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GROWTH OF JUVENILE *ASTERIAS RUBENS* L. (ECHINODERMATA: ASTEROIDEA) ON AN INTERTIDAL REEF IN SOUTHWESTERN BRITAIN

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Abstract: Growth of annual cohorts in a population of *Asterias rubens* L. on an intertidal reef in Torbay, South Devon, U.K., has been followed for 3 yr. Growth was most rapid in the year following settlement, and in the warmer months of the year. The average increase in diameter over the first year was 28.5 mm, and over the second, 13.0 mm; mean monthly increase in diameter over the whole period of the study was 2.2 mm. Starfish became sexually mature during their second year, when they had reached a diameter of ≈ 50 mm.

INTRODUCTION

The starfish *Asterias rubens* L., including its conspecific *A. vulgaris* (A. M. Clark, pers. comm.), occurs in shallow Arctic to boreal waters on both sides of the North Atlantic Ocean. Its growth was studied originally in populations on buoys (Orton & Fraser, 1930) and rafts (Barnes & Powell, 1951), and in animals confined in aquaria (Vevers, 1949). In these studies the experimental populations apparently enjoyed adequate prey food, and were probably not subjected to the same rigours, in terms of predation, water movement and temperature variation, as would be encountered on a natural reef. More recently, populations occurring on natural reefs and beds have been studied (Hancock, 1958; Nauen, 1978a,b; Nauen & Böhm, 1979; Guillou, 1980).

This paper gives details of a study of growth in a population occurring on a natural reef in southwestern Britain which has received a substantial recruitment of newly-metamorphosed juveniles during each year of the study. Size frequencies and mean sizes of starfish sampled, up to a maximum diameter of 65 mm, have been determined from April 1980 until April 1983. Over the period of the study, one cohort has been followed from settlement to an age of $2\frac{1}{4}$ yr, and at certain times during the study three separate year-classes, all < 65 mm diameter, could be identified.

MATERIAL AND METHODS

Hollicombe Reef, Torbay (Fig. 1), is part of a headland of Permo-Triassic sandstone of the Livermead Formation. At low-water it extends south-southwest from the adjacent

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point for a distance of ≈ 150 m and contains crevices, rock-pools and turnable stones. At monthly low-water spring tides, beginning in April 1980 and continuing until April 1983, the intertidal part of the reef was searched for juveniles of *A. rubens*. Each collection was divided immediately after collection into 1st year (0+, up to 40 mm diameter), 2nd year (1+, from 40 to 60 mm) and 3rd year (2+, up to 65 mm) individuals. Diameter was taken as the distance from one arm-tip to a line joining the tips of the opposite pair of arms. One hundred specimens of 0+ individuals, 50 of the 1+, and 50 of the 2+ were taken at random for measurement. At first appearance of juveniles on the shore after settlement it was sometimes not possible to find the full 100 individuals.

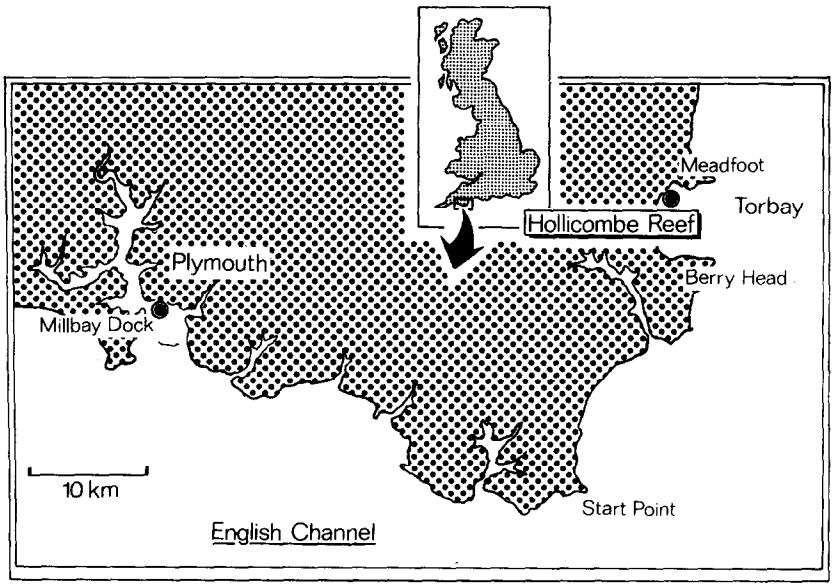

Fig. 1. Map of the Plymouth to Torbay area of south Devon, U.K., to show the location of the sampling site at Hollicombe Reef and the permanent station at Millbay Dock, from which regular sea-water temperature readings were obtained.

