FEEDING RATES OF STARFISH, *ASTERIAS FORBESI* (DESOR), AT CONTROLLED WATER TEMPERATURES AND DURING DIFFERENT SEASONS OF THE YEAR

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ABSTRACT

Starfish were held for 28 days in pans with running sea water maintained at a series of constant temperatures, with oysters as food. The average number of oysters eaten per starfish during this period was 2.3 at 5° C., 3.0 at 10° C., 4.1 at 15° C., 5.0 at 20° C., 2.8 at 22.5° C., and 1.0 at 25° C. Starfish lost weight at 25° C. To observe seasonal feeding rates, starfish and oysters were held in trays suspended in Milford Harbor, Conn. Starfish fed little from mid-January to the end of March, but the rate of feeding then increased rapidly to a maximum in late June and early July. After mid-July, starfish fed at about one-third the rate of late June. This second period of low feeding, which appeared to be associated with both high temperatures and spawning, lasted from July through September. From late October through early December the rate of feeding increased again to about two-thirds of the level in late June and early July, before decreasing again to the seasonal low in mid-January.

Information in the literature on feeding rates of starfish, *Asterias forbesi* (Desor), is limited, and no one has reported studies of feeding rates at different specific temperatures maintained within closely controlled limits. In addition, no one has reported quantitative studies that describe possible changes in feeding rates during different seasons of the year. Although Galtsoff and Loosanoff (1939) stated that starfish in Long Island Sound feed more actively during the summer than during the winter, they did not determine specific rates. Needler (1941) reported that *Asterias vulgaris* (Verrill) in waters of Eastern Canada feed mostly in the spring and fall and relatively little in the winter. (In both Long Island Sound and Eastern Canada, water temperatures fall to slightly below 0° C. in the winter.) According to Hancock (1955, 1958), *Asterias rubens L.*, which inhabit English waters, feed at a high rate throughout the winter. Near Essex, England, where the studies were made, water temperatures average 4° to 8° C. during the winter. He reported that the only important seasonal lull occurs just after the spawning season in May and that feeding increases again sometime between September and November. Because he made no controlled laboratory studies of feeding rates at a series of constant temperatures, he could not determine whether the decline in feeding after May was in response to high water temperatures, which rose above 15° C., or to spawning. Thorson (1955) found that the brittle star, *Amphiura* sp., does not feed for 1 month before spawning in late summer; after spawning it lies quiescent on the bottom, not feeding for about another month.

I have attempted to determine feeding rates of starfish at a series of constant temperatures and during different seasons of the year. In the study of seasonal feeding, I wanted especially to obtain a record of possible feeding during winter and to determine whether feeding slows down in midsummer after starfish begin to spawn. Spawning of starfish in Long Island Sound begins in the middle of June and continues intermittently through the summer (Galtsoff and Loosanoff, 1939; Loosanoff, 1961). During the experiments I also recorded the gains and losses in weight of starfish. I believed that such a study would provide important data on the biology of starfish and useful information for commercial growers of shellfish.

