

Original paper

Shallow-water asteroids, echinoids, and holothuroids at 6 sites across the tropical west Pacific, 1988–1989

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Abstract Species richness of asteroids, echinoids, and holothuroids was surveyed on shallow reefs at 6 sites across the tropical west Pacific: Seto, on the west coast of the Kii Peninsula, Honshu Island; Okinawa, Ryukyus Islands; Madang, Papua New Guinea; Palm Islands, Queensland, Australia; ‘Upolu, Western Samoa; and Moorea, French Polynesia. A total of 113 nominal species were recorded. No species was unambiguously found at all 6 sites, only 17 (15%) were found at 4 or more sites, and 63 (56%) were found at only one site. Single-site finds represented 48% of the species at Seto, 21–32% of the species at 4 other sites, and only 4% (1 species) at ‘Upolu. Madang had the most species (74), followed by Okinawa (54), Moorea (34), Samoa (25), Seto (23), and the Palm Islands (15). Although Seto had a diverse echinoid fauna (17 species), including several temperate forms, there was a dearth of asteroids (4) and holothuroids (2). In contrast, all 3 classes were well represented on the reefs of Okinawa (11 asteroids, 16 echinoids, and 27 holothuroids) and Madang (22 asteroids, 17 echinoids, 35 holothuroids), both of which had a rich diversity of widespread tropical oceanic species. Substantially fewer species were found farther to the east, at Samoa and Moorea, consistent with the pattern seen in other taxa. Species richness was surprisingly low around the Palm Islands on the inner portion of the Great Barrier Reef, perhaps because of human disturbance causing run-off from the land and siltation.

Keywords echinoderms, Indo-Pacific, species surveys, biogeography

Introduction

Echinoderms are abundant, well known, and ecologically important members of shallow-water marine communities across the tropical Pacific (Birkeland 1989). Asteroids, echinoids, and holothuroids are particularly conspicuous as many species occur in the open and are easy to observe. In their comprehensive monograph, Clark and Rowe (1971) listed 63 species of asteroids, 65 species of echinoids, and 88 species of holothuroids for tropical Pacific islands (summarized by Pawson 1995). Drawing from more recent literature, mainly from surveys in New Caledonia (Guille et al. 1986), Pawson (1995) augmented those numbers to 115 species of asteroids, 90 species of echinoids, and 114 species of holothuroids. In addition, in a thorough account of a region in the middle of the Indo-Pacific, the tropical seas off China from Vietnam to Japan, Liao and Clark (1995) reported 89, 93, and 108 species of asteroids, echinoids, and holothuroids, respectively. However, these numbers are the accumulation of many collecting efforts, both hand collecting and dredging, and they do not reflect what one can expect to

find at any one time or site. Two recent guides of the shallow reefs of the tropical Pacific (Colin and Arneson 1995) and the Indo-Pacific (Gosliner et al. 1996), intended primarily for divers, give 31, 31, and 35, and 48, 29, and 49 species of asteroids, echinoids, and holothuroids, respectively.

The above numbers are for broad regions of the tropical Pacific, or the whole Indo-Pacific. Many species are of rare occurrence or absent from specific sites so, site-specific species lists present much lower numbers. For example, in their guidebook of echinoderms in New Caledonia, Guille et al. (1986) reported 50, 34, and 54 species of asteroids, echinoids, and holothuroids, respectively. Similarly, in her guidebook of echinoderms in the Philippines, near the center of the Indo-Pacific region, Schoppe (2000) included 22, 22, and 25 species of asteroids, echinoids, and holothuroids, respectively, while Paulay (2003) listed 35, 53, and 47 species of asteroids, echinoids, and holothuroids, respectively, for the nearby Mariana Islands. On the eastern edge of the Indo-Pacific region, Guille (1985) listed 3 asteroids, 14 echinoids and 10 holothuroids for French Polynesia, while further east, in the Pitcairn Islands, Paulay (1989) reported 1 asteroid, 6 echinoids, and 3 holothuroids.

