

Patterns of reproduction of in-shore corals of the Dampier Harbour, Western Australia, and comparisons with other reefs.

J.A. Stoddart¹ and J.Gilmour²

¹MScience Pty Ltd, University of Western Australia, Crawley, Western Australia

²MER Consultants, Gardner St, Como, Western Australia

Abstract

Predictable mass-spawning over a few nights a year is a well established reproductive phenomenon in corals. However, corals show many other patterns of reproduction that may also vary between locations and communities. To date, the reproduction of corals from off-shore reefs has been better documented than that for corals growing in turbid near-shore environments. Management of near-shore communities requires a better understanding of their patterns of reproduction.

During the development of environmental protection plans for a major dredging program within the Dampier Harbour in 2004, concerns were raised that dredging and disposal during the predicted mass-spawning might pose an unacceptable hazard. The timing and magnitude of this risk was evaluated on assumptions that mass-spawning played a significant ecological role in these populations, similar to that described for off-shore populations in the nearby Dampier Archipelago.

A program was established in conjunction with the dredging environmental protection works to investigate the reproductive status of populations of corals in the Dampier Harbour during the period of mass-spawning. Based on distributional data, a large proportion of species belonged to families that are typically hermaphroditic mass-spawners. For these species (including many species of Faviidae and Acroporidae) the timing of gametogenesis and spawning during 2004 occurred as expected, and was split between the months of March and April because of the early full moon in March. However, some of the most abundant species of corals apparently did not participate in the mass-spawning, which included species of *Porites*, *Pavona* and *Turbinaria*, and the patterns of reproduction in these species remains uncertain.

Keywords: sedimentation, coral, reproduction, dredging

Introduction

General patterns of reproduction in scleractinian corals

Although knowledge of reproduction in corals has improved dramatically in the last few decades, there is still not a detailed understanding of cycles of gametogenesis and breeding for many species of corals at many locations. Nor is there a good understanding of how reproductive cycles of a single species may vary across their geographic range in response to genetic or environmental factors.

Scleractinian corals display four general patterns of reproduction, depending on their sexuality and how fertilisation and gametogenesis occur (Harrison and Wallace 1990, Richmond and Hunter 1990). These modes of reproduction are:

- Hermaphroditic brooders
- Hermaphroditic spawners
- Gonochoric brooders
- Gonochoric spawners

Hermaphroditic corals have male *and* female gametes within their polyps or colonies (sometimes sequentially), whereas gonochoric corals have separate sexes and either male *or* female gametes. In brooding corals, the eggs are fertilised within the colony's polyps and they develop into the larvae that are eventually released; whereas, spawning corals release both eggs and sperm synchronously and fertilisation, gametogenesis and larval development occur in the water column.

Most corals have distinct breeding cycles, and gametogenesis may occur monthly, seasonally, annually, or periodically among years (Fadlallah 1983, Harrison and Wallace 1990, Richmond and Hunter 1990). Gamete maturation often follows lunar or annual cycles, with egg development taking up to 10 months and sperm development around 3 months. Brooding corals tend to have one, two, or multiple gametogenic cycles within a year, and can therefore have overlapping gamete stages within a coral (Harrison and Wallace 1990). In contrast, most spawning corals have only one gametogenic cycle a year, although some populations and even some individuals have multiple cycles (Harrison and Wallace 1990, Oliver et al. 1988, Mildner 1991, Stobart et al. 1992). The number of gametogenic cycles within populations and individual corals is strongly influenced by environmental conditions and the levels of disturbance to which they are exposed (e.g. Szmant Froelich et al. 1980, Robertson 1981, Harrison and Wallace 1990). Corals in optimal conditions may reproduce many times within a year, whereas those under disturbed conditions may not reproduce at all.

Gametogenesis culminates in the maturation of gametes for breeding, when the mature eggs are either fertilised within the polyp (brooders) or in the water column (spawners). Breeding most commonly occurs during the night in late spring, summer, or autumn, but has been documented at other times (Harrison and Wallace 1990, Richmond and Hunter 1990). The proximate cues for breeding are not known; temperature certainly plays an important role, but solar insolation, day length, moonlight and tide cycles are also influential (Harrison and Wallace 1990, Richmond and Hunter 1990, Penland et al. 2004). Gamete maturation is usually synchronised within an individual, and to varying degrees among individuals within a population. Breeding and larval development is

less synchronous among brooding corals, and can occur over a protracted period of consecutive months (Harrison and Wallace 1990, Richmond and Hunter 1990, Tanner 1996). Breeding by most spawning corals is more synchronous than for brooders, and on some reefs a remarkable number of hermaphroditic spawning corals release gametes over just a few nights a year within one or two months, but on most reefs spawning is more protracted over a few months during a breeding period. Breeding periods tend to be less synchronous among gonochoric spawners (Harrison and Wallace 1990).

Many corals have been documented to participate in mass-spawning events on reefs around the world, but there is considerable variation in this general pattern of reproduction. There are still few long-term studies documenting the proportion of colonies and species that spawn their gametes during different months, but patterns clearly vary among regions, years, and species (Simpson 1988, Harrison and Wallace 1990, Richmond and Hunter 1990, Oliver et al. 1988, Babcock et al. 1994, Baird et al. 2001, Guest et al. 2002).

The mass-spawning paradigm was born out of research conducted on the Great Barrier Reef, where the greatest number of corals and species spawn synchronously over short periods each year (Harrison et al. 1984). On other reefs around the world, such as those around the equator, Okinawa, or Hawaii, spawning is far less synchronous and occurs over a greater number of months (Harrison and Wallace 1990, Richmond and Hunter 1990). In the Caribbean and Red Sea, there is comparatively little synchrony in spawning (Shlesinger and Loya 1985, Harrison and Wallace 1990). The time of mass-spawning within a location also varies by days or months among years, of which a notable example is the case of split-spawning (Willis et al. 1985). Split-spawning occurs over consecutive months when the full moon comes early in the first month and not all colonies have mature gametes. In addition to regional and temporal variation in the time of spawning, patterns of spawning and even modes of reproduction vary within some species.

Patterns of reproduction in scleractinian corals on Australian reefs

On corals reefs around Australia, reproduction has been best studied for hermaphroditic spawning corals on the Great Barrier Reef. There, around 100 species of corals have been reported to spawn within three to six nights after the full moon in October or November, and many more over the nights either side of this period (Babcock et al. 1986). However, there is variation in the pattern of mass-spawning, which can occur days before or after the predicted dates, a month earlier on near-shore reefs, and even during different seasons for some species in some regions. Additionally, there is evidence of populations and some individuals spawning twice a year, in October/November and in March/April on the Great Barrier Reef (e.g. Stobart et al. 1992, Wolstenholme 2004).

