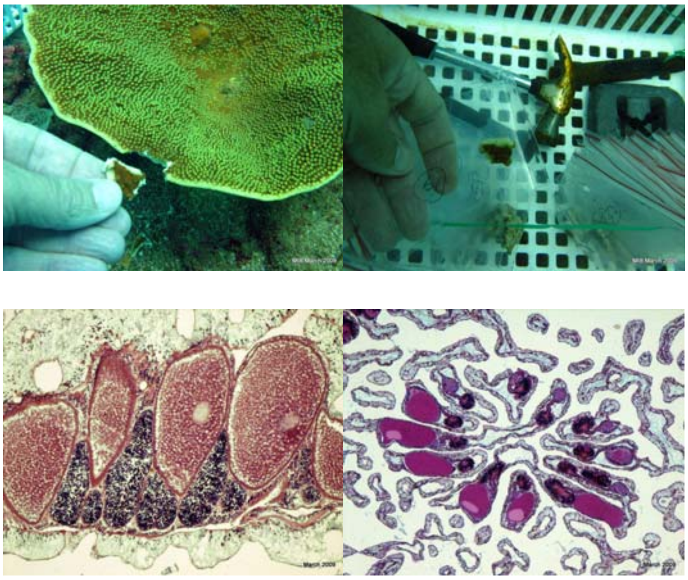
Proposed Outer Harbour Development
Port Hedland



CORAL SPAWNING SPRING SURVEYS 2009

Revision B

WV03716-MV-RP-0041

04 June 2010

Proposed Outer Harbour Development Port Hedland

CORAL SPAWNING SPRING SURVEYS 2009

Revision B

WV03716-MV-RP-0041

04 June 2010

Sinclair Knight Merz
11th Floor, Durack Centre
263 Adelaide Terrace
PO Box H615
Perth WA 6001 Australia

Tel: +61 8 9469 4400
Fax: +61 8 9469 4488
Web: www.skmconsulting.com

Limitation Statement

The sole purpose of this report and the associated services performed by Sinclair Knight Merz (SKM) is to provide details of the methods and results of coral spawning status surveys undertaken in spring 2010, in accordance with the scope of services set out in the contract between SKM and FAST JV (‘the Client’). That scope of services was defined by the request of the Client.

SKM derived the data in this report primarily from the coral spawning assessments carried out during the autumn spawning (April and May 2009) and spring spawning surveys (October, November and December 2009). The passage of time, manifestation of latent conditions or impacts of future events may require further exploration of the study area and subsequent data analysis, and re-evaluation of the findings, observations and conclusions expressed in this report.

In preparing this report, SKM has relied upon and presumed accurate, certain information (or absence thereof) relative to the proposed Outer Harbour Development, as provided by the Client. Except as otherwise stated in the report, SKM has not attempted to verify the accuracy or completeness of any such information.

The findings, observations and conclusions expressed by SKM in this report are not, and should not be considered, an opinion concerning the quality of the coral spawning assessment programme. No warranty or guarantee, whether expressed or implied, is made with respect to the data reported or to the findings, observations and conclusions expressed in this report. Further, such data, findings, observations and conclusions are based solely upon information supplied by the Client, and information available in the public domain in existence at the time of the investigation.

This report has been prepared on behalf of the Client, and is subject to and issued in connection with the provisions of the agreement between SKM and the Client. SKM accepts no liability or responsibility whatsoever for or in respect of any use of or reliance upon this report by any third party.

SKM

Contents

Figures

Tables

List of Acronyms

Acronym	Full title
AIMS	Australian Institute of Marine Science
BPP	Benthic Primary Producer
BPPH	Benthic Primary Producer Habitat
COR	Cornelisse Shoal
COX	Coxon Shoal
CTH	Cape Thouin
EPA	Environmental Protection Authority
LTI	Little Turtle Island
MIB	Minilya Bank
SKM	Sinclair Knight Merz
TSS	Total Suspended Solids
WIS	Weerdee Reef

Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
Revision A	24/03/10 29/03/10	M. Westera R. Burgess	R. Burgess	24/03/10 29/03/10	Technical Editorial
Revision B	27/05/10	S. Neale	R. Burgess	04/06/10	Final draft for client review

Distribution of copies

Revision	Copy no	Quantity	Issued to
Revision A	1	1	S. Mavrick (BHP Billiton Iron Ore) B. Jenkins (FAST JV)
Revision B	1	1	S. Mavrick (BHP Billiton Iron Ore) B. Jenkins (FAST JV)

Printed:	4 June 2010
Last saved:	4 June 2010 08:02 AM
File name:	I:\WVES\Projects\WV03716\Technical\440 Coral Spawning\Draft\Spring\M40 Spring Coral Spawning RevB.doc
Author:	Steve Neale
Project manager:	Fiona Rabone
Name of organisation:	BHP Billiton Iron Ore
Name of project:	Proposed Outer Harbour Development, Port Hedland
Name of document:	Coral Spawning Spring Surveys 2010
Document version:	Revision B
Project number:	WV03759.440

1. Project Definition

BHP Billiton Iron Ore proposes to expand their iron ore operations in the Pilbara by developing a new port. This proposed development is known as the Port Hedland Outer Harbour Development (Outer Harbour Development). The proposed Outer Harbour Development is located on the coast near Port Hedland in the Pilbara region of Western Australia.

The proposed Outer Harbour Development will involve the construction of infrastructure (jetty and wharves) and dredging, to allow ship access for loading of iron ore.

1.1. Background

In the vicinity of the proposed development are areas of benthic primary producer habitat (BPPH), which are defined by Environmental Protection Authority (EPA) Guidance Statement No. 3 (EPA 2009) as areas supporting or capable of supporting benthic primary producers (BPP). Construction, dredging and dredge spoil disposal activities have the potential to lead to direct loss of BPPH, both through removal and indirect loss through sedimentation and reduction in light availability due to turbid plumes.

The environmental approval process requires an assessment of the potential impacts from dredging on BPPH. Based on the zone of impact, estimated by preliminary numerical modelling of the sediment plume in March 2008, six BPPH sites were selected for deployment of water quality loggers and coral monitoring (**Figure 1.1** and **Table 1.1**). These sites are monitored on a monthly basis, to collect baseline data prior to dredging activities in order to document and distinguish natural variability from potential dredging impacts.

The data collected on extent and timing of coral spawning will provide assistance in predicting impacts of dredging and satisfy potential Ministerial requirements for the regulatory approval process. Furthermore, undertaking such monitoring during the pre-dredging phase will enable improved predictions of the timing, extent and duration of coral spawning in the study area.

