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Notes on molluscs from NW Borneo - Dispersal of molluscs through nipa rafts

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ABSTRACT Nipa rafts regularly form along the NW coast of Borneo, transporting live estuarine molluscs and other invertebrates. Depending on wind direction, currents and tides, they are beached, enter estuaries or float offshore. This paper discusses the potential of such rafts to transport live molluscs to other parts of the same estuary or to other estuaries, thus expanding their range. As nipa palms are known since the Late Cretaceous, transport via nipa rafts may have occurred throughout the Cenozoic.

KEY WORDS Nipa raft, rafting, distribution, estuarine molluscs, Borneo, Malaysia, Brunei

INTRODUCTION

Along the high tide line of most beaches in NW Borneo (Sarawak, Brunei, Sabah) tree trunks or logs are abundant, especially in areas where there is active transport of raw wood, as frequently part of commercial cargoes is lost during transfer. Like other rafting objects, these logs can transport live animals, that often settle on the logs after they reach the sea, especially barnacles (various species) including the goose barnacles (*Lepas anitifera* Linnaeus, 1758). Less frequently nipa rafts wash up onto beaches, and they frequently transport live molluscs and other invertebrates that already lived on the nipa palms before they entered the sea. This poses the question whether this could contribute to the distribution of estuarine molluscs. Rafts of other plants, such as *Papyrus* have been postulated as a possible means of transport for molluscs in the eastern Mediterranean (Mienis 2003). Kano *et al*. (2013) describe floating tree trunks as helping the distribution of estuarine Neritidae in Papua New Guinea. This paper is based on observations by the author made when he lived in the study area (1992-1997) and during later visits, as well as on material collected.

OBSERVATIONS

After storms, nipa rafts comprising one or several nipa palms (*Nypa fruticans* Wurmb, 1779) regularly wash up on the beaches of Sarawak and Brunei, occasionally in large numbers. The rafts transport live palm trees and their seeds, but also animals that live on various parts of these trees. Most of these live on the thick lower part of the leaf petiole and higher up on the leaves. Regularly the thick lower part of the leaf petiole is hollow, providing a well-protected hideout for live animals. Many estuarine animals can survive such trips as they are accustomed to variable salinities. In addition, the nipa trees float upright and therefore their upper parts are not constantly submerged in sea water.

After a northeasterly storm, on the 10th and 11th of August 1995 a large number of nipa rafts washed up on Piasau Beach, Miri, Sarawak (Figure 1). Live estuarine molluscs, barnacles and juvenile goose barnacles (*Lepas anitifera* Linnaeus, 1758) were observed on several rafts. Two of these rafts were closely inspected and the mollusks living on it were recorded (Table 1). The rafts were formed by 3 and 8 palm trees

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respectively and each transported 4 to 7 species of brackish water molluscs. For most species the number of live specimens was small. The bivalves and the Neritidae were found on the broad leaf bases and the *Littoraria* species on the leaves themselves. Most oysters were juveniles, the other molluscs were adults. The same storm washed up other floating objects but these had only marine species attached.

Figure 1. Large nipa raft on Piasau Beach August 1995 (no shells were collected from this raft).

The species found on the nipa rafts are typical inhabitants of the middle (brackish) part of the estuary. The author has observed various other species living on nipa palms in the middle part of estuaries including other species of *Littoraria*, *Cerithidea charbonnieri* (Petit de la Saussaye, 1851), *C. quoyii* (Hombron & Jacquinot, 1848) and *Chicoreus capucinus* (Lamarck, 1822). However, the fact that they do not appear on nipa rafts could mean that these species did not live in the estuary from which the nipa floats came, they did not live on those nipa palms that came to form the floats sampled, or they fell off during transport (the latter being likely in the case of *Cerithidea* species as they are less strongly attached as compared to species of *Littoraria* and *Nerita*).