In 1988–89, I had the opportunity to spend 1 to 3 months at 6 locations that spanned most of the tropical west Pacific, from near its center in northeastern New Guinea to near the edges on the northeast (southeast Honshu), west (Moorea), and south (Palm Islands of the Great Barrier Reef). Surveys were made at multiple locations within each site using snorkel and scuba, simply identifying and counting the asteroids, echinoids, and holothuroids seen. This account provides a list of the species found at the 6 sites and their relative abundances, with a comparison to other accounts, which on the one hand were more extensive, but on the other not as comparable across distant sites. In addition, with the major ecological changes now being seen in the world's oceans, especially in coral reef communities (Hoegh-Guldberg 1999; Fujiwara et al. 2000; Hughes et al. 2003; Bellwood et al. 2004), this account provides baseline information on what a single person could find in the late 1980s at far-flung communities across the tropical west Pacific.

Materials and methods

Five of the 6 sites were close to established marine research stations where we worked for about 1 week to 3 months in 1988–89. From northwest to southeast, they are: (1) Seto Marine Biological Laboratory, Kyoto University, near Shirahama, Honshu Island, Japan (33°41' 44"N, 135°20' 10"E), 16 June–23 July, 1989; (2) Sesoko Marine Science Center, University of the Ryukyus, Sesoko, Okinawa, Japan (26°38' 11"N, 127°51' 55"E), 12 March–16 June and 11 August–9 September 1989; (3) Christensen Research Institute (now Jais Aben Resort), near Madang, Papua New Guinea (5°09' 19"S, 145°48' 05"E), 15 August–19 October 1988; (4) Orpheus Island Research Station, Palm Islands, James Cook University, near Townsville, Australia (18°38' 03"S, 146°30' 02"E), 23–28 November and 9–12 December 1988; and (5) Richard B. Gump South Pacific Research Station, University of California, Berkeley, Moorea, French Polynesia (17°29' 26"S, 149°49' 34"W), 1 January–5 February 1989. In addition, we stayed and worked at the late Dr. Karl Marschall's private laboratory at (6) Vaoala, 'Upolu Island, Western Samoa (13°52' 26"S, 171°46' 15" W), 10 February–8 March 1989. More details of the places searched at Okinawa and Madang are given in Pearse (1998).

The surveys were done by snorkel and (except at Samoa) scuba diving to less than 20 m depth. Areas were systematically searched, turning over rubble and loose rocks, and noting the presence of species on a diver's clip board. Most species could be readily identified in the field, but those that could not, mainly holothuroids, were taken to the laboratory adjacent to the site and keyed, using Clark and Rowe (1971), Guille et al. (1986), and for holothuroids, Cannon and Silver (1986). In addition, at Seto and Okinawa, I also used Hayashi (1973), Shigei (1987), and Utinomi (1968).

Relative abundance was based on the number of individuals seen on any dive: "scarce" if less than 5 seen, "common" if 5 to 25 seen, and "abundant" if more than 25 seen (and I stopped counting.) During our stay at each site, we searched many different locations; the relative abundances reported here are for the highest values.

Some of the species names have changed since my survey. Accordingly, I checked and updated most names following the World Register of Marine Species (<http://www.marinespecies.org/>) as of 22 September 2009. Some species were not in the World Register of Marine Species, but I retained them because they were considered valid by Liao and Clark (1995) and Lane et al. (2000).

Results and discussion

A total of 113 nominal species of asteroids, echinoids, and holothuroids were recorded for the 6 sites we visited in 1988–89 (Table 1). However, their distribution among the sites was very uneven. Well over half (74) were found at Madang, Papua New Guinea, which is on the eastern edge of Indo-Malayan center of maximum marine biodiversity displayed by other taxa (Hoeksema 2007). Okinawa, the site of the second highest number of nominal species (54), is located just north of center of maximum marine biodiversity and is swept by the Kuroshio Current from the south.

In contrast, the other 4 sites had much lower numbers of nominal species. Seto, on the southeast tip of Honshu Island, was particularly depauperate in asteroids and holothuroids; all 4 species of asteroids there were not found at any other site, and although 1 of the 2 holothuroids there matched *Holothuria pervicax* in Utinomi (1968), its behavior (mostly in the open), coloration, and spicules all differed from Cannon and Silver's (1986) account for this species. On the other hand, the number of echinoids at Seto (17) matched those at Okinawa and Madang. Some were northern species near their southern limit (*Clypeaster japonicus*, *Hemicentrotus pulcherrimus*, and *Pseudocentrotus depressus*) or more typical of the Asian continent (*Anthocidaris crassispina*). However, the contrast between the richness of echinoids and the paucity of the asteroids and holothuroids is notable.