The release of larvae by brooding corals on the Great Barrier Reef is less understood, but tends to follow a lunar cycle and occurs over consecutive months, often during the spring or summer (Harrison and Wallace 1990). However, there is apparently considerable variation in this pattern

and detailed cycles of gametogenesis and larval release have been described for only a few brooding corals on the Great Barrier Reef (e.g. Kojis 1986, Tanner 1996).

On Western Australian reefs, synchronous mass-spawning events have also been documented (Simpson 1985, Babcock et al. 1994). In contrast to the Great Barrier Reef, mass-spawning on Western Australian reefs occurs around six to ten nights after the full moon, in early autumn during March and/or April. At present, there is no accepted explanation as to why mass-spawning should occur in early Autumn on Western Australian reefs but in late Spring on the Great Barrier Reef (see Simpson 1985, Babcock et al. 1994).

Timing of mass-spawning on Western Australia reefs is similar to that of some corals on Indo-Pacific reefs near the equator (Oliver et al. 1988, Baird et al. 2001, Guest et al. 2002). At Scott Reef, in far north Western Australia, there are two mass-spawning events each year; a secondary spawning at the same time as on the Great Barrier Reef and a primary spawning at the same time as most other corals on Western Australian reefs, with evidence that some populations participate in both events (Australian Institute of Marine Science (AIMS), unpublished data). On reefs further south in Western Australia, mass-spawning events of similar magnitude have not been documented during October/November, but some species do spawn in October/November, in January, and possibly other months around this period (AIMS, unpublished data).

Patterns of reproduction in scleractinian corals in the Dampier Archipelago

Mass-spawning by corals on mid- and off-shore reefs within the Dampier Archipelago was originally described by Simpson (1985) and occurs at the same time as other reefs in Western Australia in March/April. Spawning typically occurs around six to ten nights after the full moon on neap tides and involves many colonies of around 50 species of corals, although more than 80% of these species belong to the Families Acroporidae and Faviidae (Simpson 1988). In addition to the March/April spawning, mature eggs have been observed in many colonies of at least three species of *Acropora* during October/November over two years (AIMS unpublished data). The proportion of colonies and species that participate in the October/November spawning is not known, but it is certainly a smaller spawning event. Simpson (1988) sampled intensively during this period but found no mature gametes.

Patterns of reproduction by corals on near-shore reefs of the Dampier Archipelago have not been described. Indeed, patterns of reproduction have not been described for many of the dominant corals on near-shore reefs around Australia, as research is usually conducted on hermaphroditic spawning corals on mid- or off-shore reefs. Near-shore reefs tend to have many species of corals that are not hermaphroditic spawners and whose patterns of reproduction are more difficult to describe.

Within the Dampier Harbour, the relative abundance of species of corals differs from that on the off-shore reefs of the Dampier Archipelago (Blakeway & Radford, this volume). The most abundant corals are evenly split

between species that have been described elsewhere to mass-spawn, and species that either do not mass-spawn or whose modes of reproduction are poorly described. Many of the most abundant corals on near-shore reefs include species of *Porites*, *Pavona* and *Turbinaria*, which are generally not hermaphroditic spawners. Simpson (1988) found no evidence of colonies of these genera with ripe eggs or larvae on off-shore reefs in the Dampier Archipelago prior to the mass-spawning, but mature eggs have been observed in female *Porites* colonies on off-shore reefs in other years prior to the mass-spawning (unpublished data).

The Dredging Program

During January to May 2004, the Dampier Port Authority (DPA) undertook a substantial dredging program within the south-east of Mermaid Sound in the Dampier Harbour (Figure 1). Dredging involved removal and disposal of over 4Mm³ of spoil to complete the construction of a new berth and channel as part of the Bulk Liquids Berth Project (Stoddart & Anstee, this volume).

The project was referred to the Western Australian Environmental Protection Authority (EPA) in September 2003 and the recommendations of the EPA (EPA 2003) included a variety of controls in response to concerns that elevated levels of sediments or water turbidity may adversely impact coral reproduction. EPA recommendations included cessation of dredging during mass-spawning and investigation of the impacts of dredging on coral reproduction, especially spawning. In response to these concerns, the Dampier Port Authority's Interim Environmental Management Program (DPA, 2003) required an investigation into the proportion of species and corals participating in the mass-spawning during March and April 2004. Programs were conducted within this study to investigate the timing and distribution of gametogenesis in corals adjacent to the dredging and spoil disposal areas.

Methods

Site Locations

Study sites were chosen that:

- could be easily located
- had an abundance of species known to participate in mass-spawning elsewhere
- were within the predicted area of increased turbidity and sediment deposition resulting from spoil disposal, or
- were beyond the predicted area of impact from spoil disposal

On this basis, the following sites were selected (Figure 1):

- Impact Sites – Conzinc Island (CONI), Conzinc Bay (COBN)
- Control Sites – Angel Island (ANGI), North Withnell Bay (NWIT)
- Observation site – east of the Dampier Public Boat Ramp (TCIR)

Table 1. Timing of field surveys around the predicted dates of mass-spawning in March and April 2004

Trip	Dates	Objective
1.	8-10 March 2004	Initial establishment of survey sites and the inspection of coral fragments to determine the developmental stage of their gametes
2.	14-17 March 2004	Inspection of coral fragments during the March spawning
3.	29-30 March 2004	Inspection of coral fragments after the March spawning and during the April spawning
4.	10-15 April 2004	Inspection of coral fragments prior to the April spawning

The Observation site was accessible from the shore at night so that corals could be checked for their participation in the mass-spawning.

Sampling events

Field surveys were conducted during 5 trips, which spanned the predicted period of mass-spawning within the Dampier Archipelago in 2004 (Table 1). During these trips, sampling was focussed on species from the families Acroporidae and Faviidae, which are widely documented to participate in mass-spawning (Willis et al. 1997), in addition to the species from other families that were most abundant within the study area.