Immediately after measurement, and on the same low-tide, all individuals were returned to the collecting area on the reef. At least once each year, in early spring, other reefs in the region of Torbay from Berry Head to Meadfoot, some of which looked superficially similar to Hollicombe in lithology, degree of exposure, etc., were searched for recently-settled juveniles, but in each case only isolated individuals were found at these nearby sites.

At the end of the sampling period in April 1983, which coincided with the time of maximum gonad development in mature individuals, ≈ 25 individual starfish, between 35 and 60 mm diameter, were opened to assess the state of development of the gonads and the time of onset of sexual maturity.

Sea-water temperatures for the period of the study were obtained every 2–3 days from the Plymouth Environmental Health Officer's permanent station 2 m below the sea-surface at the entrance to Millbay Dock, Plymouth Sound (Fig. 1).

RESULTS

Newly-settled juveniles were collected from Hollicombe Reef on 29 July, 1980, 1 September 1981, and 22 July 1982. For the first 3 months of the study only individuals of the current 0+ year-group were measured; then, following the new settlement of recently-metamorphosed juveniles, in July 1980, both year-groups were measured; and again, after the settlement in September 1981, all three age-groups were measured, until the 3rd year (2+) group reached a diameter of ≈65 mm. Size–frequency histograms for 0+, 1+ and 2+ individuals are plotted in Fig. 2.

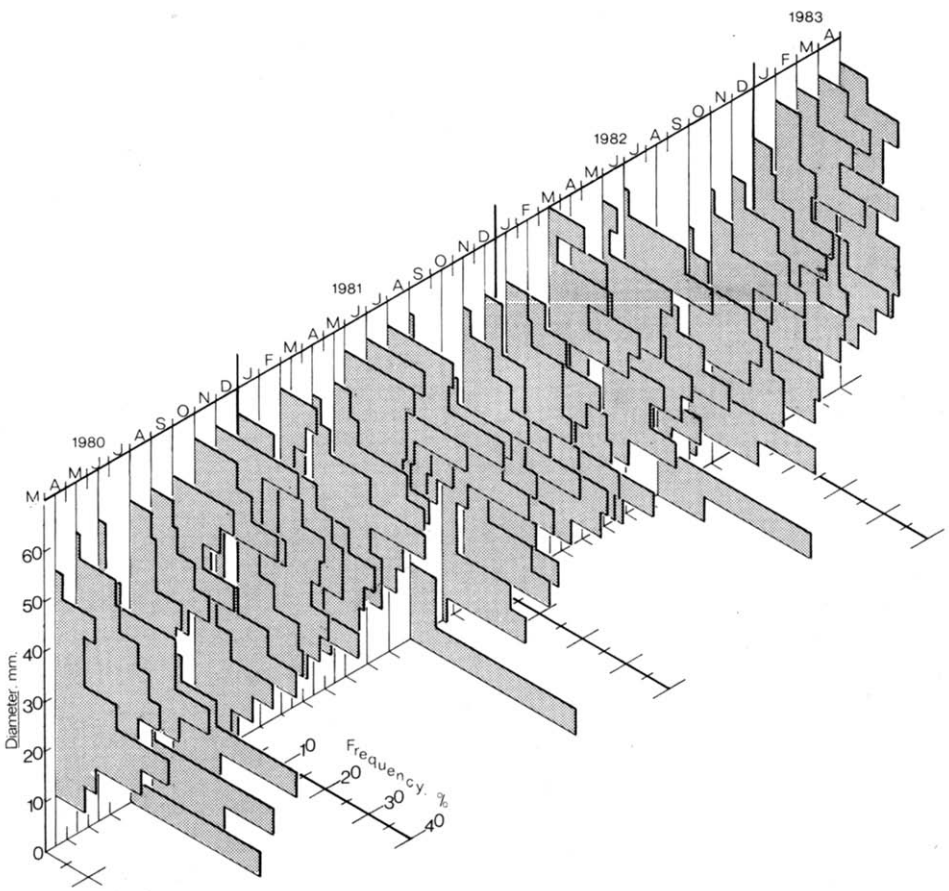

Fig. 2. Isometric projection of diameter frequency histograms at 5-mm intervals for juvenile and young adult *Asterias rubens* from Hollicombe Reef over a 3-yr sampling period.