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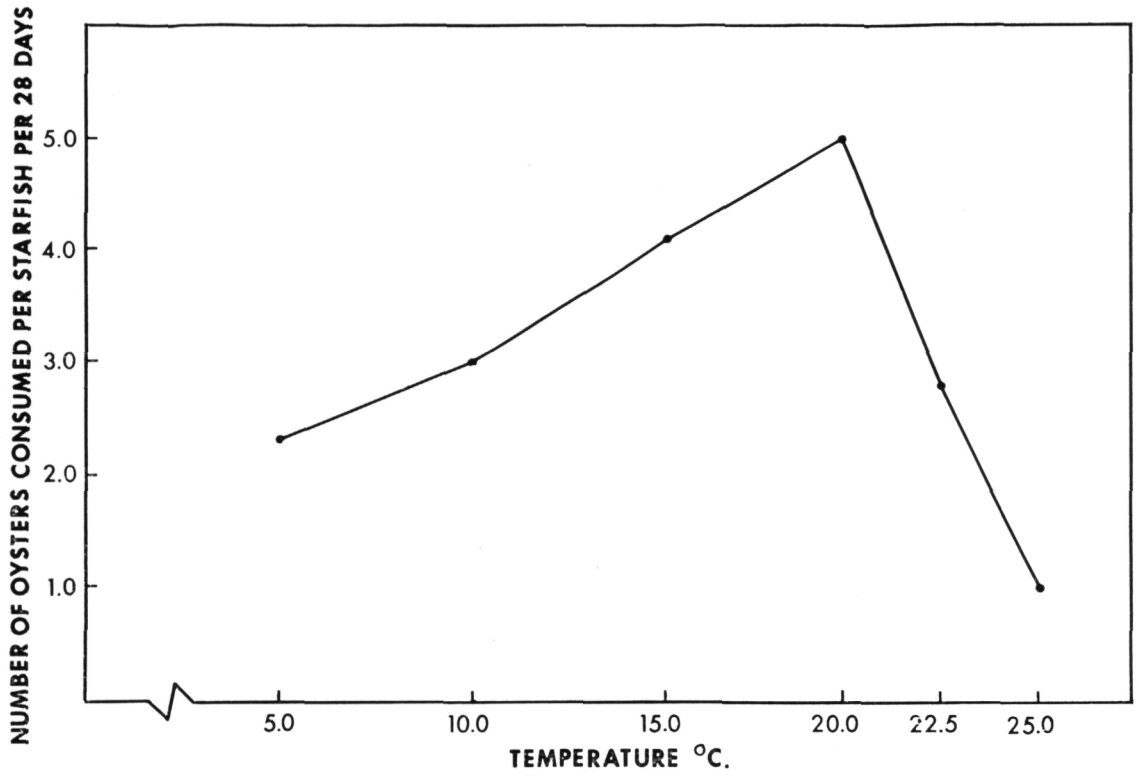

FIGURE 1.—Feeding rates of starfish on oysters at constant temperatures. (Points are based on combined data of replicates at each temperature level—see table 1.)

FEEDING RATES AT CONSTANT TEMPERATURES

METHODS

For the feeding experiments with starfish held at constant temperatures, wooden frames, constructed to hold a bank of four enamel trays (6 cm. by 43 cm. by 50.5 cm.), were arranged on laboratory tables. Each bank was supplied with a separate, continuous flow of sea water. By mixing cold and heated sea water in glass cylinders just above the frames, we maintained the water in the trays within ±1° C. of the temperature desired.

I believe the range of salinity of the water (26.8‰–28.2‰), which corresponds with that of the natural habitat of starfish near Milford, Conn., did not significantly influence the feeding rates during the experiment.

At each temperature four or eight trays were used, each containing 3 adult starfish and 40 oysters. The starfish weighed between 39 and 41 g. (starfish were drained individually for 30 seconds before weighing) and averaged 64 mm. (range 53–75 mm.) from tip of two arms nearest the madreporite to the madreporite. The heights of the oysters averaged about 50 mm. (range 34–80 mm.). Some oysters were in clusters, and others were individuals. To ensure an ample food supply for the starfish, shells of consumed oysters were removed nearly every day and replaced by live oysters.

A fresh group of starfish was obtained in Long Island Sound off Milford for each repetition of a 28-day test at a series of temperatures. These animals were placed in large containers of water at the same temperatures as when they were collected. As the water temperature gradually rose indoors to the point desired, starfish were placed in the experimental feeding trays maintained at this temperature. Oysters, acclimated to the experimental temperature in the same way, were placed in trays with the starfish 1 or 2 days later. Only one starfish died in pans in which water temperatures ranged from 5° to 22.5° C. At 25° C., however, 14 of 72 starfish died during the experiments and one additional starfish lost an arm.

RESULTS

Feeding rates are expressed as the number of oysters consumed per starfish during the 28 days

of feeding. Only one test was made at 5° C. (because low temperatures could not be maintained during late spring); three each at 10° C., 15° C., and 20° C.; one at 22.5° C.; and four at 25° C. Results obtained during replicate tests at the same temperature were similar (table 1).

