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LONGSHORE MOVEMENTS OF THE SAND CRAB, *EMERITA ANALOGA* (DECAPODA, HIPPIDAE)

BY

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INTRODUCTION

In a recent study of the sand crab, *Emerita analoga* (Stimpson, 1857), Efford (1965) concluded that aggregations remained in place on the beach except for tidal movements. On the basis of his evidence he deduced that aggregations are biological in nature and not determined by physical conditions. He was unsuccessful, however, in an attempt to find the biological stimulus. Various workers (Cox & Dudley, 1968; Efford, 1967; Osorio et al., 1967), having assumed that sand crab populations are stationary, have generated growth curves on the basis of modal size groups. Observations of distribution led us to question whether sand crab populations are static in regards to longshore movement. To explore these problems further we designed experiments by which we could follow individuals within an aggregation.

In the Santa Barbara area currents are predominantly eastward with an accompanying eastward movement of sand (Inman & Quinn, 1952; Johnson, 1956; Collins & Le Mehaute, unpublished). Barnes & Wenner (1968) suggested that changing ocean currents and shifting sand along the beaches may affect the distribution and behavior of the sand crab. The present study tests the hypothesis that sand crabs move with longshore currents.

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METHODS

This study was made on the eastern half of the beach bordering Isla Vista and the University of California at Santa Barbara between Coal Oil Point and

Goleta Point. A total of 4500 linear feet of east-west beach was used throughout most of the study, especially the 3000 feet immediately west of Goleta Point. The study was made from the last week of June through the middle of August, 1968.

Crabs were sampled for with a commercial sand crab trap purchased locally. The trap came equipped with ½ inch mesh hardware cloth. Most crabs used in the study were at least 1 inch long.

Preliminary work included testing various marking techniques. The only marking technique found in the literature is that of Jones (1936) in which he tied a thread approximately one foot long to the front leg of *Emerita emerita* (L.). We tested this method, but found that some of the crabs slipped off their threads overnight.

Attempts to color-mark with fingernail polish, crystal violet stain, and 2 brands of waterproof felt-tip pens were all at least partially unsuccessful. We felt that the lack of success was due to difficulty in drying the carapace before marking.

A notching method, as used by Gangwere, Chavin & Evans (1964) on cockroaches, was tested and found quite suitable for sand crabs. As many as 3 notches cut in the side of the carapace with cuticle clippers did not seem to affect the crabs adversely, although no more than 2 notches were cut in any one crab in our study. We could notch crabs at a rate of 100 per man-hour. Sampling for recoveries was done with the commercial crab trap.

The 3000 feet length of beach made sampling for notched crabs difficult. After one week marking was changed to one foot threads sewed through the side of the carapace. We used one color for one release point on one day with a different color for each day and point. Sampling consisted of looking for threads in the wave-wash area each day thereafter. Table I gives a breakdown of thread recoveries by thread color. Recovery correlated well with the ease of visibility. We could thread crabs at a rate of 50 per man-hour with 2 persons working.

TABLE I

Recoveries of marked crabs. The color breakdown is given for threads

Marking method	No. marked	Recovered No.	Recovered %
Notching	1520	39	2.5
Threads	1370	84	6.1
white	10	0	—
black	10	1	10.0
nylon	150	0	—
green	150	3	2.0
blue	150	7	4.7
red	150	15	10.0
yellow	150	17	11.3
pink	300	9	3.0
orange	300	32	10.7
Thread + cork	18	11	61.1

Near the end of the study threads 2 feet long were sewed and tied to 18 crabs. A piece of cork roughly the size of a pencil eraser and painted red was tied to the other end of each thread. Table I shows this marking technique to be superior to the others tested in terms of recovery per cent although this method is probably a short term method.

We checked the molting rate to determine how long a marked individual might be expected to retain its mark. We kept 2 groups of crabs in the laboratory for a week each and checked them for shed carapaces each day. July 8, 156 crabs were collected and 250 on August 6. In addition, the percentage of crabs caught in the field that were freshly molted was noted for a few weeks.