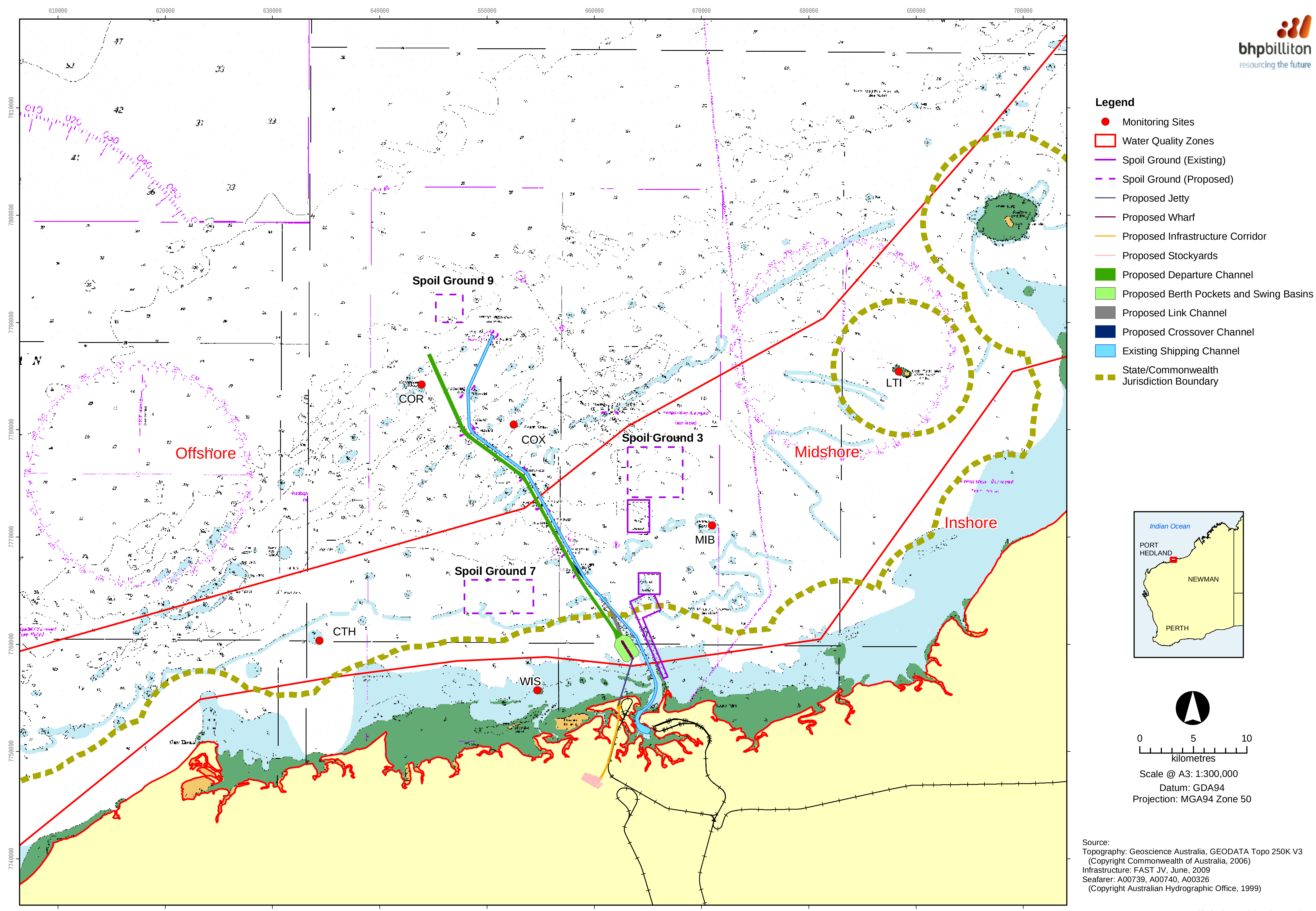


Figure 1.1 Water Quality and Coral Health Baseline Monitoring Sites and Environments

440\g310_WV03716_Rev2

- **Table 1.1 Coral monitoring sites offshore from Port Hedland**

Site Name	Code	Environment	Approx. distance from the mainland (km)	Approx. mid tidal water depth (m)	Latitude	Longitude
Weerdee Reef	WIS	Inshore	3	5	20° 17.414' S	118° 28.893' E
Cape Thouin	CTH	Midshore	10	6	20° 14.995' S	118° 17.194' E
Minilya Bank	MIB	Midshore	16	9	20° 09.002' S	118° 38.157' E
Little Turtle Island	LTI	Midshore	19	7	20° 01.081' S	118° 47.991' E
Cornelisse Shoal	COR	Offshore	33	12	20° 02.040' S	118° 22.560' E
Coxon Shoal	COX	Offshore	28	12	20° 03.998' S	118° 27.485' E

1.2. Scope of Works

1.2.1. Purpose

The purpose of this spring coral spawning study report (as outlined in the Scope of Works - WV03716-MV-PR-0008) is to provide:

- background information relating to coral spawning in the Pilbara
- methods of the investigation
- analysis of results
- discussion on any items of significance, implications to the project
- comparisons with the autumn spawning results
- conclusions.

This report supplements the Autumn Coral Spawning Report (SKM 2009a).

1.2.2. Methods

The methods used in this document include the following steps:

- the sites chosen for coral spawning assessments are identical to the six monitoring sites chosen to assess the coral health and mortality during the baseline period.
- identification of the dominant and sub-dominant coral species at the six monitoring sites
- sampling of at least 20 corals for each dominant and 10 for each sub-dominant species at each monitoring site; and examining the corals either visually or using histology
- in the event of a predicted mass spawning, further assessment after the full moon to determine whether the event is complete.

2. Introduction

Synchronous spawning or 'mass spawning' of coral colonies was first reported on the Great Barrier Reef (Babcock *et al.* 1986). 'Mass spawning' in corals is the ejection of reproductive propagules (larvae, eggs or sperm) by a large number of coral species on consecutive nights during one period of the year. Studies of coral spawning on inshore regions of north western coastline of Western Australia identified the main 'mass spawning' period to occur six to eight days after the full moon in the autumn months of March and April (Simpson 1985, Stoddart & Gilmour 2005; Baird *et al.* in prep). Recent research suggests that additional spawning for *Acropora* spp. may occur on reefs in Northern Western Australia during spring (Rosser & Gilmour 2008).

Extensive surveys of the benthic habitat offshore of Port Hedland were undertaken between December 2007 and May 2008 (SKM 2009b). These surveys indicated that the benthic habitat offshore from Port Hedland is characterised by extensive plains of sand/silt/rubble substratum and ridge lines of hard pavement often covered in a layer of sand/silt. Offshore ridge lines support occasional patches of sparse biota, including hard corals, macroalgae, sponges and soft corals. Hard corals, in particular corals from the *Turbinaria* genera, represented the most dominant BPP growing along these ridgelines.

The precedent set by Ministerial conditions for previous dredging campaigns in the region to assess the capabilities and timing of a coral community's likelihood of spawning. This firstly requires the identification of representative monitoring sites followed by an initial survey of the coral population at these sites to quantify the dominant and sub-dominant coral species composition. There may not be one clear dominant species common to all monitoring sites, so a range of different dominant and sub-dominant coral species may need to be chosen at each of the sites to reflect this variation. The dominant species at each site is described as that species which represents or occupies at least 20% of the coral biomass at that site. The sub-dominant species is the next most abundant species after the dominant species.

Assessing a coral colonies spawning status can be carried out in three ways:

1) *In situ* observations of the evidence of gametes in a coral colony by 'snapping' off a small part of the coral and examining the broken section of the piece for eggs as follows:
   - if there are no eggs the colony is deemed to have spawned recently or will not spawn in the next three or more months
   - if there are white small eggs then the coral is likely to spawn in the next three months, or
   - if there are large pink eggs then the coral is likely to spawn in the following full moon.

   This method is particularly useful for coral species where the size of the eggs is sufficient to be clearly visible to the naked eye, and there is scope for the diver to 'snap' off a piece of the coral. It is primarily used in assessments of *Acropora* spp.

2) The second method is particularly appropriate for coral species with smaller eggs (such as *Porites* spp. and some *Turbinaria* spp.), which at any stage of development are often not visible to the naked eye. It involves collection of a small sample from the target coral and examination under a microscope to determine whether there are eggs present and whether the size and/or colour of the eggs indicates an imminent spawning event.
3) The third method requires the collection of a small piece of the coral for subsequent processing at a laboratory for more detailed histological analysis under a high powered microscope. This process determines the exact stage of egg and sperm development to pinpoint more accurately the timing of spawning. The eggs are stained in this process to allow for identification. Staining removes the ability to access the time of spawning based on natural coloration; however the size of the eggs and the development stage identified can be used as an accurate indicator of timing of spawning.