The rate of feeding was strongly influenced by the temperature of the water. At 5° C. starfish consumed an average of 2.3 oysters each during the 28-day period. The rate of feeding increased by about 1 oyster for each 5° C. increase to 20° C.—to 3.0 oysters per starfish at 10° C., 4.1 at 15° C., and 5.0 at 20° C.; it then decreased to 2.8 at 22.5° C. and 1.0 at 25° C. (fig. 1). Thus, the optimum temperature for feeding of starfish on oysters was 20° C.

Additional observations showed that frequently two starfish and sometimes all three in a pan fed simultaneously on the same oyster or group of oysters in a cluster. Starfish did not always consume all the tissues of oysters they killed; a small amount often remained near the hinge of the oyster after a starfish had left it.

TABLE 1.—*Feeding rates of* A. forbesi *on oysters, height about 50 mm. (range 34–80 mm.), at a series of controlled water temperatures. Rates are given as the average number of oysters consumed per starfish in 28 days*

Temperature and test number	Starfish used in test	Oysters consumed	
		Total	Per starfish
5.0° C.	*Number*	*Number*	*Number*
1	12	27	2.3
10.0° C.			
1	12	35	2.9
2	12	32	2.7
3	24	78	3.2
15.0° C.			
1	12	57	4.7
2	12	47	3.9
3	24	94	3.9
20.0° C.			
1	12	62	5.2
2	24	116	4.8
3	24	120	5.0
22.5° C.			
1	24	67	2.8
25.0° C.			
1	12	18	1.5
2	12	13	1.1
3	24	29	1.2
4	24	12	.5

Besides observing feeding rates of starfish, I measured changes in their weight during 28-day test periods. Average gains in weight were 4.4 g. at 5° C., 7.1 g. at 10° C., 13 g. at 15° C., 13.7 g. at 20° C., and 5.8 g. at 22.5° C. At 25° C. starfish lost an average of 6.5 g. (fig. 2).

The loss in weight by starfish held at 25° C., even though they consumed food, shows that if starfish were held at this temperature for an extended period of time, they would probably die. In figure 2 the line connecting the number of grams gained or lost by starfish supplied with food crosses the point where no weight is gained or lost at about 23.5° C. It would seem, therefore, that starfish from Long Island Sound would probably die if they were maintained for a long period at temperatures above 23.5° C.

As controls in the weight studies, starfish were held in three different situations without food. Nine starfish held in a laboratory tray without food for 28 days at 15° C. lost an average of 7.1 g., and 12 held at 25° C. lost an average of 8.6 g. (fig. 2). Twelve starfish held in a small plastic screen cage in Milford Harbor from April 1 to 30, 1965, when the temperature averaged 5.8° C. (range 2.7–9.5° C.), lost an average of 3.2 g.

FEEDING RATES DURING DIFFERENT SEASONS

METHODS

To study feeding rates during different seasons, trays, measuring 14 cm. by 83 cm. by 147 cm., were suspended from the laboratory dock in Milford Harbor. They were covered and lined on the inside with plastic screening (mesh size 3 holes to the cm.). Depths of water over the trays ranged from 0.75 m. at low tide to 2.5 m. at high tide. Each tray held 20 adult starfish and 140 oysters. From January 20, 1964 to January 26, 1967, one tray was examined once every 2 to 4 weeks. An examination consisted of lifting the tray out of water, placing the starfish in buckets of water, washing the tray with a hose, counting the oysters consumed by starfish, replacing them with live oysters of the same size, returning the starfish to the tray, and then lowering the tray to its normal position.

From May 17, 1966 to January 26, 1967, a period of slightly more than 8 months, a second tray similar to the first was examined in the same manner on each date, except that after each examination the starfish and oysters were transferred to a clean replacement tray. This procedure was followed to ensure that starfish were not consuming large fouling organisms, which might have set in the tray, rather than the added oysters, thereby giving a false indication of their rate of feeding.

