TIDE AND SEAWATER TEMPERATURE DATA FROM THE NINGALOO REEF TRACT, WESTERN AUSTRALIA, AND THE IMPLICATIONS FOR CORAL MASS SPAWNING

Department of Conservation and Environment
Perth, Western Australia

Bulletin 253 March 1986

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Bulletin 253 March 1986.

ISBN 0 7309 0515 2

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ABSTRACT

Instantaneous measurements of depth (± 0.05 m), seawater temperature (± 0.02° C) and seabed irradiance (± 5%) were recorded on the Ningaloo Reef tract (21°49'-24° S; 113°24'-114°11' E) for five periods during 1985, for a total of 41 days, using *in situ* data loggers.

Measured tides were better correlated, in phase and amplitude, with the predicted tides at Carnarvon (24°53' S, 113°37' E) than Point Murat (21°49' S, 114°11' E). Tides on the Ningaloo Reef tract, as far north as Tantabiddi Creek, appear to occur 30-40 minutes ahead of the predicted tides at Carnarvon, with amplitudes up to 0.15 m greater.

Seawater temperatures in the Ningaloo Reef lagoon were highly variable in space and time. In comparison to the Dampier Archipelago (20°30' S, 116°42' E), lagoon seawater temperatures during autumn and winter were higher (by about 2° C); this may be due to the influence of the Leeuwin Current. Ningaloo Reef lagoon seawater temperatures during 1985 were significantly correlated with the adjacent ocean sea surface temperatures determined from satellite imagery. This suggests that existing satellite imagery should be useful to determine, retrospectively, spatial and temporal patterns in seawater temperatures on the Ningaloo Reef tract.

Instantaneous measurements of seabed irradiance were high and variable from mid-morning to mid-afternoon.

It is suggested that the mass spawning of corals on the Ningaloo Reef will occur after dark on April 3 and 4, 1986. This prediction is based on the lack of visible gonads in corals collected on the Ningaloo Reef during October 1985, the timing of the predicted neap nocturnal ebb tide on the Ningaloo Reef tract after the full moon in March 1986, the latitudinal synchrony of coral mass spawnings on the Great Barrier Reef, and the autumn spawnings of corals in the Dampier Archipelago.

INTRODUCTION

The recent discovery of mass spawning of scleractinian corals in the Dampier Archipelago (Fig.1) during autumn (Simpson, 1985b), in contrast to the spring mass spawnings observed on the Great Barrier Reef since 1981 (Harrison *et al.*, 1983, 1984; Willis *et al.*, 1985; Babcock *et al.*, 1986), has led to renewed speculation about the factors determining the timing of this phenomenon. Sea temperatures (Kojis and Quinn, 1981; Harrison *et al.*, 1983, 1984; Babcock *et al.*, 1986), seasonal changes in wind and water current patterns (Simpson, 1985b), tidal rhythms (Willis *et al.*, 1985; Simpson, 1985b) and diel light cycles (Babcock, 1984; Willis *et al.*, 1985; Simpson, 1985b) have been suggested as possible environmental cues for spawning synchrony. Variations in the timing of coral mass spawning at different geographical locations may help identify these factors, since any variation in the calendar date of mass spawning can be correlated with exogenous events.

This paper presents and discusses hydrographic data recorded on the Ningaloo Reef tract (NRT) during 1985. Data on tide, seawater temperature and seabed irradiance were collected on an opportunistic basis, at different locations and times, to facilitate the prediction of the timing of mass spawning of scleractinian corals in the area.

In this paper 'measured' tide refers to *in situ* tidal measurements (that is, the sum of the astronomically and meteorologically forced changes in sea level) and 'predicted' tide refers to the astronomical effects only. Measured tides along the NRT are compared to predicted tides for the standard ports of Carnarvon and Point Murat (Fig.1). The variability of lagoon seawater temperatures on the NRT is discussed and seasonal trends are compared with sea temperatures in the Dampier Archipelago where mass spawning of corals has been observed (Simpson,1985b), and with adjacent oceanic surface seawater temperatures determined from satellite imagery.

Although limited in time and space, these are the first quantitative measurements on selected aspects of the physical environment of the shallow, lagoonal waters of the NRT.