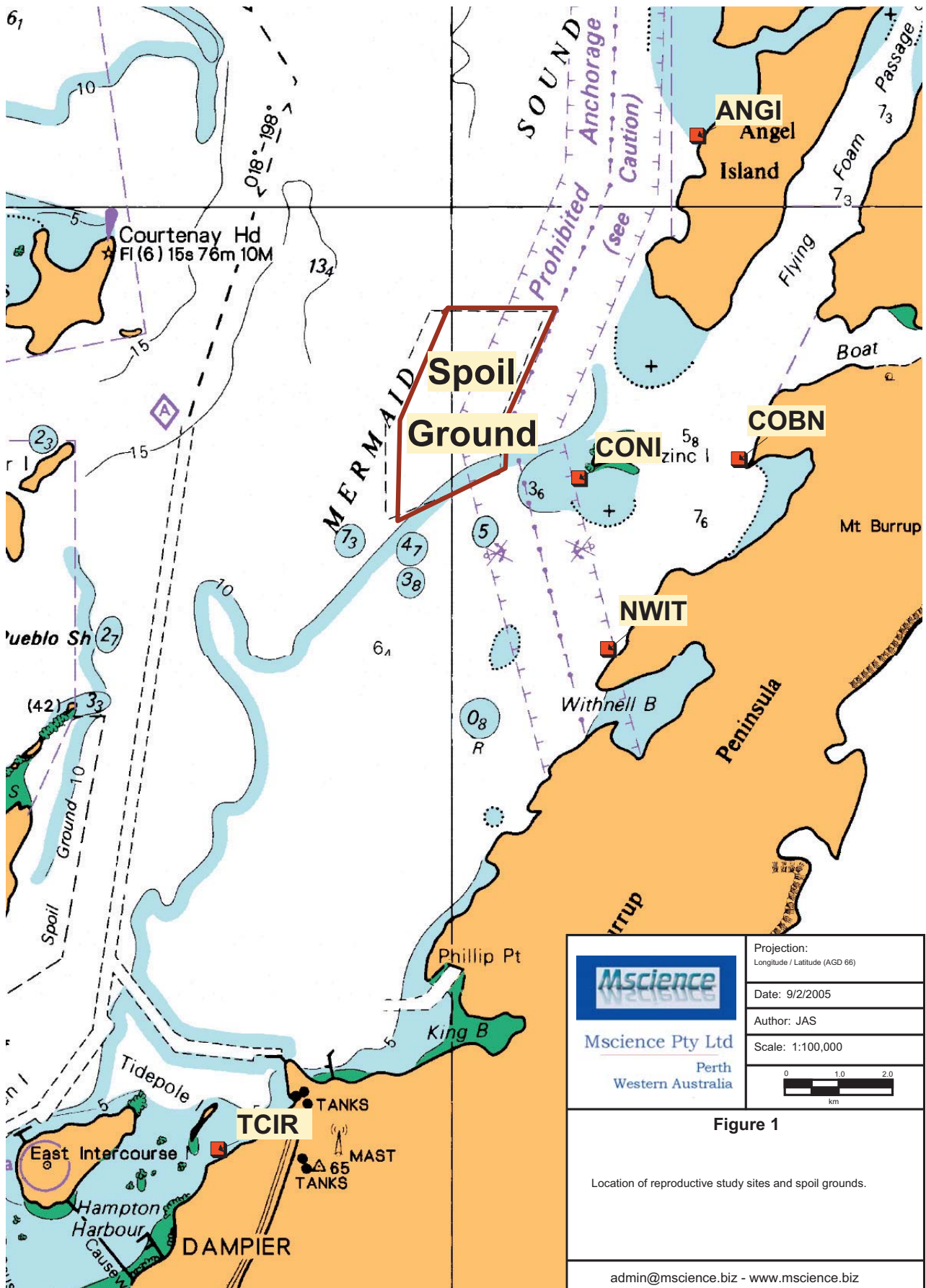
Trip 1: 8-10 March 2004

The first trip was postponed from 1-5 March due to Cyclone Monty, and conducted from 8-10 March in a limited extent because poor visibility prevented sampling at many sites. Some sites examined during this trip were severely impacted by freshwater inundation following rainfall from Cyclone Monty over a 24-48 hr period.

During the 8-10 March, divers investigated all Impact and Control sites to determine where visibility was sufficient to allow sampling. Of the sites visited, sampling was only possible at Impact Site COBN and Control sites NWIT and ANGI. At COBN, poor visibility made it impossible to locate 20 replicate colonies of different species, and replicate colonies of *Acropora* were not tagged as planned because of their sparse distribution.

A variety of species and replicate colonies of the most abundant species, were sampled. The tips of branching corals were broken below the area of recent growth and polyps examined *in situ*. Massive and sub-massive colonies were cracked with a hammer and chisel to examine polyps away from the growing edge. Samples of colonies were examined microscopically when the developmental stage of their gametes was not obvious *in situ*. Depending on the developmental stage of the gametes within polyps, colonies were scored at:

Figure 1. Location of reproductive study sites and spoil grounds.



- Stage 1: spermaries were full, eggs were large and pigmented, spawning was likely in March
- Stage 2: eggs were medium to large, not pigmented, spawning was likely in April
- Nil: no sperm or eggs were observed

Trip 2: 14-17 March 2004 (predicted spawning)

Three methods were used to determine whether corals participated in the mass-spawning in March:

1. Dives 1-2 hours after sunset at the Observation site over a patch of near-shore reef to the east of the Dampier Public Boat Ramp to directly observe spawning;
2. Indirect tests looking for the 'next day' evidence of spawning, such as the presence of eggs or slicks of spawn around bays and other sites where slicks would have been located from these inshore sites
3. Direct 'next day' tests looking at the disappearance of eggs from corals in populations tested previously.

While species of *Acropora* are most often used for the observation of spawning in the field, these do not occur in abundance in near-shore communities in Dampier. Consequently, the Observation site was chosen because it had species of Faviidae and Mussidae that had been

seen elsewhere with eggs. 'Next day' tests looking for the disappearance of eggs from corals following the predicted dates of spawning were conducted at several reefs with populations of *Acropora*.

Trip 3: 29-30 March 2004

Corals were sampled as for Trip1 to determine whether they participated in the March spawning, except that all scoring was undertaken on shore. Corals were scored using a hand lens or under a dissecting microscope.

To determine whether corals would participate in the April spawning, a range of species of *Acropora*, Faviidae and Mussidae were sampled.

Trip 4: 10 -15 April 2004 (predicted spawning)

The three methods used in Trip 2 were again used to determine whether corals participated in the April spawning. However, the 'next day' examination of gametes was only done for *Acropora* species at NWIT, which was identified as the site with the highest proportion of colonies with mature eggs in Trip 3.

Trip 5: 27-30 April 2004.

