Helgoländer wiss. Meeresunters. 24, 151–156 (1973)

The mode of dislocation of *Astropecten aranciacus*

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KURZFASSUNG: **Die Dislokationsweise von *Astropecten aranciacus*.** An der Nordküste Sardiniens wurden auf einer Sandfläche in 8 m Tiefe Exemplare des Seesterns *Astropecten aranciacus* einzeln während einer 30minütigen Beobachtungsdauer verfolgt. Jede Minute steckte ein Taucher eine numerierte Steckmarke eine Handbreite hinter dem sich fortbewegenden Seestern in den Sand. Nachher wurden die Wege vermessen. Auf diese Weise wurden 23 Seesterne verfolgt. Die Auswertung der Beobachtungsdaten erbrachte Aufschlüsse über Wegrichtung und Richtungsänderung, Geschwindigkeit der Fortbewegung, Häufigkeit und Dauer des Anhaltens, Einfluß der Sandkorngröße auf Haltefrequenz und Geschwindigkeit der Fortbewegung und Einfluß des Verlaufs und der Höhe von Rippelmarken auf die Wegrichtung.

INTRODUCTION

Burla et al. (1972) investigated the mode of dislocation of the echinoderm *Astropecten aranciacus*. During the night, they recorded the locations of tagged sea stars at two-hour intervals. The animals moved 1.8 m per hour on the average, and they changed their direction several times during the night. It remained unknown, however, what happened during the two-hour intervals. The present report intends to close this gap in our knowledge. We were mainly interested in the actual speed over a continuously surveyed track, in changes of the velocity during the period of observation, and in the pattern of changes in direction.

METHODS

The observations were made in the Golfo Pevero, South of Porto Cervo on the NE-coast of Sardinia, by means of SCUBA diving. The study area was on a level bottom covered with sand, at 7 to 9 m depth. We followed a total of 23 sea stars for 30 minutes each. At intervals of one minute, numbered marks were pushed into the sand about 10 cm behind the sea star. Afterwards, we triangulated the distances between the marks using a known distance for comparison. Following our notes, we retraced the path of each sea star. At the end of each observation period, the radius R (length of one arm from its tip to the center of the body) was measured for each traced sea star.

The sandy area was divided into two parts: one was covered with fine sand where the grain diameter was below 1 mm, the other part contained coarse sand of an average grain size of 3 mm. Of the sea stars tracked, 11 were on the fine-grained sand, the other 12 on the coarse-grained part.

The dives were made from 30 December, 1971 to 27 January, 1972, always between 15.30 and 16.30 hrs.

RESULTS

Distribution of stops and moving periods

Figure 1 shows the paths of three sea stars. Squares designate locations where the animals remained for one or several minutes (number adjacent to square). The pattern is characteristic for all sea stars observed: they do not wander continuously, instead they stop here and there. During these stops, they bury their body into the sand, often one or two arms as well. On fine sand, there were an average of 2.5 stops per 30 minutes per animal, 6 stops on coarse sand. On both types of sand, a stop lasted about 2 minutes on the average. The longest recorded stop was 8 minutes.

Subtracting the average stopping time from the 30 minute observation period gives the average running time. This was 82 % of the total observation period on fine sand, 63 % on coarse sand.

Velocity

On fine sand, the average velocity of 11 sea stars was 12 cm/min. It was computed from the distance that each animal covered in 30 minutes. This includes the periods when the animal did not move. The sea stars differed greatly in their average velocity: the fastest two animals moved seven times faster than the slowest individuals. Most recorded speeds were within 0 and 20 cm/min. The highest instantaneous velocities were 50, 80, 120 and 140 cm/min. They were performed by two animals, but these speeds were each upheld for one minute only and at best were registered three times within 30 minutes.

On coarse sand, the mean velocity of 12 sea stars was only 5 cm/min. Most animals moved at speeds of 0 to 10 cm/min. One single animal attained a record speed of 40 cm/min, but this lasted only for one minute.