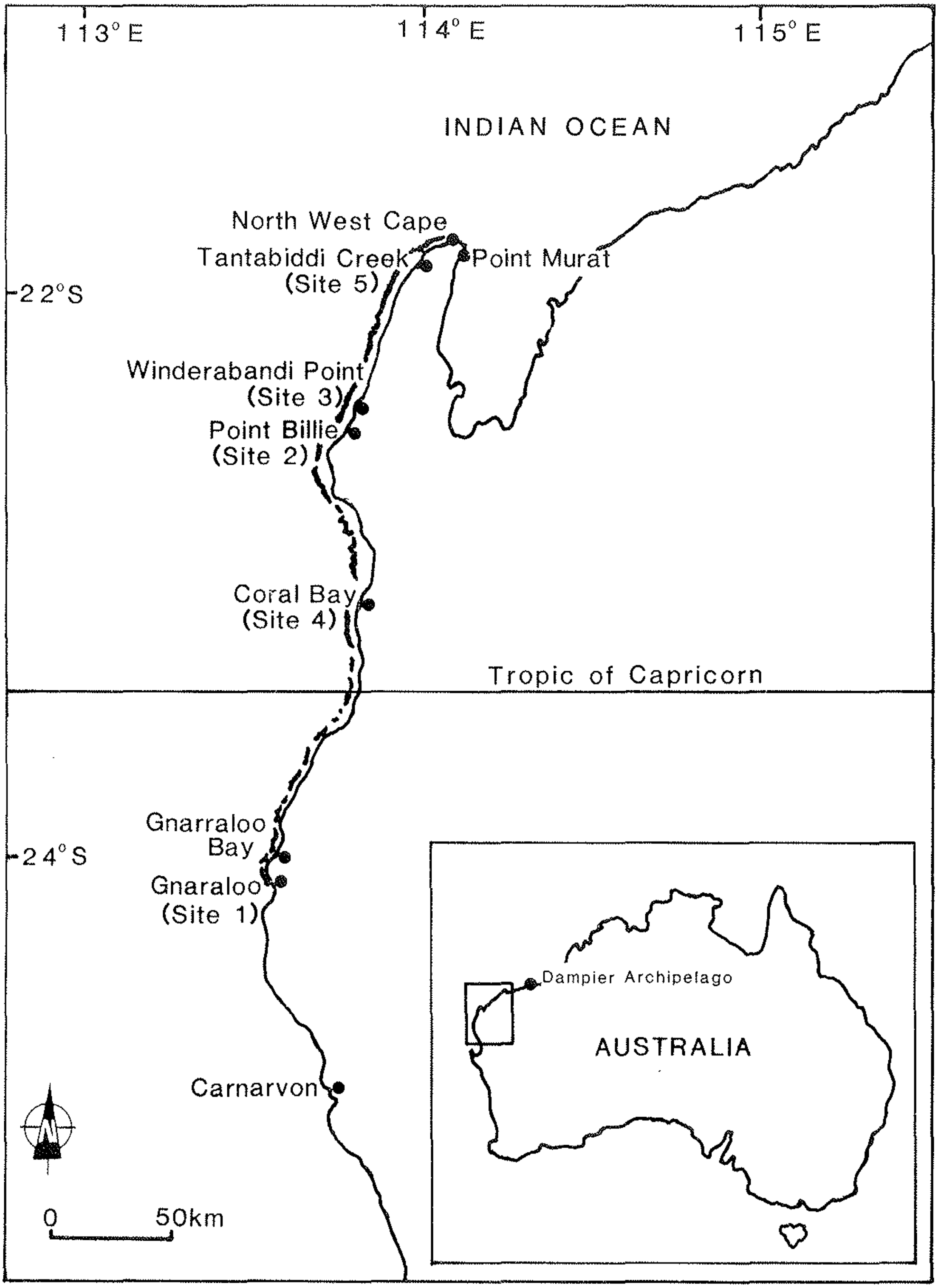

Figure 1. Location of study sites on the Ningaloo Reef tract.
Inset: Location of the Ningaloo Reef Tract and the Dampier Archipelago in Australia.

MATERIALS AND METHODS

The NRT is the largest fringing coral reef system in Australia, extending for about 280 km from Gnarraloo Bay to Point Murat (Fig.1). Data loggers (Windrift Instruments, WA) mounted in submersible housings were deployed at 5 locations (Fig.1) along the NRT during 1985. All sites were within the lagoon at depths of less than 3m. Instantaneous measurements of depth ($\pm$0.05 m), seawater temperature ($\pm$0.02 ^{o}C) and seabed irradiance ($\pm$5%) were recorded at 15 minute intervals. Data logger deployment records are summarised (Table 1). Predicted tide heights were computed, at hourly intervals, for Carnarvon and Point Murat (Hamon, 1983). Sea temperatures of the adjacent ocean waters, during each deployment period, were obtained from mean weekly sea surface temperature contour maps determined from satellite imagery (GOSSTCOMP)[1].

Table 1. Summary of deployment records for data loggers on the Ningaloo Reef tract during 1985.

Site	Location Latitude, Longitude	Depth (m)	Deployment period	Data days	Parameters measured
1	Gnaraloo 24^{o} 00' S,113^{o} 24' E	1.7	21/05-31/05	10	temperature depth
2	Point Billie 22^{o} 33' S,113^{o} 41' E	2.9	17/05-23/05	7	temperature light
3	Winderabandi Point 22^{o} 30' S,113^{o} 43' E	surface	05/08-07/08	2	temperature
4	Coral Bay 23^{o} 09' S,113^{o} 47' E	2.4	04/10-18/10	14	temperature depth
5	Tantabiddi Creek 21^{o} 54' S,113^{o} 58' E	1.4	05/12-13/12	8	temperature depth

RESULTS AND DISCUSSION

Tides

In general, the study area is located in a zone of transition between the South Western Australian tidal zone (diurnal, 'tideless') and the North Western Australian tidal zone (semi-diurnal, macrotidal). Using

[1]**GOSSTCOMP:** Global Operational Sea Surface Temperature Computation: National Environmental Satellite Service, National Oceanic and Atmospheric Administration, Washington, D. C.

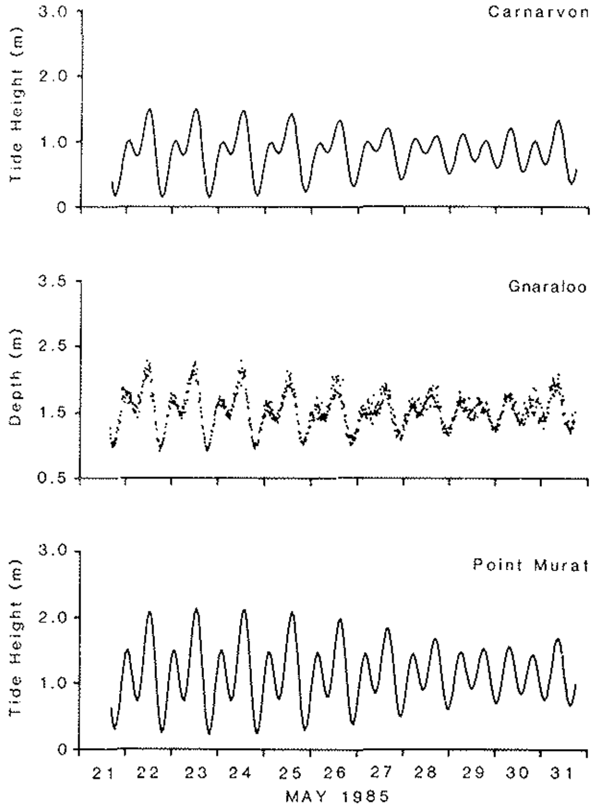

Figure 2. Measured tides (dots) at Gnaraloo (site 1) and predicted tides (solid lines) for Carnarvon and Point Murat during May 1985.
Date of full moon, May 5. Date of new moon, May 20.

