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by B.F. Phillips

Abstract

At Seven Mile Beach in Western Australia, data on water currents and the intensity of moonlight were examined for their effects upon the catches of the puerulus larvae of *Panulirus longipes*[1] by collectors composed of artificial seaweed.

The puerulus larvae enter the Seven Mile Beach area and settle on the collectors during the night. No relationships were found between the volume of water flowing into Seven Mile Beach and catches on the collectors, either as a cyclic flow related to moon phase, or from night to night at the time of settlement.

Almost all settlement on the collectors occurs near the time of new moon, most occurring during the period of no moon and ceasing when the moonlight intensity rises above a threshold value of about 10% of full moonlight.

On the nights on which settlement occurs, the puerulus may make use of the incoming water currents to aid them in swimming into the area.

It is hypothesized that the settlement on the collectors is a true reflection of the natural settlement occurring in the area.

INTRODUCTION

Phillips (1972) found that the puerulus larval stage of the western rock lobster *Panulirus longipes* (Milne-Edwards) could be captured using collectors composed of artificial seaweed, settlement following a lunar periodicity, with catches being largely confined to the new moon period. Settlement of the puerulus of *Panulirus argus* (Latreille) has also been found to follow the same pattern (Sweat, 1968).

[1]Described as a new species *P. cygnus* by George (1962), but relegated to the status of an allopatric form of *P. longipes* by Chittleborough and Thomas (1969).

Since 1972 attempts have been made to define more closely the time of settlement and to examine the effects of water currents on the catches of the puerulus on the collectors. In this paper the results of these investigations are examined and a hypothesis to explain the settlement pattern presented.

METHODS

The investigation was carried out at Seven Mile Beach (29°10'S, 114°53'E) in Western Australia. It is an area of shallow (1-5 m depth) coastal limestone reefs and sea grass beds. The water is relatively calm, being protected by a line of reefs parallel to the shore which dampens the force of wave action, which can be severe on the outside of the reefs.

Collectors

The collectors used in this study were described by Phillips (1972). All collectors were examined daily and some were examined both morning and evening.

Water Currents

Water currents were recorded with a moored current meter designed by Frassetto (1967) and built by the Division of Fisheries and Oceanography (Cresswell, 1971). The meter was positioned within the reef area adjacent to the collectors. A measure of relative overnight flow into Seven Mile Beach was calculated by summing the flow rate as recorded at each hour, from 1800 hours to 0600 hours, inclusive.

Moonlight Intensity

The relative intensity of moonlight reaching the surface of the water, for each hour, of each night in the Seven Mile Beach area was calculated as described by Austin, Phillips and Webb (in preparation). Moonlight intensity is expressed as a percentage of the intensity of the light from the full moon at its zenith.

RESULTS

Water Currents into Seven Mile Beach

A study was made of the water currents into the Seven Mile Beach area, to determine if a current pattern similar to that of the lunar cycle was present. Data for the period of 3rd October 1972 to 29th December 1972 was examined, relative overnight flow (1800 hours to 0600 hours) being calculated. Water flow during the hours of daylight was not analysed, as examination of the collectors morning and evening showed that the puerulus settled on the collectors during the night.