For autumn and spring spawning periods, method three was chosen to accurately predict the timing of spawning of the dominant and sub-dominant coral species during 2009 at the six monitoring sites offshore from Port Hedland.

Results from these surveys will be used to inform decisions about the scope and scale of future spawning assessments during dredging activities for the proposed Outer Harbour Development.

The focus of the impact of the dredging and spoil disposal activities on coral spawning should centre on the key question: 'Will the potential loss of gametes due to elevated total suspended solids (TSS) levels in the predicted zone of impact during the coral spawning adversely affect the ecology of the entire ecosystem offshore from Port Hedland?'.

3. Methods

3.1. Dominant Coral Genus and Species

The dominant and sub-dominant coral genera at each site were identified using a survey technique developed by the Australian Institute of Marine Science (AIMS) (Abdo *et al.* 2004). This involved taking 100 underwater photographs of the sea floor at random intervals across the entire coral monitoring site. Each photograph was taken 35 cm above the substrate. Photographs were then analysed using (AVTAS – AIMS Video Transect Analysis System) software (Bainbridge 1995), which superimposes five points onto each photograph in a fixed pattern. The coral genera that occurred under each point were entered into a database and the absolute percentage cover and proportional percentage cover of various coral genera at each site was then recorded. Once the dominant and sub-dominant genera were recorded, a representative species from each category was selected for coral spawning assessments.

3.2. Collection and Processing of Coral Samples

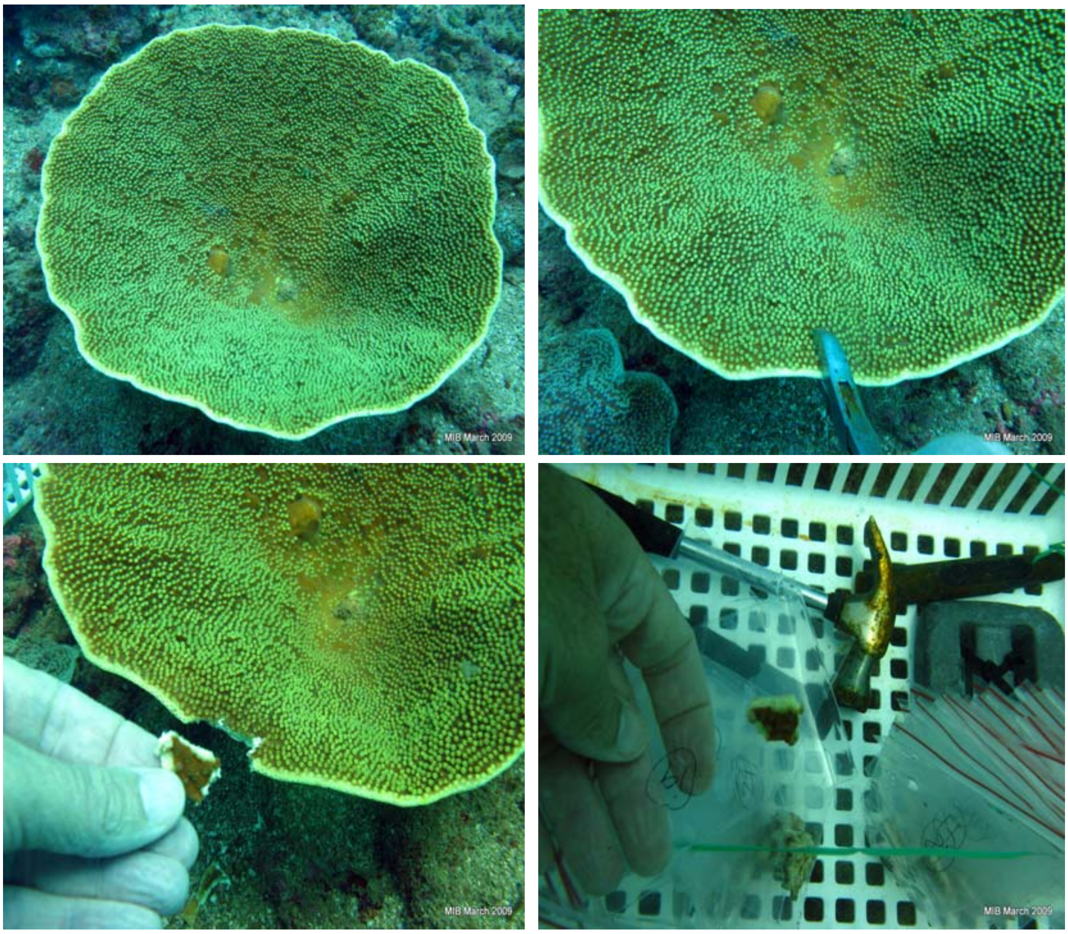
Sampling periods were planned around the full moon in the spring months of September/October, November and November/December 2009 which coincide with the predicted spring spawning events (**Table 3.1**). From each of the six monitoring sites, 20 samples from the dominant coral species and 10 samples of the sub-dominant coral species were randomly collected from coral colonies each site. Only colonies deemed to be sexually mature (>20 cm diameter) were sampled.

- **Table 3.1 Spawning, full moon and the sampling dates in spring 2009**

Full Moon 2009	Spawning window 2009	Survey dates 2009
4 October	10–14 October	29 September–3 October
3 November	9–13 November	26–30 October
2 December	8–12 December	25–29 November

Small pieces (3 cm x 3 cm) of the target coral species (dominant and sub-dominant) at each site were cut from the edge of the coral colony (**Figure 3.1**). The extreme outer edge of the excised piece was removed because the coral polyps in this area contain a substantial percentage of new growth which is unlikely to contain gonads at this stage (Wallace 1985). The sample was placed into a sample bag for subsequent histological processing and analysis as follows.

The samples from each site were fixed in 10% neutral formalin for at least 24 hours prior to decalcification in 10% formic acid. The tissue was processed through graded ethanol, chloroform and paraffin wax and each sample was bisected and embedded in both transverse and vertical orientation in the same wax block. The blocks were sectioned at 6 µm thickness and mounted on slides. Slides were stained using Mayer's haematoxylin and counterstained with Youngs eosin-erythrosine. The stages of gonad maturity in each histological section were classified using criteria cited in Baird *et al.* (in prep) and summarised in **Table 3.2**.



- **Figure 3.1 Collecting a coral sample from a colony of *Turbinaria mesenterina (March 2009)***

- **Table 3.2 Gamete identification characteristics of the four stages of oogenesis, approximate egg size and spermatogenesis in *Turbinaria***

Stage	***Turbinaria* female gametes**	**Egg Size (µm)**	***Turbinaria* male gametes**
I	Enlarged interstitial cells in the mesoglea of mesenteries nucleus make up the bulk of the oocyte. Oocytes well spaced and surrounded by cytoplasm mesoglea.	0–60	Small clusters of interstitial cells near or entering the mesoglea. Stain deep blue.
II	Accumulation of blue staining yolk around nuclei which remains in the centre of the oocyte. Still lots of cytoplasm surrounding oocytes.	60–100	Clusters of spermatocytes with distinct spermary boundary; large nuclei. Nuclei arranged peripherally.
III	Finely granular yolk staining pink. Nucleus migrates to periphery of nucleus. Still some cytoplasm between oocytes.	100–300	Spermatocytes are smaller with smaller nuclei and the number of cells within spermary is larger. Conspicuous peripheral arrangement of spermatocytes.
IV	Oocytes stain dark pink; oocytes crowded, nucleus at periphery. Clear lipid globules obvious under high power.	>300	Spermatozoa with tails.

Source: Baird et al. (in Prep.)

