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Daily activity pattern of *Astropecten aranciacus* (Echinodermata: Asteroidea) and two related species under natural conditions

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ABSTRACT: Daily activity patterns of *Astropecten aranciacus*, *A. bispinosus* and *A. jonstoni* were investigated by means of SCUBA diving. The three species generally showed two peaks of activity, at dawn and dusk. However, the activity pattern was variable, depending upon site, depth and season. Two populations of *A. aranciacus* showed only one daily peak at certain times of the year. These peaks were at night in one case, at noon in the other. Light appears to be an important factor governing the activity pattern.

INTRODUCTION

The daily activity patterns of individual species within a community may be influenced by a variety of interspecific relationships. For instance, the risk of falling prey to a diurnal predator can be reduced by adapting a largely nocturnal way of life (Ebling et al., 1966). A number of other environmental factors may also affect the activity pattern.

The two sea-stars species, *Astropecten aranciacus* and *A. bispinosus*, coexist at various localities along the Mediterranean coast (Ribi et al., 1976). Competition for food appears likely on the Costa Colostrai in Sardinia, Italy (Ribi et al., 1977). There also exists a predator-prey relationship, as *A. aranciacus* frequently feeds on the smaller *A. bispinosus*. Such circumstances may lead to local extinction of the "inferior" species, unless it has at its disposal some kind of refuge, in terms of habitat, diet, activity pattern, etc. A certain degree of ecological separation between the two species of sea stars has been established with respect to habitat and diet (Ribi et al., 1977). As *Astropecten* species show characteristic activity patterns in the laboratory (Mori & Matutani, 1952), comparative studies on this aspect have been initiated under natural conditions. It soon became evident that the activity pattern of *A. aranciacus* varied considerably; attempts were therefore made to identify the factors influencing it.

METHODS

Data were collected between September 1971 and August 1976 in Sardinia and along the Mediterranean coast of France. Observations made at various places are listed in Table 1; the locations concerned are described elsewhere (Ribi et al., 1976).

Sea stars moving about on the sea floor and thus exposed to view were classified as "active", those remaining buried in the sediment as "inactive".

Until 1973 the method introduced by Burla et al. (1972) was applied to determine the activity pattern: on a grid of 20 to 20 m sea stars were counted once every 2 h over a 24 h period. Maximum activity was assumed when sea stars were visible in greatest numbers. The disadvantages of this method were the variable number of sea stars on the grid (due to movement) and the relatively large area to be surveyed by the diver. These difficulties were overcome by maintaining a constant number of sea stars within large enclosures for a few days. As of 1973 only this method was used. The enclosures, each 40 m^2 in area, were made of nylon network held upright by buoys; the lower edge, anchored down by lead, was buried about 5 cm deep in the sediment.

To verify whether the confined sea stars behave naturally we determined the activity patterns on a grid and in two nearby enclosures simultaneously (Line 6 of Table 1).

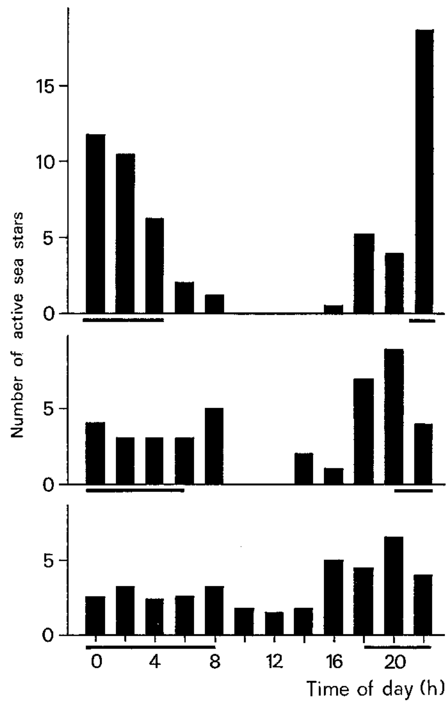

Fig. 1: Activity patterns of *Astropecten aranciacus* near Cannigione at 5-m depth in July (top), March (centre) and January (bottom) (Lines 1, 3, 6 of Table 1). Values for January and July are averages from 4 24-h periods each. In March countings were made during only one 24-h period. Horizontal bars represent the hours of darkness

Most data were collected on *Astropecten aranciacus*, with 38 observation periods of 24 h each. *A. bispinosus* and *A. jonstoni* were observed over 12 and 4 periods, respectively.