RESULTS

Starfish in trays suspended in Milford Harbor displayed the same pattern of feeding in each of the 3 years of observations (fig. 3). The rate of

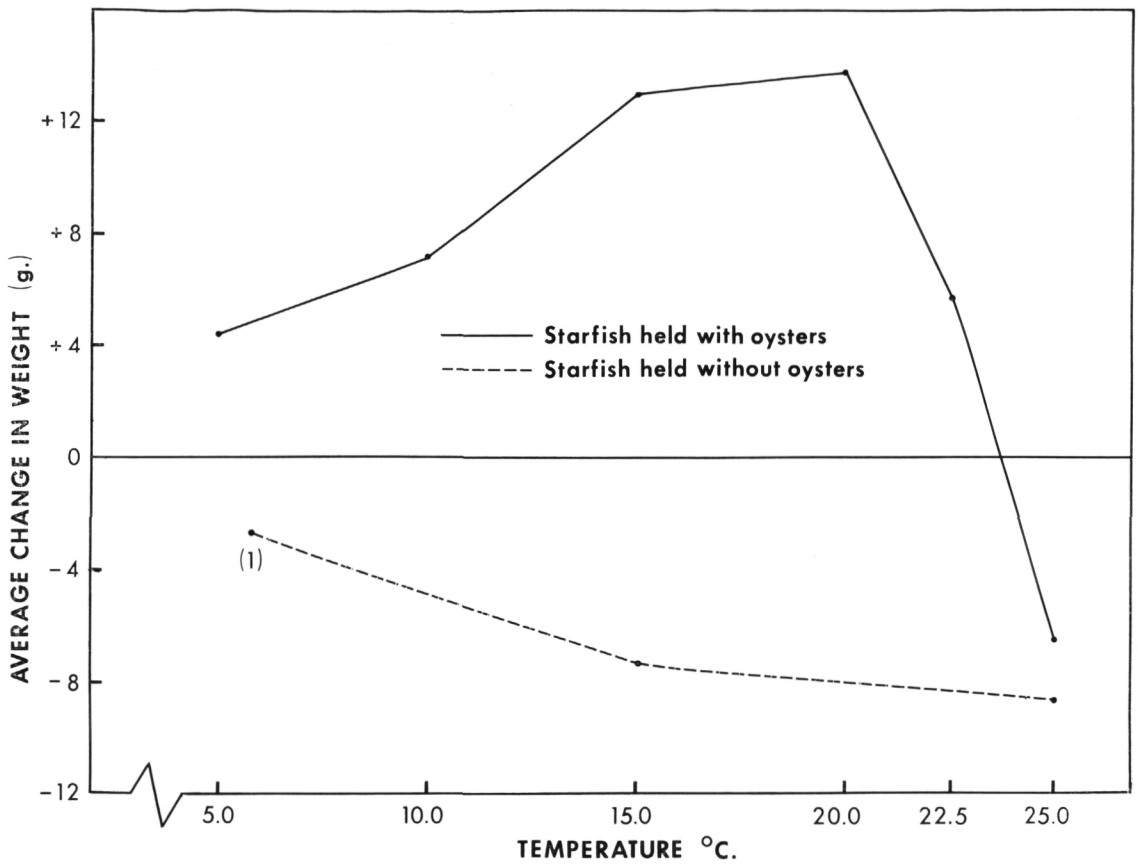

FIGURE 2.—Average weight change of starfish held at constant temperatures for 28 days, with and without food. (Points are based on combined data of replicates at each temperature.) Point (1) represents starfish held in a cage in Milford Harbor, April 1–30, when temperatures averaged 5.8° C. (range 2.7–9.5° C.).

feeding was low from mid-January until the end of March. For example, in 1965 the 20 starfish consumed about 0.6 oyster per 7 days (0.12 oyster per starfish per 28 days) during this period of 2.5 months. From mid-April to late June and early July the rate rose sharply, apparently as a result of the rise in water temperature. At the time of most intense feeding, in late June 1965, the 20 starfish ate about 20 oysters per 7 days (four oysters per starfish per 28 days). In late July, August, and September the rate of feeding decreased to about a third of its level in late June and early July. In late October, November, and early December the rate increased again to about two-thirds of the rate in late June and early July. Beginning in late December, feeding rates began to decline but did not really become low in 1965 and 1966 until mid-January. In 1967, however, because of unusually warm water, feeding had not declined to its previous winter low by late January when observations were terminated.

