Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, Florida, 7-11 July 2008
Session number 11

Multi-specific coral spawning in spring and autumn in far north-western Australia

N. L. Rosser[1], A.H. Baird[2]

1) RPS Environment, 290 Churchill Ave, Subiaco, Western Australia 6004, Australia
2) ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland, Australia

Abstract. In Australia, 'mass' coral spawning, where hundreds of coral colonies and numerous species release gametes on the same night, typically occurs in October/November (spring) on the Great Barrier Reef, and in March/April (autumn) on the Western Australian coast. To assess if Western Australian corals also spawn in spring, surveys of the reproductive status of *Acropora* were conducted at over 10 sites in two locations in north-western Australia, spanning over 1000 km and six degrees of latitude. This research found that 39% of *Acropora* species spawned in spring at the most northerly location and 7% of *Acropora* species spawned in spring at the more southerly location. This is the first time such a significant reproductive event in spring has been recorded in spring in Western Australia. While the causal mechanisms driving this second spawning period are likely to be complex, suitable environmental conditions in both spring and autumn might allow for two reproductive seasons on the far north-western Australian coast. This study suggests that the conditions that are suitable for reproduction in October/November are more favorable at the Bonaparte Archipelago than further south at the Dampier Archipelago.

Key words: biannual spawning, coral reefs, spawning synchrony, north-west Australia

Introduction

Multi-specific 'mass' coral spawning, where hundreds of zooxanthellate scleractinian corals synchronously release gametes on the same night (Harrison et al. 1984), has been found to occur on many coral reefs around the world; however, the timing and synchrony of spawning varies considerably among different geographic locations and regions (Guest et al. 2005a).

In some regions around the world, synchronous multi-specific spawning is concentrated over 2-3 months of the year (e.g. Japan, Hayashibara et al. 1993; Central Pacific, Kenyon 2008), while in other regions the length of the spawning period can extend for 5-7 months (e.g. Palau, Penland et al. 2004; Kenya, Mangubhai & Harrison 2008).

In Australia, the traditional paradigm has been that synchronous mass spawning largely occurs annually over 1-2 months, in spring (October and/or November) on the Great Barrier Reef (GBR) (Willis et al. 1985; Babcock et al. 1986), and in autumn (March and/or April) on the Western Australian coast (Simpson 1991; Babcock et al. 1994), and that most colonies of many species spawn over a few consecutive nights.

While corals on many reefs around Australia do display remarkable synchrony in their reproductive timing, there are also some noteworthy exceptions. On the GBR, a number of *Acropora* species are known to spawn several months after the mass spawning period (Wallace 1985; Kojis and Quinn 1981; Wolstenholme 2004), while others may spawn twice a year (Stobart et al. 1992). There is also evidence that in the *Acropora*, some spawning occurs following *every* full moon between October and February on the central GBR (Baird 2006).

Similarly on Western Australian reefs, synchronous spawning of multiple species has been recorded up to two months either side of the mass spawning period (Stewart 1993; Smith 1993; Rosser 2005), and a number of *Acropora* species have also been found spawning in spring (Rosser and Gilmour 2008).

Several environmental factors have been cited as influencing the timing of mass spawning in different regions. The most common include sea temperature, for its assumed role in the growth and maturation of gametes and larvae (Giese and Pearse 1974; Willis et al. 1985; Oliver et al. 1988); rainfall, for its reduction in salinity and physical impact upon gametes (Harrison et al. 1984; Mendes and Woodley 2002); tides and/or calm sea conditions, for their role in promoting fertilization and/or dispersal (Babcock et al. 1986; Hayashibara et al. 1993); and solar insolation, for its role in synchronising gametogenesis (Penland et al. 2004; van Woesik et al. 2006).

The extent to which corals participate in synchronous multi-specific spawning outside the traditional 'mass spawning period' was the focus of this research. We investigated the proportion of *Acropora* species that were likely to spawn in spring (October/November) at two locations in north-western Australia.

Material and Methods

This research was conducted at the Dampier Archipelago (20º28'S, 116º37'E) and the Bonaparte Archipelago (14º30'S, 125º0'E) (Fig. 1) in north-western Australia. Expeditions to each location were conducted independently by the authors (Rosser, Bonaparte; Baird, Dampier) as part of larger projects.

Reproductive samples were collected between 18 and 20 March at Bonaparte, and between 26 and 28 March at Dampier (full moon 2 April 2007); and between 9 and 10 October at Dampier, and between 23 and 25 October at Bonaparte (full moon 26 October 2007). Coral spawning typically occurs 8-10 days after the full moon in Western Australia so it was anticipated that spawning would occur in April and November.