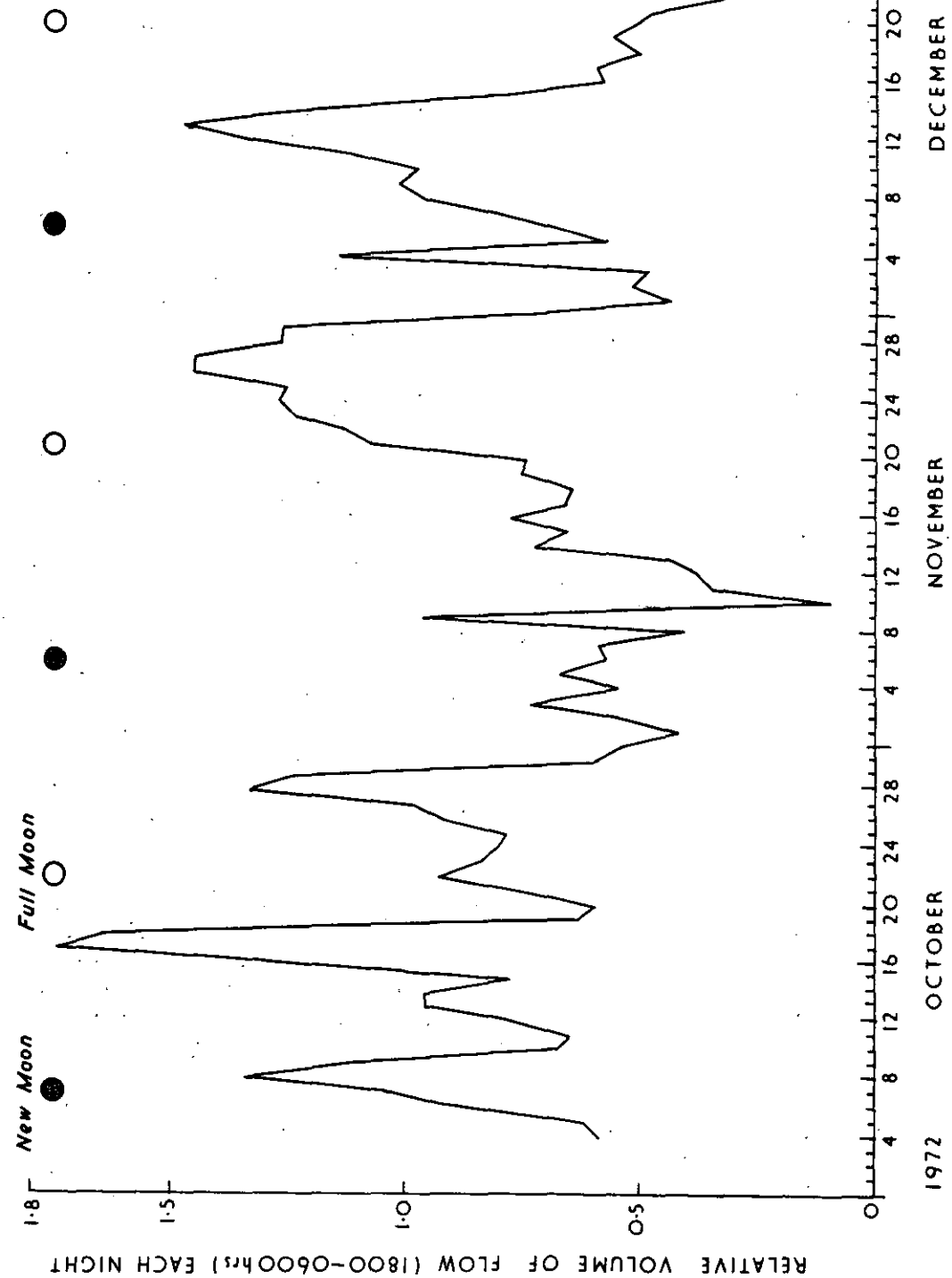

Fig. 1. Relative volume of overnight water flow into the Seven Mile Beach area.

The results (Fig. 1) show that there was no correlation of flow with lunar phase, but that the volume of water flow into the area decreased over the total period. This reduction in water flow into the Seven Mile Beach area over the period from October to December is due to a progressive lowering of the monthly sea level in this area from July to January in each year (Hodgkin and Di Lollo, 1958). The cyclical fluctuations in the rates of water flow (seen in the data) are the result of changes in sea level caused by variations in barometric pressure and associated weather features (Hodgkin and Di Lollo, 1958).

No indication of any cyclic water flow into Seven Mile Beach, which would relate to the monthly lunar settlement pattern of the puerulus larvae, is apparent.

Water Currents on the Continental Shelf

The possibility exists that a cyclic form of water movement exists outside the reef area, i.e., over the continental shelf, which could inject larvae into the reef area.