To determine whether corals participated in the April spawning, fragments of colonies of *Acropora* and Faviidae were scored *in situ* and microscopically.

Table 2. Gamete stages within colonies of different species sampled *in situ* during Trip 1 (8-10 March 2004)

Family	Species	Site	Status		
			(sample size)	1	2
Acroporidae	<i>Acropora</i> sp.1	NWIT (14)	5	8	1
		COBN (12)	4	6	2
		ANGI (19)	1	14	4
	<i>Acropora</i> sp.2	NWIT (15)	4	10	1
		COBN (10)	2	7	1
		ANGI (12)	0	12	0
	Other <i>Acropora</i>	NWIT (5)	2		3
		COBN (0)	-	-	-
		ANGI (6)	2	2	2
Dendrophylliidae	<i>Turbinaria</i> spp	NWIT (6)			6
Faviidae	Various	NWIT (21)			21
		COBN (14)			14
		ANGI (9)	2		7
Oculinidae	<i>Galaxea fascicularis</i>	NWIT (2)			2
		ANGI (2)			2
Mussidae	<i>Lobophyllia hemprichii</i>	NWIT (1)			1
Poritidae	<i>Porites ?lobata?</i>	NWIT (3)			3

Results

Gamete Development in Corals

Samples of over 250 corals from 20 species were examined. Of these, only species of *Acropora* were scored *in situ*. Eggs were visible within fragments of a few faviids *in situ*, but most were examined microscopically. Approximately 100 individuals from 18 species were examined microscopically during Trips 1 and 3.

Acroporids

When observed in early March, approximately 25% of colonies (n=109) of seven species of *Acropora* appeared ready to spawn in March, having Stage 1 eggs (Fig. 2), and approximately 50% of the colonies were expected to spawn in April, having unpigmented Stage 2 eggs (Table 2, 3). *In situ* observations of eggs indicated some variation in gamete maturation among colonies within species at each of the sites, although there was less variation among individuals examined microscopically.

Table 3. Gamete stages within colonies of different species examined microscopically during Trip 1 (8 - 10 March 2004)

Family	Species	Sampled	Status			
			# with eggs	colour	size* (um)	spawn
Acroporidae	<i>Acropora</i> sp.1	4	4	cream	400	April
	<i>Acropora</i> sp.2	3	3	cream	400	April
	<i>Acropora</i> sp.3	2	2	white	300	April
	<i>Acropora</i> sp.4	2	2	red	500	March
	<i>Acropora</i> sp.5	1	1	red	600	March
	<i>Acropora</i> sp.6	2	2	red	450	March
	<i>Acropora digitifera</i>	4	3	red	500	March
			1	cream	400	April
Agariciidae	<i>Pavona decussata</i>	5	0			?
Dendrophylliidae	<i>Turbinaria</i> spp	3	0			?
Faviidae	<i>Favites abdita</i>	2	1	red	250	March
			1	cream	200	April
	<i>Favites pentagona</i>	1	1	green	150	April
	<i>Goniastrea australensis</i>	5	5	cream	200	April
	<i>Goniastrea retiformis</i>	3	3	white	150	April
	<i>Goniastrea</i> sp.	2	2	pink	300	March
	<i>Platygyra sinensis</i>	3	3	red	250	March
	<i>Montastrea curta</i>	1	1	green	200	March or April
Oculinidae	<i>Galaxea fascicularis</i>	3	2	red	300	March
			1	cream	200	April
Mussidae	<i>Lobophyllia hemprichii</i>	1	1	cream	200	April
Poritidae	<i>Porites ?lobata?</i>	4	0			?

*- modal egg size

Resampling in late March was also consistent with a split-spawning by the *Acropora*, with almost 30% of colonies expected to spawn in April, almost 70% lacking eggs, and 3% having unpigmented eggs that were potentially spawned in May (Table 4).

During both Trip 1 and Trip 3, there was a consistently lower percentage of colonies with mature gametes at the ANGI site than at any of the other sites examined (Table 5).

Faviids

Microscopic examination of fragments of several species of Faviidae indicated that around half were ready to spawn in March, and half in April (Table 3, 4). Gamete development appeared consistent among individuals, but replication was limited. Resampling in late March confirmed the pattern of split-spawning by faviids during March and April, with some indication of variation among different species. All of the colonies of *Platygyra sinensis* that were sampled contained ripe eggs in March and April (Fig. 3), but samples were collected from different sites during each month. Some *Goniastrea* spp. from the different sites had ripe and immature eggs in March, and ripe eggs in April. *Favites halicora?* from the different sites consistently had ripe eggs in April, but was not sampled prior to the March spawning.

The most abundant species within the study area were in the genera *Pavona*, *Turbinaria* and *Porites*. During Trips 1 and 3, fragments of these species from all sites were examined to search for the presence of eggs or sperm (Table 2, 3, 4). Five colonies of *Pavona decussata*, 13 colonies of *Turbinaria* sp., and 4 colonies of *Porites lobata*(?) were sampled, and no gametes were observed in any of the polyps examined.

Observations of Spawning

Field and microscopic observations reported above confirmed that ripe eggs occurred commonly in many species (and individuals within species) prior to the predicted dates of spawning. Despite many dives from 1-2 hours after sunset during both the predicted spawning periods, no spawning or corals displaying eggs in the polyp mouth were seen. Neither were any slicks of floating spawn observed, despite calm conditions over much of both periods.

Discussion

Reproductive patterns in Dampier Harbour Corals

Spawning behaviour of corals at the inshore Dampier Harbour during 2004 was not uniform and was probably less synchronous than for the off-shore coral communities. Some of the most abundant species of inshore corals in the Dampier Harbour (species of *Turbinaria* and *Pavona*) do not mass-spawn over a few nights each year, although others (Acroporidae, Faviidae, Mussidae, Oculinidae) did spawn at similar times to corals on other reefs within the Dampier Archipelago, and Western Australia. In particular, mass-spawning by these latter corals was split over the months of March and April as a result of the full moon falling early in March.

Patterns of reproduction for *Turbinaria*, *Pavona* and *Porites* have not been widely investigated around the world. The dominant species of *Porites* on near-shore reefs in the Dampier Archipelago are *Porites solida* and *P. lobata*, of which *P. lobata* is best studied. Within the eastern Pacific and on the Great Barrier Reef, *P. lobata* is predominately a gonochoric spawner that undergoes short annual periods of spawning during one or a few months a year (Kojis and Quinn 1981, Glynn et al. 1994). However, other species of *Porites* have been found to spawn gametes over more protracted periods (Harriott 1983, Harrison and Wallace 1990).