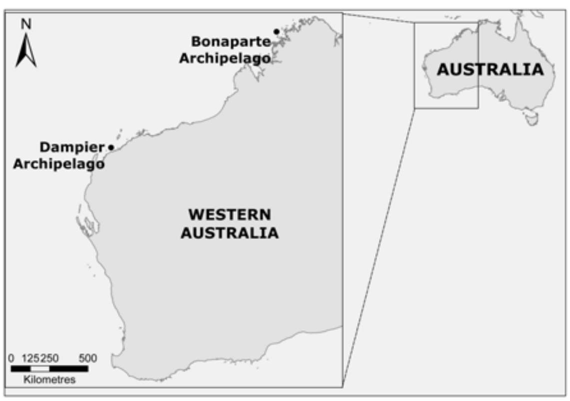

Figure 1: Location of the study sites in Western Australia

Surveys of the reproductive status of corals from the genus *Acropora* were conducted at both locations. Reproductive status was assessed by breaking up to three branches of each colony of approximately 30 species of *Acropora* (up to 700 colonies were sampled at each location). Colonies were assessed *in-situ* and scored for the presence of pigmented eggs prior to the full moon. This sampling methodology has been used previously by Harrison et al. (1984) and Baird et al. (2002) as pigmented eggs represent mature eggs that will be released shortly after the next full moon.

A lower number of *Acropora* species were sampled at the Dampier Archipelago (14 species) than at the Bonaparte Archipelago (31 species) in October due to the species assemblages in each location being different; the Bonaparte Archipelago has a much higher species diversity than the Dampier Archipelago.

Geophysical parameters including mean monthly records of sea surface temperature (SST), wind speed and rainfall for 2007 (sourced from Remote Sensing Systems satellites sponsored by NASA http://www.remss.com/) were also compared between the two locations.

Results

In the Bonaparte Archipelago, 12 species of *Acropora* (39% of the *Acropora* species sampled) were recorded with pigmented eggs in October 2007, indicating that they were likely to spawn in November (Fig. 2). Dampier Archipelago however showed a different result, with only one *Acropora* species (7% of *Acropora* species sampled) recorded with pigmented eggs in October (Fig. 2).

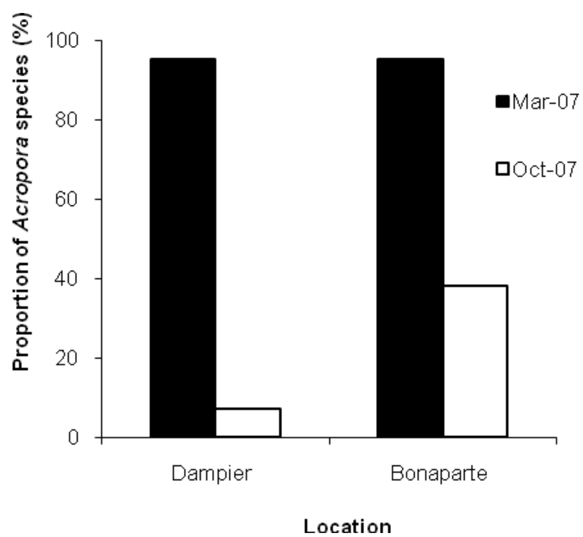

Figure 2: The proportion of *Acropora* species with pigmented eggs in March and October 2007 at the two study locations.

Ten species were sampled at both sites; of these, four species had mature colonies (40%) at Bonaparte, while only one species *Acropora humilis* (10%) had mature colonies at Dampier. For one of the four mature species at Bonaparte (*A. latistella*), only two colonies were sampled at Dampier (Table 1). For the other two mature species at Bonaparte, *A. digitifera* and *A. loripes*, 35 and 11 colonies were sampled respectively at Dampier but no colonies were found containing mature oocytes. At Bonaparte, 8 other species had colonies with mature oocytes, but these species were not sampled at Dampier (Table 1).

Table 1: The proportion of colonies (%) with pigmented eggs in each species in October 2007 from the two study sites.

	Dampier		**Bonaparte**	
	n	% pigm	n	% pigm
Acropora anthocercis			1	100
Acropora aspera			11	0
Acropora austera			4	0
Acropora bifurcata	3	0		
Acropora cerealis			2	0
Acropora clathrata			7	0
Acropora cytherea			1	100
Acropora dendrum			2	0
Acropora digitifera	35	0	14	36
Acropora divaricata	4	0		
Acropora echinata	3	0		
Acropora florida			16	0
Acropora gemmifera			14	0
Acropora humilis	13	62	34	82
Acropora hyacinthus			27	7
Acropora intermedia			20	0
Acropora latistella	2	0	4	100
Acropora loripes	11	0	16	6
Acropora microclados			1	0
Acropora microphthalma			2	0
Acropora millepora	36	0	18	0
Acropora muricata	2	0	13	0
Acropora nasuta	35	0	8	0
Acropora papillare			2	0
Acropora pulchra			2	0
Acropora pallida			1	100
Acropora robusta	1	0	4	0
Acropora samoensis			35	43
Acropora sarmentosa			19	16
Acropora secale			6	33
Acropora selago	23	0		
Acropora spicifera	5	0	2	0
Acropora striata			1	0
Acropora tenuis	6	0	13	0
Acropora valida			19	63

The proportion of colonies within each species that had pigmented eggs in October at Bonaparte Archipelago was highly variable, ranging from 5-100% (Table 1), with a mean of 47% ±7.6 (SE).