The relatively low number of nominal species for the two Polynesian sites (Samoa with 25 species and Moorea with 34 species) follows the general decline in species richness of Indo-Pacific taxa to the east and away from the Indo-Malay center of maximum diversity (Briggs 1999; Hoeksema 2007); nearly all the species found at Samoa

and Moorea were found at other sites to the west. Similarly, farther to the east, a thorough search of the Pitcairn Island group found a total of only 39 nominal species of asteroids, echinoids, and holothuroids (Paulay 1989). I should also note that I was unable to spend much time searching at Samoa, and it is the only site where I did not use scuba; the low number of species I found there probably is at least partly due to less effort.

Similarly, we were only able to search locations in the Palm Islands for a total of about a week on two different visits, but much of that time was spent scuba diving. We visited 2 locations on Pelorus Island, 8 on Orpheus Island, 1 on Fantome Island, dove at Pandora Reef, and snorkeled at Magnetic Island near the Palm Islands. The low number of species found, with only 1 that could be considered abundant (*Diadema setosum*), is likely a valid reflection of the low species diversity there. The Palm Islands are part of the inner Great Barrier Reef, only about 10 km off the coast of Australia, and have lower diversity than more oceanic portions of the reef. Moreover, human development on the mainland has greatly increased the sediment flux, which may have diminished the biota of the nearshore islands (McCulloch et al. 2003). However, there is no question that many more species of these groups occur off the northeast coast of Australia (Clark and Rowe 1971; Rowe and Gates 1995), and the low numbers we found may be a matter of relative abundance or patchiness.

A striking finding from these surveys is the low number of nominal species found at the majority of the sites (Table 2). Only 2 nominal species were found at all 6 sites, *Echinostrephus* spp. and *Holothuria "pervicax"*, and species identity is ambiguous for both. There are 2 species of *Echinostrephus*; they can not be distinguished in the field, and they are difficult to extract from their deep burrows in coral rock. *E. aciculatus* occurs mainly in the Pacific whereas *E. molaris* occurs mainly in the Indian Ocean (Clark and Rowe 1971), but they are sympatric at least in the South China Sea (Lane et al. 2000). It is possible that I found one at some sites and the other at other sites. The same complication applies to *Echinometra "mathaei"*, which was found at 5 of the sites and includes at least 3 discrete species that were not distinguished during my surveys, all with undefined

Table 1 Shallow-water asteroids, echinoids, and holothuroids seen at 6 sites in the tropical west Pacific, August 1988 - August 1989. Site abbreviations: SET, Seto, southeast Honshu Island, Japan; OKI, Okinawa, Ryukyus Islands, Japan; MAD, Madang, Papua New Guinea; PAL, Palm Islands, Queensland, Australia; SAM, 'Upolu Island, Western Samoa; MOO, Moorea Island, French Polynesia. Symbols: X, 1-4 seen, "scarce"; XX, 5-25 seen, "common"; XXX, more than 25 seen, "abundant"; ?, identity uncertain; *, only tests found

ASTEROIDS (34 species)	SET	OKI	MAD	PAL	SAM	MOO
<i>Acanthaster planci</i>		XX	X		X	X
<i>Archaster typicus</i>			X		XXX	
<i>Asterina cepheus</i> ^a						X
<i>A. pectinifera</i> ^b	XX					
<i>Asterina</i> species ^c			X			
<i>Asteropsis carinifera</i>		X			X	
<i>Celerina heffernani</i>			X			
<i>Celerina/Fromia</i> species			X			
<i>Certonearctia semiregularis</i>	X					
<i>Choriaster granulatus</i>			XX			
<i>Coscinasterias acutispina</i>	X					
<i>Culcita novaeguineae</i>		X	XX		X	XX
<i>Echinaster callosus</i>			X			
<i>E. luzonicus</i>		XX	XX	X		
<i>Echinaster</i> species			X	X		
<i>Fromia elegans</i> ?				X		
<i>F. indica</i>		X				
<i>F. milleporella</i>			X	X		
<i>Gomphia egeriae</i> ?			X			
<i>Leiaster leachi</i>	X					
<i>Linckia guildingi</i> ^d			X			X
<i>L. laevigata</i>		XX	XXX		XXX	X
<i>L. multifora</i>		XX	XX		X	X
<i>Mithrodia clavigera</i>		X				
<i>Nardoa frianti</i>		X				
<i>N. novaecaledoniae</i>			XX			
<i>N. tuberculata</i>		XX				
<i>N. tumulosa</i>		X				
<i>Neoferdina cumingi</i>			X			
<i>Protoreaster nodosus</i>			X			
<i>Tamaria fusca</i>			X			
<i>Tamaria?</i> species 1			X			
<i>Tamaria?</i> species 2			X			
<i>Thromidia catalai</i>			X			
TOTAL ABUNDANT	0	0	1	0	2	0
TOTAL COMMON	1	5	5	0	0	1
TOTAL SCARCE	3	6	16	4	4	5
GRAND TOTAL ASTEROIDS	4	11	22	4	6	6