The hydrology of the water on the shelf is not well known and is at present under investigation. However, in the account by Pashkin (1968) and CSIRO investigations (Cresswell, unpublished data) there is no evidence of any cyclic water movement which would relate to the lunar settlement pattern of the puerulus larvae.

Overnight Water Currents into Seven Mile Beach

The daily catches of the puerulus from 4th November 1972 to 10th November 1972 on 9 collectors, and 16th September 1974 to 20th September 1974 and 15th October 1974 to 18th October 1974 on 3 collectors, and the volume of overnight water flow into the area are given in Table 1. Statistical analysis of the data from each period showed that there was no significant relationship between the volume of overnight water flow into the area and the number of animals settling on the collectors ($P > .05$, in each case).

Phillips and Olsen (1975) observed the swimming behaviour of the puerulus stage at night using under water lights. They also observed that during the night surges of water coming over the reef into Seven Mile Beach (the result of wave action) brought numbers of puerulus into the area. However, there appeared to be no correlation between apparent water flow and the number of puerulus seen on different nights.

These data indicate that at the time of settlement the number of puerulus entering the Seven Mile Beach area is not related to the volume of water flow into the area, but that the puerulus larvae swimming into the area during the night may make use of the incoming water currents.

TABLE 1

CATCHES OF THE PUERULUS STAGE AND WATERFLOW INTO SEVEN MILE BEACH, W.A.

	Date	Number caught on 9 collectors	Relative overnight water flow, 1800-0600 hours each night
1972	3- 4.xi.72	0	.6038
	4- 5.xi.72	3	.7440
	5- 6.xi.72	3	.6296
	6- 7.xi.72	9	.6353
	7- 8.xi.72	13	.4310
	8- 9.xi.72	7	.7848
	9-10.xi.72	2	.1258

	Date	Number caught on 3 collectors	Relative overnight water flow, 1800-0600 hours each night
1974	15-16.ix.74	49	1.392
	16-17.ix.74	30	1.664
	17-18.ix.74	26	1.491
	18-19.ix.74	10	1.519
	19-20.ix.74	18	1.104
1974	14-15.x.74	15	1.060
	15-16.x.74	16	.787
	16-17.x.74	20	.681
	17-18.x.74	6	1.002

New Moon 6.xi.72
16.ix.74
15. x.74

COMPARISON OF THE CATCHES ON THE COLLECTORS AND *MOONLIGHT INTENSITY* AT SEVEN MILE BEACH

TABLE 2

Night	Number caught on six collectors	Moonlight intensity corrected for cloud cover (% of intensity of full moonlight)
24/25.ix.70	0	< 1
25/26.ix.70	0	< 1
26/27.ix.70	0	< 1
27/28.ix.70	9	< 1
28/29.ix.70	11	
29/30.ix.70	3	
30.ix/1.x.70	1	Dark phase
1/ 2. x.70	4	
2/ 3. x.70	1	
3/ 4. x.70	4	< 1
4/ 5. x.70	2	< 1
5/ 6. x.70	4	< 1
6/ 7. x.70	2	4
7/ 8. x.70	2	9
8/ 9. x.70	0	15

New moon 30.ix.70

TABLE 3

Night	Number caught on nine collectors	Moonlight intensity corrected for cloud cover (% of intensity of full moonlight)
30.x/1.xi.72	0	< 1
1/ 2.xi.72	0	< 1
2/ 3.xi.72	0	< 1
3/ 4.xi.72	0	< 1
4/ 5.xi.72	3	
5/ 6.xi.72	3	Dark phase
6/ 7.xi.72	9	
7/ 8.xi.72	13	< 1
8/ 9.xi.72	7	< 1
9/10.xi.72	2	< 1
10/11.xi.72	2	< 1
11/12.xi.72	2	3
12/13.xi.72	0	6
13/14.xi.72	0	9
14/15.xi.72	0	14
15/16.xi.72	0	19
16/17.xi.72	0	23
17/18.xi.72	0	28
18/19.xi.72	0	33

New moon 6.xi.72

Effects of Moonlight Intensity on Settlement

Settlement of the puerulus stage on the collectors normally occurs between two or three days before and up to a maximum of eight days after the new moon, the mode of the data being close to the night of the new moon. The data on the daily catches of the collectors were examined to determine whether settlement commences and/or ceases when a threshold level of moonlight intensity is reached.