As the experiment continued from 1964 through 1966, the starfish grew larger. The new group of oysters collected each spring was, however, of about the same average size—50 to 65 mm. (range 34–82 mm.)—as the original group fed to the starfish in 1964. Because the larger starfish consumed more oysters (of a particular size) than the smaller ones, feeding rates were higher in each successive year.

The feeding in the second tray, observed from May 17, 1966 to January 26, 1967 (to evaluate the effect of possible consumption of fouling organisms on feeding rate), was essentially similar to that in the first tray. Because the supply of oysters was low, however, it was necessary to use smaller oysters in this tray after late August. The starfish in this second tray, consequently, showed a much higher consumption of oysters than did those in the first tray which were feeding on larger oysters (fig. 3).

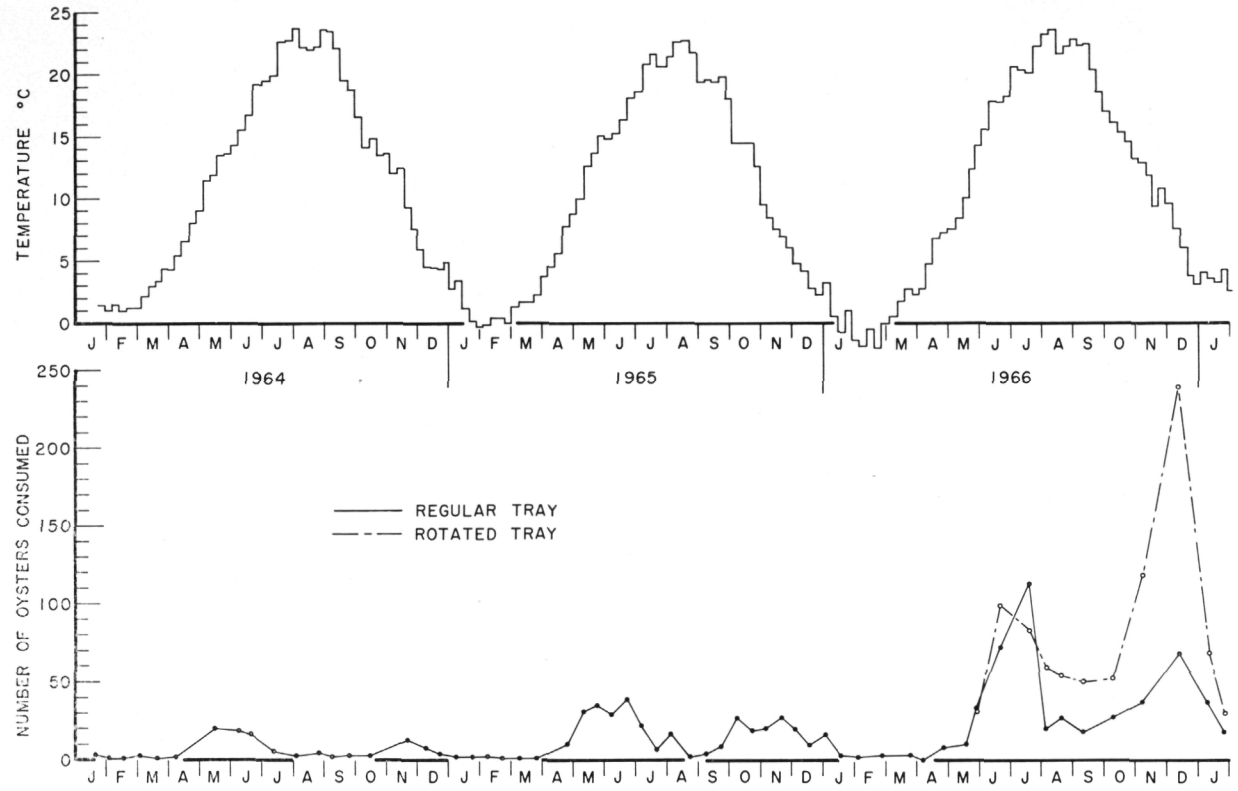

FIGURE 3.—*Number of oysters consumed by 20 adult starfish held with 140 oysters in a tray from January 1964 to January 1967 and (in a second tray) from May 1966 to January 1967. Both trays were suspended in Milford Harbor. Temperatures are given in the upper panel.*