On several occasions light intensity and ground swell were measured at the same time as observations were made. Light intensity was determined by using an exposure meter "Lunasix 3" in a watertight case. To measure ground swell, a scaled plastic slab was weighted down on the sea floor. A blade of sea grass, suspended over the slab, allowed estimation of the swell amplitude.

RESULTS

Activity pattern of *Astropecten aranciacus*

Seasonal variation and influence of depth

Figure 1 shows daily activity patterns of *Astropecten aranciacus* at the same place near Cannigione in July, March and January at a depth of 5 m. In July, there was a single marked peak around midnight and no sea stars were active during the middle

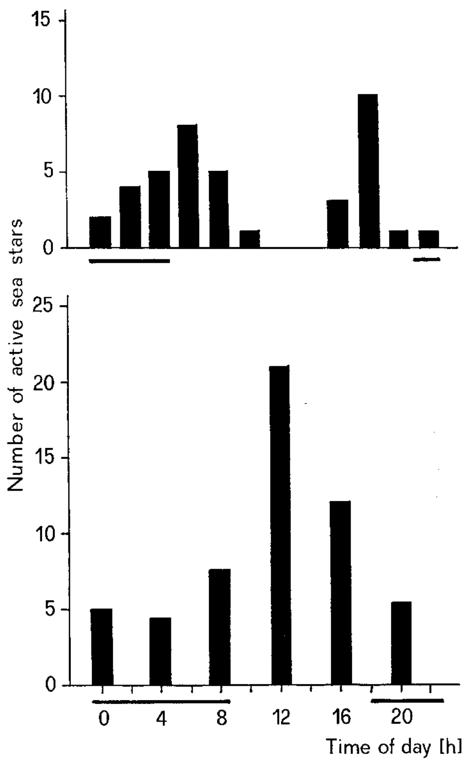

Fig. 2: Activity patterns of *Astropecten aranciacus* in the "Golfo Pevero" at a depth of 9 m in July (top) and January (bottom) (Lines 4, 5 of Table 1). Values for January are averages from two 24-h periods each. In July counts were made during only one 24-h period. Horizontal bars represent the hours of darkness

of the day. In March, the peak was less prominent and the inactive phase around noon was shorter; in January, sea stars were active throughout the day.

Activity patterns recorded at a site 10 km away, but at a depth of 9 m, were different (Fig. 2): in July, *A. aranciacus* showed two peaks of activity at dawn and dusk; in January, there was a single marked peak at noon.

On Costa Colostrai, 200 km south of Cannigione, at a depth of 7 m, differences between summer and winter were less prominent (Fig. 3): in both seasons, the activity patterns showed two peaks. However, the sea stars remained buried for a longer period of the day in summer than in winter.

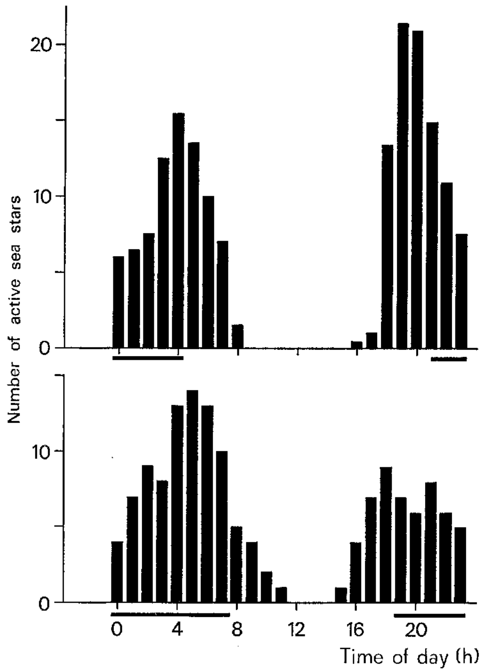

Fig. 3: Activity patterns of *Astropecten aranciacus* at Costa Colostrai at a depth of 7 m in July (top) and in January (bottom) (Lines 10, 11 of Table 1). Values for July are averages from two 24-h periods each. In January counts were made during only one 24-h period. Horizontal bars represent the hours of darkness

To test the influence of depth, we concurrently examined the activity patterns at 5 and 9 m, the two sites being 300 m away from each other (Lines 6 and 7, Table 1). Results are shown in Table 2: at 9 m sea stars were observed at all hours, whereas at 5 m they remained buried at noon.

