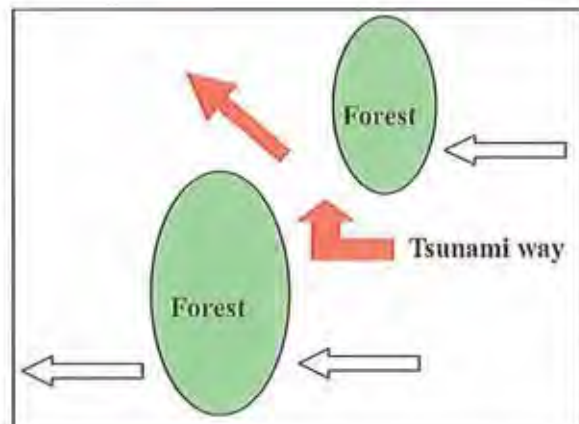


Fig. 10. Coastal vegetation can change tsunami way, In this case is *Casuarina equisetifolia* forest, in Laem Son, Thailand.

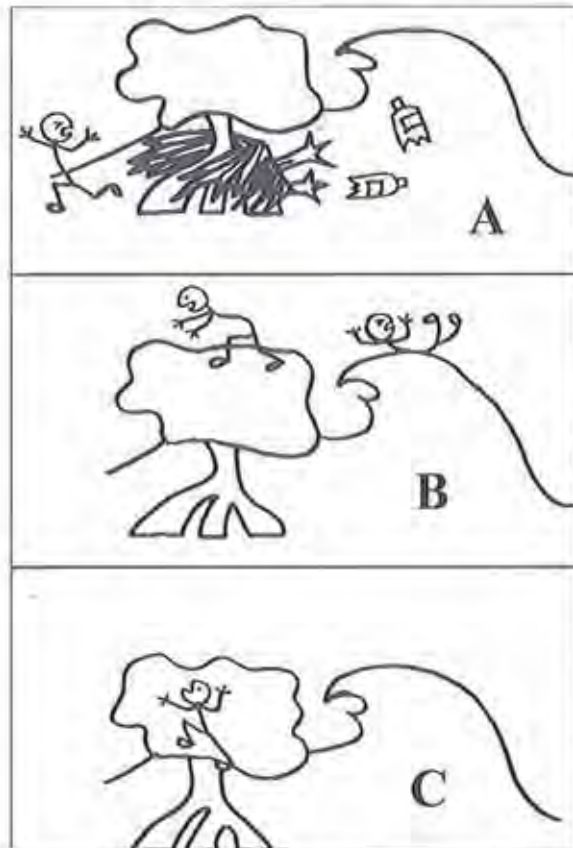


Fig. 11. Rescue effect by coastal vegetation
 A : Trap Effect
 B : Soft-landing Effect
 C : Escape Effect

sand hill has been eroded and almost connected to backward Lagoons. Those areas are also less vegetated areas. On the other hand, the sand hill area, where plant colonies such as *Ipomoea pes-caprae* and *Spinifex littoreus* have developed, have limitedly eroded within 10 to 20 cm. On the behinds of these vegetations, in *Casuarina equisetifolia* Forests, sand sedimentation has been observed in Laem Son, Thailand.

6-2 By path effect

Vegetations have no ability to repress tsunami, but they will work as wave resistance or changing pathway of tsunami.

Tsunami passing through forests such as coastal vegetations changed its way to less resistant, or less vegetated area,

7. Rescue effect by coastal vegetation

As the result of interview or survey with peoples in devastated area, many people have been rescued by

existence of coastal vegetation. These rescue effects can be arranged by following:

1. Trap Effect: coastal vegetations have effects to filter hazard outflow such as debris or scrapped boards.
2. Soft-landing Effect: people flown out by tsunami have injured or died by hitting harder buildings, but some of them have rescued by being thrown to softer coastal vegetation.
3. Escape Effect: compared with flown-out houses, coastal vegetation has not fallen or flown out, and people could escape by going up coastal vegetation.

8. Disaster prevention in coastal area.

What is the best and most possible disaster prevention under the local economical situations? Since international alert system for disaster prevention is also necessary, its effectiveness in local remoted area still have some problems. Also, in Okushiri island in Hokkaido, Japan, and the Maldives islands in Andaman Sea, modern seawall has been constructed for tidal or tsunami prevention.

However, these examples are not appropriate in developing country, because of its costs and landscapes. These methods may be limited in more populated area as well as city. Coastal vegetations in tsunami protection are eternal, low-cost, and environmental constructions; even in usual time, these have many advantages at the environmental points of view, such as wind prevention, sand prevention, ecology, or water purifications. Coastal vegetation for tsunami protection cannot repress tsunami itself. However, layouts of coastal vegetation in tsunami protection, double-layer construction, and de-fragmentation of vegetation species, provide disaster prevention effects. The suggested coastal vegetation in tsunami protection in this research will effectively bring out rescuing people and wrack-trap effect. Construction of coastal vegetation in tsunami protection, combined mangrove trees in back ground wetland area and lagoon, which is highly dense, multiple layered vegetation structure, will achieve symbiosis with coastal fishing, landscapes, and sightseeing in the area.

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Hydraulic functions of mangroves in relation to tsunamis

Yoshihiro Mazda¹⁾, Faizal Parish²⁾, Finn Danielsen³⁾ and Fumihiko Imamura⁴⁾

Abstract: Through field investigations after the Indian Ocean tsunami which occurred on the 26 December 2004 and previous researches in relation to the tsunami control forests, it is believed that mangrove forests along coastal areas protect human lives from tsunamis. Tropical mangrove areas have unique physical characteristics, compared to the coastal areas in middle latitudes. Given these characteristics and the research results on this tsunami, it is suggested that mangrove forests act in two different ways, which protect human lives from tsunamis, depending on their magnitude. Firstly, when the tsunami is of moderate force, the mangrove trees remain standing, preserving their own ecosystem and protecting the human lives behind them. Secondly, when the force of the tsunami is so great to destroy the mangrove forests, the forests protect human lives by sacrificing themselves. There are, however, very few studies on the hydraulic behavior of tsunamis in relation to the peculiar characteristics of mangrove areas. It should be, further, noted that the hydraulic function of tsunami waves in mangrove areas cannot be estimated by interpolation between the previous findings about tidal waves and sea waves in these areas. In order to obtain quantitative findings of a tsunami's impact on mangrove forests and to protect human lives and the natural environment in tropical mangrove coastal areas, the following topics urgently need to be studied through interdisciplinary researches between topography, dendrophysics, forest ecology, sedimentology, hydraulics and tsunami engineering; 1) the mechanism of hydraulic resistance in mangrove forests in relation to the time-scale of tsunami waves, under situations not only of standing trees but also of felled trees; 2) the function of tsunami waves scouring the bottom-soil and scooping up underground roots in mangrove forests; 3) the mechanism of deformation/attenuation of tsunami waves at a reef edge and over a wide shallow tidal flat; and 4) the hydraulic criteria which can be used as a quantitative standard for planning tsunami control forests, based on the results in the above 1) to 3).