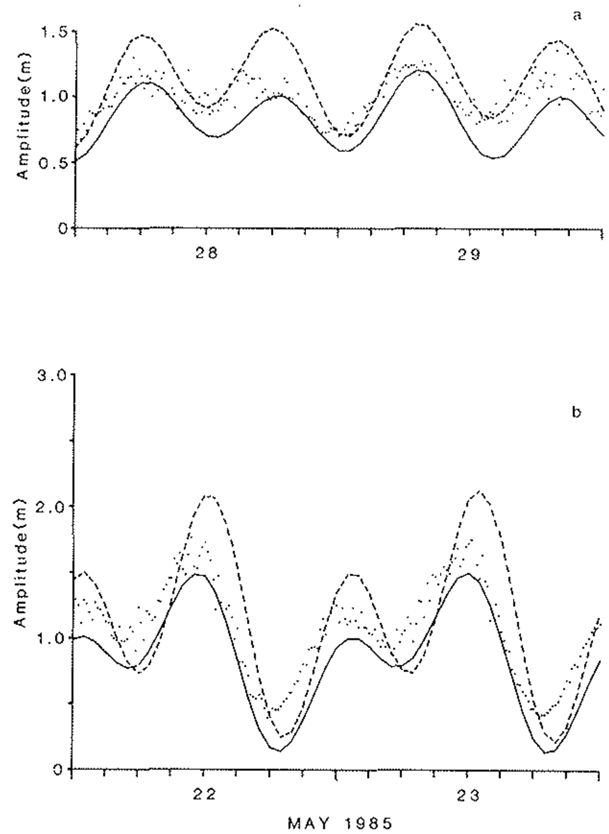

Figure 3. Measured tides (dots) at Gnaraloo (site 1) and predicted tides (solid lines) for Carnarvon and Point Murat during (a) neap and (b) spring tides.
Solid line (Carnarvon); dashed line (Point Murat).

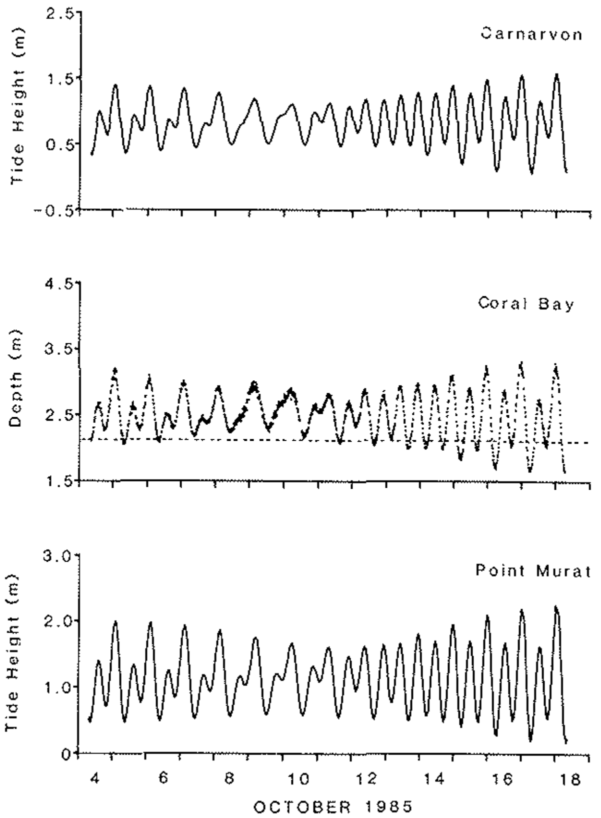

Figure 4. Measured tides (dots) at Coral Bay (site 4) and predicted tides (solid lines) for Carnarvon and Point Murat during October 1985.
The dashed horizontal line shows the approximate depth at site 4 (Coral Bay), in relation to tide height, at which the outer reef and some lagoon corals were exposed.
Date of full moon, September 29; Date of new moon, October 14.

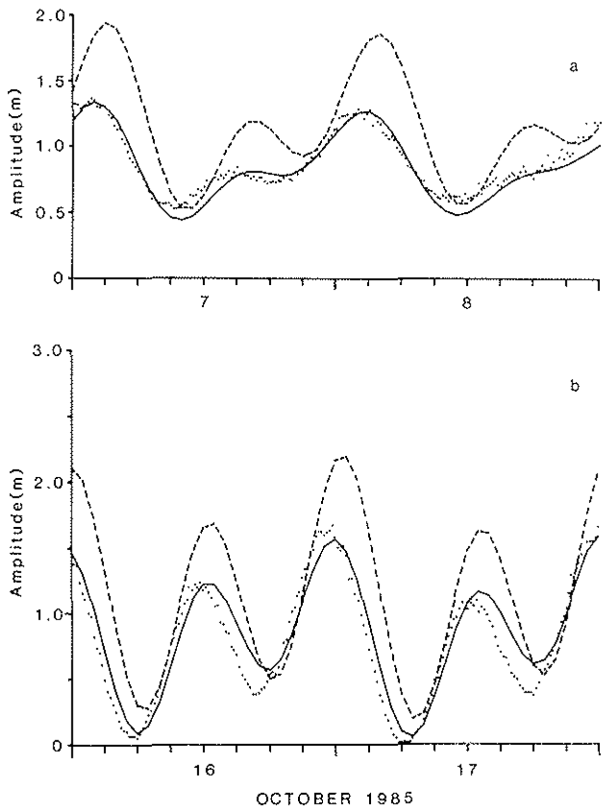

Figure 5. Measured tides (dots) at Coral Bay (site 4) and predicted tides for Carnarvon and Point Murat during (a) neap and (b) spring tides.
Solid line (Carnarvon); dashed line (Point Murat).

tidal constants, tides at Carnarvon may be defined as mixed and microtidal whereas tides at Point Murat may be classified as semidiurnal, with diurnal inequalities and mesotidal (Easton, 1970).

Phase and amplitude

During the deployment periods, measured and predicted tides were semi-diurnal, with spring and neap tides occurring 2-4 days and 8-10 days respectively, after a full or new moon (Figs 2, 4 and 6). Measured tides at Coral Bay (site 4) and predicted tide heights at Carnarvon for October 7 and 8, 1985 showed a semi-diurnal pattern (Fig. 5a), though the Australian National Tide Tables 1985 predicted diurnal tides at Carnarvon on those dates (Anonymous, 1984). Figures 3, 5, and 7 show the relationships between the tidal phase and amplitude measured at sites 1,4 and 5, and those predicted at Carnarvon and Point Murat, for 2 days approximating to periods of neap and spring tides. In general, measured tides on the NRT occurred approximately 30-40 minutes earlier than the predicted tides at Carnarvon, and 60-90 minutes earlier than those predicted at Point Murat (Figs 3, 5 and 7). At Tantabiddi Creek (site 5) the phase of the nocturnal ebb neap tide (the tidal state during coral mass spawning in the Dampier Archipelago) appeared closer to the predicted tidal phase at Point Murat than at Carnarvon (Table 2).