SKM

4. Results

4.1. Dominant Coral Genus and Species

The dominant coral genus and representative species sampled for coral spawning assessments are summarised in **Table 4.1**. Over 50% of all corals growing at five of the six monitoring sites were corals from the hard coral genus *Turbinaria* (**Figure 4.1**). The most dominant species within this genus was *Turbinaria mesenterina* and 20 samples in total were taken from this species for histological processing and analyses from the five sites. At the Cornelisse Shoal monitoring site the cover of hard corals was sparse (<15%, refer to **Figure 4.2**) and the dominant genus was *Acropora* from a range of species (**Figure 4.3b** and **Figure 4.3c),** with no one species dominating. As was done for the Autumn survey undertaken in March 2009, twenty samples from this genus were taken for histological processing and analysis.

- **Table 4.1 Dominant coral genus and representative species used for coral spawning assessments**

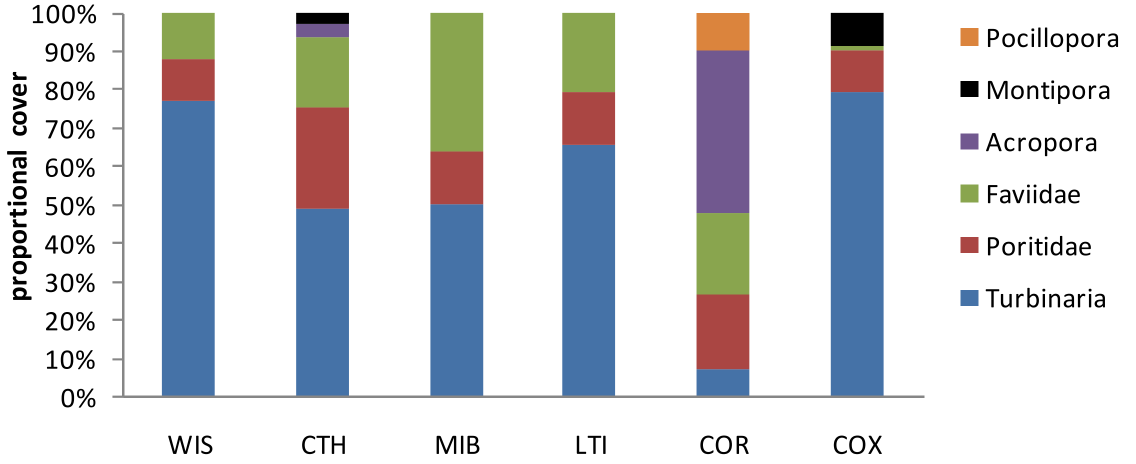
Site	**Dominant Genus**	**Species used**
Weerdee Reef	*Turbinaria*	*Turbinaria mesenterina*
Cape Thouin	*Turbinaria*	*Turbinaria mesenterina*
Minilya Bank	*Turbinaria*	*Turbinaria mesenterina*
Little Turtle Island	*Turbinaria*	*Turbinaria mesenterina*
Cornelisse Shoal	*Acropora*	A range of *Acropora spp.*
Coxon Shoal	*Turbinaria*	*Turbinaria mesenterina*

The sub-dominant genera at five of the six monitoring sites were corals from the Faviidae family and in particular the species *Favites pentagona* (**Figure 4.3a**). Ten samples of this species were collected for further analysis of their spawning status from each of the five sites. At the Coxon Shoal monitoring site, the sub-dominant coral was *Montipora undata* (**Figure 4.3c**) and ten samples from these colonies were sampled for analysis (as was completed for the spring spawning survey in March 2009).

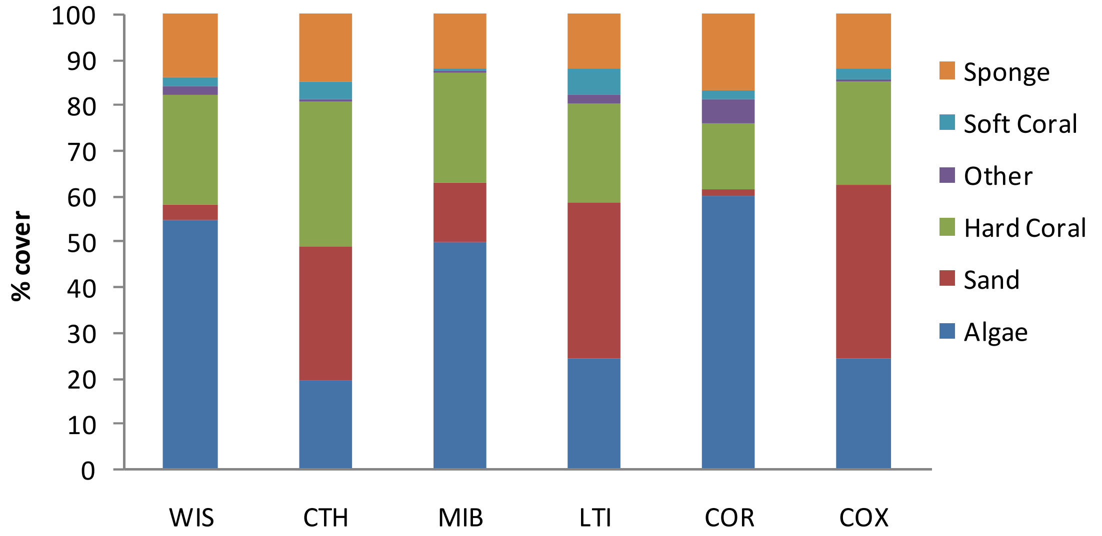
A total of 120 samples of the dominant species and 60 samples of the sub-dominant species were collected from the six monitoring sites during each spawning assessment survey.

Corals from the Poritidae family were not chosen as a candidate for spawning assessment for the following reasons:

- there were several genera represented from Poritidae including Goniopora and Porites
- the absolute and relative cover of these two genera indicated no dominance by either genus
- within each of these genera there was no one dominant species represented.

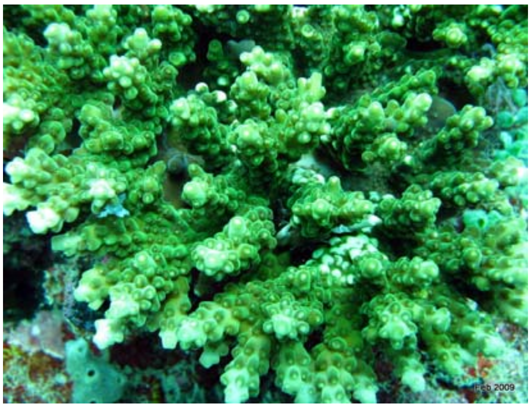


- **Figure 4.1 The proportional percentage cover of the dominant coral taxa at the six monitoring sites**



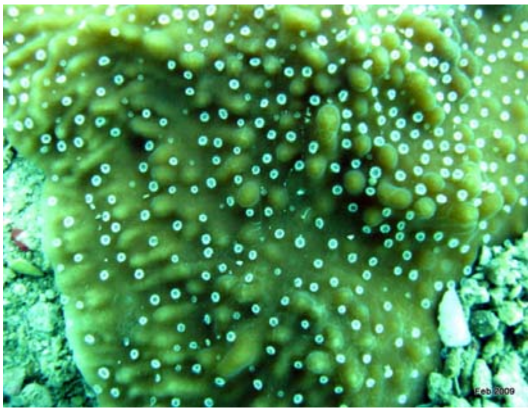
- **Figure 4.2 The absolute percentage cover of the dominant coral taxa at the six monitoring sites**