In 1964, 1965, and 1966, during the period of little feeding from mid-January to the end of March, water temperatures averaged 1° C. (range −2.2° to 3.2° C.). Observations of starfish in trays in Milford Harbor and of those dredged from the bottom showed that they feed on oysters and other food at temperatures at least as low as 0.2° C. Temperatures increased to 7° to 9° C. by the end of April, to 13.5° to 15° C. by the end of May, and to 18.5° to 19.5° C. by the end of June (when the rates of feeding were highest). By mid-to-late July temperatures reached 22.5° C. and stayed at or above that level until early or mid-September (during the period when rates of feeding were about a third as intense as they were in the spring). In the 3 years temperatures averaged 13.5° to 15.3° C. during October, 7.9° to 11.6° C. during November, and 3.6° to 5.8° C. during December, and during this period of 3 months feeding rates were about two-thirds as intense as they were in late June.

SUMMARY OF EFFECTS OF WATER TEMPERATURES AND SEASONS ON FEEDING RATE

A comparison of feeding rates of starfish at constant temperatures with those in different seasons shows that the rates in different seasons are controlled primarily by seasonal temperatures. Though laboratory studies were not conducted to determine feeding rates at temperatures below 5° C., low rates from mid-January to the end of March are undoubtedly a result of temperatures which average only 1° C. As temperatures rise in the spring to nearly 20° C., the optimum temperature for feeding, by the end of June feeding increases rapidly.

In summer the decline in feeding coincided with high temperatures. For example, in 1964 temperatures exceeded 22.5° C., the temperature at which feeding probably begins to decline, on July 15, about 2 weeks after a sharp decline in feeding had already begun. In 1965 temperatures rose to above 22.5° C. for only a few days during July, coincid-

ing with the decline in feeding. In 1966 temperatures rose above 22.5° C. on July 7 shortly before feeding declined. In 1964, because feeding began to slow down before temperatures reached 22.5° C. and continued low in late September and early October after temperatures dropped well below 22.5° C., some other factor—probably the effects of spawning which started in mid-June—seemed to be partly responsible for the low feeding rate. In 1965, the possible effects of spawning were observed through September because feeding was low even though temperatures were 16° to 21° C. In 1966, low feeding was recorded from mid-September through early October when temperatures ranged from 16° to 22.5° C. The rate of feeding increased again in late October and remained high through most of November as temperatures dropped to 15° C. and lower. Feeding rates declined in late December when temperatures fell to 2° to 4° C. and reached the winter low by mid-January when the temperature fell to about 1° C.

Asterias forbesi in Long Island Sound exhibits a reduction in feeding in midsummer similar to that reported by Needler (1941) for *A. vulgaris* in Eastern Canada and by Hancock (1955, 1958) for *A. rubens* in English waters. In contrast to *Amphiura* sp., as described by Thorson (1955), *A. forbesi* apparently feeds actively right up to the time it spawns.

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LITERATURE CITED

GALTSOFF, PAUL S., and VICTOR L. LOOSANOFF.
1939. Natural history and method of controlling the starfish, *Asterias forbesi* (Desor). Bull. U.S. Bur. Fish. 49: 75–132.

HANCOCK, D. A.
1955. The feeding behaviour of starfish on Essex oyster beds. J. Mar. Biol. Ass. U.K. 34: 313–331.
1958. Notes on starfish on an Essex oyster bed. J. Mar. Biol. Ass. U.K. 37: 565–589.

LOOSANOFF, VICTOR L.
1961. Biology and methods of controlling the starfish, *Asterias forbesi* (Desor). U.S. Fish Wildl. Serv., Fish. Leafl. 520, 11 pp.

NEEDLER, A. W. H.
1941. Oyster farming in Canada. Bull. Fish. Res. Bd. Can. 60, 83 pp.

THORSON, GUNNAR.
1955. Modern aspects of marine level-bottom animal communities. J. Mar. Res. 14: 387–397.

U.S. GOVERNMENT PRINTING OFFICE: 1969