Table 2. Difference in phase between measured and predicted nocturnal spring and neap ebb tides on the Ningaloo Reef tract.
Phase differences (minutes) measured from mid-point in tide; neap tides in brackets; [a], nocturnal flood tide.

Site	Date	Carnarvon	Point Murat
1	23/05 (29/05[a])	+31 (+41[a])	+72 (+53[a])
4	17/10 (08/10)	+31 (+36)	+84 (+88)
5	12/12 (06/12)	+33 (+52)	+69 (+20)

Measured tidal amplitudes along the NRT were closer to predicted amplitudes at Carnarvon than at Point Murat. Measured amplitudes at sites 1, 4 and 5 were slightly greater on spring tides and less on neap tides than predicted amplitudes at Carnarvon, and always less than predicted amplitudes at Point Murat (Table 3). For 1985, the Australian National Tide Tables predicted maximum spring tidal amplitudes at Carnarvon and Point Murat (on December 12-14) of 1.6m and 2.2m, respectively (Anonymous, 1984). On December 13, 1985, the measured maximum tidal amplitude at site 5 was 1.7 m (Fig. 6).

Table 3. Difference in amplitudes (m) between measured and predicted nocturnal spring and neap ebb tides on the Ningaloo Reef tract.
Neap tides in brackets; [a], nocturnal flood tide.

Site	Date	Carnarvon	Point Murat
1	23/05 (29/05[a])	-0.05 (+0.06[a])	+0.50 (+0.32[a])
4	17/10 (08/10)	-0.15 (+0.08)	+0.35 (+0.57)
5	12/12 (06/12)	-0.20 (+0.08)	+0.15 (+0.26)

Overall, the phase and amplitude of measured tides at sites 1 and 4 were very similar to predicted values at Carnarvon, whereas site 5 (Tantabiddi Creek) appears to represent an intermediate stage between the predicted tides at Carnarvon and at Point Murat.

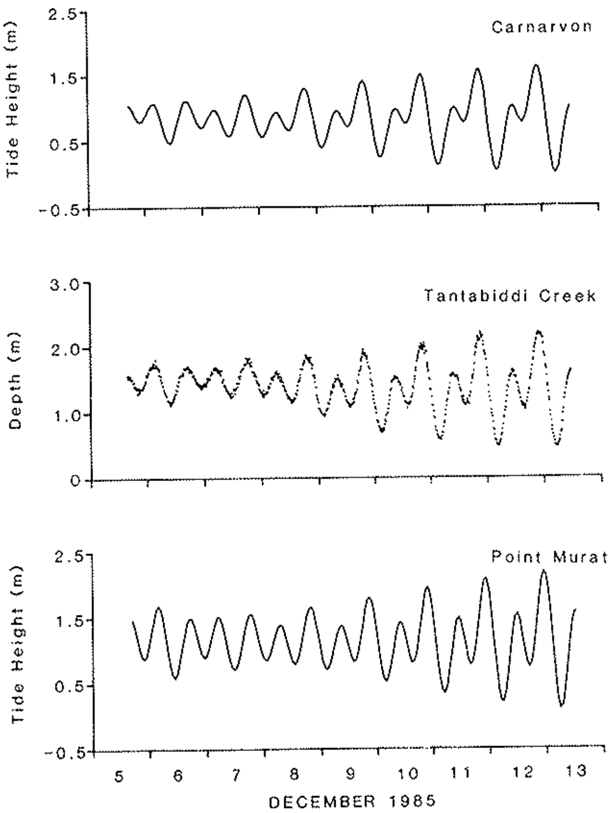

Figure 6. Measured tides (dots) at Tantabiddi Creek (site 5) and predicted tides for Carnarvon and Point Murat during December 1985.
Date of full moon, November 27; Date of new moon, December 12.

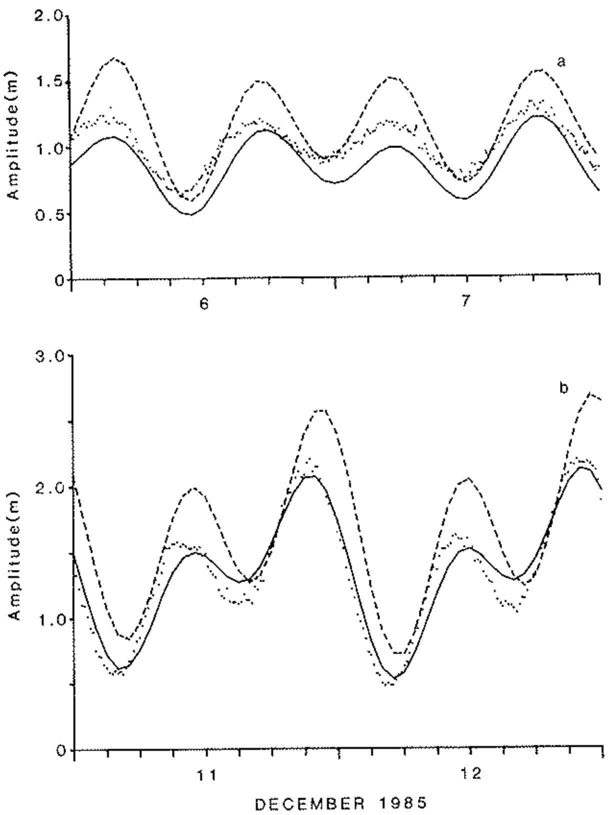

Figure 7. Measured tides (dots) at Tantabiddi Creek (site 5) and predicted tides for Carnarvon and Point Murat during (a) neap and (b) spring tides.
Solid line (Carnarvon); dashed line (Point Murat).

These data suggest that tides in the lagoon, along most of the NRT, are better correlated in phase and amplitude with the predicted tides at Carnarvon than at Point Murat.