Goose barnacles do not tolerate the brackish water of estuaries – the author never observed them alive in estuaries. They are very common – in huge numbers – on all types of objects floating at sea, as can be noted from

Group	Family	From	Registration number	Species	Raft 1 (8 nipa trees)	Raft 2 (3 nipa trees)	On drum	On driftwood
Bivalves	Ostreidae	E	T0484	*Crassostrea rivularis* (Gould, 1861)	◯			◯
Bivalves	Anomiidae	E	T0727	*Enigmonia aenigmatica* (Holten, 1802)	◯	○		
Bivalves	Mytilidae	M	T0474	*Brachidontes striatulus* (Hanley, 1843)				⬤
Bivalves	Mytilidae	M	T0470	*Brachidontes variabilis* (Krauss, 1848)				⬤
Bivalves	Trapeziidae	M	T1679	*Neotrapezium sublaevigatum* (Lamarck, 1819)			○	
Polyplacophora	Chitonidae	M	T1680	Polyplacophore (unidentified species)			●	
Gastropods	Neritidae	E	T2918	*Nerita balteata* Reeve, 1855		○		
Gastropods	Neritidae	E	T2917	*Neritina cornucopia* Benson, 1836	●	○		
Gastropods	Neritidae	E	T1496	*Neritodryas dubia* (Gmelin, 1791)	●			
Gastropods	Littorinidae	E	T2914	*Littoraria conica* (Philippi, 1846)	●			
Gastropods	Littorinidae	E	T2916	*Littoraria pallescens* (Philippi, 1846)		●		
Gastropods	Littorinidae	E	T2915	*Littoraria vespacea* Reid, 1986	○			
Gastropods	Muricidae	M	T0600	*Teguella granulata* (Duclos, 1832)			○	
Gastropods	Siphonariidae	M	T1663	*Siphonaria javanica* (Lamarck, 1819)			◯	
Gastropods	Onchidiidae	E	not collected	*Onchidium* spec	●			
Barnacles	(Balanoidea)	M	not collected	Barnacle (unidentified species)	◯	◯		
Barnacles	Lepadidae	M	not collected	*Lepas anitifera* (Linnaeus, 1758)	◯	◯		

LEGEND	
●	1
○	4-10
◯	11-100
⬤	>101

Table 1. Species found on two nipa rafts, a floating drum and drift wood washed up on Piasau Beach, Miri, Sarawak on 11th August 1995. M = species from marine habitat; E = species from estuarine habitat.

beach debris. Their size (on one of the rafts up to 5 mm, on the other up to 8 mm) therefore gives an indication of the minimum time these rafts have spent at sea. The growth rate of goose barnacles recorded by Evans (1958) and MacIntyre (1966) and analysed in Cupul-Magaña *et al.* (2011) and Magni *et al.* (2014) indicates the rafts have been in sea water for at least a week. Based on the strength of water currents in the area, and the time spent at sea, these rafts may have moved over many tens of kilometers, possibly over a hundred kilometers.

Where did these rafts come from?

This section focuses on the possible origin of the rafts studied. Even though no firm conclusion is reached, there are strong indications that nipa rafts can transport estuarine species over substantial distances.

Where estuaries have sufficient freshwater swamp behind them, estuaries are generally lined by mangrove vegetation. In the more saline parts of the estuary, the mangroves are dominated by mangrove trees with stilt roots or with pneumatophores that protect the sediment from erosion. Where there is strong freshwater were broken off during floods forming dramaticinflux the mangrove communities are dominated by nipa palms. These typically form large clusters along the edge of distributary channels or the bay, which exposes them to strong waves and currents. The author observed blocks of nipa vegetation becoming detached and forming rafts along the Seria river (Brunei, October 2006), a slow process during normal tides: a virtually disconnected raft stayed in position for at least 4 days during calm weather. On the other hand, once disconnected rafts can move quickly: within a few minutes a raft on the Tutong river (Brunei, November 2013) moved tens of meters on the strong ebb current in the main river channel. Large stands of nipa palms were broken off during floods forming clumps on the Seria beach, Brunei (McIlroy & Obendrauf 2008: 57 and Figure 2). Rafts can also be formed where erosion exposes nipa vegetation directly to the sea as observed S of Bakam, Sarawak in 1997 (see Figure 8).

Figure 2. A large number of nipa rafts on the beach. Panaga beach near Seria, Brunei. (Photo courtesy of Roger McIlroy).