(a) *Favites pentagona*



(b) *Acropora* sp. 1

(c) *Acropora* sp. 2



(d) *Montipora undata*

Source: SKM 2009a

- **Figure 4.3 Photographs of the coral genera and species targeted for coral spawning assessments at the six monitoring sites other than *Turbinaria***

4.2. Assessing the Reproductive Stages of Coral Colonies

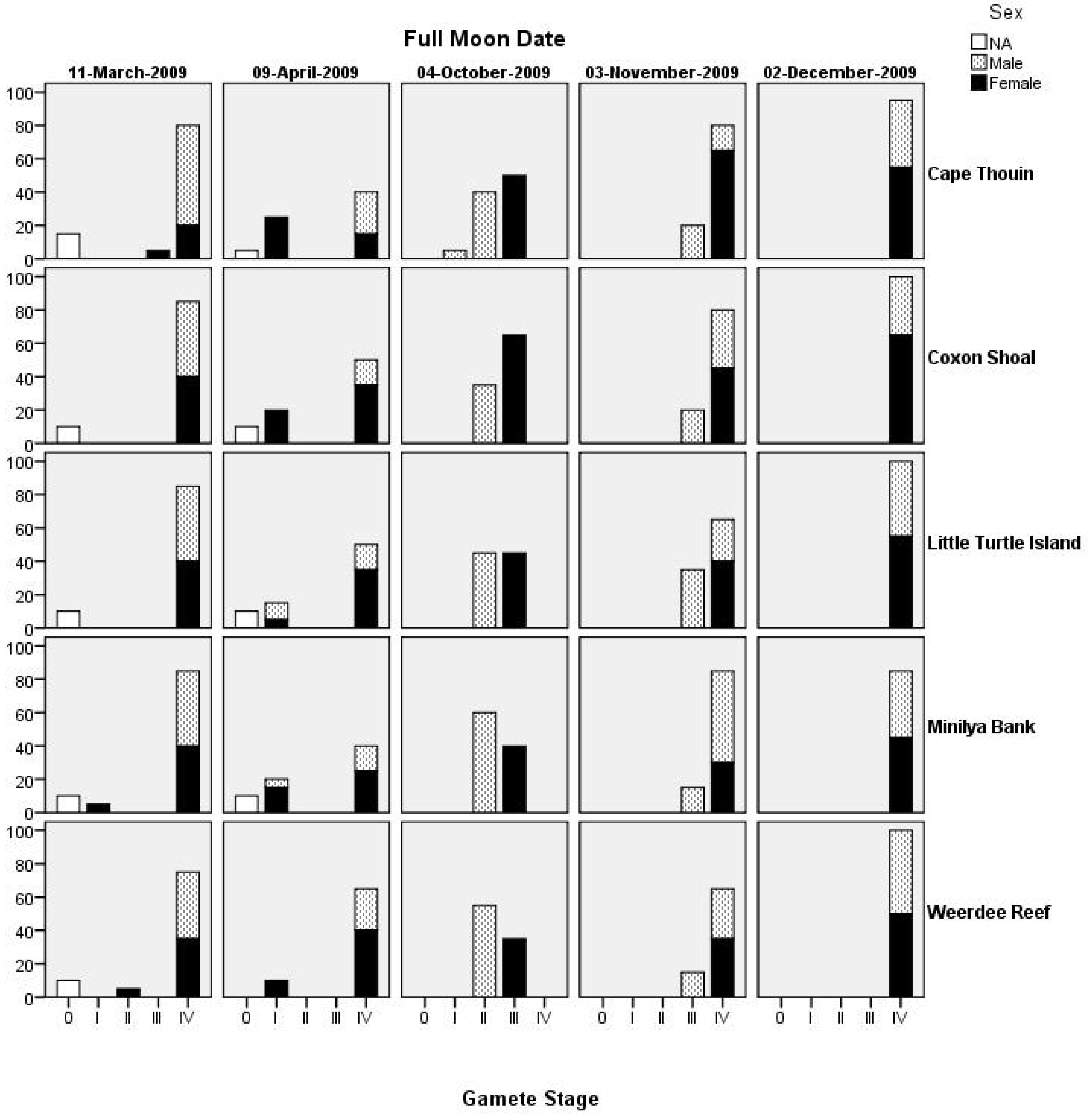
The reproductive stage of each coral colony sample from *Turbinaria mesenterina, Favites pentagona, Montipora undata* and *Acropora* were assessed based on criteria outlined in Baird *et al.* (in prep). Stage I and II represents the beginning of the process of gametogenesis, and oocytes (eggs) or spermatocytes (sperm) at this stage are very small, usually in the range of 0–100 µm. Stage III and IV represent the final two stages of gamete development and both oocytes and spermatocytes are well developed and generally range in size from 100–300 µm and are visible under a low powered microscope. The data for autumn and spring spawning surveys are presented graphically for the dominant and sub-dominant species at each site. Only specific details on the spring spawning (October/November/December) are discussed here; specific details on the autumn spawning are outlined in SKM (2009a).

Figure 4.4 shows a summary of the recorded stages of gamete development for *Turbinaria mesenterina*. Many *Turbinaria mesenterina* samples had combinations of reproductive stages present. If two stages of gamete development in a single colony were observed; only the highest stage of development is presented on the graphs in **Figure 4.4**.

During the October 2009 surveys, the most dominant reproductive stages observed in *Turbinaria mesenterina* were stage II male and stage III female gametes (**Figure 4.4**). At Cape Thouin there were two colonies that contained stage I male gametes.

In the November surveys, the presence of stage IV in both male and female gametes in the *Turbinaria mesenterina* samples indicate a potential for those colonies to spawn in the following spawning window. In the late November surveys, 100% of all samples contained stage IV male and female gametes indicating that all colonies were likely to spawn to some degree in the following spawning window in early December.

The number of colonies that contain any stage IV eggs or stage IV sperm, which may potentially indicate a spawning occurring on the following full moon in both autumn (March and April) and spring (October/November/December) are presented in **Table 4.2**.



- **Figure 4.4 The percentage of *Turbinaria mesenterina* colonies (n = 20 per site) collected during the five sampling periods (full moon dates shown above the graphs) at each monitoring site showing each stage (and combinations) of gamete development NA = no gametes found.**

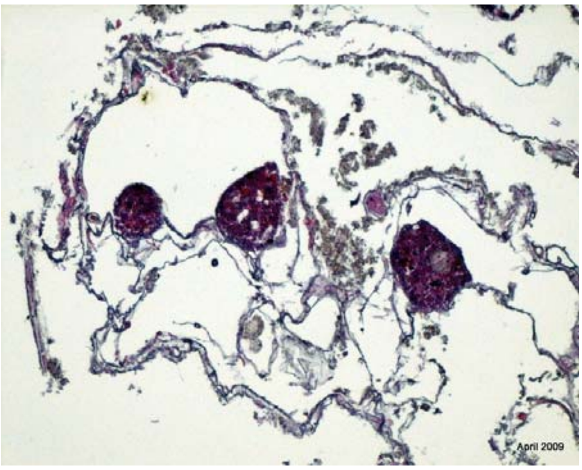
- **Table 4.2 The number and percentage of *Turbinaria* and *Acropora* colonies potentially spawning after the March/April (autumn) full moons and the October/November/December (spring) full moons**