Crude means of samples of all age-groups are plotted in Fig. 3. The cohort that settled in July 1980 was followed for 27 months. During its 0+ year the mean diameter increased to 34.36 mm, while the contemporaneous 1+ year-group that had settled in 1979 increased by only 14.24 mm (Table I). During its 1+ year the 1980 cohort increased by a further 11.56 mm, while over the same period the new (1981) settlement group increased by an average 22.58 mm. The 1982 settlement cohort was followed for 9 months until sampling ceased in April 1983, when this 0+ year-group had reached a diameter of 20.77 mm.

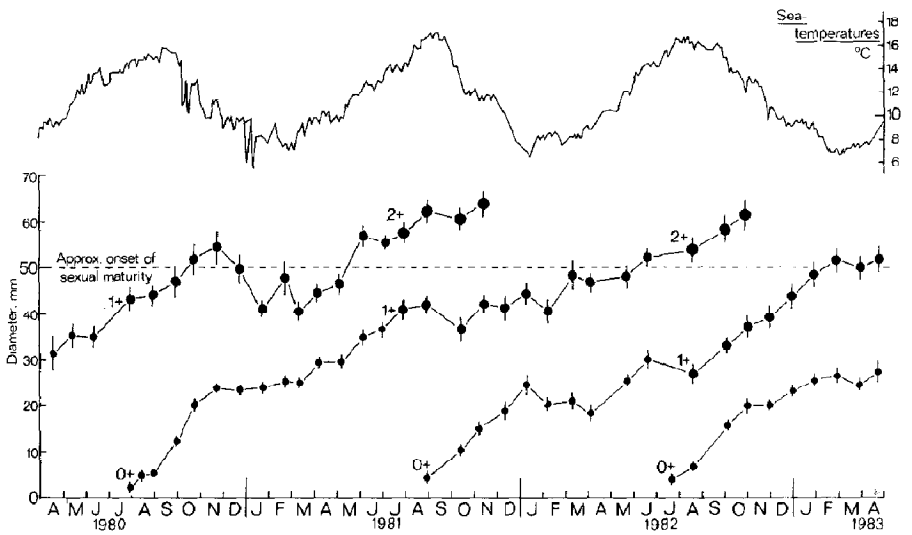

Fig. 3. Mean diameters from approximately monthly samples of annual cohorts of *Asterias rubens* from settlement to the early part of the third (2+) year-group: sample sizes are, 100 for 0+, and 50 each for 1+ and 2+ year-groups; vertical bar-lines are SE; sea-water temperatures (top) are from Millbay dock, Plymouth Sound, ≈75 km from the sampling site.

As shown in Fig. 3, there is a noticeable decline in the rate of increase in mean size over the autumn and winter months, compared with spring and summer; indeed, there is an apparent decrease in mean size over certain periods in all cohorts. In Table I, each year has been subdivided into 4-month periods, roughly corresponding to late summer, winter and early summer. In the case of the 1980 settlement group, the mean increase in diameter for the first 4 months after settlement (August to November) was 21.51 mm, while the mean increase for the next 4 months (December to March) was only 1.14 mm; then, for the April to July period the mean increase in diameter was 11.55 mm. Similarly for the 1981 settlement, the mean increase in size for the 4 months of late summer was 14.73 mm, over the winter period there was virtually no change, and finally, for the early summer period the mean increase was 11.33 mm. For the 1982 settlement group, the initial (late summer) 4-month period showed a mean increase in diameter of 15.84 mm, but the winter period a mean increase of only 4.93 mm. Overall, the period of late

TABLE I

Changes in mean size (mm) of settlement-groups of *Asterias rubens* at Hollicombe Reef, Torbay, from April 1980 until April 1983, in 4-monthly sectors from the usual settlement-time of August.