Exposure of the outer reef and lagoon corals

The Australian National Tide Tables 1985 predicted the lowest tides at Carnarvon in 1985 to occur between October and December (Anonymous, 1984). At 0730h on October 4, 1985, the reef crest along the entire portion of the offshore barrier reef, adjacent to the Coral Bay settlement, was fully exposed. Additionally, the upper tips of some lagoon corals (mainly arborescent *Acropora* spp.) were also exposed. Indeed, the tidal records at site 4 indicate that October 7, 8, 9 and 10 (1985) were the only dates between October 4 and 18 when the reef crest and lagoon corals were not exposed (Fig. 4). These dates coincided with a period of neap tides. Furthermore, the reef crest was well exposed at 0730h on October 4, indicating that exposure occurred earlier than 0730h. Many lagoon corals were exposed at 0630h on October 18, 1985 (M. J. Forde, personal communication). One of the lowest tides of the year was predicted at Carnarvon at 0723h on this date (Anonymous, 1984).

These data suggest that the reef crest and the larger arborescent *Acropora* spp. in the lagoon near Coral Bay, are continuously immersed for substantially less than 120 hours during each 14 day tidal cycle, and that periods of exposure can exceed 5 hours. Mass spawning of scleractinian corals on an intertidal reef in the Dampier Archipelago, during March 1985, occurred on the two nights during the period of maximum continuous water immersion in the 14 day tidal cycle (Simpson, 1985b). The relationship between exposure of the lagoon corals at Coral Bay and tide height, suggests that vertical growth of these corals is limited to below about mean low water neap datum (Fig. 4).

Seawater temperatures

General

Little is known about the spatial and temporal variability of seawater temperatures in the shallow, lagoonal waters of the NRT. Meagher (1980) states that lagoon seawater temperatures range from 24^{o} C in mid-winter to about 29^{o} C in mid-summer. Additionally, in areas of the lagoon with restricted flushing, minimum seawater temperatures in winter may be close to ambient air temperatures (18^{o} C-

20^{o} C), resulting in steep temperature gradients between the lagoon and the open ocean. May *et al.* (1983) state the range of seasonal seawater temperatures in the lagoon to be 22^{o} C to 29^{o} C.

Temporal variation

Diel patterns

Seawater temperatures recorded at 5 sites along the NRT during 1985 showed a pronounced diel variation (Figs 8 and 9b), consistent with heating during the day by insolation (Fig. 9a, b), and cooling at night. The mean diel seawater temperature range, for all deployments, was about 3^{o} C. A maximum diel variation of 4.2^{o} C was recorded, at site 5, between 1600h on December 9 and 0730h on December 10, 1985 (Fig. 8d). During the October temperature record at site 4 (Coral Bay), the modal diel minimum and maximum seawater temperatures occurred between 0600h-0700h and 1500h-1600h, respectively. The mean diel temperature had a bimodal distribution, at 1000h-1100h and 2000h-2100h (Fig. 10b). For all records there was a general pattern of minimum seawater temperatures around sunrise, a maximum in mid-afternoon, with mean temperatures 1-2 hours before noon and approximately 2 hours after sunset.

There were other short term temperature fluctuations, which differed from the general pattern (for example, around midnight on May 19, 20 and 21; Fig.9b). These variations, which may have been caused by the mixing of water masses with different physical properties (for example, the intrusion of oceanic water into the lagoon during flood tides), were usually less than 0.5^{o} C (Fig. 9b).

These data have important implications if instantaneous measurements are used to construct long term (for example, monthly) averages, which is the usual instance in many ecological studies (Potts and Swart, 1984). Additionally, to quantify the spatial variability of seawater temperature in shallow lagoonal waters, knowledge of diel variability is essential.

Short term fluctuations (days)

The temperature records at site 1 and 4 show a slight increase (about 1^{o} C) in mean daily temperatures around neap tides (Figs 8a, c). At site 5 (Tantabiddi Creek) in December, an 8.5^{o} C

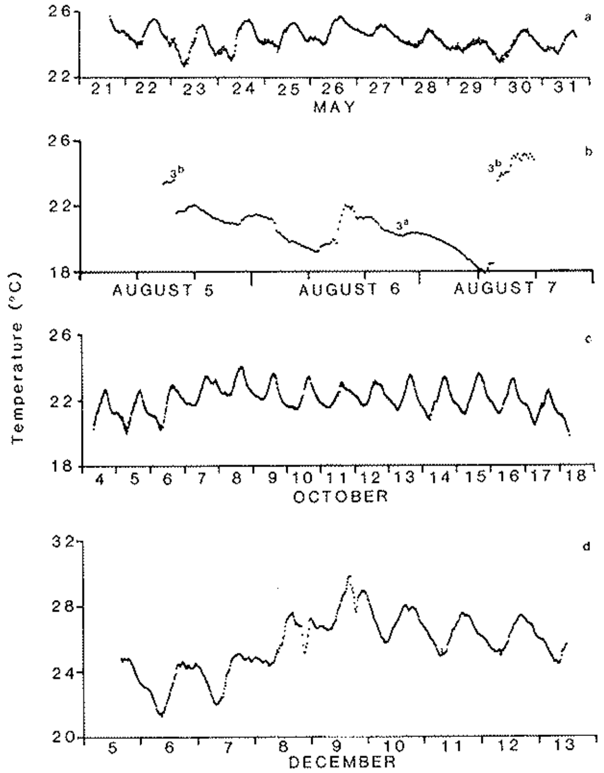

Figure 8. Seawater temperature records at different locations on the Ningaloo Reef tract during 1985.
8(a) Gnaraloo (site 1), 8(b) Winderabandi Point (site 3^a, nearshore; site 3^b, outer reef); 8(c) Coral Bay (site 4) and 8(d) Tantabiddi Creek (site 5).