Site	Dominant Genus	Species used	Number of Colonies with Stage IV gametes				
			March	April	October	November	December
Weerdee Reef	*Turbinaria*	*Turbinaria mesenterina*	17 (85%)	18 (90%)	0 (0%)	14 (70%)	20 (100%)
Cape Thouin	*Turbinaria*	*Turbinaria mesenterina*	16 (80%)	14 (70%)	0 (0%)	16 (80%)	20 (100%)
Minilya Bank	*Turbinaria*	*Turbinaria mesenterina*	17 (85%)	14 (70%)	0 (0%)	17 (85%)	19 (95%)
Little Turtle Island	*Turbinaria*	*Turbinaria mesenterina*	18 (90%)	15 (75%)	0 (0%)	13 (65%)	20 (100%)
Cornelisse Shoal	*Acropora*	A range of *Acropora spp.*	0 (0%)	0 (0%)	0 (0%)	18 (90%)	1 (5%)
Coxon Shoal	*Turbinaria*	*Turbinaria mesenterina*	18 (90%)	14 (70%)	0 (0%)	16 (80%)	20 (100%)

4.2.1. *Favites pentagona* Spawning Patterns

Corals from the Faviidae family are primarily mass spawning hermaphrodites which mean each individual colony contains both male and female gametes (**Figure 4.5**). Ten samples were collected from each of the five monitoring sites where *Favites pentagona* was recorded, except during the December surveys where no samples were collected from Weerdee Island and Little Turtle Island due to weather constraints. Results of analysis of *Favites pentagona* show a complete lack of individuals with stage IV gametes present during the spring surveys. Some individuals during November contained stage III gametes, however no stage III or IV gametes were found in the subsequent surveys (**Figure 4.6**). This leads to two possibilities, the corals did spawn during November or the sample size was insufficient to adequately detect broad scale patterns of spawning for this species.

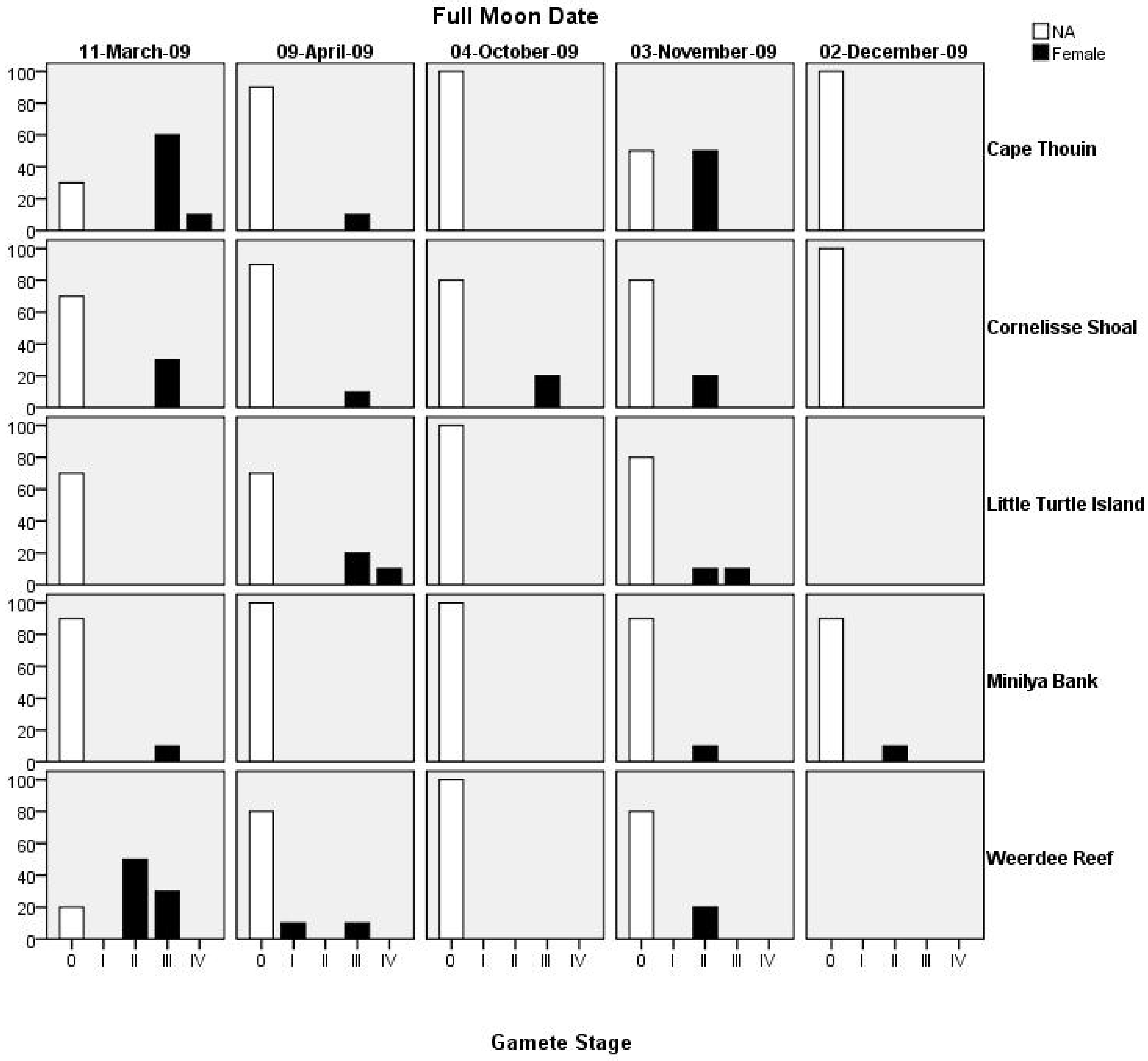
Pooling the results from all sites to examine the broad patterns of spawning for this sub-dominant species indicated that most of the spawning occurred during the autumn period (**Figure 4.7**). However, over 25% of colonies sampled did not contain any evidence of gametes in the March 2009 (autumn) surveys suggesting that some colonies of this species may spawn during periods outside of autumn.



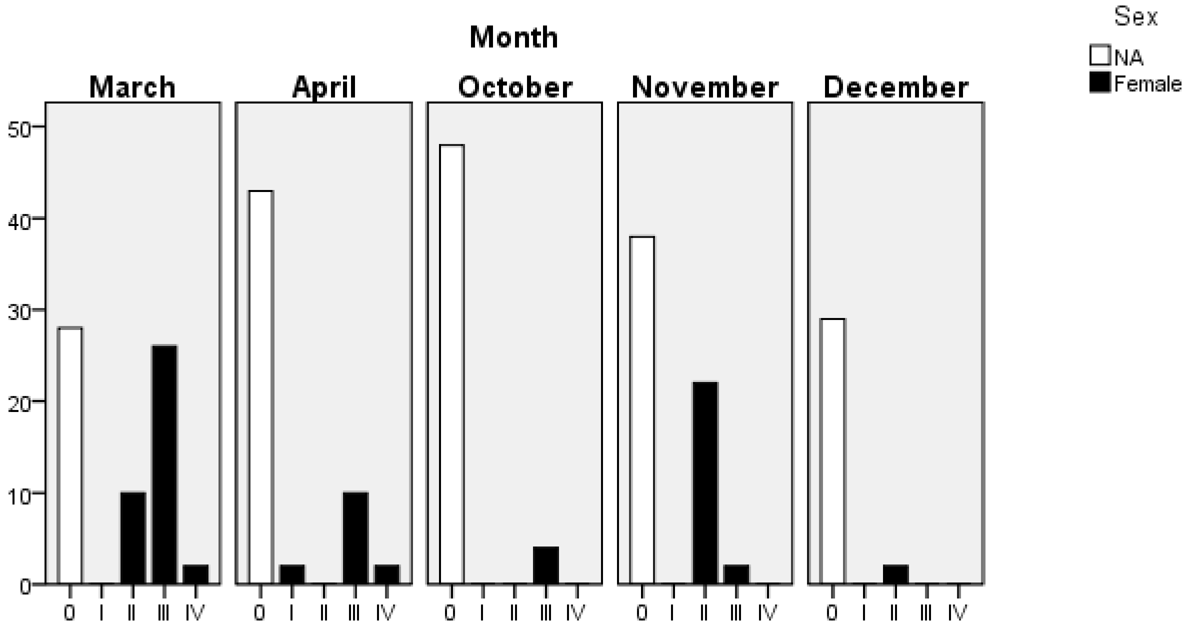
(a) Stage I oocytes

(b) Stage III oocytes (pink) and stage III spermatocytes (black)