	First year (0+ group)			Second year (1+ group)			3rd (2+)	Average increases		
Settlement year	Aug.–Nov.	Dec.–Mar.	Apr.–July	Aug.–Nov.	Dec.–Mar.	Apr.–July	Aug.–Nov.	0+ Year	1+ Year	Overall monthly
1979			11.60	11.0	−8.8	14.86	3.31		14.25	1.8
1980	21.51	1.14	11.55	1.1	5.32	5.04	9.2	34.36	11.56	2.17
1981	14.73	−0.34	11.33	12.34	10.56			22.58		2.4
1982	15.84	4.93								2.5
Mean size increase (± SE)	17.36 ± 3.0	1.91 ± 2.2	11.5 ± 0.1	8.15 ± 5.0	2.36 ± 8.2	9.95 ± 4.9	6.25 ± 2.9	28.47	12.91	2.22

TABLE II

Gonad development from part of a 1+ year-group of *Asterias rubens* collected on 27 April 1983 at Hollicombe Reef.

Starfish diameter (mm)	47 48 49	51	54	56	58	60
Sex		Male	Male		Male	Male
Gonad length (mm)	no gonads	7	11	no gonads	9	7
State of development		Many active sperm	Some active sperm		Some active sperm	Some active sperm

summer growth in the 1st year, that is, the period immediately after settlement, shows the largest mean increase in any of the 4-month periods up to a size of 65 mm diameter.

Over the period studied here, two cohorts were each followed for a full year from settlement and two throughout their entire 2nd year. Taking the average of these figures, the increase in diameter over the 1st year of life is more than twice that over the 2nd, and the average monthly increase for all cohorts was 2.22 mm.

From a study of starfish of between 47 and 60 mm diameter opened in April, which is the time in the annual cycle when the gonads, if present, would be expected to be at their maximum size, only starfish of > 50 mm diameter were found to contain gonads (Table II). All specimens opened which were assignable to sex were male, and all showed the presence of active sperm. A diameter of 50 mm is attained towards the end of the 2nd year (Fig. 3).

Discussion

Over the same period as the study of growth reported here, samples of mature starfish from the same reef were examined to assess the cycle of gonadal activity (Barker & Nichols, 1983; Nichols & Barker, 1984). From peaks in the cycle of gonadal indices, it is deduced that spawning commenced in April in 1980 and 1982, but not until May to July in 1981. This comparative lateness of the reproductive season in 1981 is also reflected in the late appearance of recently-settled juveniles on Hollicombe Reef that year (September 1981, compared with July in both 1980 and 1982), reported in this paper. So a period of 10–12 wk in the larval phase is suggested, which accords with previous observations on the same animal (Gemmill, 1914; Guillou, 1980), and the results of larval rearing experiments (Barker & Nichols, 1983).

Rapid growth occurs over the late summer and autumn periods: after settlement, the young juveniles increase by ≈ 17 mm in the period August to November, but by only ≈ 2 mm in December to March, rising again to an increase of 11 mm in April to July. But the late-summer rapid increase is not maintained in this population throughout the age-range studied: for the 1st year group, the August to November increase is 17 mm, for the 2nd year group it is 8 mm, and for the 3rd year group 6 mm. The reduction in growth over this period in 2nd and 3rd year starfish could result from energy channelled into reproduction, as starfish become sexually mature in this locality in their 2nd year.

There are some anomalous periods shown in the results. For instance, a decrease in mean size of the 1 + year group is shown between November 1980 and March 1981, coincident with a period of only small increase in mean size in the 0 + year group at this time. Similarly, an apparent decrease in size occurred in the 1 + year group between September and October 1981 and in the 0 + group between January and April 1982; slight decreases are also shown by both 0 + and 1 + year groups over March 1983. Whether these represent true decreases in mean size cannot be adduced from our work, since it is impractical to tag or cage individual starfish to the extent that would be

necessary to ensure the collection and measurement of the same individuals month by month.

