Landscape Diversity and Connectivity of Tropical Coastal Ecosystems

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ABSTRACT

Coral reefs, mangrove forests, seagrass beds, and sandy beaches are fundamental ecosystems on tropical or subtropical coasts, and their ecosystem function and services have been discussed intensively to clarify their importance. Landscape diversity constructed by these ecosystems should be discussed from the viewpoint of interactions and ecological connectivity among these ecosystems. As such, biogeochemical linkage and animal migration must be important topics for this discussion.

The biodiversity has to be discussed from various viewpoints, and one of the benefits of biodiversity is the provision of insurance that the ecosystem is stabilized against natural and anthropogenic environmental changes. However analysis of landscape diversity has frequently been ignored simply because of a lack of scientific background on the ecological connectivity among them.

Today, I will talk about the ecological connectivity among the tropical and subtropical coastal ecosystems, emphasizing the scientific interest in landscape diversity with some case studies in Okinawa, southern Japan.

The ecological study on the fish communities in seagrass beds and coral reefs gives us useful message for the discussion of ecological connectivity. According to visual surveys in the seagrass beds and adjacent coral reefs, most of the fish species were roughly divided into 4 groups based on habitat use patterns; (1) permanent residents (e.g. *Stethojulis strigiventer* and *Calotomus spinidens*); juveniles and adults living only or mainly in seagrass beds, (2) seasonal residents (e.g. *Cheilodipterus quinquelineatus* and *Lethrinus atkinsoni*); juveniles living only or mainly in seagrass beds, (3) transients (e.g. *Parupeneus indicus*); occurring in seagrass beds in the course of foraging over a variety of habitats, and (4) casual species (e.g. *Acanthurus blochii*); occurring only occasionally in seagrass beds. Some seasonal residents showed a possible ontogenetic habitat shift from seagrass beds to coral reefs. These results indicated that seagrass habitat use patterns by fishes changed temporally and regionally and there may be habitat connectivity between seagrass beds and coral reefs via foraging or ontogenetic migration. In addition, high fish diversity is maintained by healthy landscape diversity.

A major functional consequence of landscape diversity also derives from the complex ontogenic habitat shift characteristic of many marine animals whose larvae have a long pelagic life stage. Tropical seagrass and mangrove habitats serve as nursery areas for many fishes that live as adults on nearby reefs. Thus, the proximity of different habitats in the landscape is critical to the populations of these fishes.

Other large animals showing high mobility also have a possibility to move between different ecosystems and affect the flora and fauna via their feeding behavior. Sea turtles, for example, migrate in much wider areas, visiting different ecosystems including the open sea, coral reef and sandy beach. Dugongs also come in to intertidal zones with seagrass beds during high

tides. The connectivity between intertidal and subtidal zones is also an important research topic.

Mangrove forests, which are predominant in river mouth areas or the inner part of bays in tropical and subtropical regions, are characterized by high primary production. The organic material produced by mangroves enriches the bottom substrates and has been offering food sources during their decomposition processes to various animals living in mangrove forests and neighboring ecosystems. However, quantitative studies on the transportation and dynamics of the organic materials produced by mangroves are insufficient and more discussion is required to clarify the role of mangroves on coastal zones. For example, there are different reports, i.e. some reports have emphasized that mangroves are important for sustaining the microbial food chain and nutrient regeneration in adjacent ecosystems, but other ones did not.

The dynamics of particulate organic matter (POM) and mangrove litter were investigated in a subtropical mangrove in Okinawa, in order to quantify the impact of mangrove POM on adjacent intertidal sediments. A distinct seasonal pattern was found with maximum litter fall during the autumn season, and minimum during winter. Analysis of fatty acids in the surface sediments of an adjacent mud flat and sand flat during the winter, spring, and autumn seasons indicated that outwelling of POM from the mangrove ecosystem occurs. However, it is spatially restricted to within 300 m from the mangrove forest. The magnitude of the outwelling increased during spring and autumn consistent with the increase in the total litter production. Despite the presence of mangrove-derived organic matter in the estuarine surface sediments, autochthonous sources of organic matter, green macroalgae (*Ulva pertusa* and *Enteromorpha intestinalis*), diatoms and bacteria are the main contributors of sedimentary organic matter.

We have been studying the role of mucus produced by corals in a coral reef ecosystem. The organic matter, chlorophyll *a* concentration, microalgal density, and bacteria-derived fatty acid contents of mucus aggregates were higher than those observed in sediment, suggesting that mucus aggregates, which are carried to various places in a reef, contain not only high levels of organic matter, but also dense concentrations of microalgae and bacteria. Therefore, mucus aggregates trapping a large number of diatoms may serve as a qualitatively more energetic food source for benthic fauna compared to sediments.

In conclusion, research in a wide range of ecosystems demonstrates that interactions among the communities of different habitats on coastal and river ecosystems, mediated by both migrations of animals and the transportation of organic materials and nutrients, can influence community structure and ecosystem function. Such landscape diversity should be essentially important to the functioning of marine systems.