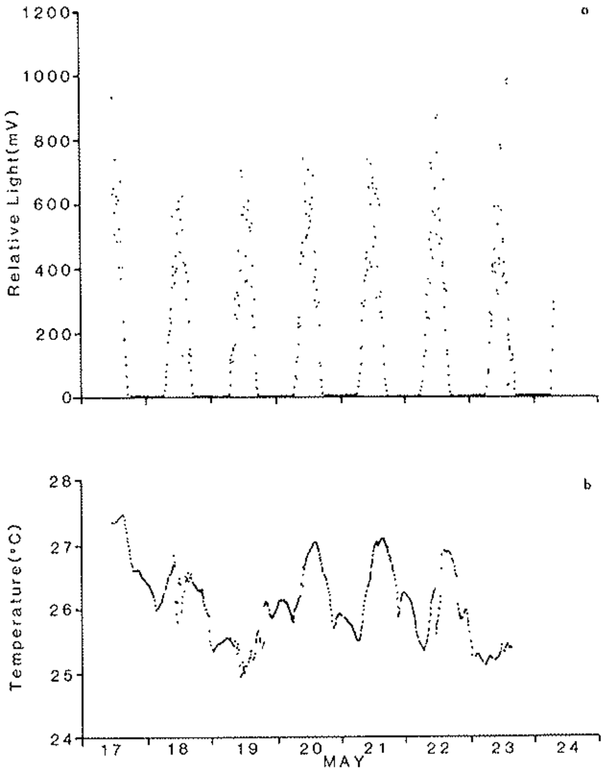

Figure 9. (a) Seabed irradiance and 9(b) seawater temperature records for Point Billie (site 2) during May 1985.

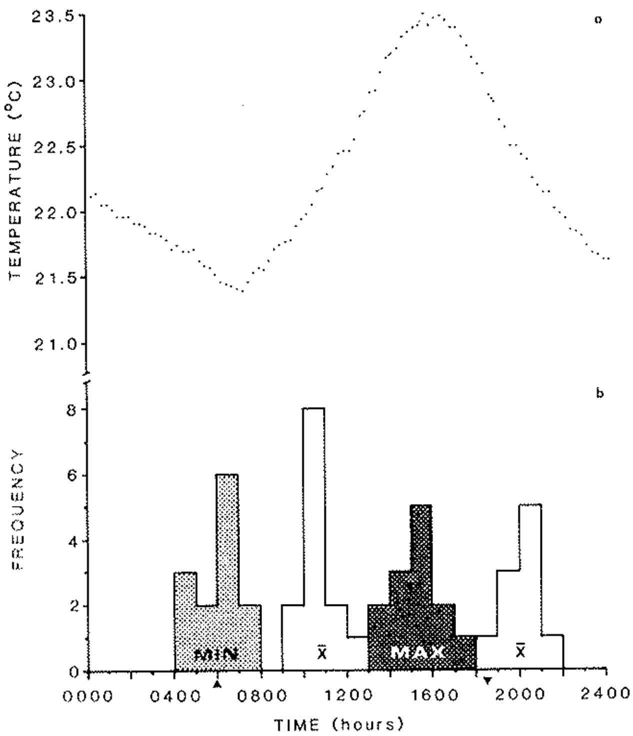

Figure 10. (a) Diel variation in seawater temperature at Coral Bay (site 4) on October 15,1985.
10(b) Modal time of minima, maxima and mean daily seawater temperatures at Coral Bay (site 4) between October 4-18, 1985.
(▲, sunrise, ▼, sunset).

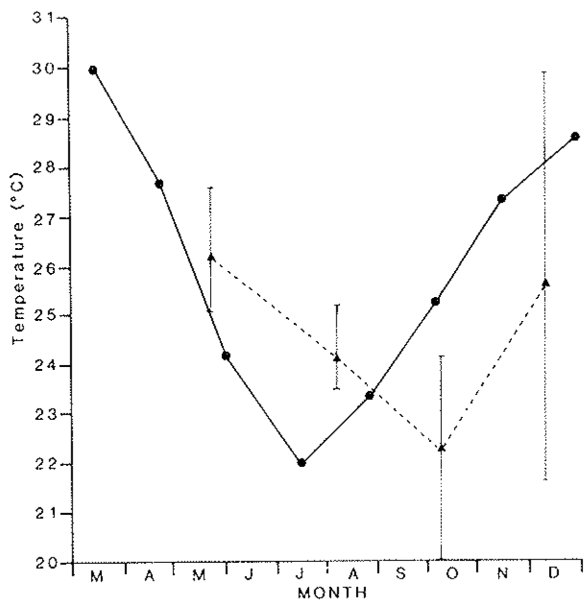

Figure 11. Seasonal variation in seawater temperature in the Dampier Archipelago during 1982 and the lagoon waters of the Ningaloo Reef tract in 1985.
Monthly mean temperatures in the Dampier Archipelago (●) from Simpson (1985a); mean temperatures and range on the Ningaloo Reef tract (▲; sites 2, 3^b, 4 and 5).

variation in seawater temperature was recorded over about 72 hours (Fig. 8d). Between December 5 and 7, the mean temperature was about 23° C, with a mean diel variation of approximately 3° C. From about 1600h on December 7 the diel pattern ceased, there was no decrease in nocturnal seawater temperatures, and a stepwise increase in temperature occurred, during the day, on December 8 and 9. The diel pattern resumed on December 9 and continued to the end of the record. Between December 9 and 13 the mean daily temperature was approximately 27° C, with a mean diel variation of about 3° C. These data indicate that an unusually cool water mass was advected into the lagoon from the open ocean, and mixed with the lagoon waters. This assumes that the temperatures recorded on December 5, 6 and 7 were atypically low for this time of the year. Alternatively, a water mass within the lagoon was cooled and subsequently heated. Considering the diel variation in seawater temperatures before and after this sudden change, the near constant nocturnal temperatures on December 7/8 and 8/9 and the magnitude of the temperature change, this alternative hypothesis seems untenable. The advection of oceanic water into the lagoon is likely to be greater during neap tides (December 5, 6 and 7) when the outer reef is continuously covered by water, and supports the hypothesis that this event was caused by an intrusion of cool water into the lagoon rather than local heating and cooling of the same water mass. Further seawater temperature anomalies occurred on May 19 and 23, 1985 at site 2, when daytime maxima were about 2° C lower than would have been expected from temperatures on preceding days (Fig. 9b). The absence of corresponding salinity data during these events precludes any conclusive interpretation although, again, these data illustrate the high variability of seawater temperatures in the shallow Ningaloo Reef lagoon.

Seasonal pattern

Lagoon water temperatures showed marked seasonality, with a recorded range of 12.0° C (Table 4). Although these temperature records are from different locations, satellite temperature data indicate that latitudinal variation in surface temperature of the adjacent ocean waters during this period rarely exceeded 1° C along the length of the tract. Mean temperatures varied from 26.1° C in May (site 2), to 22.1° C in October, to 25.6° C in December (Fig.11). A mean of 20.5° C, recorded in August at a nearshore site near Winderabandi Point (site 3^a), is omitted from the seasonal pattern as it is assumed to represent poorly flushed, shallow, nearshore lagoon waters. This assumption is supported by satellite sea surface temperatures over the same period which were 23^{o} C-24^{o} C. The mean temperatures at sites 2, 3^{b}, 4 and 5, for the periods shown, lie within the the mean weekly isotherms from the satellite sea surface temperatures, with site 1 being 0.5^{o} C lower (Table 5).