In summary, the activity pattern of *Astropecten aranciacus* is variable. Nevertheless there is a common feature in the behaviour of the species in all situations: sea stars reduced their diurnal activity with increasing day length and decreasing depth. Since both, depth and day length, influence light intensity on the sea floor, we assume that light is an important factor governing the activity pattern of *A. aranciacus*.

The relationship between number of sea stars counted and light intensity was

Table 1

Periods of data collection in chronological order. Le Lavandou is on the Mediterranean coast of France; the other sites are in Sardinia (Italy). In the column "sea-star species", *a* stands for *Astropecten aranciacus, b* for *A. bispinosus* and *j* for *A. jonstoni.* The numbers of captive sea stars in each enclosure ranged from 8 to 20 individuals

Line	Location	Month	Year	Sea-star species	Depth (m)	Method Grid	Method Enclosure	Number of 24-h periods of obser-vation	Time interval between conse-cutive obser-vations in hours
1	Cannigione	Jul./Aug.	1971	*a*	5	1		4	2
2	Le Lavandou	Sep.	1971	*j*	7	1		3	2
3	Cannigione	Jan.	1972	*a*	5	1		4	2
4	Golfo Pevero	Jan.	1972	*a*	9	3		2	4
5	Golfo Pevero	Jul./Aug.	1972	*a*	9	1		1	2
6	Cannigione	Mar.	1973	*a*	5, 9	1	4	6	2
7	Cannigione	Sep.	1973	*a*	5, 9		4	8	4
8	Cannigione	Sep.	1973	*a, b*	5		3	6	4
9	Costa Colostrai	Sep.	1974	*a, b*	7		16	2	2
10	Costa Colostrai	Jul.	1975	*a, b*	7		4	2	1
11	Costa Colostrai	Jan.	1976	*a, b*	7		3	1	1
12	Costa Colostrai	Jul.	1976	*j*	3		2	1	1
13	Costa Colostrai	Aug.	1976	*a, b*	7		8	1	1

Table 2

Activity pattern of *Astropecten aranciacus* at depths of 5 and 9 m (Lines 6, 7 of Table 1). Each column gives proportions of sea stars active at different times of the day, expressed as percentages of the sum total (n) of active sea stars counted throughout the day. Sea stars were counted every four hours; the bottom row gives mean values calculated from the data collected at 20:00, 24:00, 04:00 and 08:00 h

Time of day	5 m March (n = 50)	5 m September (n = 96)	9 m March (n = 272)	9 m September (n = 80)
12:00	0	0	10	4
16:00	4	8	14	16
20:00 to 08:00	24	23	19	20

Table 3

Spearman's rank correlation coefficients calculated from light intensity and number of sea stars counted. Values in italics differ significantly from 0 at the 5 % level

Line of Table 1	Depth (m)	Month	Year	Numbers of measurements of light intensity	Rank correlation coefficient
3	5	Jan.	1972	8	— *.4688*
4	9	Jan.	1972	21	.3333
5	9	July	1972	6	— .6439
6	9	Mar.	1973	18	— *.6321*
7	9	Sep.	1973	11	— .2864
7	5	Sep.	1973	12	— *.7045*

examined. Because values were not distributed normally, Spearman's rank correlation coefficients were calculated. These were all negative with one exception (Table 3). This suggests that the number of active sea stars tends to decrease with increasing light intensity.

Other factors affecting the activity pattern

The activity pattern of *Astropecten aranciacus* is influenced not only by light, but also by weather: heavy ground-swell forces sea stars to remain buried in the sediment (Table 4).