We photographed the cliff face along the length of beach utilized. We then measured the beach starting at the east end and marked the photographs every 50 feet. By referring to features of the cliff face it was easy to locate the corresponding point on a photograph and estimate its distance from the zero point to the nearest 5 feet. Experience indicated results were repeatable within about 5 feet, usually within 2 feet or less.

During part of the study particular release points were used corresponding to prominent features of the cliff face. In some cases crabs were collected randomly along the beach and released at a given point after marking. In other cases animals were collected only to the east or only the west of the release point, mostly the latter. During part of the study animals were collected only from one aggregation and released back into that aggregation after marking. The location of the aggregation was noted.

One group of 8 cork-marked crabs (table IV) was watched for one hour after release. After an intervening period of 2 hours the crabs were watched for an additional 1-1/4 hours. We searched for them on the following days as usual.

Shoreline currents (table V) were measured with the aid of a light-weight plastic practice golf ball with holes in it. The ball floated under the surface of the water. The ball was thrown into the surf at a given point and followed until it beached at which time we recorded the time and distance from point of origin. The ball was usually thrown into the water from 1 to 6 times for a total time in the water of 20 to 30 minutes (range of 4½ to 65 minutes). It was tossed back in the water either where beached or at another spot. The ball was used for two periods of 5 and 9 consecutive days. Though the ball was in the surface currents and the crabs swim in the bottom currents, Inman & Quinn (1952) demonstrated that the two currents are similar in velocity and identical in longshore direction.

The positions of 6 aggregations were noted for 14 days in a 16 day period. This was done to determine whether or not aggregations at this beach remained in place as did those studied by Efford (1965).

Animals seemed to act much the same no matter how marked and regardless of site caught or released. Animals caught and released without marking appeared, as far as could be seen, to act the same as marked animals. On these bases we assumed that marked animals behaved normally after their initial escape action.

RESULTS

Field results indicated that about 3% of the animals molted each night. Laboratory results indicated an average of only 1.1% (July 8) to 0.7% (August 6) molted each 24 hours. All of these figures are for large animals only. Boolootian et al. (1959), reported an egg carrying period of 29 to 32 days. All of this evidence indicates that carapace marks could last up to a month under favorable circumstances.

A total of 114 returns will be considered. Of these, 99 were unquestionable as to time and distance covered by the crab. The other 15 could have been released at either of 2 times and/or places and the minimum values were used. Table II shows the recoveries each day after release and the distance from the release point. Each release was counted as day zero and point zero for table II. Distances marked *w* were recovered west of their release point, all others were east.

The overall mean eastward movement of the 114 crabs was 47.6 feet per day. The median movement was 30 feet per day eastward. One half of the crabs moved 40 feet or less per day in any direction. One quarter moved 15 feet or less per day, one quarter moved at least 90 feet per day. The most rapidly moving crab was one which moved eastward 2275 feet in 5 days, a mean of 455 feet per day.

TABLE II

114 recoveries of marked animals giving days found after release and distance from release point in feet. Those found west of release point are marked with a *w*.

Days	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*18*	*22*	*23*	*26*	*27*
	0	0	0	50	35	10	0	15	75	85*w*	1135	365	570	525
	5	0	0	60	120	15*w*	40	75*w*	505	200*w*		1400		600
	5	0	40	90	185	95	90	110				1960		
	5*w*	5	50	160	275*w*	140	120	170*w*						
	10	10	50*w*	295	360	250	180*w*	220*w*						
	10	30	80	540	460	700	300	350						
	15*w*	30*w*	100	590	2275	760	490*w*	635						
	20	50*w*	140	850			540							
	20	55*w*	160				615							
	30	75	220*w*				620							
	40	75	290				1815							
	50*w*	85	355				2995							
	85	115	385											
	90*w*	120	390											
	100	120	445											
	110	120	450											
	130	125												
	150	170*w*												
	170	175												
	190	220												
	220	240*w*												
	255	245												
		250												
		340												

Table III shows the 32 returns of orange-threaded crabs day by day in relation to the release point. The direction of the prevailing water currents is given for each day. Pictorializing the returns of any other group of threaded crabs would show the same pattern but with smaller numbers.