Keywords: Tsunami, Mangrove, Hydraulic function, Indian Ocean tsunami

1. Introduction

We express our heartfelt sympathy to all people who sustained damage during the disaster caused by several earthquakes and the associated tsunamis which occurred in the Indian Ocean in December 2004. Several researches have been conducted to find out the reasons for such catastrophic disaster in these areas. With a desire to prevent such a disaster from recurring in the future, we wish to highlight some important functions that mangrove forests may have played in shielding human lives from the tsunami, and to propose that a quantitative understanding of the behavior and hydrodynamics of tsunamis especially in tropical mangrove areas is needed urgently.

Danielsen *et al.* (2005) have reported their research results in Cuddalore District in Tamil Nadu, India (Fig.1) just after the Indian Ocean tsunami. A few hamlets behind mangrove forests fringing the coast survived from the attack of the tsunami, even though the waves damaged areas unshielded by vegetation.

Kathiresan and Rajendran (2005) investigated the

damage by this tsunami in 18 hamlets along the south-east coast of India. According to their report, there was no loss of human lives in three hamlets, and the human death toll was low in four. All were situated behind mangrove forests. Parish *et al.* (unpublished) collected satellite images (Fig.2) of a western bay on Katchall Island belonging to the Nicobar Islands shown in Fig.1.

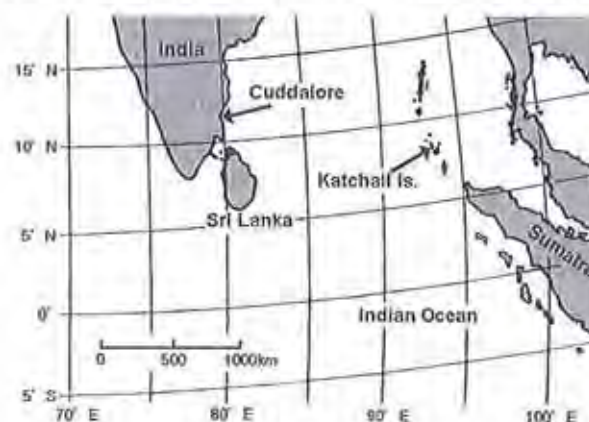


Fig. 1. Map of Indian Ocean

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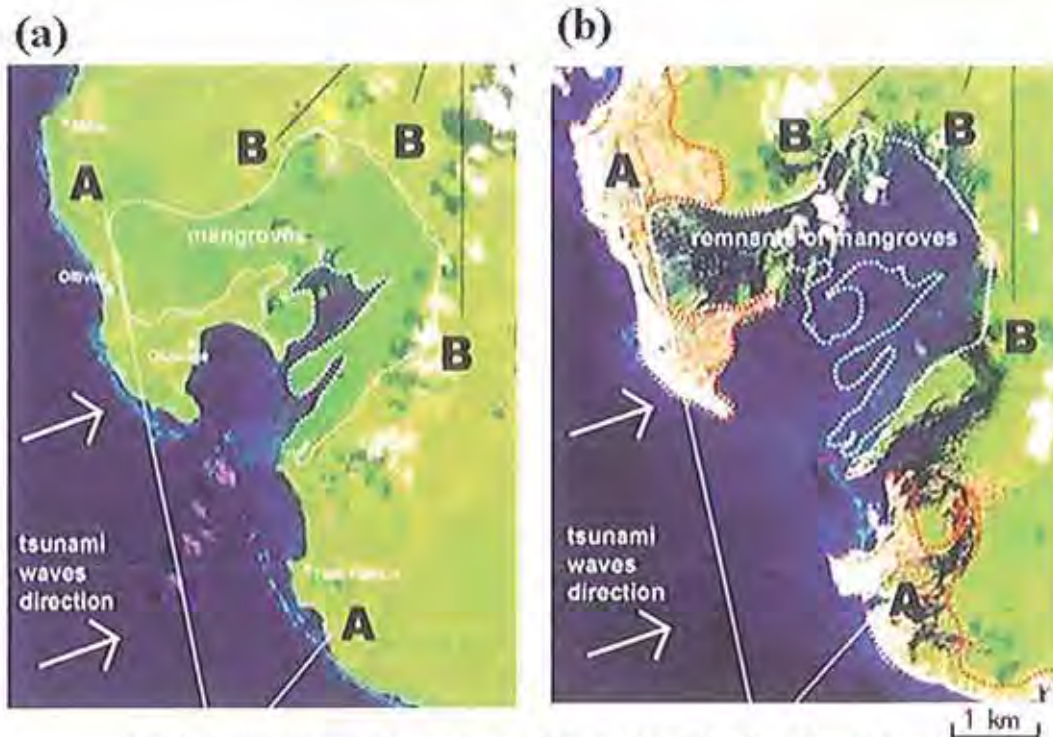


Fig. 2. Satellite images of a west coast of Katchall Island, Nicobars, Indian Ocean
 (a) Before the Indian Ocean tsunami occurred on 26 December 2004
 (b) After the tsunami

This figure shows the destruction of the mangroves on a large scale by the tsunami and the mangrove's potential protection function. Figures 2a and 2b are the images taken before and after the attack of the tsunami, respectively. The tsunami washed along the white arrows as shown in the figures. The bay area is bordered by a white dotted line. Before the attack by the tsunami, the bay area had been covered with mangrove canopies. After the attack, however, no mangroves could be seen in the bay on the satellite image. This means that the tsunami scoured the bottom soil in the bay and uprooted or snapped off all of the mangrove trees. After the attack of the tsunami, our assessment of satellite images suggests that vegetation and villages in the area marked "B" behind the mangroves were not badly impacted by the tsunami disaster, while villages and agricultural areas marked "A" without mangroves were destroyed or severely damaged by the tsunami. A comparison of these two satellite images suggests that the tsunami was huge, given that all of the mangroves in the bay seemed to have been destroyed. Notwithstanding that, land areas behind the mangroves were protected perhaps by sacrificing mangroves. These observational results suggest a typical function of mangrove forests protecting human lives

from tsunamis. Based on these findings, we discuss the hydraulic functions of mangroves in relation to tsunami waves.

2. Systems preventing tsunami disasters

Through previous studies and the field investigation of the Indian Ocean tsunami, the following four kinds of systems, which prevent tsunami disasters, can be pointed out.

- 1) The system that dams up (reflects) the tsunami energy, protecting useful facilities behind the system.
- 2) The system that lets the tsunami energy pass through, preserving the system itself.
- 3) The system that disperses the tsunami energy, both preserving the system itself and protecting facilities behind it.
- 4) The system that is destroyed by the tsunami energy, sacrificing the system itself but protecting facilities behind it in exchange.

Examples of 1) are artificial tsunami gates and tsunami embankments that reflect the tsunami waves (Tomita, 2005). An example of 2) is a piloti. In coastal zones in Hawaii, it is recommended that the ground floors of houses should be built on stilts alone, without walls



Fig. 3. Examples of mangrove trees

(Urban Regional Research, 1988). Imamura (2005) has also reported the significant effect of the piloti on coastal buildings in Sri Lanka, based on his field research following the Indian Ocean tsunami. In Aceh in Indonesia the only buildings which survived the tsunami were mosques which had large archways and windows which allowed the wave to pass through the lower part of the building. An example of 3) is a tsunami control forest. The tsunami control forests are usually facilitated along the Japanese coasts in order to protect the residential areas from winds, sea waves and storm surges (Harada and Imamura, 2003; Harada and Imamura, 2005). Data from Cuddalore in India mentioned above (Danielsen *et al.*, 2005) also suggests an example of 3). An example of 4) is the case of Katchall Island shown in Fig.2.