Moreover, the activity pattern is related to the size of the sea stars. Large specimens spread their activity over a longer section of the day, while smaller ones tend to concentrate their emergence within distinct periods of time (Burla et al., 1972).

Another factor influencing the activity pattern observed appeared to be the time of day when specimens were obtained. Sets of 15 individuals each were collected at 17:00 to 18:00 h and at 22:00 to 23:00 h, respectively, and were placed in separate enclosures. The activity patterns of the two sets were sampled on four days within a period of ten days (Fig. 4): sea stars collected between 17:00 and 18:00 h distributed

Table 4

Number of sea stars observed at different intensities of ground swell. On a grid of 1'200 m^2 situated at a depth of 9 m, sea stars were counted on 8 consecutive days at noon (Line 4 of Table 1). The amplitude of the swell was measured a few cm above the sea floor

Date (January 1972)	Amplitude of swell (cm)	Numbers of active sea stars counted
20	< 10	23
21	< 10	16
22	30	3
23	100	0
24	< 10	19
25	< 10	25
26	50	2
27	< 10	26

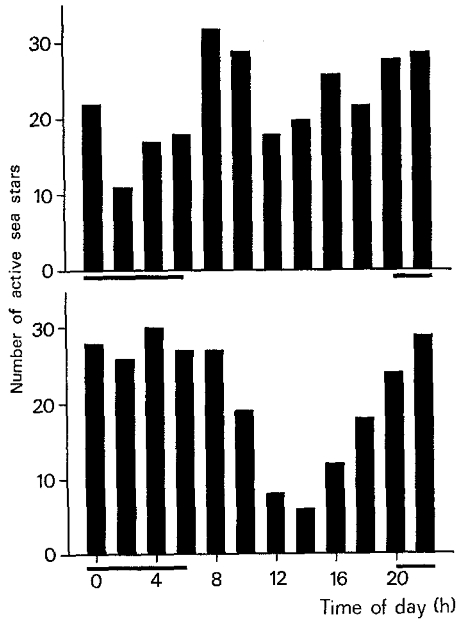

Fig. 4: Activity patterns of *Astropecten aranciacus* collected at different times of the day at the same site (Line 6 of Table 1). Sea stars were collected between 17:00 and 18:00 h (top) and between 22:00 and 23:00 h (bottom). Values are summed up over four 24-h periods each. Horizontal bars represent the hours of darkness

their periods of activity more or less evenly throughout the day, whereas the activity of specimens collected between 22:00 and 23:00 h showed a trough in the early afternoon.

While the activity pattern of *A. aranciacus* varied seasonally (see above), it was very similar to the pattern observed for the same season in different years, as indicated by observations made on Costa Colostrai for three consecutive summers (Table 5, left).

Table 5

Summer activity pattern of *Astropecten aranciacus* and *A. bispinosus* on Costa Colostrai over three year span (Lines 9, 10, 13 of Table 1). The percentages were calculated as in Table 2

Time of day	1974 (n = 75)	1975 (n = 90)	1976 (n =79)	1974 (n = 76)	1975 (n = 86)	1976 (n = 75)
00:00	3	8	1	1	1	0
02:00	7	7	5	1	0	0
04:00	21	14	13	9	0	0
06:00	13	16	18	13	26	3
08:00	3	8	20	21	23	17
10:00	1	0	0	1	3	27
12:00	0	0	0	1	0	0
14:00	0	0	0	0	0	0
16:00	1	0	1	4	8	9
18:00	19	8	16	30	26	31
20:00	28	23	24	18	12	9
22:00	4	17	1	1	1	0

