

GROWTH OF THE BAY SCALLOP, *ARGOPECTEN IRRADIANS*, IN A WASTE RECYCLING AQUACULTURE SYSTEM*

ROGER MANN and RODMAN E. TAYLOR, JR.

Woods Hole Oceanographic Institution, Woods Hole, MA 02543 (U.S.A.)

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ABSTRACT

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Growth of the bay scallop *Argopecten irradians* in a pilot scale waste recycling aquaculture system was examined over a 32-week-period at 14°C. *A. irradians* increased from initial live and dry meat weights of 1.15 g and 0.043 g, respectively, to terminal values of 9.08 g and 0.599 g, respectively. This corresponds to instantaneous growth rates for live weight (G) and dry meat weight (M) of 0.009 and 0.013, respectively. High mortalities were evident towards the end of the experiment with a terminal value of 33% giving an instantaneous mortality rate (Z) value of 0.0016. In laboratory experiments of 12 weeks duration at, 12, 15, 18 and 21°C juvenile *A. irradians* gave values of 0.01, 0.013, 0.018 and 0.016 for G ; 0.015, 0.015, 0.016 and 0.013 for M ; and 0.038, 0.038, 0.037 and 0.040 for Z at the respective temperatures. Shell deformities were evident in laboratory grown individuals. *A. irradians* exhibits specific growth rates comparable to or higher than those previously recorded for other bivalve species cultured in waste recycling systems; however, a considerable reduction in the presently high mortality rate will be required to make *A. irradians* a prime candidate for practical application.

INTRODUCTION

In recent publications Mann and Ryther (1977) and Mann (1978) described the growth of six species of bivalve mollusc in a pilot scale, waste recycling aquaculture system at Woods Hole, MA. Through a co-operative effort with the NMFS-NOAA laboratory of Milford, CT the opportunity arose to examine the growth of hatchery reared bay scallops, *Argopecten irradians*, in the Woods Hole system. This report presents results of studies of the growth of *A. irradians* in both a pilot scale waste recycling aquaculture system, and in laboratory systems at four temperatures when fed on phytoplankton cultured in sewage-seawater mixtures.

METHODS

Pilot scale studies

The Woods Hole waste recycling aquaculture pilot scale facility has been described previously (Huguenin, 1975; Ryther et al., 1975). Operating procedures for this system during the present study were as described previously by Mann (1978). Seawater temperature was maintained at $14 \pm 2^\circ\text{C}$. Phytoplankton food was cultured exclusively in a 15% secondary sewage effluent in seawater mixture, and during the period considered here, consisted primarily of the diatoms *Phaeodactylum tricornutum* (weeks 0–6, mean cell density $9.29 \times 10^5/\text{ml}$) and *Skeletonema costatum* (weeks 7–32, mean cell density $2.69 \times 10^5/\text{ml}$).

Two thousand and fifty juvenile *A. irradians* were obtained from NMFS-NOAA, Milford. Fifty animals were removed at random and deep frozen for subsequent estimation of mean live weight, and dry meat and dry shell weights (as measured after 24 h at 100°C). The remaining animals were divided into eight populations of 250 individuals. Each population was stocked in a separate, labelled shellfish holding tray and subsequently placed in the outdoor raceway system of the pilot facility. Four populations were located in corresponding positions in each of two raceways. All other trays in the raceway system were filled with juvenile *Crassostrea gigas* at a density of 500 g live weight/tray except for four trays in one raceway which contained *Mytilus edulis* at a density of 1000 g live weight/tray.

At monthly intervals the experimental populations were removed from the raceway, cleaned of adherent deposits and epifauna, counted, weighed, and a subsample of ten animals from each population removed for estimation of mean dry weight. The growth trial was terminated after a duration of 32 weeks.

Laboratory experiments

All laboratory experiments were carried out in four wooden tanks of 3 m (length) \times 0.75 m (width) \times 0.75 m (height). Each tank was supplied with sand filtered seawater at a rate of 8 l/min and a culture of *Skeletonema costatum*, cultured in a 15% sewage-seawater mixture and diluted with the seawater to a mean concentration of 2.5×10^5 cells/ml, at a rate of 800 ml/min. Both seawater and phytoplankton were supplied at one end of the tank to flow through a number of plastic trays (60 \times 6 \times 6 cm, Nestier Corp., Cincinnati, OH) which held the shellfish, and then to waste via a standpipe. Salinity was maintained in excess of 30‰ throughout the study. Seawater temperature was maintained at 12, 15, 18 and 21°C respectively in the four tanks.