In the western bay of Katchall Island, the mangrove forest and the ecosystems were entirely destroyed by the tsunami invasion. However, human lives behind the forest were protected perhaps by sacrificing the forest. Of course, the conservation of mangroves is important from the viewpoints of natural environment, food resources, wood resources and land protection (Vannucci, 1989; Hong and an, 1993). But, mangroves can recover either



Fig. 4. Mangrove trees (*Bruguiera* sp.) scooped their underground roots and felled by ship waves, along the bank of the Nakama-gawa river in Iriomote Island, Japan

naturally or through reforestation, although it takes many years (Hong, 2004). As explained in detail in Section 3.2, destroyed mangroves consume tsunami energy greatly, compared to the case of 3). Thus, the function of 4) is very different to that of 3). It should be recognized that the role of mangroves as a sacrifice is very important especially in a worst case scenario such as the huge tsunami that occurred on the 26 December 2004.

3. Hydraulic functions of mangroves

3.1 Construction of mangrove areas

Mangrove areas in tropical regions have the following unique physical characteristics, compared to coastal areas in middle latitudes.

- Mangrove forests are reciprocally flooded and exposed to the air with a diurnal or semi-diurnal period.
- Mangrove trees are closely entangled with each other (Nakasuga, 1991).
- Mangrove trees have a vertical configuration with roots above and below the ground, plus trunks and canopies (Sato, 1984; Sato, 1989; Mazda *et al.*, 1997b).
- The underground roots are confined to a shallow depth below the bottom substrate (Komiyama *et al.*, 1989).
- The extent of spread and the spatial density of roots under the ground are comparable to the total amount of the mangrove trees above the ground (Komiyama *et al.*,

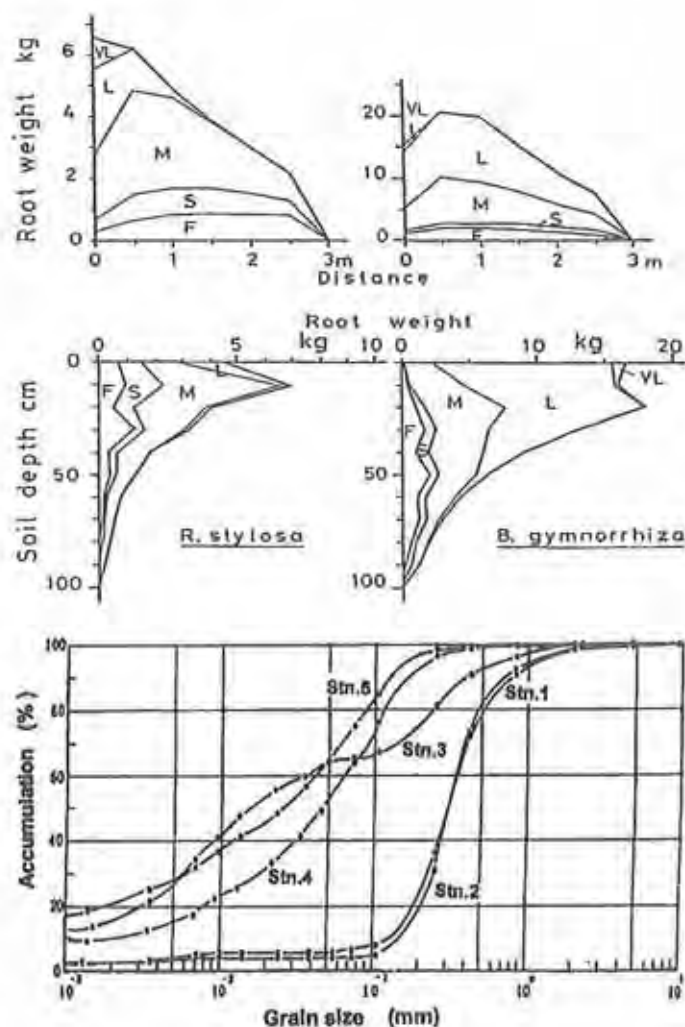


Fig. 5. Estimated root form of *Rizophora stylosa* (left) and *Bruguiera gymnorrhiza* (right) (after Komiyama *et al.*, 1989).

F: fine root;

S: small root;

M: medium root;

L: large root;

VL: very large root

Top: horizontal root distribution. Bottom: vertical root distribution.

Fig. 6. Grain-size distributions of sediments in a swamp and a tidal creek of the Kesaji-gawa river, Okinawa Island, Japan (after Sato, 1975). Stns.1 and 2 are sites in the tidal creek, and Stns.3-5 are sites in the mangrove swamp.

2000).

- f) The bottom soil is loose because of fine sediments, animal burrows and the reciprocating tidal flow over and under the ground (Sato, 1975; Susilo and Ridd, 2005; Mazda *et al.*, 2006a).
- g) Tidal flats adjacent to the mangrove forests expand widely toward the open sea, and at the end of the tidal flat such as reef edges the water deepens substantially (Mazda *et al.*, 2006b).

Depending on these characteristics, mangrove areas have unique hydraulics as follows. Mangrove forests experience flooding every day. The flooding by tidal action, however, is very slow compared to that by tsunamis. The behavior of tsunamis in mangrove forests may depend on whether the tsunami occurs at high tide or at the exposure of the bottom substrate, while tsunamis in middle latitudes always overflow onto the dry land. Further, the flow in the forest depends on the vegetation density. The vegetation density in mangrove forests is

very high up to 2 trees/m² (Nakasuga, 1991; Mazda *et al.*, 1997b), while within pine forests such as tsunami control forests in Japan it is in the order of 0.3 trees/m² (Harada and Imamura, 2005). As can be seen in Fig.3, the configuration of mangrove roots above the ground varies by species. The roots of each species individually play an effective role in resisting water flow (Mazda *et al.*, 1997a; Mazda *et al.*, 2005; Mazda *et al.*, 2006b). Figure 4 shows *Bruguiera* species, fringing the Nakama-gawa river in Iriomote Island, Japan. Ship waves induced by sightseeing boats have easily scoured sediment off the creek bottom and the bank, because the soil is loose due to fine sediments, animal burrows and the reciprocating tidal flow over and under the ground. As a result, the underground roots have been exposed, and trees have fallen into water, because the depth of the roots under the ground is less than 1 m (Fig.5). We can also see in Fig.4 that the extent of the spread and the spatial density of the roots under the ground are comparable to the total amount of the trees

above the ground. In Fig.5

Komiyama *et al.* (1989) show the spatial distribution of the underground roots. They have stated that the underground roots extended horizontally up to 3 m. Further, Komiyama *et al.* (2000) have stated that in a *Ceriops tagal* forest, nearly 50 % of the total biomass was allocated to the underground roots, compared to 10-20 % in tropical inland forests. These values, though being measured in weight, suggest the importance of the underground roots as hydraulic resistance when the trees fell into the water. Figure 6 shows the distributions of grain size at a tidal creek on the Kesaji-gawa river and fringing mangrove swamps, Okinawa Island, Japan (Sato, 1975). As seen in the figure, generally, the grain-size in mangrove swamps is considerably finer than that in tidal creeks and adjacent coastal areas. Accordingly, the bottom soil of mangrove swamps is easily scoured and swept away by waves and water flows. Generally, mangrove forests contact to the open tidal flats which expand widely toward the open sea over 10 km, and at the end of the tidal flat such as a reef edge the water deepens substantially. This bottom profile typical in tropical mangrove regions is very different to that within middle latitudes.