On the Great Barrier Reef, *Turbinaria mesenteria* has been observed to spawn over extended periods between March and May, which is around five months later than the mass-spawning (Willis 1987). Eggs in colonies were apparently of sufficient size to be spawned in October, but they were retained until after March and another gametogenic cycle commenced so that the two cycles overlapped within the colonies. However, some colonies of *T. retiformis* have been observed to spawn in October, and it is possible that a proportion of colonies of both species spawn at the two times. The spawning of many *T. mesenteria* colonies months after the mass-spawning on the Great Barrier Reef suggests a similar variation in timing could exist in the Dampier Archipelago, but rather than spawning months later, colonies may be spawning earlier, possibly during October/November.

There is little reliable information about the pattern of reproduction in species of *Pavona* on the Great Barrier Reef (including *P. decussata*) although there are suggestions of spawning (Willis, pers com, 2004). Glynn et al. (1996,

Table 4. Gamete stages within colonies of different species during Trip 3 (29 – 30 March 2004)
a) *Acropora*

SITE	STATUS		
	I	II	X
ANGEL IS	2	-	20
CONI	5	-	7
COBN	3	1	8
NWIT	6	1	6
TOTALS	16	2	41

Figure 2. Mature eggs in *Acropora* spp

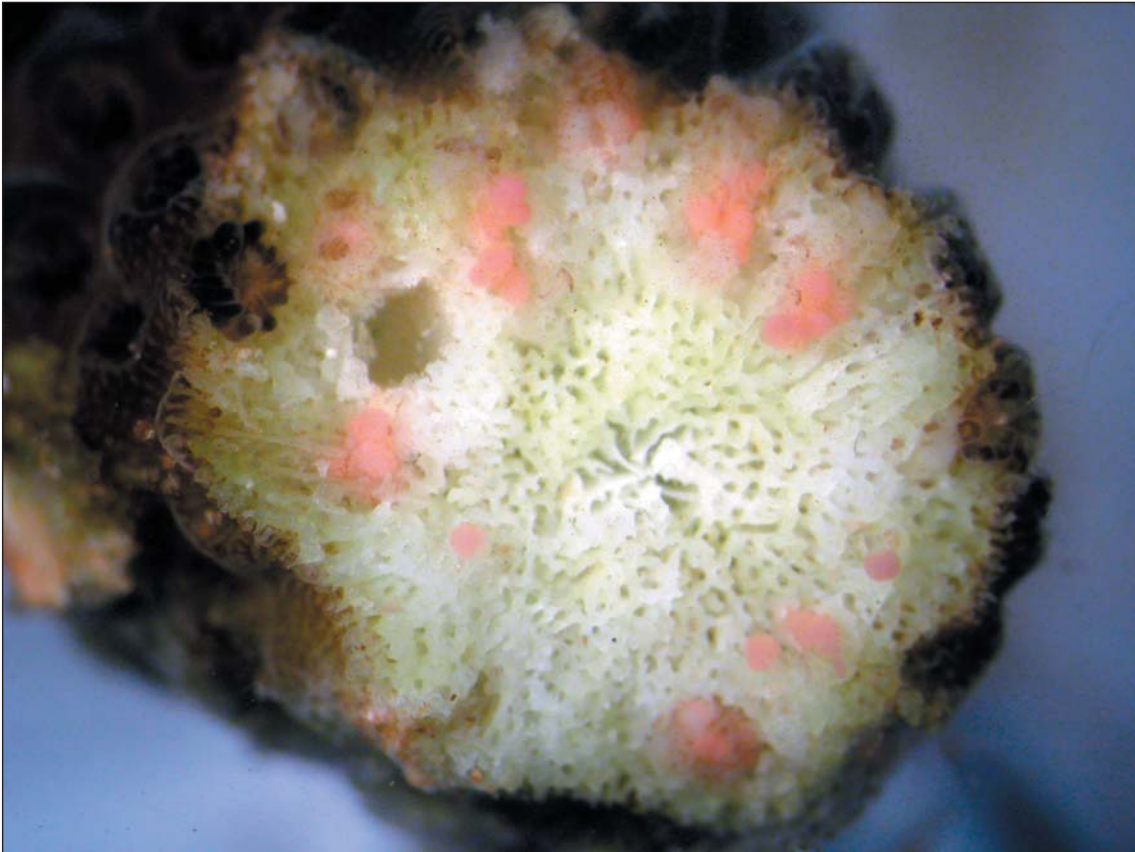


Figure 3. Eggs in *Platygyra sinensis*

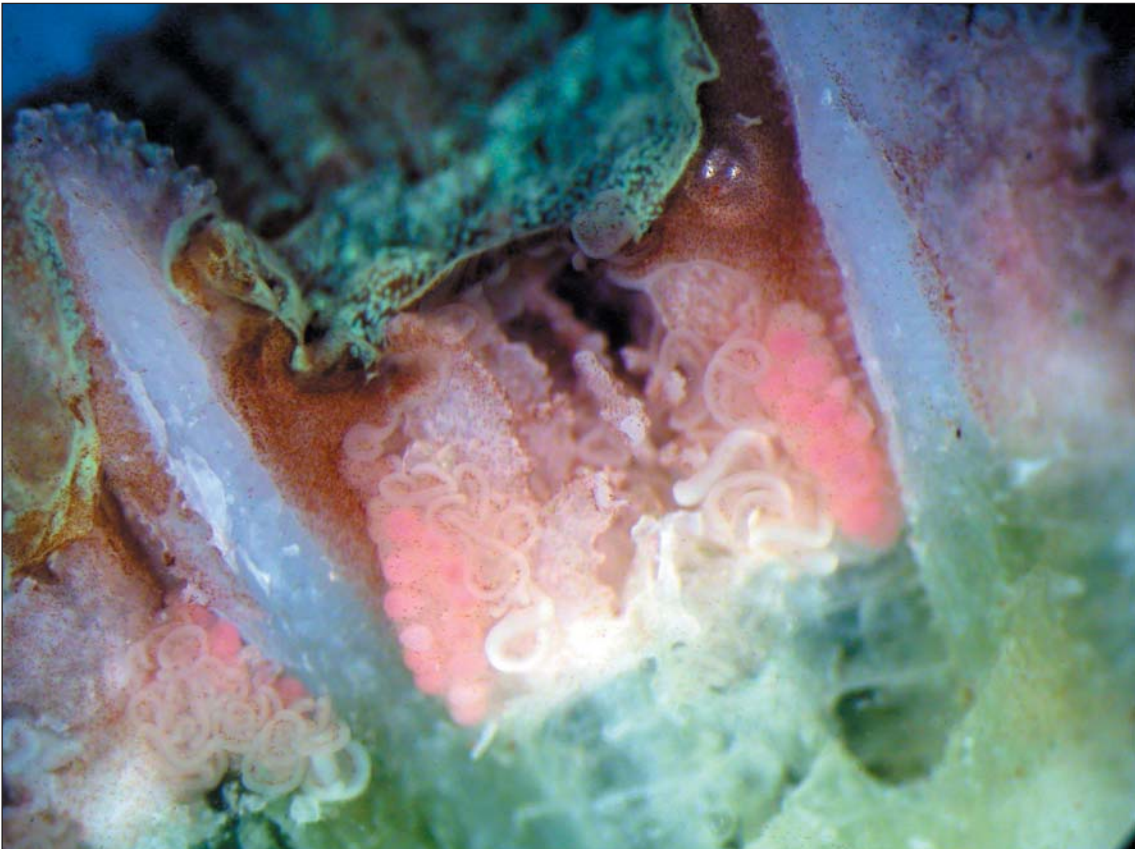


Table 4. (cont)
b) Favilids / Mussids

Family	Species	Sampled	Status			
			# with eggs	colour	Size (µm)	spawn
Location - ANGI						
Acroporidae	<i>Montipora</i> sp	1	0			-
Faviidae	<i>Favites abdita</i>	1	0			-
	<i>Favites</i> sp	4	0			-
	<i>Favites</i> sp	1	?sperm			?
	<i>Goniastrea australensis</i>	3	3	pink	<150	April
	<i>Platygyra sinensis</i>	2	2	red	350-400	April
	<i>Lobophyllia hemprichii</i>	1	1	pink	500	April
Mussidae						
Location - COBN						
Dendrophyllidae	<i>Turbinaria mesenterina</i>	3	0			-
	<i>Turbinaria peltata</i>	2	0			-
Faviidae	<i>Favites halicora</i>	3	3	red	250-350	April
	<i>Platygyra sinensis</i>	3	3	red	400-450	April
	<i>Montastrea curta</i>	2	0			-
Merulinidae	<i>Merulina</i> sp?	1	0			-
Mussidae	<i>Lobophyllia hemprichii</i>	1	1	pink	500	April
Location - CONI						
Faviidae	<i>Favites halicora</i>	3	3	pink	250-300	April
	<i>Favites</i> sp?	1	0			-
	<i>Goniastrea</i> sp?	1	1	pink	450	April
Location - NWIT						
Dendrophyllidae	<i>Turbinaria mesenterina</i>	3	0			-
	<i>Turbinaria peltata</i>	2	0			-
Faviidae	<i>Caulastrea tumida</i>	1	0			-
	<i>Favites</i> sp?	1	2	pink	250-300	April
	<i>Favites halicora</i>	1	1	red	250-300	April
Mussidae	<i>Platygyra sinensis</i>	1	0			-