By omitting the periods of no motion, we compute mean velocities of 15 cm/min for the 11 animals on fine sand, and 8 cm/min for the 12 animals on coarse sand.

The smallest sea star had a radius (R) value of 5 cm, the largest R was 15 cm. Using a simple linear regression, we checked whether velocity depends on body size. For the 11 animals on fine sand we computed a regression coefficient $b = 0.79$, for the 12 animals on coarse sand $b = 0.04$. Both values are not significantly different from zero.

Direction of movement

Most of the sea stars moved in fairly straight paths (A and B in Fig. 1). In three animals the track formed a loop, whereby the directions at the beginning and at the end were similar (C in Fig. 1). Only 2 sea stars returned to the vicinty of their starting point.

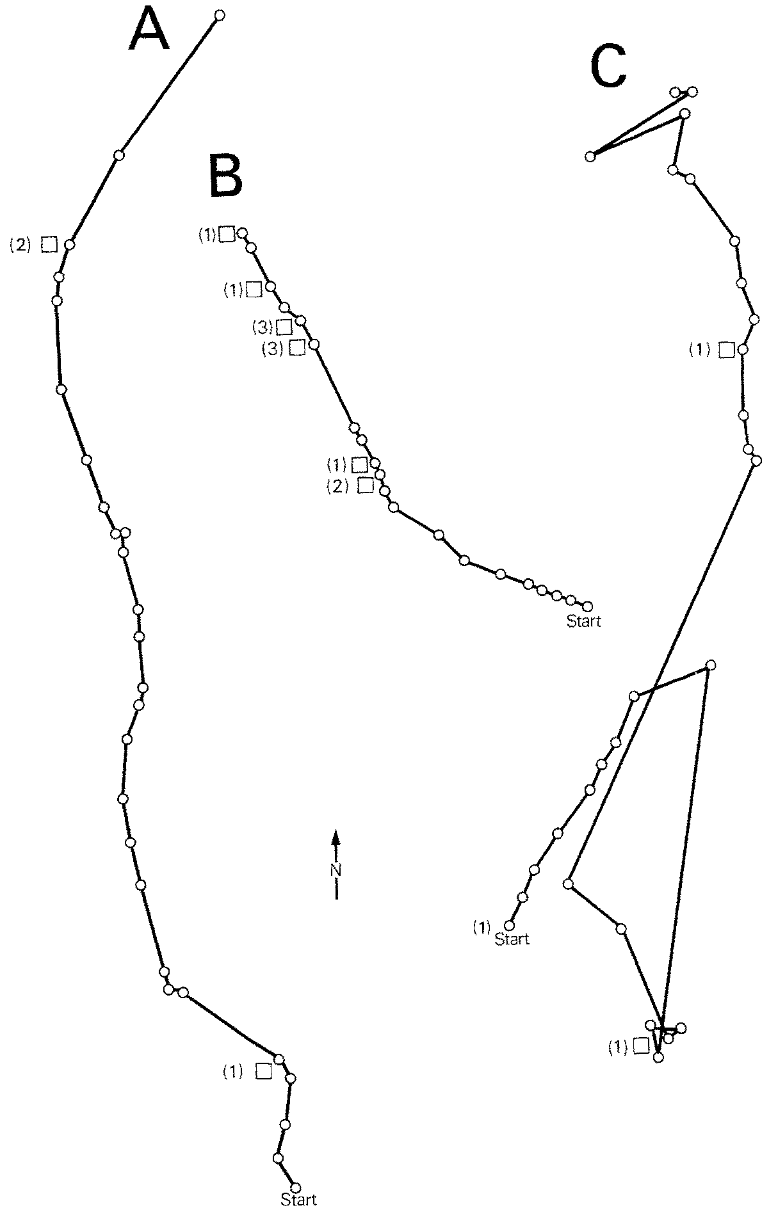

Fig. 1: *Astropecten aranciacus*. 3 selected tracks of 30 min duration. Small circles show position at one-minute intervals. Squares indicate locations where sea stars stopped; the duration of each stop in min is given in parenthesis. Track A is from a fast-moving animal on fine sand, track B from a slow moving animal on coarse sand. Both animals maintained their direction. Track C contains a loop, but directions at the beginning and at the end correspond. In the middle section, crossing the beginning of the loop, is the record distance of 1.4 m which was covered in 1 min. All 3 sea stars moved northward