The following observational results suggest the significant effects of the various characteristics listed above. On coasts in Thailand and Sri Lanka, Sasaki *et al.* (2006) have estimated that the bottom soil in mangrove swamps was scoured to a depth of up to 1 m by the Indian Ocean tsunami. Havanond (2007) has also stated that on the Andaman coast the sediment erosion due to this tsunami was 0.5-2.0 m in depth. Similarly, on an Andaman coast, Miyagi (personal communication) has estimated that the roots of *Avicennia* species were scooped up by the strong water flow caused by this tsunami. Kathiresan and Rajendran (2005) have introduced that the island chain of Surin off the west coast of Thailand escaped heavy destruction, because the ring of coral reefs and mangroves surrounding the island helped to break the lethal power of this tsunami.

3.2 Two systems in which mangrove forests protect human lives

Given the above, mangrove forests can act in two ways, i.e. 3) and 4) classified in Section 2. When the tsunami energy is moderate, the mangrove trees survive or remain standing. In this situation, the terms of b) and c) in Section 3.1 function together to disperse the tsunami energy due to hydraulic resistance. Thus the force of the tsunami doesn't reach deep into the mangrove forests, resulting in the survival of the mangrove ecosystem and the protection of human lives. The following paradox,

however, should be noted. The laboratory research by Hamzah *et al.* (1999) has suggested that the water flow velocity behind the mangrove vegetation doubles because of narrowing the flow section when the mangroves vegetate too densely. Further, it is noted that in R-type mangrove forests (see Appendix) the tsunami waves propagate to a long distance upstream through the creek without energy reduction, because there is no vegetation in the creek.

On the other hand, when the tsunami energy is great, the tsunami waves deform into a bore (Sato, 1995), creating a strong water flow due to g), and digging the mangrove roots up from under the ground due to d) and f), felling trees into the water. Since the flood and exposure are reciprocal with the tidal period as stated in a), the bottom substrate always contains a lot of water, resulting in the loose bottom soil which accelerates the above effect. In this situation, considering e) and the fact that canopies dip into the water too, the tsunami energy is effectively dissipated by these strong resistances (canopies, trunks, branches, roots above and below the ground), compared to the former case when the trees stand still normally. As a result, even if the tsunami energy is so great that mangrove forests are destroyed, the land and human lives behind them can be protected by this sacrifice.

It has been pointed out that trees forming coastal forests would be destroyed and washed away by a huge tsunami, causing secondary damage by attacking houses and human lives like floating weapons (Shuto, 1987). However, given that in mangrove areas the fallen trees are restricted to being washed away because of b), it should be noted that human lives behind mangrove forests can be saved. Furthermore, Danielsen *et al.* (2005) and Parish *et al.* (unpublished) have pointed out the effect of mangroves to stop drifts such as floating wood, boats and debris, based on their field investigation just after the Indian Ocean tsunami. In conclusion, mangrove forests can act as two systems against tsunami intrusions. Firstly, when the tsunami energy is moderate, the mangrove trees remain standing, preserving their own ecosystem and protecting the human lives behind them. Secondly, when the tsunami energy is great enough to destroy the mangrove forests, the forests absorb the huge wave energy by sacrificing themselves, protecting human lives.

4. Hydraulic studies within mangrove areas

4.1 Present studies on tsunami control forests

Studies on hydraulic behavior of tsunami waves have been widely conducted (Iida and Iwasaki, 1983; Hebenstreit, 1997; Satake, 2005). As the latest works,

Hamzah *et al.* (1999), Harada *et al.* (2000), Aburaya and Imamura (2002), Harada *et al.* (2002), Harada and Imamura (2003), Hiraishi and Harada (2003), Harada and Imamura (2005) and Imai and Matsutomi (2005) have discussed the effect of hydraulic force in tsunami control forests, mainly based on laboratory experiments and numerical simulations. Imai and Matsutomi (2005) have pointed out the importance not only of the drag force due to vegetation but also of the inertial force at the bore-like wave front and the wave-making force due to the shaking of tree foliage, Harada and Imamura (2005) have summarized effects of forest width, vegetation density and wave period on the reduction of tsunamis, and proposed the criteria to identify quantitatively the relation of the tsunami intensity to disaster, which can be used as a quantitative standard to design a coastal forest as a tsunami countermeasure. These studies, however, have not been specifically designed for mangrove areas. On the other hand, Hamzah *et al.* (1999) and Harada *et al.* (2000) have experimented on the behavior of the drag force taking into consideration the vertical configuration of the mangrove trees.

As shown in Appendix, Cintron and Novelli (1984) have classified the mangrove landform into three types, riverine forest (R-type), fringe forest (F-type) and basin forest (B-type). Regarding the F-type and B-type, the tsunami waves intrude into mangrove swamps perpendicular to their coastal lines. For the R-type, however, the tsunami waves go up the creek, and then inundate the mangrove swamp. The behavior of the tsunami going upstream is quite different from that when inundating the mangrove swamp. These different behaviors should be studied separately. It should be noted that since the swamp water is dragged by the flow going up the creek, thus flowing parallel to the creek, the viscous force (shear force) plays an important role as well as the drag force (Asano *et al.*, 2001; Kobashi and Mazda, 2005; Mazda *et al.*, 2005). The viscous force along the creek might reduce the tsunami energy going up the creek. There are, however, very few studies on the tsunami waves which consider these unique characteristics of mangrove areas.

4.2 Differences in the hydraulic behavior of tsunami, tidal and sea waves in mangrove areas

Figure 7 shows the hydraulic resistance of mangrove vegetation in a range of sea waves with a period of less than about 20 seconds (Mazda *et al.*, 1997a). The data was obtained at a mangrove area of *Kandelia candel* in northern Vietnam. The abscissa in Fig.7 is the water depth, which changes with tidal phase, and the ordinate is the coefficient

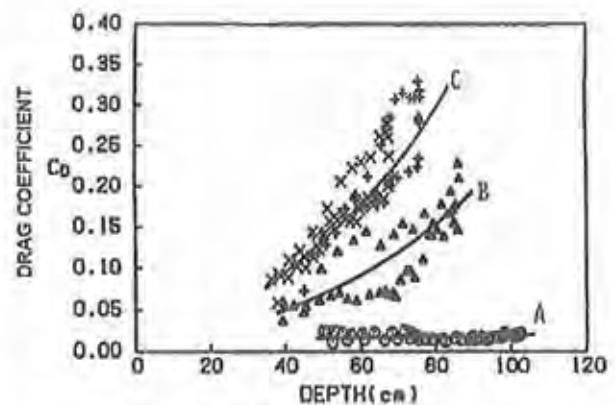


Fig. 7. Variation in the drag coefficient C_D , with the water depth (Mazda *et al.*, 1997a).

of hydraulic resistance, i.e. the drag coefficient due to mangroves. The magnitude of this coefficient roughly means that of the reduction in wave energy. "A" is the case where there is no vegetation in the area. "B" is the case where 5-6 year old mangroves cover the area. And "C" is the case where mature mangroves cover the area. The difference between A, B and C in Fig.7 suggests that the hydraulic resistance due to mangroves depends on the growth level, i.e. the vertical configuration of mangrove trees. In addition, it seems that the hydraulic resistance depends on the amount of vegetation submerged in the water. Mazda *et al.* (2006a) have also found that the effect of the hydraulic resistance differs considerably between roots, trunks and canopies, based on observations in an area vegetated by *Sonneratia ceccolalis*.