Table III

Daily returns of orange-threaded crabs. Scale is in feet, zero represents the release point, west is left, east is right. 300 crabs were released August 8. Direction of prevailing longshore currents is given for each day at the left side of the table.

Date	500	400	300	200	100	0	100	200	300	400	500	600	700
8-9		West				1,2,2	1						
8-10		West (weak)			1	3		1					
8-11		West				2 1							
8-12		East (strong)				1	1					1	
8-13		East											
8-14		East					1 1	1					1
8-15	1	East		1		1 1	1		1		1	1	
8-16		East			1		1			1			

The movements of the 8 cork-marked crabs which we followed are shown in table IV. Only those observations are given which demonstrate activity. We made observations for 1 hour and 10 minutes after release, halted for 2 hours, and resumed for an additional 1 hour and 15 minutes. The prevailing longshore currents were eastward during these periods of observation. This aggregation, however, was on a cusp and waves receded in both directions. We also made observations twice on the following day and once 2 days after release. Even though the corks were relatively easy to follow, some animals did disappear and reappear later during the early observation periods.

Table IV

Movements of 8 cork-marked crabs immediately after release and for 2 days after. Zero represents the release point, the scale is in feet. Time is hours and minutes after release.

Time	60	50	40	30	20	10	0	10	20	30	40	50	60	70	80	90	100	110	120
0:00				West			8		East										
:02							6	2											
:08						1	5	2											
:10						2	4	2											
:14						1	1 4	2											
:15						1	3	3											
:25						1	1	3	1				1						
1:10							1	3	2				1						
3:25	1			1				1	1	1	1								
3:55	1			1				1	1	1									
4:10	1			1				1	1	1		1							
4:15	1			1				1	1										1
19:00					1						1							1	
24:30															1				
43:00																		1	

The longshore water currents were quite variable from day to day and from place to place on any given day. E.g., on 3 different days the longshore currents varied from 0 to 41 feet per minute, from 44 to 120 feet per minute, and from 7.5 feet per minute east to 20 feet per minute west. Inman & Quinn (1952) also found inshore currents to be highly variable. Table V gives the mean longshore currents for 14 days. The mean for the eastward currents was 28.5 feet per minute, for the westward currents it was 5.1 feet per minute. The net movement for the time measured was 15.4 feet per minute eastward.

TABLE V

Mean longshore currents in feet per minute.

Date	Velocity	Direction
7-29	60.2	East
7-30	16.7	East
7-31	14.2	West
8- 1	25.3	East
8- 2	9.3	East
8- 6	1.7	West
8- 7	10.0	East
8- 8	10.3	West
8- 9	1.2	West
8-10	13.0	West
8-11	72.5	East
8-12	17.7	East
8-13	21.2	East
8-14	23.3	East
Net	15.4	East

TABLE VI

Daily distribution of 6 aggregations (designated by letters). Distances are in feet from a zero point. Other (?) aggregations which appeared later are shown between columns. A dash indicates no visible aggregation in the vicinity.

Day	A			B				C	D	E	F
1	0			105				355	405	435	555
2	0			—	180	210		355	—	—	—
3		30	50	105			315		420	445	525
4	—			105				—	—	—	—
5	0			105				355	—	465	555
6	—			—				—	—	—	—
7	—			—				—	—	—	—
9	0			125	175			355	—	450	565
10	—	40		120				355	405	455	560
11	0			—	155			355	—	435	570
13		25		—				355	405	425	—
14	—			120				355	—	—	—
15	0			105				—	405	435	555
16	—			—				—	—	—	—

The 6 aggregations observed seemed to maintain their positions along the beach fairly regularly with some lateral movement (see table VI). More noticeable than movement was the apparent disappearance and reappearance of all aggregations. The most any single aggregation seemed to be present was on 8 of the 14 occasions. Aggregations were generally only visible when small cusps were present on the beach. The aggregations were on the sides of the cusps.