Oculinidae	<i>Lobophyllia hemprichii</i>	1	0			-
Siderastreidae	<i>Galaxea fascicularis</i>	2	0			-
	<i>Coscinarea columna</i>	1	0			-

Table 5. Egg development in *Acropora* spp at various sites (% of individuals sampled with mature eggs - sample sizes ranged from 11 - 22 individuals per site).

Site	Type	Trip 1	Trip 3
COBN	Impact	27	25
CONI	Impact	N/A	42
ANGI	Reference	4	9
NWIT	Reference	31	46

2000) conducted detailed long-term studies of several other species of *Pavona* on reefs near the equator in the Eastern Pacific. There was some variation among the populations, and among individuals within the populations, but these species of *Pavona* spawned gametes and colonies were mostly sequential hermaphrodites, although some were gonochoric. Colonies had gametes year round and they spawned regularly, as often as every two or four weeks within a six to twelve month breeding season. In such cases, eggs and sperm were released alternately over consecutive spawning episodes, and the overlapping oogenic and spermatogenic cycles within colonies of *Pavona* has caused much confusion. However, corals on equatorial reefs tend to have a more protracted breeding period and less synchronous spawning than those on the Great Barrier Reef, or in Western Australia, and potentially a greater number of gametogenic cycles. Thus, the multiple spawning and even the patterns of reproduction documented on equatorial reefs probably do not apply to the Dampier Archipelago.

There was no evidence from *in situ* and microscopic examination of individuals of *Pavona*, *Turbinaria* and *Porites* from the inner Dampier Harbour that these species participated in the mass-spawning in 2004. Similarly, Simpson (1988) found no evidence of colonies of these genera with ripe eggs or larvae on off-shore reefs in the Dampier Archipelago prior to the mass-spawning, but mature eggs have been observed in female *Porites* colonies on off-shore reefs in other years prior to the mass-spawning (unpublished data).

In evaluating this result, it is important to consider that very few colonies were sampled, and that:

- eggs of these species are small and difficult to see *in situ*, and some do not pigment when they become mature, making it difficult to distinguish them from the skeletal and polyp mesenteries,

- most of these species are probably gonochoric, so it is possible that only males were collected, and spermaries are particularly difficult to see even under a microscope unless they are mature,
- there is typically variation in patterns of reproduction for species within these genera, so that some colonies during some years may not spawn, or may spawn at different times to other colonies.