Figure 8 shows a concrete effect of hydraulic resistance due to mangroves, according to Case C in Fig.7. Within the area investigated, the mangrove trees vegetate with a 1 m interval up to 1.5 km from the coast toward the open sea and 3.0 km along the coast line. The wave height at the point 1.5 km from the coast reduces to 5 % at the coast due to the resistance of the mangroves. If there were no vegetation, 75 % of the wave height at the open sea would arrive at the coast. This result suggests the effectiveness of the hydraulic resistance of mangroves against the sea waves in a typhoon that has wave periods of less than 20 seconds. However, as described below, this finding cannot be directly applied to the case of tsunami waves.

Figure 9 shows the behavior of the coefficient of hydraulic resistance due to mangroves in a range of tidal waves with a semi-diurnal period, based on field observations in many mangrove swamps individually dominated by *Rhizophora* species or *Bruguiera* species (Mazda *et al.* 2005). The abscissa is arranged according to the following parameter, i.e. Reynolds Number.

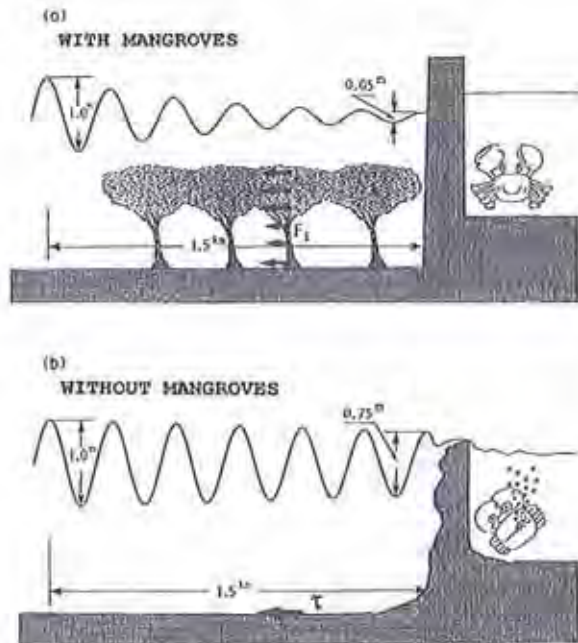


Fig. 8. Differences in the effect of wave reduction (a) with and (b) without mangroves (Mazda *et al.*, 1997a). In (a) the drag force on the plants ΣF_d occurs throughout the water depth. In (b) the bottom friction τ occurs only at the bottom floor.

$$Re = \frac{uL}{\nu} \dots\dots\dots(1)$$

where ν is the kinematic viscosity, u is the water velocity in the swamp caused by the tidal motion, and L is the effective interval between trees, which depends on the vegetation density, the vertical configuration of vegetation and the water depth.

The figure shows that the coefficient of the resistance, which varies within a wide range of 0.5 to 10, depends on the magnitude of L , i.e. the effective interval between trees. On the other hand, for sea waves with periods of less than 20 seconds, the coefficient is at most 0.4, as shown in Fig.7. Further, Hamzah *et al.* (1999) have measured the magnitude of the coefficient as ranging from 0.5 to 1.5 for *Rhizophora* species, based on a laboratory experiment for tsunami waves.

The above findings suggest that the hydraulic behavior of waves in mangrove swamps greatly depends on their periods. Figure 10 shows the spectrum of waves in water areas, after Munk (1951). The abscissa is the period of waves on a logarithmic scale. The periods of tsunami, tidal and sea waves are each very different. The period of tsunami waves is in a range of 10 minutes to 2 hours, and vary different both from the sea waves (< 20 seconds) and the tides with diurnal and semi-diurnal periods. Further, it

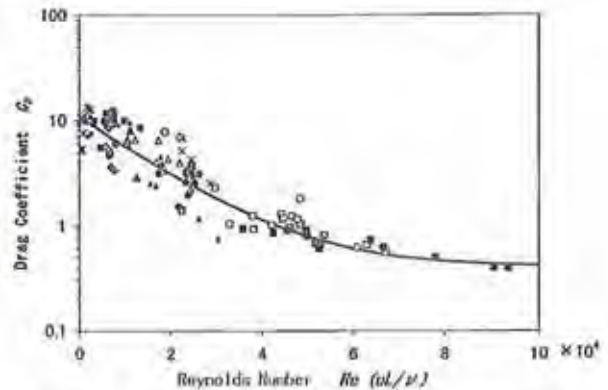


Fig. 9. The relationship between the drag coefficient C_d and the Reynolds Number Re (Mazda *et al.*, 2005). The marks indicate the different observation sites and species.

should be noted that the water velocity in tsunami waves is extremely large compared with those of tidal waves and sea waves. The tsunami thus transcends the range of the abscissa on Fig.9, which is defined by Eq.(1).

Within the tidal-scale hydrodynamics of mangrove swamps, the inertial force caused by the acceleration of water mass is neglected, because the tidal flow can be approximated to a steady flow (Mazda *et al.*, 1997b). However, as mentioned previously (Imai and Matsutomi, 2005), the inertial force cannot be neglected for the case of tsunami waves, because they are in a transient process with a large acceleration at the wave front. Especially, given g) in Section 3, which is a unique condition in tropical areas, it is suspected that the inertial force plays an important role as follows, compared with those in middle latitudes. Tsunami waves break at coral reef edges, twist their waveform, then arrive at mangrove forests after passing a long distance across a tidal flat as a strong flow with a sharp front like a huge bore. This strong flow with a sharp front is suspected to form a significant inertial force, resulting in great destructive energy to mangrove trees.

In conclusion, as Kathiresan and Rajendra (2005) pointed out, the hydraulic function of tsunami waves in mangrove areas cannot be estimated by interpolation between those of tidal waves and sea waves. We have to investigate separately quantitative behavior of tsunamis in mangrove areas, though the previous findings regarding the hydraulic behavior of tidal waves and sea waves in these areas can be qualitatively referred to for tsunami.

5. Future studies

According to the above discussion, the following studies

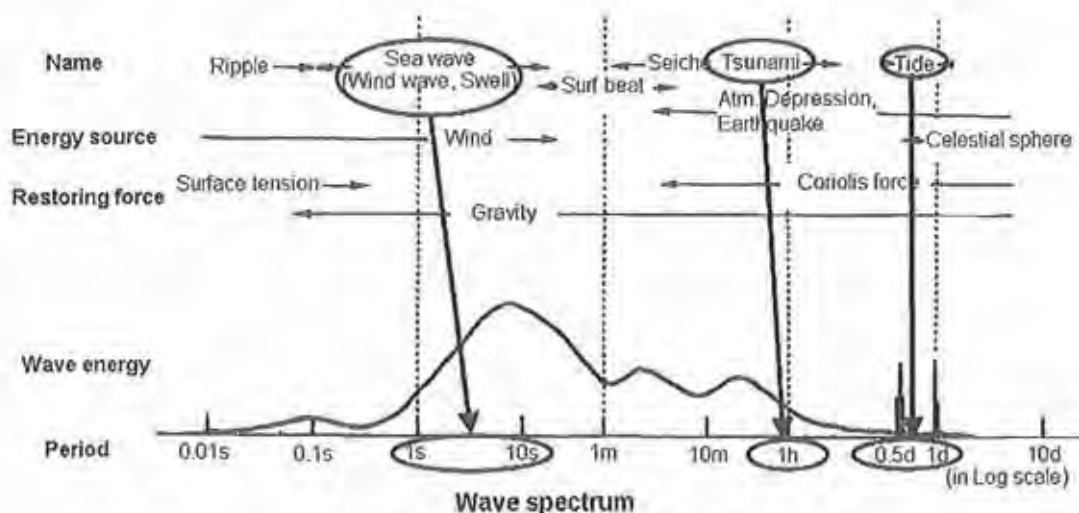


Fig. 10. Wave spectrum (after Munk, 1951).

on tsunamis should be conducted from the standpoint of mangrove hydraulics.