- **Figure 4.5 Micrograph of histological sections of *Favites pentagona* collected from sites during March and April 2009**



- **Figure 4.6 The percentage of *Favites pentagona* colonies (n=10 per site) collected during the five sampling periods (full moon date shown above the graphs) showing each stage of gamete development. NA = no gametes found.**



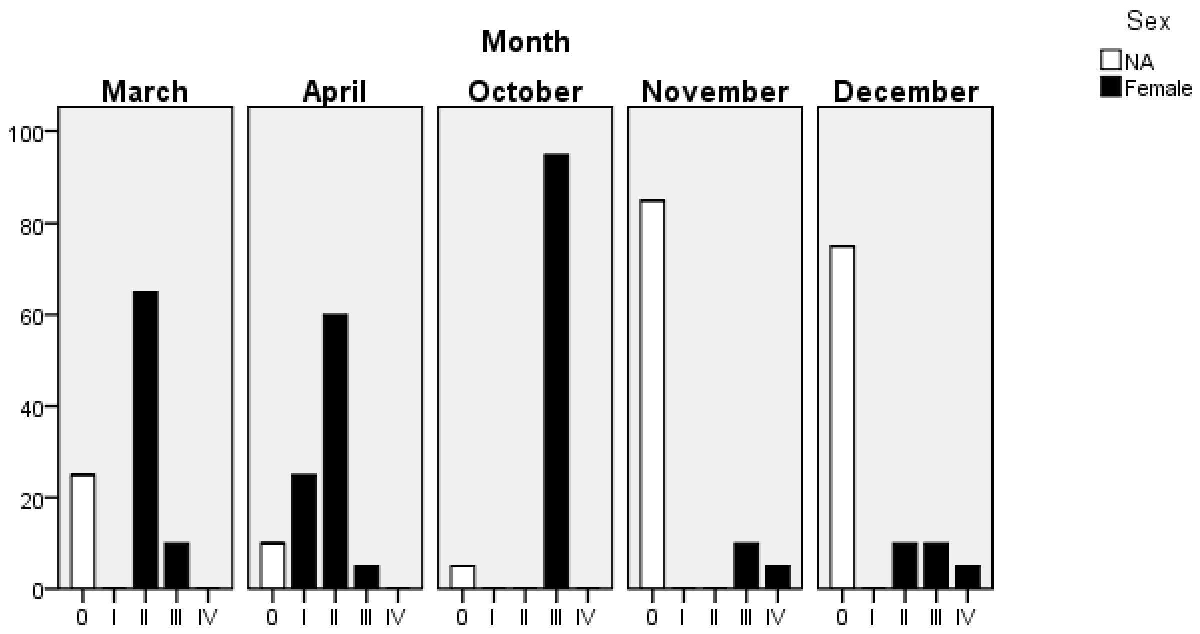
- **Figure 4.7 The mean percentage of *Favites pentagona* colonies collected during the five sampling periods (all sites pooled) showing each stage of gamete development**

4.2.2. Acropora and Montipora Spawning

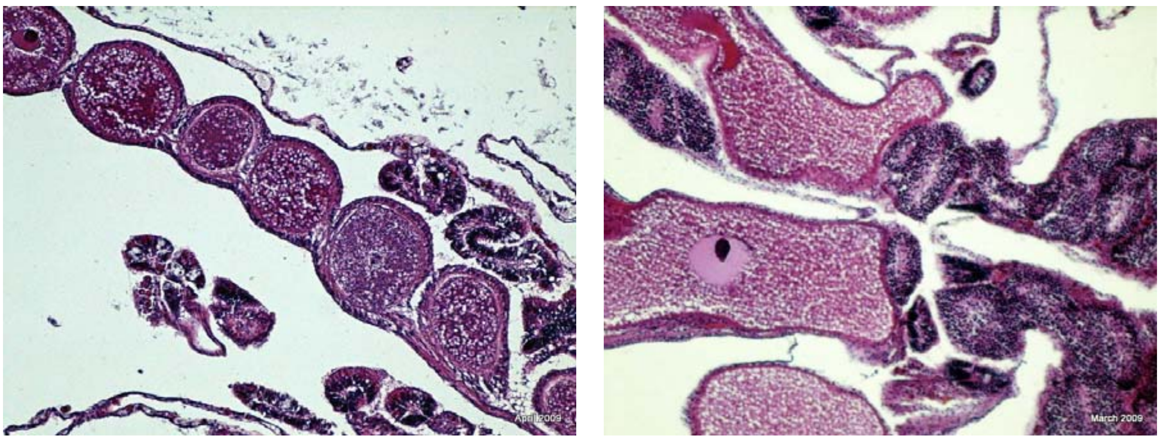
Coral colonies from the genus *Acropora* participate in mass spawning and individuals may contain both male and female gametes. During the September surveys, >90% of sampled colonies contained stage III eggs (**Figure 4.8**). In the subsequent survey in late October, >80% of colonies contained no eggs suggesting the primary spawning for *Acropora* occurred during the early October full moon. The presence of stage III and IV eggs in subsequent surveys suggest additional spawning occurred after the November and December full moons.

Coral colonies from the genus *Montipora* participate in mass spawning and individuals may contain male and female gametes. Only at the Coxon Shoal monitoring site were encrusting *Montipora* found in abundance. In November and December up to 50% of the colonies sampled (**Figure 4.10**) contained stage III gametes indicating spawning was likely to occur after the December full moon.

SKM



- **Figure 4.8 The percentage of *Acropora* colonies (n=20) collected during the five sampling periods showing each stage (and combinations) of gamete development**

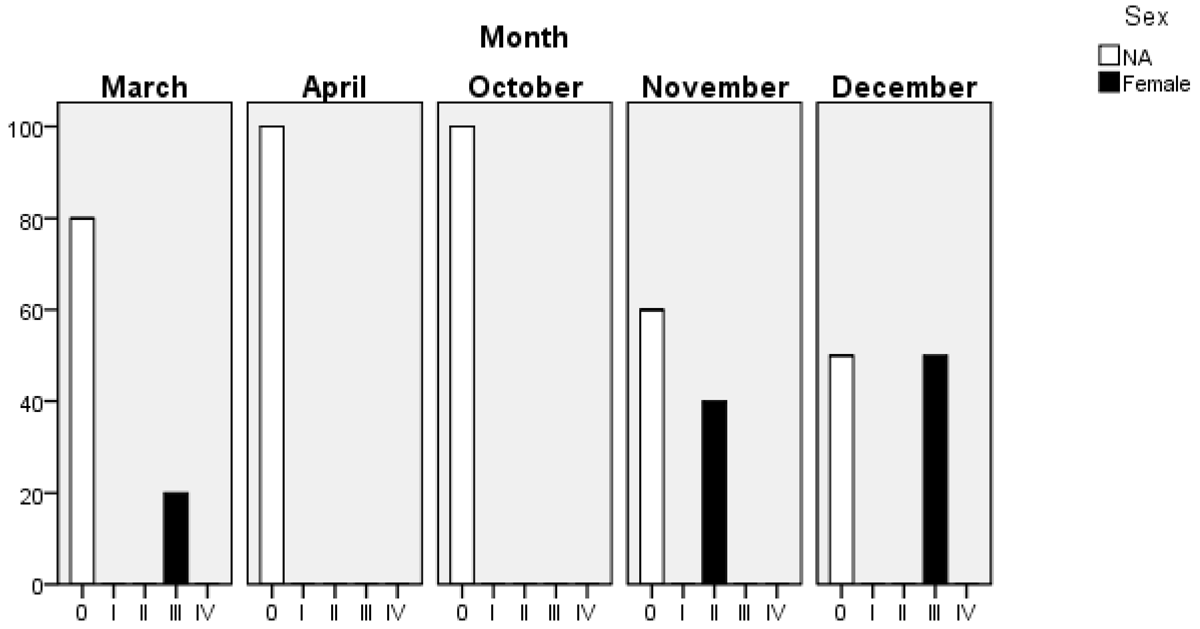


(a) stage I and II oocytes

(b) stage III oocytes (pink left) and stage III spermatocytes (dark right)