When a large number of rafts are beached it appears likely they were detached from one of the larger estuaries, as longer stretches of nipa will be exposed in such areas, whereas in smaller or narrower estuaries the currents and waves are insufficiently strong to form numerous rafts in a single event. It is impossible to determine with certainty from which estuary the rafts were detached, but some information is available. As the storm blew from the NE, it is most likely the rafts came from that direction. The largest estuaries with nipa are those of the Baram river in Sarawak and the Seria and Tutong rivers plus Brunei Bay in Brunei (Figure 3). Locations further away in Sabah are considered too remote. Based on simulations (Alas & Bentillo 1992), during the NE monsoon it would take an oil slick from the Champion field 3-4 days to reach the coast near Seria (about 80 km); nipa rafts would travel a similar distance.

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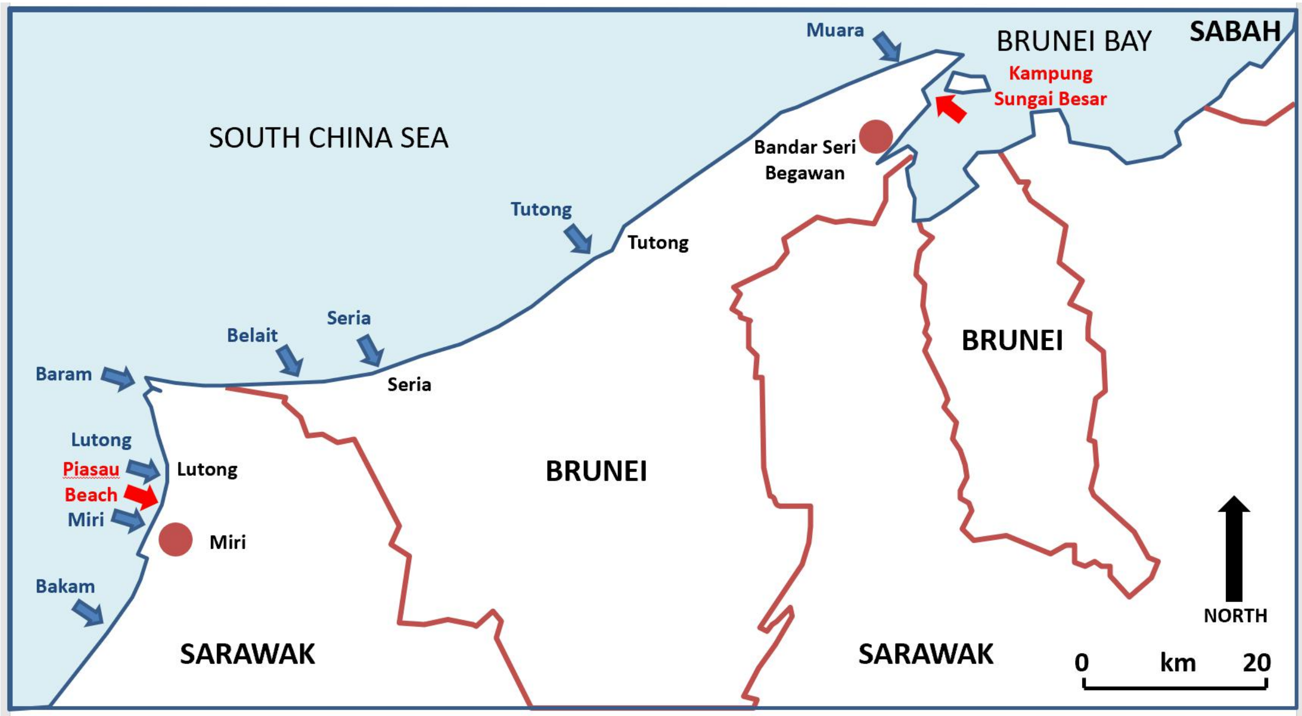

Figure 3. Northwest Coast of Borneo. Selected cities and villages are indicated in black; estuaries sampled are indicated with blue arrows; the possible origin and end point of the nipa rafts are indicated with red arrows.

An indication is provided by one of the gastropod species found on the rafts. *Nerita balteata* Reeve, 1855 occurs in many estuaries, but in the 1990's not in those near Piasau beach. The nearest occurrences or *N. balteata* are from the Bakam river (~40 km to the SW) and the Seria river (~40 km to the NE). Only the specimens from Brunei Bay (Kampong Sungai Besar, Muara, author's collection) are similar to those collected from the rafts (Figures 4-6), having their thick and dark spiral ribs dissolved (except near the aperture), thus exposing the underlying yellowish layer. Such dissolution of sculpture and early whorls (due to acidity of the water) is frequent in freshwater shells in NW Borneo. Also, the shells of *Neritina cornucopiae* Benson, 1836 from the rafts have dissolution spots (Figure 7). The rafts, therefore, may have originated in Brunei Bay (~150 km to the NE of Piasau Beach), but at least came from an estuary further than 40 km away.