Interestingly, at both Dampier and Bonaparte Archipelagos, 95% of *Acropora* species had pigmented eggs in March 2007 (Fig. 2).

A comparison of geophysical parameters across the two locations showed that SST was higher at the Bonaparte Archipelago than at the Dampier Archipelago, though the annual variation in SST was similar at both locations (4ºC).

Average monthly wind speed showed that in the Bonaparte Archipelago there were two distinct periods of low winds: March and October, while in the Dampier Archipelago wind speed was more constant, with a drop in wind speed occurring only in March.

Monthly rainfall patterns were similar at both locations, with the highest monthly rainfall occurring in March (at both locations).

Discussion

Here we provide clear evidence that at the Bonaparte Archipelago in Western Australia, multi-specific spawning is occurring twice a year, in both spring and autumn, with March/April being the primary spawning period and October/November being the secondary spawning period.

Our finding that a substantial proportion of the *Acropora* populations in north-western Australia participate in a second mass spawning event is of particular interest because previously, the secondary spawning event was considered to be relatively minor. Rosser and Gilmour (2008) found that 36% of *Acropora* species were likely to spawn between October and December at Barrow Island (in north Western Australia), and the mean proportion of colonies in each species participating was 27% ± 7.4 (SE). The spring spawning event at Bonaparte Archipelago described here, involves a greater number of *Acropora* species and almost double the proportion of colonies from each species participating.

Multi-specific spawning periods in both spring and autumn have been recorded in other regions, however the number of species and colonies involved is generally much lower (Wolstenholme 2004; Guest et al. 2005b).

We provide no evidence to suggest that individual colonies spawned twice, because most *Acropora* species are considered to have a single annual gametogenic cycle (Wallace 1985; Mangubhai and Harrison 2008; Rosser & Gilmour 2008). Rather, we suggest that different individuals within a single species spawn at different times.

The most northerly location, Bonaparte Archipelago, had a higher number of *Acropora* species spawning in November 2007 than at the southern location in the Dampier Archipelago. While a greater number of species was sampled at Bonaparte than at Dampier due to different species assemblages at each location, the trend in this data suggests that the magnitude of spring spawning is greater at

Bonaparte than at Dampier. The causal mechanisms resulting in differential spawning patterns are likely to be complex and have yet to be fully resolved. The comparison of geophysical data between the two locations may, however, provide some insight into causal mechanisms.

In October and November, sea surface temperature was 2-3ºC lower at the Dampier Archipelago than at the Bonaparte Archipelago, and this may explain why the magnitude of spawning was much lower at Dampier in November. A meta-analysis of coral spawning in the Caribbean showed that monthly mean SST has a significant relationship with gamete release, therefore suggesting that an optimal temperature is necessary for gamete maturation and that this temperature window may be quite narrow (van Woesik et al. 2006). In this respect, it is possible that sea surface temperature is sub- optimal for gamete maturation in October/November at the Dampier Archipelago.

Secondly, there was a distinct drop in mean monthly wind speed during October and November at the northerly location, whereas wind speed remained relatively constant throughout spring at the Dampier Archipelago (a drop in wind speed occurred only during March). Wind strength is considered to be an important factor influencing spawning time because spawning during a period of slack water is likely to increase fertilisation success (Babcock et al. 1986). Therefore, a distinct period of low winds in October at the Bonaparte Archipelago could be advantageous for spawning during this period.

The data from this study suggests that conditions for reproduction in October/November are more favorable at the Bonaparte Archipelago than at the Dampier Archipelago, however sampling over more years is required to substantiate this. While it is possible that a combination of low SST and relatively strong winds could make conditions less favorable for reproduction in the Dampier Archipelago, additional data over a longer time period together with more detailed comparisons between the two locations is required to elucidate any strong conclusions. The spatio-temporal variability of coral spawning in Western Australia is only just beginning to be revealed, but offers much scope for further research into the factors constraining spawning time.

Acknowledgements

MScience, Rio Tinto Iron Ore, Woodside Energy Ltd, Inpex Browse Ltd and RPS Environment for funding, logistical and field support of expeditions. We thank Zoe Richards, Patrick Hollingworth, Glen Nuttall, James Guest and Ken Clifton for their excellent editorial suggestions.