Effects of dredging

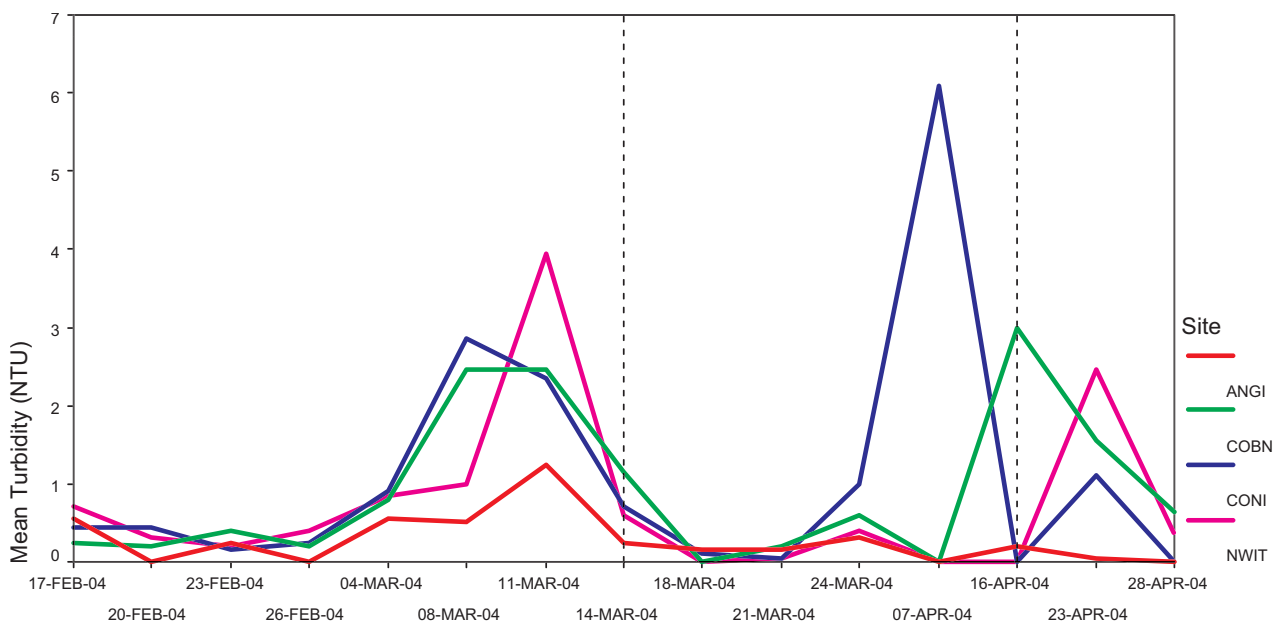
Much of the intended sample design to assess whether dredging operations impacted on coral spawning was negated by the inability to sample corals immediately adjacent to areas being dredged, as water turbidity was too high to allow diving at those sites. Sites which were sampled adjacent to the spoil disposal area, showed elevated turbidity levels prior to spawning (Fig.4) – although of much lesser elevation than around dredging sites where turbidity commonly reached values above 10 NTU (Stoddart & Anstee, this volume).

Qualitative findings from the observations here confirmed that many species did spawn as predicted over both months. Data from the *Acropora* species suggested that inter-site differences in the frequency of spawning corals were larger than observed differences between the Control and Impact sites, confounding our attempt to evaluate the effects of dredging on reproductive output.

Non-spawning indicators of dredging impact

Spawning is an easy part of the reproductive cycle to observe, but reproductive success also requires gametes released to be fertilised, develop into planulae and to settle successfully. Post-spawning processes are much harder to quantify.

Figure 4. Turbidity levels at reproductive study sites - dotted lines represent start of predicted spawning periods.



Several authors have commented on the potential for suspended sediments to adversely impact on fertilisation of coral spawn in the water column and Gilmour (1999) has shown that suspended sediments may significantly decrease fertilisation, larval survival and settlement, – although without inhibiting subsequent development of embryos post-fertilisation. Sediments used in Gilmour's studies were derived from Dampier Harbour dredge spoil – although they were applied to corals from clearer waters at Coral Bay, WA.

Other factors relevant to Dampier may also impact on the survival of coral spawn in the water column. Richmond (1996) shows that freshwater from rainfall or runoff can cause total loss of reproductive popagules when salinity drops below 28g/L. Had the rainfall from Cyclone Monty occurred 3 weeks later, consequences may have been severe and widespread.

Successful settlement of coral planulae can be retarded by sediments both from a layer of fine sediment coating substrates when planulae attempt to attach to the bottom and by the smothering of newly settled corals which are highly susceptible to sedimentation. Many studies have shown that these effects can be significant threats to successful establishment of new corals (Babcock and Davies 1991; Hodgson 1990; Stafford-Smith 1993).

While Hughes et al. (2000) postulate that larval supply of corals is dependent on the abundance and reproductive intensity of adult populations, those populations may be spread over large areas. In the case of near-shore Dampier coral populations, larvae may be derived locally or from corals further off-shore (depending on current movements in the weeks after spawning). Subject to future events within the Harbour, investigation of the density of coral recruits surviving during 2005-2008 could provide the best test of the impacts of dredging and the cyclone on reproduction in 2004.

Suggestions for further research

To provide a better understanding of the reproductive patterns of inshore Dampier corals to aid in future management decisions, research into the following would be most productive:

- Establish the reproductive characteristics and timing the abundant species of *Turbinaria*, *Porites* and *Pavona* decussata at this location;
- Assess the known mass-spawning species for any evidence of spawning during October/November which has been suggested to occur on off-shore reefs of the region;
- Evaluate the degree to which spawning in all species occurs in the months either side of the predicted mass-spawning event.