Discussion - rafts and other floating objects

Nipa rafts are not unique. Live animals have also been collected from numerous other rafting objects that can transport them over long distances (*e.g.* brown kelp distributing Trochidae from Australia to Peru (DeVries 2007: 117), pumice dispersing more than 80 species over >5000 km in 7-8 months (Bryan *et al.* 2012)). Typically, these studies focus on the dispersal of marine organisms, albeit Gillespie *et al.* 2012 give an overview for terrestrial and littoral organisms. Much less is known about the transport of brackish water species, therefore the paper by Kano *et al.* (2013) is welcomed. It focuses on the role of drift wood in the dispersal of several species of estuarine Neritidae.

Rafting on floating vegetation may be an important mechanism for the dispersal, gene flow and geographic range expansion of benthic

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Figures 4-6. *Nerita balteata.* Figure 4 Specimen (width 29 mm) with corroded apex from raft 2, Piasau Beach, Miri, Sarawak; Figures 5-6 Specimens from Kampong Sungai Besar, Muara, Brunei; Figure 5 Specimen with corroded apex (width 28 mm); Figure 6 Specimen with corrosion limited to the early whorls (width 28 mm).

brackish animals, as suggested for the mangrove species of the littorinid snail genus *Littoraria* (see Reid 1986: p. 66). Okutani (2000: p. 869) reports the mussel *Adipicola longissima* (Thiele & Jaeckel, 1932) as specifically known from sunken nipa, at depth of 500-1800 m from the area between Indonesia and Japan.

In the study area, drift wood is the most abundant form of raft, mostly originating from logging as can be judged from the straight edges of the logs and the clear markings. Most of the rafting logs end up along the high tide line of beaches and lower (but substantial) numbers along the high tide line in estuaries. Finding more than ten logs in a small estuary (like that of the Lutong river N of Miri, Sarawak) is not exceptional. It appears that rafts frequently enter estuaries, which can be explained by the strong currents that form during rising tides.

Some of the drift wood found on the beach has rafted long enough to be overgrown with barnacles, goose barnacles, oysters and/or other molluscs including marine representatives of the Neritidae and to be drilled by marine species of the bivalve family Teredinidae – but all beached logs observed by the author comprised only marine molluscs. They are ideal for transporting marine animals as they lie horizontally in the water with most of the trunk submerged and the remainder regularly splashed by waves.

Some of the drift wood found in estuaries is inhabited by molluscs. Marine species might survive briefly in estuaries but cannot really thrive there. The author has not seen any evidence of marine species alive on drift wood in estuaries. On the other hand, he found the brackish water species *Bactronophorus thoracites* (Gould, 1856) [a wood boring bivalve of the family Teredinidae] in logs along the high tide line in several estuaries in NW

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Figure 7. *Neritina cornucopiae* shells showing dissolution. From raft 1, Piasau Beach, Miri, Sarawak (width 22 mm).

Borneo. Several adults at the Lutong river estuary and another estuary 6 km further North, North of Miri, Sarawak, Malaysia and a single juvenile at Kampong Pohon Batu, Labuan, Sabah, Malaysia. At the first locality, they were accompanied by another brackish water species of the Teredinidae: *Nausitora hedleyi* Schepman, 1919. The Teredinidae may have colonised the logs once they entered the estuaries, but they can survive in water of different salinity as they can close the tube they form with their pallets. Turner (1966: 52-56) already indicated rafting as an important means of dispersal for some species of the Teredinidae, including the brackish water species *Nausitora dunlopei* Wright, 1864. The larvae of that species settle on drift wood, some of which may float out of the estuary, pass time at open sea before they reach other estuaries. Upon reaching brackish water the adults are likely to spawn (Turner, 1966: p. 52). During periods of rising tides, the incoming tides typically lift drift wood and displace it further into the estuary until it reaches areas that are very infrequently flooded and where the Teredinidae eventually die (author's observation). Such logs start rotting and become the preferred habitat of the terrestrial gastropod *Ellobium aurisjudae* (Linnaeus, 1758). (Raven & Vermeulen 2007).