distributions (Nishihira et al. 1991; Palumbi et al. 1997; Geyer and Palumbi 2003). As noted above, the specimens of *Holothuria "pervicax"* at Seto did not match those seen at the other sites, and in my opinion they represent an undescribed species.

In contrast to the few species found at most sites, a high number of species were found at only one or a few sites

(Table 2). Over 70% of all the species seen were found at only 1 or 2 sites. Most of these records were for rarely seen species, which might have been present but missed at other sites, but a few were common or even abundant at a single site and not seen elsewhere. Two abundant species seen only at Seto were northern, non-tropical forms, *Clypeaster japonicus* and *Hemicentrotus pulcher-*

Table 1 Continued

ECHINOIDS (34 species)	SET	OKI	MAD	PAL	SAM	MOO
<i>Anthocidaris crassispina</i> ^e	XXX					
<i>Arachnoides placenta</i> ^e				X*		
<i>Asthenosoma ijimai</i> ^e	X					
<i>Brissopsis luzonicus</i>					XX*	X*
<i>Brissus latecarinatus</i>			X			
<i>Clypeaster japonicus</i>	XXX					
<i>Diadema paucispinum</i> ^f	X	X	X			
<i>D. savignyi</i>	XXX	XX	XXX		XXX	XXX
<i>D. setosum</i>	XXX	XXX	XXX	XXX		
<i>Diadema hybrids</i> ^g	XX	X	X			
<i>Echinodiscus bisperforatus</i>			X			
<i>Echinometra "mathaei"</i> ^h	XXX	XXX	XXX		XXX	XXX
<i>Echinoneus cyclostomus</i>		X*				
<i>Echinoneus</i> species						X*
<i>Echinostrephus aciculatus</i>	XXX	X	XXX	X	XX	XXX
<i>Echinothrix calamaris</i>	X	X	X		X	XX
<i>E. diadema</i>		XX	XX		XX	XX
<i>Eucidaris metularia</i>			X			
<i>Fibularia</i> species				X		
<i>Hemicentrotus pulcherrimus</i> ^c	XX					
<i>Heterocentrotus mammillatus</i>		X				
<i>Laganum depressum</i>			XX	XX*	XX	
<i>Lovenia elongata</i>		X*	X			
<i>Mespilia globulus</i>	XX		X		XX	
<i>Nudechinus ambonensis</i> ^c						X
<i>Parasalenia gratiosa</i>		X	XX	X		
<i>Pseudoboletia maculata</i>	X	XXX				
<i>Pseudocentrotus depressus</i>	X					
<i>Stomopneustes variolaris</i>		XX				
<i>Temnopleurus toreumaticus</i>	X					
<i>Tripneustes gratilla</i>	X	XXX	XX			XXX
<i>Toxopneustes pileolus</i>	XX	XXX			X	
unident. cidaroid			X			
unident. spatangoid				XX*		
TOTAL ABUNDANT	6	5	4	1	2	4
TOTAL COMMON	4	3	4	2	5	2
TOTAL SCARCE	7	8	9	4	2	3
GRAND TOTAL ECHINOIDS	17	16	17	7	9	9

rimus, and a third, *Anthocidaris crassispina*, is mainly of the Asian continent (Clark and Rowe 1971), so it is not surprising that they were not found elsewhere. However, most of the other species that were found to be common or abundant at only 1 or 2 sites are widespread in the tropical Pacific or even the whole Indo-Pacific region.