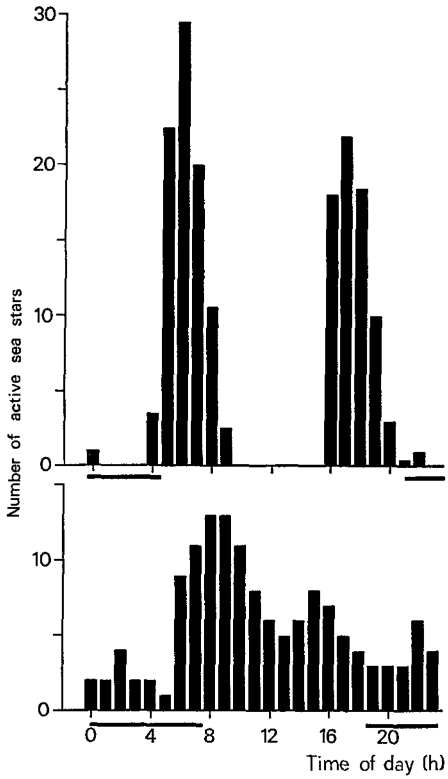

Fig. 5: Activity patterns of *Astropecten bispinosus* at Costa Colostrai at a depth of 7 m in July (top) and in January (bottom) (Lines 10, 11 of Table 1). Values for July are averages from two 24-h periods each. In January counts were made during only one 24-h period. Horizontal bars represent the hours of darkness

Activity pattern of *Astropecten bispinosus*

Figure 5 shows the activity pattern of *Astropecten bispinosus* on Costa Colostrai in January and in July. Sea stars were active at all hours in winter, but only at dawn and dusk in summer. Compared to *A. aranciacus,* peaks of activity were displaced towards midday by about two hours. As with *A. aranciacus,* the activity pattern of *A. bispinosus* remained largely the same from year to year in summer (Table 5, right).

Activity pattern of *Astropecten jonstoni*

Astropecten jonstoni was most active at dawn and dusk; but unlike the other two species, *A. jonstoni* was also active at noon in summer (Table 6).

Table 6

Activity patterns of *Astropecten jonstoni* (Lines 2, 12 of Table 1). The percentages were calculated as in Table 2

Time of day	Le Lavandou (n = 113)	Colostrai (n = 84)
00:00	0	2
02:00	0	2
04:00	0	6
06:00	0	24
08:00	36	11
10:00	15	2
12:00	9	2
14:00	15	8
16:00	25	11
18:00	0	17
20:00	0	12
22:00	0	2

DISCUSSION

Several authors have reported that the activity patterns of various Echinoderm species are influenced by light (Mori & Matutani, 1952; Magnus, 1963; Fenchel, 1965). In Norfolk, *Asterias rubens* exhibited daily migrations between the upper and lower side of rocks. When sea stars were subjected to light and dark periods of four hours respectively, under laboratory conditions, the activity pattern followed the new light regime (Thain, 1971).

Our results from the sea floor are consistent with the findings of Mori & Matutani (1952), who investigated the activity pattern of *Astropecten polyacanthus* in the laboratory. *A. polyacanthus* was also active at dawn and dusk. Light appeared to be the most important factor governing the activity pattern. Physico-chemical factors and food availability were of minor importance.

Two of the *Astropecten aranciacus* populations studied did not always exhibit the commonly observed activity pattern of two peaks per day. During a certain time of the year these two populations showed only one daily peak, which was situated around midnight in one case (Fig. 1, top), at noon in the other (Fig. 2, bottom). The reason for this is not yet clear. The following explanations might be considered: the activity could be governed by two or more superimposed factors. Such a system has been described for *Carcinus maenas*, the activity pattern of which is influenced by the tides and by the time of day (Naylor, 1958). According to the relative position of the tides with respect to the time of day, peaks of activity are enlarged or suppressed. Another possibility could be conditioning, which is known to occur in *Asterias rubens*. Castilla (1971) states that "responses to light of *A. rubens* were found to be different in freshly collected animals and in those which had experienced periods of light and dark adaptation in the laboratory". A seasonal difference in some physiological condition might also explain the variations in activity patterns, and a number of other explanations could be conceived.

Where *Astropecten aranciacus* and *A. bispinosus* coexist, their peaks of activity are separated by about two hours (Figs. 3 and 5), even though their overall periods of activity overlap considerably. The difference in activity peaks may reflect different ecological requirements, or it could be part of a strategy of *A. bispinosus* to avoid contact with its predator *A. aranciacus*; which of these – or other – possibilities applies can not be determined on the basis of the data available.

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