References

- Babcock, R. C., and Davies, P. 1991. Effects of sedimentation on settlement of *Acropora millepora*. *Coral Reefs* 9:205-208.
- Babcock, R.C., Wills, B.L., and Simpson, C.J. 1994. Mass spawning of corals on a high latitude coral reef. *Coral reefs* 13:161-169.
- Baird, A. H., Sadler, C., and Pitt, M. - 2001. Synchronous spawning of *Acropora* in the Solomon Islands. *Coral Reefs* 19:286.
- DPA 2003. Dampier Bulk Liquids Berth Project (BLBP): Interim Environmental Management Plan. R996, URS for the Dampier Port Authority, Perth WA.
- EPA 2003. Dampier Port Authority - Port Expansion and Dredging Program. Dampier Port Authority, Report and recommendations of the Environmental Protection Authority. Bulletin 1116. Environmental Protection Authority, Perth, Western Australia.
- Fadlallah, Y.H. 1983. Sexual reproduction, development and larval biology in scleractinian corals: A review. *Coral reefs* 2:129-150.
- Fautin, D. G. 2002. Reproduction of Cnidaria. *Can.J.Zool.*, 80:1735 - 1754.
- Gilmour, J. 1999. Experimental investigation into the effects of suspended sediment on fertilization, larval survival and settlement in a scleractinian coral. *Marine Biology*, 135(3):451-462.
- Glynn, P.W., Colley, S.B., Eakin, C.M., Smith, D.B., Cortes, J., Gassman, N.J., Guzman, H.M., Del Rosario, J.B., and Feingold, J. S. 1994. Reef coral reproduction in the eastern Pacific: Costa Rica, Panama, and Galapagos Islands (Ecuador). II. Poritidae. *Marine Biology*, 118:191-208.
- Glynn, P.W., Colley, S.B., Gassman, N.J., Black, K., Cortes, J., and Mate, J.L. 1996. Reef coral reproduction in the eastern Pacific: Costa Rica, Panama, and Galapagos Islands (Ecuador). 3. Agariciidae (*Pavona gigantea* and *Gardineroseris planulata*). *Marine Biology*, 125:579-601.
- Glynn, P. W., S. B. Colley, J. H. Ting, J. L. Maté, and Guzmán, H. M. 2000. Reef coral reproduction in the eastern Pacific: Costa Rica, Panamá and Galápagos Islands (Ecuador). IV. Agariciidae, recruitment and recovery of *Pavona varians* and *Pavona* sp.a. *Marine Biology*, 136:785-805.
- Guest, J. R., Chou, L. M., Baird, A. H., and Go, B. P. L. 2002. Multispecific, synchronous coral spawning in Singapore. *Coral Reefs*, 21:422 - 423.
- Harriott, V.J. 1983. Reproductive ecology of four scleractinian species at Lizard Island, Great Barrier Reef. *Coral reefs* 2:9-18.
- Harrison, P. L., Babcock, R. C., Bull, G. D., Oliver, J. K., Wallace, C. C., and Willis, B. L. 1984. Mass-spawning in tropical reef corals. *Science*, 223:1186 - 1189.
- Harrison, P. L., and Wallace, C. C. 1990. Reproduction, dispersal and recruitment of scleractinian corals. *Coral Reefs*, Z. Dubinsky, ed., Elsevier Science Publishers, Amsterdam, Ch.7: 133 - 207.
- Hodgson, G. 1990. Sediment and the settlement of larvae of the reef coral *Pocillopora damicornis*. *Coral Reefs*, 9:41-43.
- Hughes, T. P., Baird, A. H., Dinsdale, E. A., Moltschanivskyj, N. A., Pratchett, M. S., Tanner, J. E., and Willis, B. L. 2000. Supply-Side Ecology Works Both Ways: The Link Between Benthic Adults, Fecundity, And Larval Recruits. *Ecology*, 81(8):241-2249.

- Kojis, B.L. 1986. Sexual reproduction in *Acropora* (*Isopora*) (Coelenterata: Scleractinia). 2. Latitudinal variation in *A. palifera* from the Great Barrier Reef and Papua New Guinea. *Marine Biology* 91:311-318.
- Kojis, B.L. and Quinn, N.J. 1981. Aspects of sexual reproduction and larval development in the shallow water hermatypic coral, *Goniastrea australensis* (Edwards and Haime, 1857). *Bull. Mar. Sci.* 31: 558-573.
- Marshall, S. M., and Stephenson, T. A. 1933. The breeding of reef animals. Part 1. The corals. *Sci. Rep. Gt. Barrier Reef Exped.* 1928-1929., 3:219 - 245.
- Mendes, J. M., and Woodley, J. D. 2002. Timing of reproduction in *Montastraea annularis*: relationship to environmental variables. *Mar. Ecol. Prog. Ser.*, 227:241-251.
- Mildner, S. 1991. Aspects of the reproductive biology of selected scleractinian corals on Western Samoan and Fijian reefs. Thesis, James Cook University of North Queensland, 118 pp.
- Mscience 2003. Dampier Port Authority Dredging Project: Benthic Coral Community Monitoring - Baseline Data Report. MSA09R1, Unpublished report to Dampier Port Authority by Mscience Pty Ltd, Perth, WA.
- Oliver, J. K., Babcock, R. C., Harrison, P. L., and Willis, B. L. 1988. Geographic extent of mass coral spawning: Clues to ultimate causal factors. Townsville. Proceedings of the 6th International Coral Reef Symposium, Australia. 2:803-810
- Penland, L., Kloulechad, J., Idip, D. and van Woeseik, 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.
- Richmond, R.H. 1996. Reproduction and recruitment in corals: critical links in the persistence of reefs. In: C.E. Birkeland (Ed) *Life and Death of Coral Reefs*, Chapman Hall Publishers, N.Y. pp 175-197.
- Richmond, R.H. and Hunter, C.L. 1990. Reproduction and recruitment of corals: Comparisons among the Caribbean, the Tropical Pacific, and the Red Sea. *Marine Ecology Progress Series*, 60:185-203.
- Robertson, J. 1981. Intra- and Interspecific interactions of two species of *Montipora*. Thesis, James Cook University of North Queensland, 80 pp.
- Shlesinger, Y., and Loya, Y. 1985. Coral community reproductive patterns: Red Sea versus the Great Barrier Reef. *Science*, 228:1333-1335.
- Simpson, C. 1985. Mass-spawning of scleractinian corals in the Dampier Archipelago and the implications for management of coral reefs in Western Australia., Dept of Conservation & Environment, Bull. 244., Perth, WA.
- Simpson, C. J. 1988. Ecology of scleractinian corals in the Dampier Archipelago, Western Australia. *Technical Series 23*, Environmental Protection Authority, Tech.Series No.23, Perth, Western Australia.
- Stafford-Smith, M. G. 1993. Sediment rejection efficiency of 22 species of Australian scleractinian corals. *Marine Biology*, 115:229-243.
- Stobart, B., Babcock, R. C., and Willis, B. L. 1992. Biannual Spawning of Three Species of Scleractinian Coral from the Great Barrier Reef. *Proceedings of the Seventh International Coral Reef Symposium* 1: 494-499
- Szmant-Froelich, A.M., Yevich, P. and Pilson, M.E.Q. 1980. Gametogenesis and early development of the temperate coral *Astrangia danae* (Anthozoa: Sceractinia). *Biol. Bull.* 158: 257-269
- Tanner, J.E. 1996. Seasonality and lunar periodicity in the reproduction of Pocilloporid corals. *Coral Reefs*, 15:59-66.
- Willis, B.L. 1987 Morphological variation in the reef corals *Turbinaria mesenterina* and *Pavona cactus*: Synthesis of transplant, histocompatibility, electrophoresis, growth, and reproduction studies. Thesis, James Cook University of North Queensland, 202 pp.
- Willis, B. L., Babcock, R. C., Harrison, P. L., and Oliver, J. K. 1985. Patterns in the mass-spawning of corals on the Great Barrier Reef from 1981 to 1984.," *Proceedings of the 5th International Coral Reef Congress*, Tahiti, French Polynesia, 343-348.
- Willis, B. L., Babcock, R. C., Harrison, P. L., and Wallace, C. C. 1997. Experimental hybridization and breeding incompatibilities within the mating systems of mass-spawning reef corals. *Coral Reefs*, 16(5).