Table 4. Summary of lagoon seawater temperatures recorded on the Ningaloo Reef tract during 1985.
(3^{a}, nearshore; 3^{b}, outer reef channel; n, number of records)

Site	Month	n	Mean (^{o} C)	Min-Max (^{o} C)	Range (^{o} C)
1	May	1029	24.4	22.7-26.0	3.3
2	May	661	26.1	24.9-27.5	2.6
3^{a}	August	179	20.5	17.8-22.1	4.3
3^{b}	August	29	24.1	23.1-25.1	2.0
4	October	1339	22.1	20.0-24.1	4.1
5	December	752	25.6	21.3-29.8	8.5

The data reported here provide real-time 'ground truthing' of satellite sea surface temperatures, and suggest that sites 1, 2, 3^{b}, 4, and 5 are well flushed.

Table 5. Comparison of lagoon seawater temperatures on the Ningaloo Reef tract, with satellite mean weekly sea surface temperatures (GOSSTCOMP) for the adjacent ocean waters during 1985.
(3^{b}, outer reef channel; n, number of records)

Site	Date	n	Mean (^{o} C)	Min-Max (^{o} C)	GOSSTCOMP (^{o} C)
1	22/05-28/05	672	24.5	22.7-25.7	25-26
2	15/05-21/05	437	26.2	24.9-27.5	26-27
3^{b}	31/07-06/08	8	23.2	23.1-23.5	23-24
4	09/10-15/10	672	22.2	20.8-23.6	22-23
5	04/12-10/12	515	25.3	21.3-29.8	25-26

The significant correlation (Fig.12) between measured temperatures in the lagoon and ocean surface temperatures determined from satellite imagery (as the mid-point between isotherms) indicates that satellite sea temperature data should be useful to examine spatial and temporal (long and short term) patterns of lagoon temperatures along the NRT.

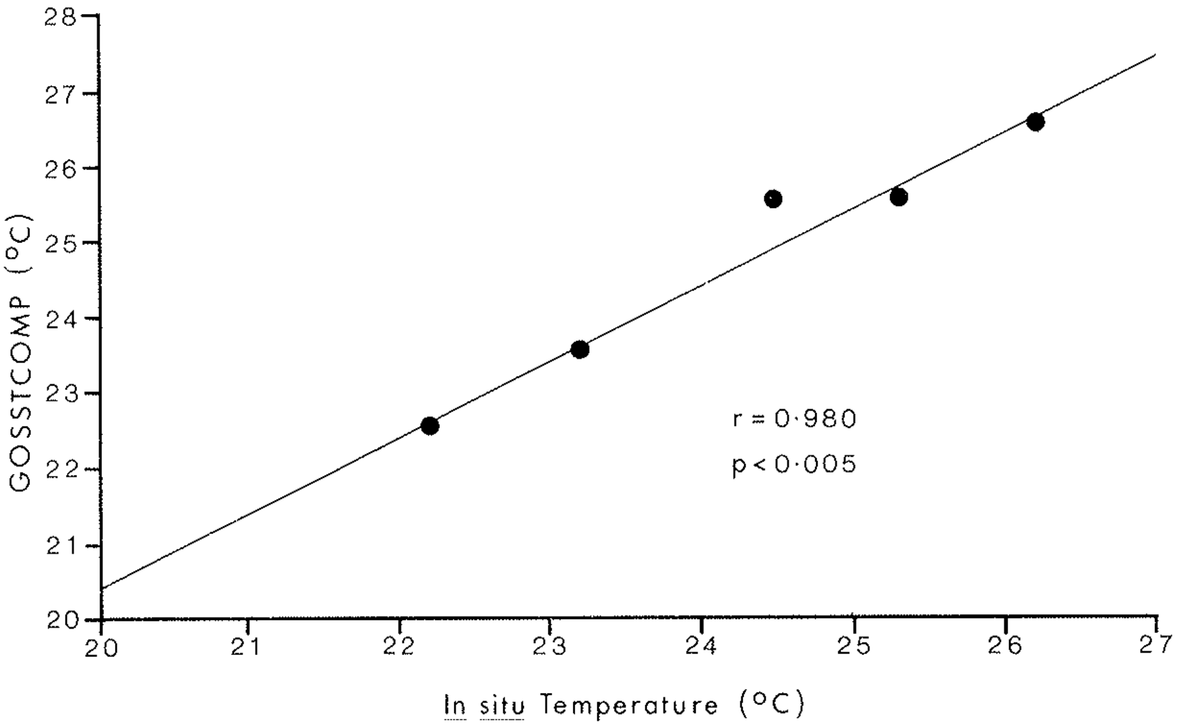

Figure 12. Correlation between measured mean seawater temperatures in the Ningaloo Reef lagoon and mean weekly sea surface temperatures of the adjacent ocean from satellite imagery.

Comparisons with the Dampier Archipelago

In the Dampier Archipelago, maxima occur typically in late summer (March), followed by a sharp decline in autumn (April to June), to minima in mid-winter (July/August) (Simpson, 1985a). Seasonal seawater temperatures in the Dampier Archipelago during 1982, and the NRT in 1985, are shown (Fig. 11). By comparison, seawater temperatures on the NRT during 1985 were higher (by about 2° C) during autumn and winter, with a minimum occurring in spring (September/ October). These high autumn and winter seawater temperatures (NRT) are probably due to the influence of the Leeuwin Current, a poleward flow of water of tropical origin along the coast of Western Australia during autumn and winter (Cresswell and Golding, 1980). The range of temperatures recorded at sites 1 and 2 during May 1985 (Table 4) are within the May 1982 isotherms of the Leeuwin Current reported by Thompson (1984) in the adjacent ocean waters off the NRT.