Drift wood therefore demonstrates how large rafting objects can transport live marine and estuarine animals, although the author has no evidence of other species than the Teredinidae that live inside the wood reaching estuaries. The only record of other estuarine species using drift wood is Kano *et al.* (2013) who observed estuarine Neritidae on drift wood in Papua New Guinea and Vanuatu. On the other hand, nipa palms are ideally positioned to transport a wider range of live estuarine species. Such palms are frequently found in the middle part of the estuary and typically form the vegetation directly lining the water, which causes them to be easily detached. The author has frequently observed such rafts moving around within estuaries before they are expelled to the sea. Nipa rafts float with the trees in natural (upright) position, which means the live estuarine species may be decimeters to meters above the waves which allows them to successfully survive during their trip. Nipa rafts thus perform a similar role to *Papyrus* rafts in the Mediterranean which transport freshwater species (Mienis 2003).

Estuaries themselves have a very discontinuous distribution. In the area studied (northern Sarawak, Brunei, southern Sabah), each estuary has a different subset of the species present. Typically, the larger and more open estuaries offer a wider range in habitats comprising a larger number of species. Rafts may play a role in the exchange of species between estuaries.

Transport of live animals on rafts can facilitate the distribution of species within an estuary – as the raft moves up and down with the tides it can get stuck anywhere on its voyage - or to other estuaries (see also Kano *et al.* 2013). River-dominated estuaries (salt wedge estuaries, *e.g.* that of the Baram river) offer the most challenges to the entrance of nipa rafts as they are typically narrow and have a continuous seaward flow of fresh water at their surface. Most estuaries in NW Borneo are wider with

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stronger tidal influence and have partially mixed or vertically homogeneous water circulation facilitating the entrance of rafts after which tides and wind push them towards the high-tide line on the river banks or marshes.

Will a single specimen reaching an estuary be sufficient? Some species will require at least a representative of each sex to reproduce. However, a single female neritid may keep laying fertilized eggs with sperm from previous mating that are retained for a long time in the spermatophore sac and/or seminal receptacle (Kano *et al.* 2013: p. 380, quoting Andrews 1937). Previously laid egg capsules could easily be transported on these trunks - they hatch after 2-3 weeks with veliger larvae being released (as observed by Govindan & Natarajan 1972 in similar Indian species).

This dispersal method is only suitable for species living on nipa palms, not those living in other parts of the estuary or on other substrates (*e.g.* the many species living in or on mud). On the other hand, many of the species found on the raft have planktotrophic larvae, which offers them an alternative dispersal method. The rafts therefore are just one of several possible dispersal methods.

Nipa rafts and the geological record

It is likely that nipa floats played a similar role in distributing species throughout the Cainozoic. Mangrove pollen are known from the Late Cretaceous, whereas fossilized nipa nuts are known from the Eocene of Europe, North & South America and Tasmania (*e.g.* Gee 2001). Especially during intervals with rapid changes in sea level rafts may have helped dispersal. For example, between 12,000-6,000 Before Present time ("BP") sea levels rose from about -120 m to current levels, as a result of which, all along the NW Borneo coast rivers were forced to retreat and estuaries constantly changed, disappeared or new estuaries were formed depending on the existing topography. Even today such changes continue, albeit on a much-reduced scale (Figure 8). Throughout this period nipa rafts may have helped species settle in the other parts of estuaries or in other estuaries.

Figure 8. Due to the retreating coastline 2 km south of Bakam (northern Sarawak, Malaysia) the beach has reached the nipa palms of a small estuary and is breaking away nipa rafts (March 1993). This nipa forest has now fully disappeared (satellite images - Google Maps) as has also happened with other nipa occurrences between Bakam and Tanjung Batu (20 km further SW).

RESULTS

Nipa rafts are common and as the plants stay upright, the rafts are well-suited for transporting living estuarine molluscs. The rafts can transport molluscs to other estuaries or other parts within the same estuary and thus provide an alternative dispersal mode for estuarine species. Additionally, nipa rafts may float to open sea (through which estuarine shells could end up in fully marine thanatocoenoses) and eventually sink (providing a substrate for other species). Nipa rafts may have played this role throughout the Cainozoic.

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