The directions of the movement were recorded at intervals of 5 minutes. A clockwise change in direction was considered positive, a counter-clockwise change negative. For each animal we obtained 3 to 6 angles between successive parts of their

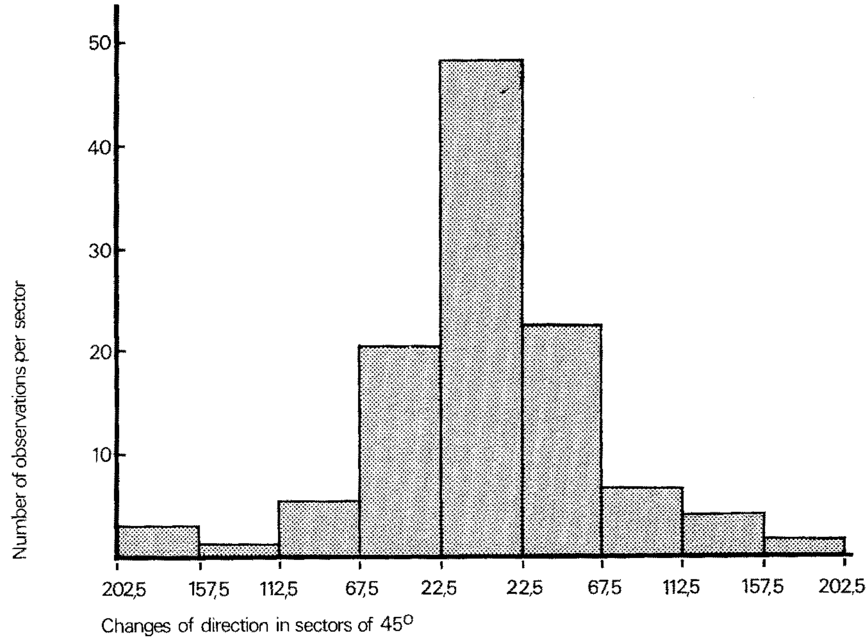

Fig. 2: *Astropecten aranciacus.* Change of direction within a track; totalled for 23 sea stars. Abscissa: angle between two subsequent sections of the tracks; each section of 5 min duration, grouped into sectors of 45°. Ordinate: number of observations for each sector. An angle of 0° means no change in direction. A clockwise change of direction was called positive, counter clockwise negative. The peak in the middle section of the abscissa means that most sea stars maintain their course. The symmetrical shape of the histogram shows that changes of direction to the left and to the right were about equally frequent

track. Using sectors of 45°, the zero sector is the most frequent (Fig. 2). The middle of this sector represents "no change in direction", the angle of value zero; it is obvious that there is a tendency to maintain a direction once chosen.

On the fine sand, the crests of the ripple marks were 5 to 8 cm high. They did not seem to influence the direction of movement. In the area of coarse sand, however, the crests were up to 25 cm high. Five of the sea stars moved along in a ripple mark valley without traversing a crest. Four of the animals moved along parallel to a crest on its slope. Three of the animals moved diagonally to the ripple mark pattern, and changed their direction of traverse a crest at a right angle.

Summing up the distances covered during each of the one minute intervals, we get the total distance (W) run by a sea star in 30 minutes. On fine sand, the average total distance was 3.7 m, 1.6 m on coarse sand. Connecting the start and end positions of a sea star's path with a straight line gives the distance (D). W is equal to or only slightly larger than D, if an individual moved in a straight line. But W increases relative

Table 1

Astropecten aranciacus. Distribution of the ratio W/D (see text)

	W/D	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	>2	>3
Number of specimens	on coarse sand	2	1	2	1	1	–	–	1	1	1
	on fine sand	–	3	–	–	2	1	1	–	2	2

to D the more the path deviates from a straight line. Thus the ratio W/D characterizes the overall degree to which a sea star maintains a given direction (Table 1).