- 1) The mechanism of hydraulic resistance in mangrove forests in relation to the time-scale of tsunami waves, under situations not only of standing trees but also of felled trees.
- 2) The function of tsunami waves scouring bottom-soil and scooping up underground roots in mangrove forests, as well as snapping mangrove trunks.
- 3) The mechanism of deformation/attenuation of tsunami waves at reef edges and over a wide shallow tidal flat.
- 4) The hydraulic criteria which can be used as a quantitative standard for designing and establishing tsunami control forests, based on the results in the above 1) to 3).

As mentioned previously, since the fallen trees do not drift due to b) in Section 3.1, human lives behind the forest can survive. However, it depends on the vegetation density. Generally, since coconuts, palms and casuarinas in tropical coastal zones don't vegetate closely, compared to mangrove forests, the trees once destroyed by tsunamis drift away, attacking human lives like floating weapons (Shuto, 1987). Furthermore, as mentioned previously, the water flow velocity doubles behind the mangrove trees when the mangroves vegetate too densely, resulting in the destruction of human lives behind the forest. It is feared that the fallen trees play the part of a double-edged sword. In order to find the quantitative relationship between the suitable vegetation density and the force of the tsunami waves, first of all, the above mechanism 1) which controls the hydraulic resistance in densely vegetating mangrove forests have to be analyzed for each mangrove species.

The critical point that mangrove forests can tolerate the tsunami energy depends both on the magnitude of tsunami waves and the hydraulic functions of mangroves. Further, magnitude of the hydraulic function of tsunamis that scours bottom-soil and scoops up underground roots may depend on whether the bottom substrate is in an exposed condition or already in a flooded condition because of the tide when the tsunami arrives. Therefore, the function 2) and the mechanism 3) should be analyzed. Finally, in order to design the coastal mangrove forest as a tsunami countermeasure, the hydraulic criteria 4), which can be used as a quantitative standard, should be formulated according to the findings obtained through the processes 1) to 3), in consideration of the peculiar characteristics of the tropical mangrove areas.

6. Summary

In order to prevent tsunami disasters, there are four kinds of systems classified in 1)-4) of Section 2. As examples of systems 3) and 4), mangrove forests along coastal areas seem to have protected human lives from the Indian Ocean tsunami occurred on 26 December 2004.

Mangrove areas have peculiar physical characteristics, as summarized in a)-g) of Section 3.1. Given these characteristics, it is suggested that mangrove forests act as two systems 3) and 4), depending on the magnitude of tsunamis. Firstly, when the tsunami energy is moderate, the mangrove trees remain standing, preserving their own ecosystem and protecting the human lives behind them. Secondly, when the tsunami energy is great enough to destroy the mangrove forests, the forests protect human lives by sacrificing themselves.

Mangrove roots underground have great spatial density and extent of spread. When mangrove trees fall down, therefore, the underground roots create great hydraulic resistance in the water. At the same time, the resistance of the canopy is superimposed on this resistance. It should be noted, thus, that the hydraulic resistance of felled-mangrove trees plays a considerably different role in a tsunami disaster from that of standing trees.

There are, however, very few studies on the hydraulic behavior of tsunami that take into consideration the peculiar characteristics of tropical mangrove areas. It should be noted that the hydraulic function of the tsunami waves in the mangrove areas cannot be estimated by interpolation between the previous findings about tidal waves and sea waves in these areas. There is a need for interdisciplinary research between topography, dendrophysics, forest ecology, sedimentology, hydraulics and tsunami engineering, in order to obtain quantitative findings particularly of the following topics and to protect human lives and the natural environment in tropical mangrove coastal areas:

- 1) The mechanism of hydraulic resistance in mangrove forests in relation to the time-scale of tsunami waves, under situations not only of standing trees but also of felled trees.
- 2) The function of tsunami waves scouring bottom-soil and scooping up underground roots in mangrove forests.
- 3) The mechanism of deformation/attenuation of tsunami waves at reef edges and over a wide shallow tidal flat.
- 4) The hydraulic criteria which can be used as a quantitative standard for planning the tsunami control forest, based on the results in the above 1) to 3).

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Appendix

Based on topographical features of mangrove areas, Cintron and Novelli (1984) have classified mangrove landform into three types, riverine forest, fringe forest and basin forest, as shown schematically in Fig.A.

1) Riverine forest (R-type; Fig.Aa) is defined as that found on a floodplain with long tidal creeks, which is

inundated by most high tides but dry up at most low tides. Most tidal creeks meander and intertwine with each other. The tidal flow goes up the creek without energy reduction, then inundates the mangrove swamp at flood tide. The swamp water in the vicinity of the tidal creek is dragged by the tidal flow of the creek, thus flowing parallel to the creek, while the flow in the swamp is predominantly perpendicular to the creek due to the water surface slope between the swamp and the creek (Kobashi and Mazda, 2005; Mazda *et al.*, 2005).

2) Fringe forest (F-type; Fig.Ab) is defined as

that found on shores facing open sea, and is directly exposed to the action not only of tidal water but also of sea waves. Sea waves reduce in the swamp because of the resistance of thick mangrove trees and their roots emerging from the soil (Mazda *et al.*, 1997a; Massel *et al.*, 1999).

3) Basin forest (B-type; Fig.Ac) is defined as that found in a partially impounded depression, which is inundated by few high tides during dry season but many high tides during wet season.

It should be recognized that the dominant water movements differ between the R-type, F-type and B-type

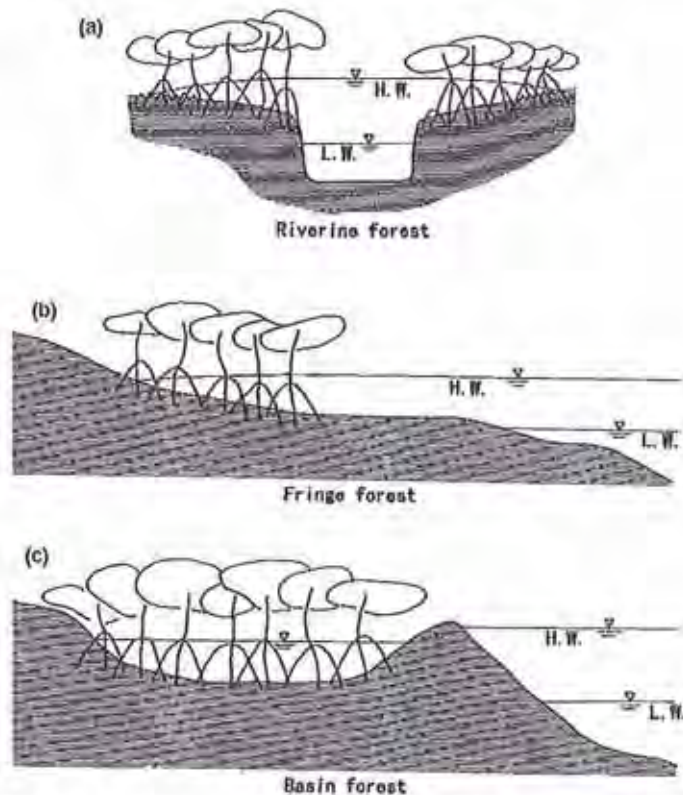


Fig. A. Classification of mangrove topography (after Cintron and Novelli, 1984)