I did not collect specimens as vouchers during these surveys, and the species lists are not backed up with specimens that can be verified. As my colleague Kathy Ann Miller, a phycologist and systematist, has said: "Names without vouchers are just rumors." However,

most of the nominal species I observed are not difficult to identify in the field, or in the case of some holothuroids, by examination of their spicules. Question marks after names in Table 1 indicate specimens for which I had doubts, and I also list species that I could not identify to species. But even the questionable records reported in Table 1 were almost certainly distinct species different from others on my list. Indeed, recent molecular analyses are revealing more and more species complexes of morphologically similar species (e.g. O'Loughlin and Waters 2004). The value of these surveys, in my opinion, is that

Table 1 Continued

HOLOTHUROIDS (45 species)	SET	OKI	MAD	PAL	SAM	MOO
<i>Actinopyga echinites</i>		XXX	XXX			
<i>A. lecanora</i>		XX	XX			
<i>A. mauritiana</i>		XXX	XXX			XX
<i>A. miliaris</i>		X	XX			
<i>Bohadschia argus</i>		XX	XX			XXX
<i>B. maculisparsa?</i> ⁱ			X			
<i>B. similis</i> ^j		XX	X			
<i>B. vitiensis</i> ^k		XX	XXX		XX	XXX
<i>Chiridota rigida</i>						XXX
<i>Cladolabes aciculus?</i>						XXX
<i>C. crassus?</i>		XX				
<i>Euapta godeffroyi</i>			XX		X	X
<i>Holothuria arenicola</i>		X				
<i>H. atra</i>		XX	XXX		XX	XX
<i>H. cinerascens</i>		X				
<i>H. coluber</i>		X?	XX			
<i>H. difficilis?</i>			X			X
<i>H. edulis</i>		XX	XX			
<i>H. flavomaculata</i>			X	X		
<i>H. fuscocinerea</i>					X	
<i>H. fuscopunctata</i>		X	X			
<i>H. hilla</i>		XX	XX		XXX	
<i>H. impatiens</i>		X	X			X
<i>H. leucospilota</i>	XX	XXX	XX		XX	XXX
<i>H. nobilis</i>		XX	X			X
<i>H. pardalis</i> ^l		X	X			X
<i>H. pervicax</i>		X	XX	X	X	XX
<i>H. "pervicax"</i> ^m	XX					
<i>H. remollescens?</i>			X			
<i>H. rigida</i>			X			X
<i>H. scabra</i>			XX			
<i>H. verrucosa</i>		X				
<i>Labiodemas semperianum</i> ⁿ						X?
<i>Neothyonidium magnum</i>			XX			
<i>Pearsonothuria graeffei</i>			XX			
<i>Polyplectana kefersteini</i> ^o			XXX			
<i>Stichopus chloronotus</i>		XX	XX		XXX	
<i>S. horrens</i>		X	XXX	X	X	X
<i>Synapta maculata</i>		X	X?	X?	XXX?	XXX?
<i>Thelenota ananas</i>		X	XX			X
<i>T. anax</i>			XX			
<i>T. rubralineata</i>			X			
unident. dendrochirote		X				
unident. synaptid 1			X			
unident. synaptid 2						X
TOTAL ABUNDANT	0	3	6	0	3	6
TOTAL COMMON	2	10	16	4	3	4
TOTAL SCARCE	0	14	13	0	4	9
GRAND TOTAL HOLOTHUROIDS	2	27	35	4	10	19

Table 1 Continued

ALL 3 CLASSES (113 species)	SET	OKI	MAD	PAL	SAM	MOO
TOTAL ABUNDANT	6	8	11	1	7	10
TOTAL COMMON	7	18	25	6	8	6
TOTAL SCARCE	10	28	38	8	10	18
GRAND TOTAL ALL	23	54	74	15	25	34
% TOTAL SPECIES	20.4	47.8	65.5	13.3	22.1	30.1