Seven hundred and fifty *A. irradians* were obtained from NMFS-NOAA at Milford, Connecticut. From these, 560 individuals were selected and subdivided into 28 populations of 20 individuals each. Seven populations were

assigned to each of the four experimental temperatures. Animals were acclimated as follows. Initially all populations were held at 12°C for 3 days. Twenty-one populations were subsequently transferred to the 15°C tank for a further 3 days. Fourteen populations were then transferred from the 15°C tank to the 18°C tank and, following a further 3 days, seven of these populations were transferred to the 21°C tank. Thus, by 10 days, seven populations were maintained at each experimental temperature. To facilitate handling and sampling with a parallel growth study on three other species of bivalves, single populations were transferred to holding trays containing corresponding populations of 20 juvenile *Crassostrea gigas*, 25 juvenile *Ostrea edulis* and 20 *Tapes japonica*.

At intervals of 14 days one population from each tank (= temperature) was sacrificed for estimation of live weight, dry meat weight and dry shell weight as previously described. The study was terminated after a duration of 12 weeks. Throughout the study daily checks were made of flow rates, phytoplankton density and water temperature. Frequent but irregular comparisons were made, by fluorometry, of the phytoplankton chlorophyll content of the influent sand filtered seawater, the tank contents adjacent to the mixing of the seawater and phytoplankton inlets, and the tank effluent. Phytoplankton chlorophyll in the tank effluent was consistently lower than that measured at the mixing of the influent seawater and phytoplankton indicating that the experimental animals were feeding on the available phytoplankton food.

RESULTS

Pilot scale studies

No significant differences were found between growth rates of any of the eight populations. Therefore, data for these populations have been pooled and are given in Fig. 1. Mean live weight increased slowly from 1.12 g to 3.03 g over the first 18 weeks of the study. A corresponding increase in mean dry meat weight from 0.043 to 0.109 g was recorded. A marked increase in growth rate was evident between weeks 18 and 32 of the study with terminal mean values of 9.98 g live weight and 0.599 g dry meat weight being recorded. A 3.3% mean mortality was recorded during the first 8 weeks of the study; however, following this period a rapid increase in mortality was evident with a mean value of 33.0% mortality being recorded at termination of the experiment. Unlike dry meat and live weight data, a considerable range in population mortality levels was recorded. It is relevant to note that mortalities were consistently higher in the populations in one raceway than in the other (range of terminal values 18–30% versus 33–47%) although no obvious explanation for this dissimilarity is evident. Combining growth and mortality data allows the calculation of mean population biomass (mean dry weight \times 250 \times % survival). A period of 18 weeks, during which both

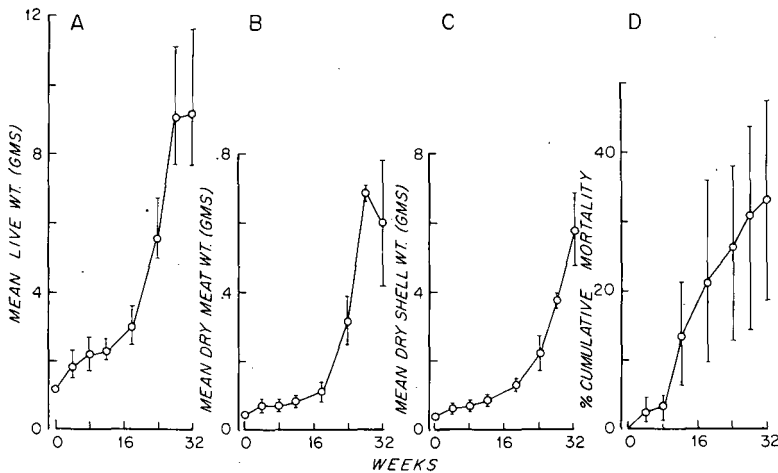


Fig. 1. Growth of the bay scallop *Argopecten irradians* in a waste recycling aquaculture system over a 32-week-period at 14°C. All data are the mean and range of individuals from eight populations.

P. tricorutum and *S. costatum* were available as food, was necessary to effect a doubling of initial biomass level; however, during the subsequent 14 weeks when only *S. costatum* was available a fivefold increase in this factor was recorded.

Laboratory studies

During the initial acclimation period high (44%) mortalities were evident. These were considered to be related to the combined stress of transportation and subsequent handling in that low mortalities (1.4%) were evident during an 18-day-period following the completion of the transfers described above and prior to day 0 sampling. Gradual increments in mean live weight, dry meat and dry shell weights were evident throughout the experimental period, these being especially notable at 18 and 21°C during weeks 10–12 of the experiment (Fig. 2). A high and consistent mortality rate was evident throughout the study with terminal values ranging from 30.1 to 45%. Gonadal development and spawning was evident at 18 and 21°C towards the end of the experiment.