Spatial variation

It is clear that marked variability can exist in the seawater temperatures in the lagoon of the NRT, and this may be due to variations in the amount of flushing. As an example, surface seawater temperature on the outer reef, west of Winderabandi Point (Site 3^b), was 23.7° C at 1315h on August 5, 1985 and agreed with GOSSTCOMP temperatures (Table 5). At 1330h on the same day, at an inner lagoon nearshore location (site 3^a) about 2.5 km east of site 3^b, surface seawater temperature was 21.6° C. At 1000h on August 7, at the same site (3^a), surface water temperature was 18.6° C. Forty-five minutes later, at the outer reef, the seawater temperature was found to be 23.5° C (Fig. 8b). Thus there was marked cooling of inner lagoon water at a time of relatively constant seawater temperatures further offshore. These data illustrate the need for a spatial perspective and underline the importance of preliminary surveys, spatially and temporally, before long term monitoring stations are established in lagoon waters.

Seabed irradiance

Irradiance at a depth of about 3 m increased sharply at sunrise (at about 0600h) to a maximum around noon. Seabed irradiance was high and variable from mid-morning to mid-afternoon with a sharp decline in the late afternoon to night levels just after sunset (Fig. 9a). The scatter of light values during the middle of the day result from reflection and focussing of light by waves in the shallow, clear waters of the lagoon.

Predicted timing of mass spawning of corals on the Ningaloo Reef tract.

Gonads were not visible under a dissecting microscope in preserved samples of corals (acroporiids and faviids) collected on October 3, 1985 at Coral Bay (site 4). This was about 4 weeks before the 1985 mass spawning of corals at Magnetic Island on the Great Barrier Reef, and indicates that coral mass spawning on the NRT is not synchronised with the spring mass spawnings on the Great Barrier Reef.

Mass spawning of corals in the Dampier Archipelago is predicted to occur after dark on April 3 and 4, 1986 (Simpson, 1985b). The Ningaloo Reef tract is approximately 2° (latitude) south of the Dampier

Archipelago and synchronous spawning on the Great Barrier Reef has been observed on reefs separated by as much as 5^{0} of latitude (Babcock *et al.*, 1986). The nights of April 3 and 4, 1986 fall on neap tides on the Ningaloo Reef tract, with an ebb tide predicted to occur during darkness, conditions similar to those predicted for the Dampier Archipelago (Table 6).

Table 6. Predicted times of high water (HW) and low water (LW) for the nocturnal ebb tide on April 3 and 4, 1986 in the Dampier Archipelago (Anonymous,1985) **and on the Ningaloo Reef** (adjusted from Hamon,1983).

Date	Tide state	Dampier Archipelago	Ningaloo Reef
03/04	HW	1608	1620
03/04	LW	2337	
04/04	LW		0020
04/04	HW	1853	1820
05/04	LW	0248	0150

On the basis of these data, we predict that the mass spawning of scleractinian corals on the Ningaloo Reef tract will occur on these nights, in synchrony with the events in the Dampier Archipelago.

SUMMARY

Tides measured on the Ningaloo Reef tract during 1985 were closer in phase and amplitude to the predicted tides at Carnarvon than at Point Murat. Measured tides occurred 30-40 minutes earlier than predicted tides at Carnarvon. Amplitudes were 0.05 m (site 1) to 0.15 m (sites 4 and 5) greater than predicted values on or near spring tides and about 0.1 m (sites 1,4 and 5) less on neap tides.

Between October 4 and 18, 1985 at Coral Bay, the outer reef crest and some of the larger arborescent *Acropora* spp. in the lagoon were exposed at least once a day, except during neap tides (October 7, 8, 9 and 10).

Lagoon seawater temperatures on the Ningaloo Reef were highly variable, both temporally and spatially. This variability should be considered when 'spot' measurements are taken or when long-term monitoring stations are established. Seasonal lagoon temperature patterns appear to be influenced by the Leeuwin Current, resulting in relatively high (compared to the Dampier Archipelago) seawater temperatures during autumn and winter.

The significant correlation between measured sea temperatures in the lagoon and sea surface temperatures of the adjacent ocean, as determined from satellite imagery, suggests that satellite remote-sensing should be useful in establishing seasonal and inter-year differences in sea temperature patterns, to provide information on the spatial variability of seawater temperatures along the Ningaloo Reef tract, and to make retrospective measurements of surface seawater temperature.

The use of computed hourly tide heights in preference to the predicted times of high and low water from the Australian National Tide Tables 1985 provides a more comprehensive prediction of the state of the tide at any given time. Additionally, there was a higher correlation between the measured tides along the Ningaloo Reef tract and the computed hourly tides for Carnarvon.

The timing of the neap nocturnal ebb tides on the Ningaloo Reef tract after the full moon in March 1986, the latitudinal synchrony of coral mass spawnings on the Great Barrier Reef, and the timing of

mass spawning in the Dampier Archipelago, lead us to predict that mass spawning of corals on the Ningaloo Reef tract will occur, after dark, on April 3 and 4, 1986 (that is, synchronously with coral mass spawning in the Dampier Archipelago).

ACKNOWLEDGEMENTS

The authors thank the people involved in the deployment and recovery of instruments including: K. A. Grey, M. J. Forde, G. R. Bastyn, L. M. Marsh and members of the University of Western Australia Underwater Club. The manuscript was reviewed critically by Associate-Professor A. J. Mc Comb, Dr J. R. Ottaway, A. F. Pearce and Dr D. A. Mills. Satellite temperature data was supplied by A. F. Pearce and tidal predictions were computed from the computer programme devised by B. V. Hamon and modified by A. F. Pearce. Laboratory and computing facilities were supplied by the Botany Department, University of Western Australia.

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Note added in proof: March 4, 1986

On February 28 and March 1, 1986, corals tagged at site 4 in October 1985 were resampled for assessment of reproductive status. This period was about 4.5 weeks before the spawning time we predicted in this paper. Most acroporiid species had well developed gonads (some species had eggs with a diameter exceeding 500 um) and all specimens except one had non-pigmented (white) eggs. Faviid species all contained large, light green eggs. A random survey of a further 32 untagged acroporiid and faviid colonies confirmed the widespread presence of well developed gonads, as described above, in many corals of the area. Babcock *et al.* (1986) found that egg pigmentation in faviid and acroporiid species occurred 4-6 weeks and 3-4 weeks, respectively, before spawning.

These observations and data strengthen our prediction that coral mass spawning will occur on April 3 and 4, 1986 , on the Ningaloo Reef tract.

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