- a. The asterinid on Moorea is *Indianastra rapa* (G. Paulay, pers. com.)
 b. = *Patiria pectinifera*, (O'Loughlin and Waters 2004)
 c. *Asterina* has been extensively revised (O'Loughlin and Waters 2004)
 d. Probably the brownish-pink form of *L. laevigata* (G. Paulay, pers. com.)
 e. Not in World Register of Marine Species, in Lane et al. (2000)
 f. Not in World Register of Marine Species, see Lessios et al. (2001)
 g. See Lessios and Pearse (1996)
 h. There are 4 species on Okinawa and elsewhere, see Palumbi et al. (1997)
 i. Probably a hybrid between *B. argus* and *B. vitiensis* (G. Paulay, pers. com.)
 j. = *B. marmorata* (G. Paulay, pers. com.)
 k. This is an undescribed species on Moorea (G. Paulay, pers. com.)
 l. Probably *H. inhabilis* (G. Paulay, pers. com.)
 m. In Utinomi (1968); not the same as *H. pervicax* in Clark and Rowe (1971), Cannon and Silver (1986), or Liao and Clark (1995)
 n. There are several very similar species of *Labidodemas* (Samyn et al. 2005)
 o. There are several very similar species of *Polypsectana* (G. Paulay pers. com.)

Table 2 Number of nominal species found at only 1, 2 to 5, or all 6 sites surveyed

Number of sites	1	2	3	4	5	6
Asteroids (34 species)	25	4	1	4	0	0
Echinoids (34 species)	18	3	6	3	3	1?
Holothuroids (45 species)	20	10	9	2	3	1?
Total (113 species)	63	17	16	9	6	2?
% total species	55.8	15.0	14.2	8.0	5.3	1.8

they provide some insight into what a person could find at these sites in the late 1980s and how the sites varied in species richness. They also might be of value for comparison with future surveys by others.

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University of Ryukyus on Biodiversity and Adaptive Strategies of Coral Reef Organisms in commemoration of the 20th anniversary of the Sesoko Marine Science Center, University of the Ryukyus in November 1992. Only an abstract of that presentation has been published (Pearse 1996). It is a pleasure to now have the opportunity to more fully publish an account of my observations. I thank in addition, my son Devon Pearse for spending so much time with me searching for echinoderms, and my wife Vicki Pearse for her extensive help in the field, editorially, and in every other way.