Unlike the pilot scale studies a number of individuals developed the shell deformity reported previously by Epifanio (1976). Many of these individuals began to show evidence of this deformity immediately after the initiation of the growth experiments (this juncture was clearly marked by a distinct growth line on the scallop shell and a notable change in shell colour). Although a number of these animals died, others with quite gross deformities, including an individual with a perforated valve, survived to the completion of the experiment, exhibited good meat growth, gonad production and even spawning.

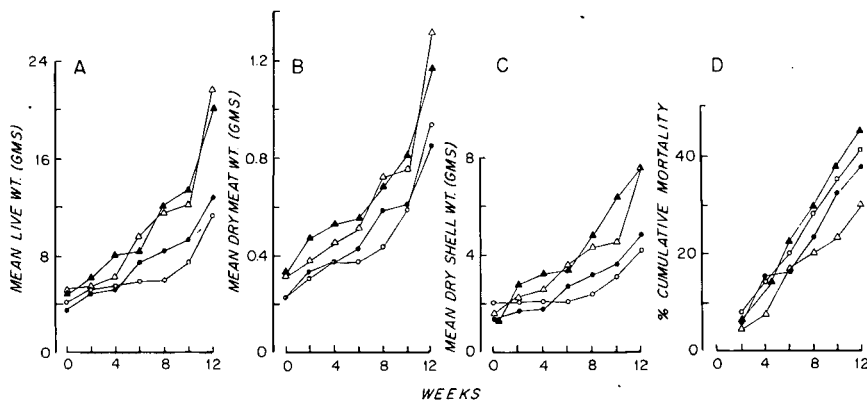


Fig. 2. Growth and mortality of the bay scallop *Argopecten irradians* in laboratory experiments, on diets of phytoplankton cultured in sewage-seawater mixtures, over a 12-week period at four temperatures: \circ = 12°C; \bullet = 15°C; \triangle = 18°C; \blacktriangle = 21°C. All values are the mean of populations of 20 individuals.

DISCUSSION

The present study indicates that juvenile *A. irradians* can be grown successfully on a diet of phytoplankton cultured in sewage-seawater mixtures. Mortality during this process are, however, high. Table I summarises the best growth data obtained to date for five species of bivalve mollusc, at various temperatures in both laboratory and pilot scale experiments, on diets of phytoplankton grown in sewage-seawater mixtures. Data are recalculated in terms of instantaneous growth rate (Ricker, 1968) for both live weight (G) and dry meat weight (M) where:

$$G \text{ or } M = \frac{\ln W_2 - \ln W_1}{t}$$

and for instantaneous mortality rate Z (Walne, 1976) where:

$$Z = - \frac{\ln N_1 - \ln N_0}{t}$$

Classically the functions W_1 and W_2 are the weights, and N_0 and N_1 the numbers of animals alive at the beginning and end of time interval t . In the present case the functions $(\ln W_2 - \ln W_1)$ and $(\ln N_1 - \ln N_0)$ have been estimated from the slope of the linear regressions of the natural logarithms of G or M (for growth rate), or percentage cumulative mortality versus time. In all calculations t equals one day. Values of G for *A. irradians* are comparable to or exceed values recorded for all other successfully cultured bivalve species, and values of M for *A. irradians* for the present study are only exceeded by those previously recorded for *Crassostrea gigas*. Values of M are also higher

TABLE I

A comparison of instantaneous growth and mortality rates of five species of bivalve mollusc cultured at various temperatures in laboratory and pilot scale systems on a diet of phytoplankton cultured in sewage-seawater mixtures. (—) indicates data not available