(a) Riverine forest type; (b) Fringe forest type; (c) Basin forest type

平成 16 年度日本マングローブ学会大会プログラム (於: 東京農業大学 13 号館 2 階)

第一日目 (11 月 6 日)

ヤエヤマヒルギ胎生種子の林内生長と母樹の分布について

桑原連 (東京農大)

マングローブ生態系における海水流動の役割 (2) - 樹木の浸水特性 -

神山健太郎 (東海大院)・丁子統一・戸来太郎・土紀勲・
銭田祐介・鈴木雄二・荻原祐介・石原佑典・三田良樹・
松田義弘 (東海大)

マングローブ域の海水流動に対する樹木群の影響

松田義弘 (東海大)・小橋大地郎 (Louisiana S. Univ.)・
岡田聡 (日本海洋事業㈱)

マングローブ CDM 植林における衛星データの実用的な利用
手法の開発

石井孝・立田穰 (電中研)・Gullaya Wattayakorn
(Chulalongkorn Univ.)・島海治彦 (EAAJ)

吹通川マングローブ水域における水表面浮遊物に関する検討

二瓶泰雄・中村武志・堀内重樹・宮部皓太 (東京理科大)・
太田和裕介 (㈱横河ブリッジ)

マングローブ堆積物における有機炭素収支

立田穰・石井孝・今村正裕 (電中研)・北村菜穂・松岡
雪子 (東京医薬)

特別講演

Future research activities for conservation of mangroves
and coastal environment in Thailand

Sonjai Pavanond (Dep. of Marine and Coastal
Resources, Thailand)

Lenticels and junctions structures of mangrove root
Avicennia marina in relation to air conducting network

Hery Purnobasuki・関正典・鈴木三男 (東北大院)

ヤエヤマヒルギ支柱根における通気組織の連続性の解析

関正典・Hwry Prunobasuki・鈴木三男 (東北大院)

ニュージーランドのマングローブ土壌特異性

河口定生 (九州大)・Gordon S. Maxwell (Hong Kong
Open Univ.)

西表島で採取された *Sonneratia alba* 特異的な担子菌について

須原弘登 (㈲有明環境整備公社)・前川二太郎 (南草研)・
金城一彦 (琉球大)・星良和 (有明高専)・近藤隆一郎 (九州大)

ヤエヤマヒルギにおける胚軸表面の遮光および通気抑制処理が胚軸根内 O_2 濃度および溶面コンダクタンスにおよぼす影響

吉井秀樹・北宅善昭・渋谷俊夫・清田信 (大阪府大院)

マヤブシキ (*Sonneratia alba*) 子葉の液体培養細胞系確立

川名祥史・菅本浜子 (横浜国大院)

沖縄県西表島におけるマングローブ林の立地変動と分布
データベース試作

林一成 (東北学院大院)・宮城豊彦 (東北学院大)・馬場
繁幸 (琉球大)・遠藤由更 (東北学院大)

懇親会 農大ミュージアム「食と農の博物館」

第二日目 (11 月 7 日)

潮汐傾度に沿って変化するマングローブ林の攪乱体制と更新
パターン

今井伸夫 (東京農大院)・中村幸人 (東京農大)

エーヤワデーデルタ・マングローブ資源の持続的利用に關
する研究 I - 住民の利用実態に基づく資源の定量的評価の
試み -

大野勝弘・鈴木邦雄 (横浜国大院)

ベトナム、カンザー地区マングローブ再造林プロジェクト
の 3 年目の状況報告

石原修一 (駒場東邦中・高・南遊の会)・澤本潤 (南山
大・南遊の会)・井上いつか (南山大院)・Vien Ngoc
Nam (Forestry Dep. of HCMC)・Cat Van Thanh (The
People Committee of Can Gio District)

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山本規子・小林桃子・皆川礼子・豊原秀和 (東京農大)
前面群落に共存する *Avicennia alba* と *A. marina* の空間分布
緒方淳二・富田瑞樹・鈴木邦雄 (横浜国大院)・中村武
久 (東京農大)

マングローブの多面的価値

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和を目指して

あいさつ 中村武久

話題提供

1: Sustainable conservation and utilization of Mangroves
in S.E. Asia Sanit Aksornkoae (Thailand Environment
Institute)

2: マングローブ植林の実際活動から
松井直弘 (㈱関西総合環境センター)

3: マングローブ林の保全と環境変動
古川恵太 (国土技術政策総合研究所)

4: マングローブの生態遷移の視点から
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総合討論

平成 17 年度日本マングローブ学会大会プログラム (於: 東京農業大学 13 号館 2 階)

第一日目 (11 月 5 日)

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河合省三 (東京農大)

II-アルカンを用いたマングローブ堆積物における有機炭素の起源推定の試み

立山 隆 (電中研)・小竹由美・鈴木育美 (東京医薬)

静穏時のマングローブ林内の連続する 1 潮毎の堆積量

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藤本 隆 (南山大)・持田幸良 (横浜国大)・菊池多賀夫・田淵隆一 (森林総研)

パラオ共和国 Ngeremedauu 湾マングローブ林におけるセジメント輸送について

古川 憲太 (国総研)・Steven Victor (パラオサンゴ礁センター)

公開シンポジウム インド洋大津波とマングローブ

課題説明 佐々木 寧 (埼玉大)

1: インド洋大津波とマングローブ林が果たした役割 - タイ国アングマン海沿岸 -

宮城豊彦 (東北学院大)・林一成 (東北学院大)・柳沢英明 (東北大)・Charichai Tanavud (Prince of Songkla Univ. Thailand)

2: インド洋大津波と海岸林が果たした役割 - タイ、スリランカ沿岸 -

佐々木 寧 (埼玉大)・Samang Homochuen (Khon Kaen University)・田中 規夫 (埼玉大)

3: 津波に対するマングローブの力学的機能

松田 義弘 (東海大)・Faizal Parish (Global Environmental Centre)・Finn Danielsen (Nordic Agency for Development and Ecology)・今村文彦 (東北大)

4: Physical Effect of Tsunami in Thailand

Suwit Ongsomwang (Ministry of Natural Resources and Environment, Permanent Secretary Office)

5: Effects of Tsunami on Coastal and Mangrove Resources Disaster in Thailand Sonjai Havanond (Department of Marine and Coastal Resources, Thailand)

総合討論

懇親会 農大ミュージアム「食と農の博物館」

第二日目 (11 月 6 日)

マングローブ植物の葉における塩分集積過程の解明

寺澤弘陽 (東北大院)・鈴木三男 (東北大)