There are four possible reasons to account for the apparent reduction in mean size over these periods. First, it could be a real decrease in body tissues under conditions of poor food supply: Vevers (1949) reported a specimen of *A. rubens* decreasing in radius from 60 mm to 38 mm after starvation for 5 months, and Hancock (1958) maintained starfish in an aquarium without food for $7\frac{1}{2}$ months and reported a reduction in mean radius from 20 mm to 11–14 mm. Secondly, there could have been further spawnings, and subsequent settlements, later in the year. Our study of gonadal indices suggests, however, that this population (and presumably also others in neighbouring waters) are spawned out by about July each year, so it is unlikely that a second settlement occurs as a result of an extended spawning period, at least to account for the negative growth phases appearing in January to April. Thirdly, some larvae may have undergone protracted planktonic development, causing them to settle late, so that a number of very small individuals appeared on the reef in late autumn to affect the average size, although our examination of local plankton samples has not revealed larvae later than July each year. Finally, and most likely, it is possible that at certain times each year, and particularly in winter, more small individuals may emerge from crevices, perhaps in search of food, to come to lie on the more exposed, and easily searched, parts of the reef. That a greater range of sizes is present in the samples at these times of apparent decline in mean size is suggested by the slightly higher confidence limits that accompany the decline (Fig. 3). In a similar study of *A. rubens* on a natural mussel bed in southern Brittany, Guillou (1980) found a similar irregularity of growth over the year, with increase in mean size slowing, and even regressing, in the colder months and accelerating in the warmer. Nauen (1978a) and Nauen & Böhm (1979), investigating growth in the same animal from natural beds at the eastern end of the English Channel, assume that a slow growth phase immediately following settlement in this population indicates a "waiting stage" for at least part of the cohort, the young starfish "waiting for a free seat in the ecological niche".

Our results give an average increase in diameter of 2.2 mm per month, with a maximum over a 4-month period of 5.4 mm per month (0 + group, August to November 1980). Several previous attempts have been made to assess the average monthly increase in size in *A. rubens*, although methods of measurement have varied widely: Orton & Fraser (1930) used the length of a line joining alternate arm-tips; Bull (1934) calculated a mean radius from the radii of all normal-lengthed arms; Vevers (1949) measured the distance from anus to arm-tip; Barnes & Powell (1951) used the distance from the centre of the disk to the tip of the longest arm; and Guillou (1980) used the distance from the longest arm-tip to the opposite interradius. Furthermore, some workers used fresh material while others used preserved, and Orton & Fraser (1930) suggest that preservation can reduce the dimensions appreciably. So it is not straightforward to compare growth rates obtained here with those of previous workers. In general, where the linear dimension measured by previous investigators has been less than that used here (e.g,

radius, as opposed to diameter), one might expect our figures to be the higher, but this is not so. Orton & Fraser (1930) quote figures of 2.5 mm increase per month on average, and 5.0 mm per month maximum, Bull (1934) gives an increase in radius of 3.3 mm per month average and 6.0 mm per month maximum, Vevers (1949) quotes 5 mm per month average and 10 mm per month maximum, Barnes & Powell (1951) 4.4 mm per month average and 10.4 mm per month maximum, and Guillou (1980) gives 1.5 mm per month average and 2.5 mm per month maximum. Both Orton & Fraser (1930) and Barnes & Powell (1951) followed growth of populations on floating structures upon which starfish and their prey-food settled after metamorphosis during one season, so their "captive" populations were apparently not subject to immigration from outside the area or from cryptic regions within it; they also apparently had an abundant supply of food and were not subjected to the temperature fluctuations experienced by intertidal populations. Similarly, Vevers (1949) remarks that his aquarium population was provided with "an excess supply" of food, and it can be presumed that the water temperature was fairly constant. The fact that the rates of growth described in this paper, using diameter rather than any of the measurements used before, were substantially less suggests that Hollicombe Reef may not necessarily provide a plentiful supply of suitable food to the vast numbers of juvenile starfish that settle on it each year. Other studies of *A. rubens* from natural situations show results which are broadly comparable with those given in this paper: while we have recorded a mean increase in diameter over the whole period of our study of 2.2 mm per month for southwestern Britain, Hancock (1958), for the southern North Sea, and Guillou (1980), for southern Brittany, give mean increases in radius of 1.7 mm and 1.5–2.5 mm per month, respectively.

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