Species	Temperature (°C)	Growth period weeks	Live weight (G)		G	Meat weight (G)		M	Mortality (%)	Z	Scale	Source
			Initial	Final		Initial	Final					
<i>Argopecten irradians</i>	14	32	1.15	9.08	0.009	0.043	0.599	0.013	33.0	0.016	Pilot	Present study
	12	12	4.08	11.26	0.010	0.22	0.93	0.015	41.3	0.038	Laboratory	Present study
	15	12	3.52	12.71	0.013	0.22	0.84	0.015	37.9	0.038	Laboratory	Present study
	18	12	5.36	21.57	0.018	0.31	1.31	0.016	30.1	0.037	Laboratory	Present study
	21	12	5.13	20.02	0.016	0.32	1.16	0.013	45.0	0.040	Laboratory	Present study
	7-16	13	—	—	—	0.15	0.24	0.005	20.0	0.003	Laboratory	Tenore and Dunstan, 1973
<i>Mytilus edulis</i>	14	32	5.5	11.9	0.004	0.11	0.90	0.009	4.2	0.006	Pilot	Mann, 1978
<i>Crassostrea gigas</i>	12	19	5.2	23.5	0.011	0.089	1.736	0.029	0		Laboratory	Mann, 1979a
	15	19	5.2	28.2	0.014	0.089	1.253	0.021	0		Laboratory	Mann, 1979a
	18	19	5.2	34.6	0.014	0.089	1.322	0.020	0		Laboratory	Mann, 1979a
	21	19	5.2	38.7	0.015	0.089	1.219	0.017	0		Laboratory	Mann, 1979a
<i>Ostrea edulis</i>	12	19	4.1	10.6	0.006	0.095	0.445	0.011	0		Laboratory	Mann, 1979a
	15	19	4.1	13.6	0.007	0.095	0.566	0.012	0		Laboratory	Mann, 1979a
	18	19	4.1	19.3	0.011	0.095	0.617	0.013	0		Laboratory	Mann, 1979a
	21	19	4.1	22.3	0.011	0.095	0.756	0.014	0		Laboratory	Mann, 1979a
<i>Tapes japonica</i>	12	19	6.8	10.3	0.003	0.291	0.958	0.009	1.2	0.001	Laboratory	Mann, 1979b
	15	19	6.8	9.7	0.002	0.291	0.733	0.007	5.6	0.0026	Laboratory	Mann, 1979b
	18	19	6.8	10.6	0.003	0.291	0.735	0.006	4.4	0.0021	Laboratory	Mann, 1979b
	21	19	6.8	10.8	0.002	0.291	0.586	0.003	17.2	0.0199	Laboratory	Mann, 1979b

than those recorded previously for *A. irradians* by Tenore and Dunstan (1973), probably reflecting the inconsistent experimental temperature regime used by the latter authors. The authors can find no data for instantaneous growth rates for either live or dry meat weights in field populations of *A. irradians*. However, Gutsell (1930) described both the seasonal size distribution of *A. irradians* and water temperature at Pivers Island, NC. From his length and temperature data (his Table 4 and 10) it is possible to first plot growth on a monthly basis, subsequently calculate instantaneous growth rates in terms of shell length (L), using the equation of Ricker (1968) as given, at temperatures corresponding to those of the present study, and thus effect a comparison between experimental and natural systems. The values of L obtained for 12, 14, 15, 18 and 21°C are 0.007, 0.010, 0.011, 0.015 and 0.024, that is generally lower than G or M values from the present experimental system except at the highest temperature. It is, however, relevant to note that the maximum value of L in Gutsell's study, 0.027, was recorded at 25°C, well above the highest temperature used in the present study.

It is ironical to note that while values of G or M for laboratory populations of *A. irradians* were higher than those for the pilot scale study, values of Z exhibited similar trends. The cause of the observed mortalities is, as yet, unclear. They do not, however, appear to be related to the observed shell deformities. Epifanio (1976) suggests that this shell deformity is due to some nutritional deficiency in the available phytoplankton. This seems unlikely in that such a deficiency would usually be expected to eventually result in 100% mortality of the population. Also, the fact that some individuals survived and grew rapidly in the present study without developing abnormal shells indicates that the nutritional status of the available phytoplankton food was adequate. As deformities were only evident in the laboratory populations the possibility exists that the presence of other species of bivalves in the holding trays may have influenced the incidence of deformities. A complete discussion of the possible causes of shell deformity in laboratory reared *A. irradians* is given in Palmer (1980). It seems improbable that such gross deformities would ever be recorded in natural populations of *A. irradians* as any minor impediment to swimming ability would markedly increase the susceptibility of an individual to predation.

The public health related aspects of culture of *A. irradians* in waste recycling systems has, to date, received little attention. However, a considerable body of data exists on the uptake and depuration of trace metals (Mann and Ryther, 1979), organic contaminants (Mann and Taylor, in press) and viruses (R. Mann, J.M. Vaughn and E.F. Landry, unpublished data, 1980) in *Crassostrea gigas* and, to a lesser extent, *Ostrea edulis* and *Crassostrea virginica* to suggest that the practical problems of depuration of shellfish cultured in waste recycling systems are surmountable. Certainly any future developments to reduce mortality in cultured *A. irradians*, combined with the demonstrated fast growth of the species, would undoubtedly make *A. irradians* a prime candidate for practical application in waste recycling — bivalve mollusc aquaculture systems.

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