References

Babcock RC, Bull GD, Harrison PL, Heyward AJ, Oliver JK, Wallace CC, Willis BL (1986) Synchronous spawnings of 105 scleractinian coral species on the Great Barrier Reef. Mar Biol 90:379-394

Babcock RC, Willis BL, Simpson CJ (1994) Mass Spawning of Corals on a High-Latitude Coral-Reef. Coral Reefs 13:161-169

Baird (2006) Predicting patterns of coral spawning at multiple scales. On the use of coral spawning predictions for management: workshop proceedings The University of Western Australia, May 2006. MScience, Perth, p159

Baird AH, Marshall PA, Wolstenholme J (2002) Latitudinal variation in the reproduction of *Acropora* in the Coral Sea. Proc 9th Int Coral Reef Symp I:385-389

Giese AC and Pearse JS (1974) Introduction: general principles Giese AC and Pearse JS (Ed) in Reproduction of marine invertebrates. Volume 1. Acoelomate and pseudocoelomate metazoans., Academic Press, New York and London, p 37

Guest JR, Baird AH, Goh BPL, Chou LM (2005a) Seasonal reproduction in equatorial reef corals. Invert Reprod & Dev 48:207-218

Guest JR, Baird AH, Goh BPL, Chou LM (2005b) Reproductive seasonality in an equatorial assemblage of scleractinian corals. Coral Reefs 24:112-116

Harrison PL, Babcock RC, Bull GD, Oliver JK, Wallace CC, Willis BL (1984) Mass spawning in tropical reef corals. Science 223:1187-1188

Hayashibara T, Shimoike K, Kimura T, Hosaka S, Heyward A, Harrison P, Kudo K, Omori M (1993) Patterns of Coral Spawning at Akajima Island, Okinawa, Japan. Mar Ecol Prog Ser 101:253-262

Kenyon, JC (2008) *Acropora* (Anthozoa: Scleractinia) reproductive synchrony and spawning phenology in the Northern Line Islands, Central Pacific, as inferred from size classes of developing oocytes. Pac Sci 62(4):569-578

Kojis BL and Quinn NJ (1981) Aspects of Sexual Reproduction and Larval Development in the Shallow Water Hermatypic Coral, *Goniastrea australensis* (Edwards and Haime, 1857). Bull Mar Sci 31(3): 558-573.

Mangubhai S, Harrison PL (2008) Asynchronous coral spawning patterns on equatorial reefs in Kenya. Mar Ecol Prog Ser 360:85–96

Mendes JM and Woodley JD (2002) Timing of reproduction in *Montastraea annularis*: relationship to environmental variables. Mar Ecol Prog Ser 227: 241-251

Oliver JK, Babcock RC, Harrison PL, Willis BL (1988) Geographic extent of mass coral spawning: Clues to ultimate causal factors. Proc 6th Int Coral Reef Symp. 2:803-810

Penland L, Kloulechad J, Idip D, van Woesik R (2004) Coral spawning in the western Pacific Ocean is related to solar insolation: evidence of multiple spawning events in Palau. Coral Reefs 23:133-140

Rosser NL, Gilmour JP (2008) New insights into patterns of coral spawning on Western Australian reefs. Coral Reefs 27:345-349

Rosser NL (2005) Reproductive seasonality and biannual spawning of *Acropora* on two north-west Australian reefs. Honours Thesis, Murdoch University, Perth, p117

Simpson CJ (1991) Mass spawning of corals on Western Australian reefs and comparisons with the Great Barrier Reef. J R Soc West Aust 74:85-91

Smith RA (1993) Mass spawning in the Faviidae on the Ningaloo Reef Tract. Honours Thesis, Murdoch University, Perth, p126

Stewart RR (1993) Mass spawning in the Acroporidae on the Ningaloo Reef Tract. Honours Thesis, Murdoch University, Perth, p 94

Stobart B, Babcock RC, Willis BL (1992) Biannual spawning of three species of scleractinian coral from the Great Barrier Reef. Proc 7th Int Coral Reef Symp 1:494-499

van Woesik R, Lacharmoise F, Koksal S (2006) Annual cycles of solar insolation predict spawning times of Caribbean corals. Ecol Lett 9:390-398

Wallace CC (1985) Reproduction, recruitment and fragmentation in nine sympatric species of the coral genus *Acropora*. Mar Biol 88:217-233

Willis BL, Babcock RC, Harrison PL, Oliver JK (1985) Patterns in the mass spawning of corals on the Great Barrier Reef from 1981 to 1984. Proc 5th Int Coral Reef Congr 4:343-348

Wolstenholme JK (2004) Temporal reproductive isolation and gametic compatibility are evolutionary mechanisms in the *Acropora humilis* species group (Cnidaria; Scleractinia). Mar Biol 144:567-582