マヤブシキ (*Sonneratia alba*) の液体培養細胞に及ぼす 4 種の塩の影響

川名祥史・河合史樹・笹木浜子 (横浜国大院)

メヒルギの液体培養と内生アブシジン酸量

河合史樹・川名祥史・笹木浜子 (横浜国大院)

メキシコ・ユカタン半島のマングローブの枯死林形成と塩分

宮城豊彦 (東北学院大)・漢 漢靖 (JICA)・Marco Antonio Plata Mada (リアセレストン生物圏保護区)

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八木厚志 (大阪大院)・宮城豊彦 (東北学院大)・Phan Nguyen Hong (ハノイ大)

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藤知 顯 (沖縄日立ネットワークシステムズ㈱)・佐藤一弘 (琉球大)・建石隆太郎 (千葉大)

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須原弘登 (九州大院)・前川二太郎 (鳥取大)・金城一彦 (琉球大)・近藤隆一郎 (九州大院)

ベトナム・カンザー地区マングローブ再造林プロジェクトの 4 年目状況報告

石原修一 (駒場東邦中高校・南遊の会)・藤本 隆 (南山大・南遊の会)・Vien Ngoc Nam (Nong Lam Univ.)・Le Van Sinh・Cat Van Thanh (The People Committee of Can Gio District)

前面群落に共存する *Avicennia* 属 2 種の樹形および樹冠形の比較

緒方淳二・富田瑞樹・鈴木邦雄 (横浜国大院)・中村武久 (東京農大)

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荒木祐二 (横浜国大院)・Dornng Powdhy (Peace in Tour Angkor)・平吹喜彦 (東北学院大)・Chay Rachana (Authority for Information Protection and Management of Angkor and Region of Siem Reap)・塚脇真二 (金沢大)・富田瑞樹・鈴木邦雄 (横浜国大)

Survival and growth performances of the mangrove species replanted in the ex-agricultural land of the Ayeyarwady delta in Myanmar

Maung Maung Than・持田幸良 (横浜国大院)

Sonneratia alba と *Avicennia alba* の立地環境

大谷真弓・早坂大亮・藤原一繪 (横浜国大院)・中村武久 (東京農大)

琉球列島におけるマングローブ林の成帯構造に関する研究 - 緯度に沿った構造の変化 -

諏訪 隼平・萩原秋男 (琉球大)

平成 18 年度日本マングローブ学会大会プログラム (於：東京農業大学 13 号館 2 階)

第一日目 (10 月 21 日)

ベニマヤブシキ (*Sonneratia caseolaris*) 葉および子葉の組織、細胞培養系開発

山本来紀・川名祥史・持田幸良・鈴木邦雄・笹本浜子 (横浜国大)・馬場繁幸 (琉球大)

Bruguiera sexangula および *B. gymnorrhiza* のプロトプラスト単離と培養

栗山真悟・河合史樹・川名祥史・持田幸良・笹本浜子 (横浜国大)・三村徹郎 (神戸大)

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持田幸良 (横浜国大)・Charlene Mersai・Arius Merap・Geory Mereb・行平英基 (パラオ国際ンゴ礁センター)・馬場繁幸 (琉球大)

植生から学んだいくつかのマングローブの性質と生態ー

1 C A インドネシアマングローブ実証プロでの経験ー

田淵隆一 (森林総研)・羽鳥祐之 (JICA 国総研)

マングローブ堆積物からの CO₂ 放出量の定量

立田穰 (電中研)・鈴木育美・益満裕梨 (東京医薬)

マングローブ林と波浪の相互作用について

古川恵太 (国総研)・平石哲也 (港湾空港技術研)

公開国際シンポジウム 熱帯アジアのマングローブ・湿地生態系研究

共催：横浜国立大学 21 世紀 COE プログラム (生物・生態リスクマネジメント)

総合司会 檜垣宮都

あいさつ 鈴木邦雄 (横浜国大)

1: タイ・マングローブ研究 30 年

中村武久 (前・日本マングローブ学会会長・東京農業大学名誉教授)

2: Characteristics of flora and vegetation in the southern part of Thailand

Sridith, kitichate (Prince of Songkla University, Thailand)

3: 複合的な植物利用におけるマングローブの資源評価ーエーヤワディーデルタの事例からー

大野勝弘・鈴木邦雄 (横浜国大)

4: タイ国バンガ湾・マングローブ植生の構成種

皆川礼子・鈴木邦雄 (横浜国大)・中村武久 (東京農大) 総合討論

懇親会 農大ミュージアム「食と農の博物館」

第二日目 (10 月 22 日)

Morning Lecture

Kandelia candel and '*Kandelia obovata*': ecotypes, varieties or different species?

Gordon S. Maxwell (Tropical Biosphere Research Center, Univ. of Ryukyus)

マングローブ樹木の耐塩性機構ーバクチンメチルエステラーゼー

露木泰成・飯島倫明・檜垣宮都 (東京農大)

マヤブシキの葉の内部構造および NaCl 局在の解析

寺澤弘陽・鈴木三男 (東北大)

タイ国バンガ湾マングローブ林のカイガラムシ

沼倉由香里・河合省三・足達太郎 (東京農大)

MANGROVE SCIENCE 投稿規定

1. 本学会誌への投稿論文の種類は、原著論文、総説論文、短報、資料とする。
本会正会員であれば本学会誌へ投稿できる。また著者複数の場合は少なくともその内の一人が正会員でなければならない。但し、編集委員会の依頼原稿はこの限りではない。
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執筆要領

1. 論文原稿は和文または英文とし、つぎの順序で記述する。

- A. 和文の場合：①表題、②英文表題、③著者名、④ローマ字著者名、⑤所属、⑥英文アブストラクト、⑦Key Word (アルファベット順に5語以内)、⑧本文、⑨文献
 B. 英文の場合：①表題、②著者名、③所属、④英文アブストラクト、⑤Key Word (アルファベット順に5語以内)、⑥本文、⑦文献

2. 和文・英文原稿の詳細フォーマットは、編集委員会にお問い合わせください。フォーマットの見本を電子ファイルで送付します。

3. 論文中に引用した文献はすべて記載するものとし、文献の書式は下記の例にならい、配列は著者のABC順とする。Webサイトの記載はそのアドレスとする。

<例>

Briggs S. V. (1977): Estimates of biomass in a temperate mangrove community. *Journ. Austral. Ecol.*, 2, 369-373.

田川日出夫 (1982): マングローフとマンガルの生態 I. 海洋と生物 4, (2): 82-91.

藤間剛・中村久美他 (1991): 冠水深と植栽密度がヒルギマシ *Avicennia marina* の直立気根に与える影響. *TROPICS* 1, (1): 75-82.

Watson J. G. (1928): Mangrove forest of the Malayan Peninsula. *Malay. For Rec.* 6, 275 pp.

4. 和文原稿で動植物名を書く場合、和名はカタカナ書き、学名はイタリック体とする。

5. 論文中への図表の使用は自由であるが、そのまま印刷できる清書した図表であること。また写真は原則として白黒プリント写真とする。ただしカラー写真を印刷希望の場合は、印刷費を著者負担とする。

6. 図表および写真には英文でキャプションをつける。その説明は別紙に書き図表と一致するよう番号または記号で (Fig. 1, Tab. 1.) 明示する。

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