DISCUSSION

The three successful marking methods used in this study each have advantages and disadvantages. Notching was the most rapid method of marking and yielded returns much longer than the other two methods. However, sampling was slow and disturbed the animals. Corks were easily seen without disturbing the animals and yielded a high percentage of returns, but preparation and marking time were long and marked animals soon disappeared. The last may reflect in part the small number of crabs used. In general, threads sewed to the carapace constituted the best marking method for this study. We could see threads without disturbing the crabs; marking time, percentage of returns, and length of time of returns were all intermediate between the other two methods used.

Net movement of crabs and water were both to the east. Both were variable in terms of speed and direction. This is illustrated by tables III, IV and V. According to MacGinitie (1936) crabs make mass movements in and out with the tide about once per hour. We observed that, at least under some tidal conditions, the animals do not follow the tide all of the way out. Instead, they migrate part way out, stop moving and feeding, and wait for the tide to come back in before resuming their activities. Hypothetically, if a crab swam for about 10 seconds each time it migrated and if it migrated once per hour with the tide about 18 hours per day, its total swimming time would be 3 minutes per day. The net movement of crabs eastward per day was approximately the same as the net movement of water eastward in a 3 minute period during our study.

Marked crabs were generally put back in the sand near the top of the wave wash area. Several were observed on different days as they swam out with a wave. Nearly every animal observed swam with the wave in whatever direction the water was moving. This was best seen when cork-marked crabs were used as illustrated in table IV. These observations and the general results of the experiment indicate that crabs move with the longshore currents. Because net current movement is eastward, net crab movement is eastward. Another observation which bears this out is that there seems to be an accumulation of animals at the east end of the beach on the west side of Goleta Point. This accumulation of animals at the east end of the beach seems to be born out by an ongoing study at another beach (Knapp, unpublished).

Because the individual crabs move but the aggregations do not appear to move laterally along the beach, the aggregations must be made up of an ever-changing set of crabs. If the aggregations are made up of different individuals from day to day, this raises the question of whether the aggregations have a biological or a physical basis. Efford (1965) ruled out a physical basis; however, our study of movement and the association of aggregations with cusps is very suggestive of a physical basis for aggregation formation.

In view of the data presented we strongly question the validity of growth curves generated on the assumption that sand crab populations are stationary. It is easy to conceive that a population sampled in one place may have moved many miles away within a few weeks time. Barnes & Wenner (1968) indicate that the population structure of the species differs from beach to beach and that an aggregation is not necessarily characteristic of the entire beach population. This may indicate that different size classes have different migration rates.

ZUSAMMENFASSUNG

Wir haben Markierungsmöglichkeiten für Sandkrabben (*Emerita analoga*) geprüft und entdeckten 3 brauchbare Methoden. Auf dem Rückenschild angenähte Fäden erwiesen sich als die wirksamste Methode mit Rückfangraten von 6,1 Prozent. 114 bezeichnete Sandkrabben wurden 1 bis 27 Tage nach ihrer Freilassung östlich und westlich des Aussetzungsorts mit einer durchschnittlich östlichen Versetzung (Wanderung) von 47,6 Fuß pro Tag wiedergefunden. Die Durchschnittsgeschwindigkeit der Wasserströmung betrug 15,4 Fuß pro Minute ostwärts. Die Ansammlungen neigten dazu, in der gleichen relativen Lage (Verbindung mit Sandspitzen) zu bleiben. Die ostwärts gerichtete Entfernung einzelner Sandkrabben deutet darauf hin, daß diese eher eine physikalische als eine biologische Ursache hat. Wir bezweifeln die Gültigkeit von Wachstumskurven, die auf der Annahme beruhen, daß der Sandkrabbenbestand seßhaft bleibt.

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