Source: SKM 2009a

- **Figure 4.9 Micrographs of histological sections of *Acropora* samples**



- **Figure 4.10 The percentage of *Montipora* colonies (n=10) collected during the five sampling periods showing each stage (and combinations) of gamete development**

5. Discussion

The results of surveys to determine the dominant and sub-dominant coral species occurring at the six monitoring sites indicated the most dominant corals at five of the six sites were from the genus *Turbinaria* and the sub-dominant species at five of the six sites was from the genus *Favites*. Branching *Acropora* and encrusting *Montipora* spp. corals were found in small numbers only at the offshore ridgelines in deeper water (>12 m) at Cornelisse and Coxon Shoals respectively. Only one or two colonies of each of these two genera were found growing at the other four monitoring sites located in shallower coastal waters.

5.1. Comparison between Autumn and Spring Spawning Events

Turbinaria

The results of the autumn spawning surveys indicated no real period that could be defined as a 'mass spawning' of *Turbinaria* colonies. There is evidence of mature eggs and sperm being produced before and after the March and April 2009 full moons with a potential for the stage IV gametes to be held until the following full moon in May 2009. This genus is predicted to have a 13 to 14 month reproductive cycle (Willis 1987) on the Great Barrier Reef. Based on the appearance of early stage I eggs and sperm during the April 2009 surveys, this may indicate maturity and spawning could occur again in the following March, April or May 2010. Alternatively the appearance of stage I eggs and sperm may indicate spawning will occur before the following autumn. Studies of the timing of spawning in *Turbinaria* in the Pilbara also concluded that corals from this genera are not typical 'mass spawners' and have multiple spawning events from November to April (Baird *et al.* in prep).

The results from the spring spawning surveys found 100% of all *Turbinaria* colonies sampled in late November contained large stage IV eggs (>350 µm) and sperm. This may indicate a potential 'mass spawning' for *Turbinaria* following the full moon on 2 December 2009. If this was the case, and the majority of *Turbinaria* spawned in December, there is insufficient time for the full cycle of gametogenesis to occur before the autumn spawning period in the following March/April. A plausible explanation may be that most *Turbinaria* colonies are expelling the stage IV gametes over an extended period from December to April with the main spawning period occurring over several months in autumn; a similar conclusion was reached by Baird *et al* (in prep).

Favites, Acropora and Montipora

The spawning of *Favites pentagona* appears to occur primarily in the autumn months. There was some evidence of spawning outside of this period by a quarter of the individuals examined, and this proportion of individuals may have spawned in the spring months given that some stage III gametes were found in some colonies during spring. Based on the collected information, *Favites pentagona* does not appear to have a distinct period of 'mass spawning' in which the majority of individuals spawn.

SKM

The spawning of *Acropora spp* appears to occur primarily (80% of sampled colonies) in the early spring after the October full moon. This may be considered as a 'mass spawning' event. There is some evidence of additional spawning after this full moon by less than 10% of individuals.

The spawning of *Montipora* appears to occur primarily in the late spring after the December full moon. There is some evidence of additional spawning after in the autumn months by less than 20% of individuals sampled.

Implications for dredging

The corals growing on inshore and midshore ridges are more likely to be potentially impacted upon by the dredging activities associated with the proposed Outer Harbour Development. The timing of spawning for the two genera, *Turbinaria* and *Favites* should be the main focus of any efforts to quantify the potential effects of dredging related activities on gamete fertilisation and larval survival. The autumn and spring coral spawning studies suggest that these two most dominant genera do not have any periods of 'mass spawning', but spread their spawning effort across a number of months during summer and autumn. Periods of 'ecological significant' spawning, in which >50% of sampled individuals show signs of spawning, primarily occurs during the autumn months. This 'ecological significant' spawning window should be the main focus of attempts to mitigate the potential impact of dredging and spoil activities on coral spawning.

6. Conclusions

Conclusions and recommendations arising from the autumn and spring coral spawning surveys are presented below:

- The most abundant dominant (*Turbinaria*) and sub-dominant genera (*Favites*) of corals found at the inshore and midshore monitoring sites most likely spawned following the full moons March and April 2009, however there is evidence of some coral colonies of both genera spawning throughout the summer period.
- Corals from the *Montipora* genera spawned in over several months in spring.
- 80% of the sampled corals from the *Acropora* genera spawned after the October full moon; this may be considered as a ‘mass spawning’ event for this genera.
- Coral from the *Acropora* and *Montipora* genera are primarily found at offshore locations and in very low abundance and are not located in the areas potentially impacted by the proposed Outer Harbour Development.
- Because of the lack of evidence suggesting the two most dominate coral genera have a ‘mass spawning’ period, a more conservative approach is to identify an ‘ecologically significant’ spawning window, and target this spawning window for mitigation of potential impacts due to dredging and spoil activities.

7. References

Abdo D, Burgess S, Coleman GJ & Osborne K (2004) *Surveys of benthic reef communities using underwater video*. Standard operational procedure No.2 3rd Revised Edition. SOP 2 (3rd rev ed). Australian Institute of Marine Science. 61 p.

Babcock RC, Bull GD, Harrison PL, Heyward AJ, Oliver JK, Wallace CC & Willis BL (1986) 'Synchronous spawning of 105 scleractinian coral species on the Great Barrier Reef'. *Marine Biology* 90, 379-394.

Baird AH, Blakeway DR, Hurley T J & Stoddart J A (in prep). *Coral spawning on inshore reefs of Western Australia's Pilbara coast.*

Bainbridge, S. (1995). AVTAS User Manual. Australian Institute of Marine Science, Townsville.

Environmental Protection Authority (EPA). (2009). *Benthic Primary Producer Habitat Protection for Western Australia's Marine Environment, Guidance Statement 3*, Government of Western Australia.

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

Simpson CJ (1985). Mass spawning of Scleractinian corals in the Dampier Archipelago and the implications for management of coral reefs in Western Australia. Department of Conservation and Environment Bulletin 224, Perth, Western Australia.

SKM (2009a) *Coral Spawning Autumn Surveys 2009.* Report prepared for BHP Billiton Iron Ore.

SKM (2009b). *Port Hedland Outer Harbour Development – Baseline Benthic Marine Survey*. Report prepared for BHP Billiton Iron Ore.

Stoddart JA & Gilmour J (2005). 'Patterns of reproduction of in-shore corals of the Dampier Harbour'. In: *Corals of the Dampier Harbour: Their Survival and Reproduction during the Dredging Programs of 2004*. Published by MScience. Editors - JA Stoddart and SE Stoddart.

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

Willis BL (1987). *Morphological variation in the reef corals Turbinaria mesenterina and Pavona cactus: synthesis of transplant, histo-compatibility, electrophoresis, growth and reproduction studies*. Ph.D Thesis James Cook University. Townsville. Queensland.