The means of the ratio W/D were 1.9 on fine sand, 1.6 on coarse sand. Although the animals covered longer average distances on fine sand than on coarse sand, the grain size of the sediment does not seem to influence the ratio W/D. We conclude that the movement pattern is about the same on both types of sand.

DISCUSSION

The speed of movement varied mainly between 0 and 20 cm/min for the 23 sea stars observed. Romanes & Ewart (1881) recorded higher speeds (30 to 60 cm/min) in the laboratory. Weber (1965) estimated 50 cm/min while diving off Sardinia. According to Feder & Christensen (1966), all these reports probably do not represent the average of the cruising speed, but concern a maximum which occurs only "when they have scented food or in order to avoid an immediate danger". Such maxima speeds, which occur only for a short period of time, were also recorded in our observations. The observation on *Asterias forbesi* by divers in the Long Island Sound is characteristic: they recorded speeds of 15 to 20 cm/min (Loosanoff 1958), while in the laboratory speeds of 25 to 35 cm/min had been measured (Galtsoff & Loosanoff 1939). It is likely that the same phenomenon holds for our observations on *Astropecten aranciacus* as for *Asterias forbesi:* animals held under artificial conditions move faster than under natural conditions.

The distance W is almost twice as long as D, the distance between the first and the last location. Burla et al. (1972) measured at two-hour intervals a D value of 3.6 m. Their investigations were on rather coarse sand. For a D of 3.6 m we would expect a value W = 6.3 m. This fits closely with our measurements of 1.6 m/30 min or 6.4 m/2 h. This indicates that sea stars have a similar pattern of movement over short time periods and over longer ones.

It is likely that both types of sand present different conditions in several respects; not only for the mechanics of locomotion of the sea stars, but also with respect to the trophic contents of the sediments.

Several questions remain unanswered. The majority of the animals moved from south to north. This means for the particular coastal location that the animals moved parallel to the coastline, parallel to the crests of the ripple marks, and within the same depth zone. It is also possible that there might have been a weak current along the coast always at the same time of the afternoon, and that it might have had an effect. The external conditions were certainly not as homogeneous as they could have been kept in an aquarium. Thus, the animals had several potential possibilities for their orientation. The maintenance of a direction does not have to be due to an endogenous factor, but it may be the result of continuous re-orientation by the sea stars.

SUMMARY

1. The mode of dislocation of the sea star *Astropecten aranciacus* was investigated on 23 individuals at the NE-coast of Sardinia. All were small to medium-sized representatives of the species; their radius (R) varied between 5 and 15 cm. The observations were carried out on 2 level sediments with different sand-grain diameter. Each sea star was followed for 30 min and its locations were recorded every minute.
2. *A. aranciacus* does not move continuously. It stops intermittently for an average duration of 2 minutes. On coarse grained sand, stops occur more frequently than on fine grained sand.
3. The average distance travelled in 30 min was 3.7 m on fine sand, 1.6 m on coarse sand. Including the stops, the cruising speed varied mostly between 0 and 20 cm/min on fine sand, and between 0 and 10 cm/min on coarse sand.
4. Generally, the observed paths were all or partially straight. In accord with this, the ratio W/D between the distance travelled (W) and the shortest between the starting and end position (D) was smaller than 2 for most animals.
5. Small ripple marks (on fine sand) do not seem to influence the direction of dislocation. Single observations indicate, however, that more pronounced ripple marks (on coarse sand) may have an influence.

Acknowledgments. This paper was presented by GEORG RIBI, who took part in the divings together with BEN PABST and HEINZ MAAG. Professor HANS BURLA helped with the manuscript, and ROBERT FURRER translated it into English. PIERRE BRAUCHLI drew the figures. The work was supported by the "Karl-Hescheler-Stiftung" and the "Georges und Antoine Claraz-Schenkung".

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