熱帶海岸生態系統之景觀多樣性及關聯性

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摘 要

珊瑚礁、紅樹林、海草床、以及沙質海灘是構成熱帶或亞熱帶海岸的基本生態系統，其生態系統功能及優點經過諸多討論，重要性已是不言自明。應由各生態系統間的互動及生態關聯性觀點切入，進而討論這些生態系統所構築起的景觀多樣性。如此一來，生物地質化學及動物遷徙必成為此中討論的重點。

須由多方面的觀點切入討論生物多樣性；無論受到自然或人為因素而造成的環境變化影響，生物多樣性均能夠確保生態系統的穩定─這正是其好處之一。但是針對不同系統間彼此生態關聯性卻缺乏科學性的背景研究，以致於大眾忽略了景觀多樣性的分析。

我今天要講的是關於熱帶及亞熱帶海岸生態系統間的生態關聯性，所強調的重點將放在景觀多樣性的科學價值，並引用一些在日本南方的琉球所做的個案研究。

針對海草床及珊瑚礁中魚群的調查，為生態關聯性的相關研究提供了重要的訊息。藉由觀察可將海草床及鄰近珊瑚礁當中的魚種，依其棲息模式分為以下 4 類：(1)永久居民 (像是虹紋紫胸魚還有台灣鸚鯉)；僅是或主要生活在海草床中的幼魚及成魚；(2) 季節性居民 (像是五線巨齒天竺鯛及太平洋黃尾龍占)；僅是或主要生活在海草床中的幼魚；(3) 過住旅客 (像是印度海緋鯉)；在眾多棲所間遊牧時會出現在海草床；以及(4) 偶遇物種 (像是布氏刺尾魚)；僅是偶爾現身在海草床。在某些季節性居民身上會有從海草床轉向珊瑚礁的個體發育棲所轉變情形發生。前述的結果說明，以魚群所劃分出的海草床棲所模式會因時間性及地域性變化，而透過遊牧行為或是個體發育遷徙，海草床及珊瑚礁可能因此存在著棲所關聯性。另外，健全的景觀多樣性才能夠維持高度的魚種多樣性。

許多海洋生物的幼體在漫長遠洋生命階段裡頭，會因為複雜的個體發育而造成棲所轉變，而這正是造成景觀多樣性的關鍵性因素。許多生活在鄰近礁岩區的成魚會將熱帶海草及紅樹林生態區作為繁衍後代的溫床。所以在同一個景觀裡頭是否涵蓋不同棲所，對於這些魚種的數量來說是很重要的。

其它機動性較高的大型生物也有可能在不同的生態系統之間穿梭來回，而他們的進食行為也進而影響到該區的動植物生態。以海龜為例，在較大的區域中悠遊、遷徙，會越過外海、珊瑚礁還有沙質海灘等不同的生態系統。儒艮在漲潮的時候會隨著海草床一起來到潮間帶。潮間帶及次潮間帶之中的關聯性也是個值得研究的課題。

紅樹林大多生長在熱帶地區及亞熱帶地區的河口或是內灣，高度初級生長力為其特性。紅樹林所產生的有機物質使得底部基質更為肥沃，而在分解腐爛的過程中則成為棲息在紅樹林及鄰近生態系統中動物的食物來源。不過目前針對紅樹林所產生的有機物質所做的量化研究並不充分，須要更進一步的討論才能夠釐清紅樹林之於海岸地區的角色定位。當前的研究並沒有整合出統一觀點，像有些報告中強調的是對於鄰近的生態系統而言，紅樹林在維生物食物鏈及養份更新方面都扮演著舉足輕重的角色；但其他報告卻對此不置可否。

為了能夠量化紅樹林中有機質(particulate organic matter, POM)對於鄰近潮間帶的沉積影響程度，所以在沖繩的某處亞熱帶紅樹林生態區中，仔細地調查了有機質及紅樹林枯枝落葉間的動態機能。從研究結果可以明顯看出季節性的差異，最大落葉量出現在秋季；而冬季的落葉量則是最小。在不同的季節裡頭於一處鄰近的泥層及沙層中採樣分析沉積表面的脂肪酸，發現了紅樹林有機物溢出的情況。不過這情形僅發生於以紅樹林為中心的 300 公尺範圍內。在春季及秋季的溢出增加幅度與總落葉量的增加值一致。雖然紅樹林的有機質造成了部份入海口的表面沉積物，但原生有機質、大型綠藻(孔石蓴和腸滸苔)、矽藻跟細菌才是造成沉積有機物的重要推手。

我們已針對珊瑚礁生態系統中，珊瑚所產生的黏液進行角色定位的研究。黏液中無論是有機質、海域綠素濃度(chlorophyll a concentration)、微藻密度(microalgal density)、還是因細菌而產生的脂肪酸總計，均較沉積物當中的數值高；表示黏液當中不僅含有大量的有機質，更含有高濃度的綠藻及細菌。正因為會在珊瑚中不同的部位出現，其中更含有大量的矽藻，所以對於海底動物而言，黏液可能是比沉積物更營養的食物。

無論是動物的遷徙還是有機物質或營養物的移動，都可能促使不同生態系統間的互動，而從廣泛的研究這些系統中發現，再微小的互動也會影響到整個生態的結構及系統的功能。如此的景觀多樣性應是維持海洋系統運作的重要因素。