Comparison of the number of puerulus caught on the collectors and the moonlight intensity in September/October 1970 and November 1972 are given in Tables 2 and 3. The threshold intensity appears to be near to 10% of full moonlight, and it is clear that settlement of the puerulus commenced with the start of the dark phase of the moon and ceased as soon as the moonlight intensity rose above the threshold level.

Settlement of the puerulus on the collectors is then confined to the period of new moon, with most settlement occurring during the period of no moon and all settlement ceasing when the moonlight intensity is above about 10% of full moonlight.

DISCUSSION

From these results it is apparent that there is no relationship between the number of puerulus settling on the collectors and the water flow into the Seven Mile Beach area, either as a cyclic flow related to moon phase, or from night to night at the time of settlement. The puerulus stage may make use of the incoming water flow to aid them in swimming into the area, during the nights on which settlement occurs.

It appears that moonlight intensity normally prevents settlement on the collectors at nights other than near the time of new moon. However, it is apparent that since settlement did not commence until after the start of the dark phase, although the light levels in the last four nights of the last quarter of the moon were extremely low, that light intensity alone does not fully describe the pattern of puerulus settlement. The manner in which the moonlight acts on the puerulus to prevent settlement is unknown, as are also the reasons for the daily variations in the numbers settling on the collectors at each monthly period.

There are two likely alternative explanations for the observed pattern of settlement on the collectors. Puerulus larvae may be entering the Seven Mile Beach area throughout the month, and moonlight and/or the effects of yet unidentified factors, may prevent the puerulus settling on the collectors except near the time of new moon, i.e., settlement could still be occurring in the area throughout the rest of the month, but not on the collectors. The second explanation is that the puerulus only enter the Seven Mile Beach area around the time of new moon, and that the settlement recorded on the collectors is a true reflection of the settlement occurring in the area.

In support of the second hypothesis, recent sampling of the water over the continental shelf, offshore from Seven Mile Beach, during July to November 1974 (CSIRO unpublished data) showed that 48 puerulus stage larvae were caught in 71 hauls around the time of new moon, compared to 1 puerulus in 48 hauls around the time of full moon. Phillips and Rimmer (1975) successfully sampled the surface plankton for the puerulus stage inside the Seven Mile Beach reef areas around the time of new moon in November 1971 and 1972. Sampling with the same equipment at the time of full moon in November 1971, and during daylight in November 1971 around the time of new moon, was unsuccessful.

Increased predator effectiveness near the times of full moon may account for the low numbers of animals successfully crossing the shelf and settling about the time of full moon, or alternatively the settlement pattern may be one which is evolved to reduce predator pressure on the settling stage. Animals which enter the Seven Mile Beach area during the night and fail to successfully settle, either on the collectors or on natural substrates, before daylight are presumably predated during the day.

Further studies of the behaviour of the puerulus stage, including an examination of the spectral sensitivity may assist our understanding of the settlement pattern. Experimental approaches which have been tried, have been unsuccessful because of an inability to make the puerulus stage swim in response to stimuli after settlement. The act of settling elicits a rapid metamorphosis into the next development stage of the life cycle.

The spectral sensitivity of the puerulus stage, the location of the puerulus during the part of the lunar cycle when settlement does not occur, and its location during daylight at time of settlement, are all aspects that warrant further study.

Acknowledgements

Mr N.A. Campbell, Division of Mathematics and Statistics, CSIRO, for assistance and advice in the treatment of data. Dr G.R. Cresswell who collected and processed the data on water currents. Officers of the Department of Fisheries and Wildlife of Western Australia assisted with the field programmes.

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