References

- Bellwood DR, Hughes TP, Folke C, Nyström M (2004) Confronting the coral reef crisis. *Nature* 429: 929–933
- Birkeland C (1989) The influence of echinoderms on coral-reef communities. In: Jangoux M, Lawrence JM (eds) *Echinoderm Studies*, Vol 3. AA Balkema, Rotterdam, pp 1–79
- Briggs JC (1999) Coincident biogeographic patterns: Indo-West Pacific ocean. *Evolution* 53: 326–335
- Cannon LRG, Silver H (1986) *Sea cucumbers of Northern Australia*. Queensland Museum, Brisbane
- Clark AM, Rowe FWE (1971) *Shallow water Indo-Pacific echinoderms*. British Museum (Natural History), London
- Colin PL, Arneson C (1995) *Tropical Pacific invertebrates*. Coral Reef Press, Beverly Hills
- Fujiwara S, Shibuno T, Mito K, Nakai T, Sasaki Y, Dai C-F, Chen G (2000) Status of coral reefs of east and northeast Asia: China, Japan, Taiwan. In: Wilkinson C (ed) *Status of Coral Reefs of the World*, Australian Institute of Marine Science, Townsville, pp 131–140
- Geyer LB, Palumbi SR (2003) Reproductive character displacement and the genetics of gamete recognition in tropical sea urchins. *Evolution* 57: 1049–1060
- Gosliner TM, Behrens DW, Williams GC (1996) *Coral reef animals of the Indo-Pacific*. Sea Challengers, Monterey
- Guille A (1985) *Echinodermata*. 5th Int Coral Reef Congr 1: 456–458
- Guille A, Laboute P, Menou J-L (eds) (1986) *Guide des étoiles de mer, oursins et autres échinodermes du lagon de Nouvelle-Calédonie*. Éditions de l'ORSTOM, Paris
- Hayashi R (1973) *The sea-stars of Sagami Bay, collected by His Majesty the Emperor of Japan*. Biological Laboratory Imperial Household, Japan
- Hoegh-Guldberg O (1999) Climate change, coral bleaching and the future of the world's coral reefs. *Mar Freshw Res* 59: 839–866
- Hoeksema BW (2007) Delineation of the Indo-Malayan centre of maximum marine biodiversity: The coral triangle. In: Renema W (ed) *Biogeography, time, and place: Distributions, barriers, and islands*. Springer, pp 117–178
- Hughes TP, Baird AH, Bellwood DR, Card M, Connolly SR, Folke C, Grosberg R, Hoegh-Guldberg O, Jackson JB, Kleypas J, Lough JM, Marshall P, Nyström M, Palumbi SR, Pandolfi JM, Rosen B, Roughgarden J (2003) Climate change, human impacts, and the resilience of coral reefs. *Science* 301: 929–933
- Lane DJW, Marsh LM, VandenSpiegel D, Rowe FWE (2000) Echinoderm fauna of the South China Sea: An inventory and analysis of distribution patterns. *Raffles Bull Zool Suppl* 8: 459–493
- Lessios HA, Pearse JS (1996) Hybridization and introgression between Indo-Pacific species of *Diadema*. *Mar Biol* 126: 715–723
- Lessios HA, Kessing DB, Pearse JS (2001) Population structure and speciation in tropical seas: Global phylogeography of the sea urchin *Diadema*. *Evolution* 55: 955–975
- Liao Y, Clark AM (1995) *The echinoderms of southern China*. Science Press, Beijing
- McCulloch M, Fallon S, Wyndham T, Hendy E, Lough J, Barnes D (2003) Coral record of increased sediment flux to the inner Great Barrier Reef since European settlement. *Nature* 421: 727–730
- Nishihira M, Sato Y, Arakaki Y, Tsuchiya M (1991) Ecological distribution and habitat preference of four types of the sea urchin *Echinometra mathaei* on the Okinawan coral reefs. In: Yanagisawa T, Yasumasu I, Oguro C, Suzuki N, Motokawa T (eds) *Biology of Echinodermata*. AA Balkema, Rotterdam, pp 91–104
- O'Loughlin PM, Waters JM (2004) A molecular and morphological revision of genera of Asterinidae (Echinodermata: Asterozoa). *Mem Mus Victoria* 61: 1–40
- Palumbi SR, Grabowsky G, Duda T, Geyer L, Tachino N (1997) Speciation and population genetic structure in tropical Pacific sea urchins. *Evolution* 51: 1506–1517
- Paulay G (1989) *Marine invertebrates of the Pitcairn Islands: Species composition and biogeography of corals, molluscs, and echinoderms*. *Atoll Res Bull*. 326: 1–28
- Paulay G (2003) The Asterozoa, Echinodea, and Holothurozoa (Echinodermata) of the Mariana Islands. *Micronesica* 35–36: 563–583

- Pawson DL (1995) Echinoderms of the tropical island Pacific: Status of their systematics and notes on their ecology and biogeography. In: Maragos JE, Eldredge MNA, Bardach JE, Takeuchi HE (eds) Marine and coastal biodiversity in the tropical island Pacific region, Vol 1 Species systematics and information management priorities. East-West Center, Honolulu, pp 171–192
- Pearse JS (1996) Coral reef echinoderm diversity across the tropical west Pacific. *Galaxea* 13: 124
- Pearse JS (1998) Distribution of *Diadema savignyi* and *D. setosum* in the tropical Pacific. In: Mooi R, Telford M (eds) Echinoderms: San Francisco. AA Balkema, Rotterdam, pp 777–782
- Rowe FWE, Gates J (1995) Echinodermatata. In: Wells A (ed) Zoological catalogue of Australia, Vol 33. CSIRO Australia, Melbourne
- Samyn Y, Appeltans W, Kerr AM (2005) Phylogeny of *Labidodemas* and the Holothuriidae (Holothuroidea: Aspidochirotida) as inferred from morphology. *Zool J Linn Soc* 144: 103–120
- Schoppe S (2000) A guide to common shallow water sea stars, brittle stars, sea urchins, sea cucumbers and feather stars (Echinoderms) of the Philippines. Times Media Private Limited, Singapore
- Shigei M (1987) A study of the echinoids fauna of Okinawa Island. *Galaxea* 6: 109–113
- Utinomi H (1968) Coloured illustrations of seashore animals of Japan. Hoikusha, Osaka

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