# Polyspecies aquaculture systems: The detrital trophic level[1]

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## ABSTRACT

The production of species belonging to the detrital trophic level was investigated in a model-sized aquaculture system, with flowing, filtered seawater and controlled phytoplankton addition to experimental tanks containing the oyster, *Crassostrea virginica*. The biodeposits of feces and pseudofeces of the oysters supported on the bottom of one tank a population of the nereid polychaete, *Nereis virens* and in the other tank a mixed community of the capitellid polychaete, *Capitella capitata* and the amphipod, *Corophium* sp. The nereids showed a 2.8 fold increase in average weight of worm in 100 days and the *Capitella-Corophium* community reached a standing biomass of 24.4 grams carbon/m$^2$. These data suggest the feasibility of successful culture of such species in polyculture systems. Polyculture both increases and diversifies the crop production and eliminates the build-up of detrital wastes characteristic of simple food chains in aquaculture.

## 1. Introduction

In studies at the Woods Hole Oceanographic Institution on aquaculture systems we have used secondary-treated sewage effluent as a nutrient source for culturing marine phytoplankton that may be used as food for rearing bivalves (Ryther, 1971; Ryther *et al.*, 1972). Research on this system has stressed the approach of food chain dynamics in attempting to predict and optimize production in such man-controlled ecosystems. For example, laboratory experiments in flowing systems receiving continuous additions of different levels of phytoplankton have determined the effect of phytoplankton species composition and concentration on feeding and biodeposition rates of several bivalve species (Tenore and Dunstan, 1973a and b). In addition, larger scale studies have been conducted in experimental tanks holding 760 liters of seawater and receiving 500 liters/day of phytoplankton culture. These studies compared the feeding

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rate and growth efficiencies of the oyster, hard clam, and edible mussel (Tenore *et al.*, 1973). On going experiments with 10,000 liter algae ponds and 14 m long raceways will investigate production rates of several species in a pilot-sized aquaculture facility.

Results from our earlier experiments suggest that the most efficient and productive multispecies systems should represent organisms of different trophic levels able to exploit energy losses inherent in a simple food chain. In naturally-occurring food chains, primary producers (e.g., phytoplankton) and herbivores (e.g., oysters) are seldom the only trophic levels represented. From the view-point of bionergetics, the energy transfer in such a simple food chain is never 100% efficient and energy "leaks" are usually exploited by other organisms. For example, high egestion rates of unassimilated food by bivalves in the form of feces and pseudofeces result in significant amounts of biodeposits of detritus that can be utilized by deposit-feeders such as polychaetes. These worms may, in turn, be consumed by primary carnivores.

Similarly, soluble excretory products (metabolites) may be utilized by other primary producers such as seaweeds or periphyton that may serve as a food source for browsers, e.g., shrimp or abalone. This concept of a polyspecies aquaculture system has been one of the main thrusts of our research at Woods Hole (Ryther *et al.*, 1972; Tenore *et al.*, 1973). The present paper deals with estimations of the magnitude of biodeposits available to species of the detrital trophic level and production rates of detritivores in experiments with 760 liter tanks.

## 2. Materials and Methods

During the summer of 1973, experiments were carried out in moderate sized algae and invertebrate tanks to study the food chain dynamics of a polyspecies aquaculture system (Figure 1). Two algal growth tanks (fiber glassed wood), each 2.3 m in diameter and 50 cm deep and containing about 2000 liters, were continuously supplied with a mixture of secondary-treated sewage effluent and filtered seawater. The nutrient and productivity data from these algal ponds will be reported elsewhere. The harvest continuously overflowed from these algal tanks (about 500 liters/day/tank) and was fed by gravity into the various invertebrate cultures. There was no attempt to control the species composition of the phytoplankton cultures and a succession in dominance by marine pennate diatoms was observed during the course of the experiment. Initially and until mid-June, *Phaeodactylum tricornutum* dominated the phytoplankton; after this period, a series of large naviculoid diatoms usually were the dominant phyto-plankter. During the early stages of the experiments a great amount of coumping of the phytoplankton necessitated the use of an in-line homogenizer to assure algal suspension for bivalve feeding.

The invertebrate set up was essentially the same as that used in previous experiments (Tenore *et al.*, 1973). A large container constructed of epoxied wood

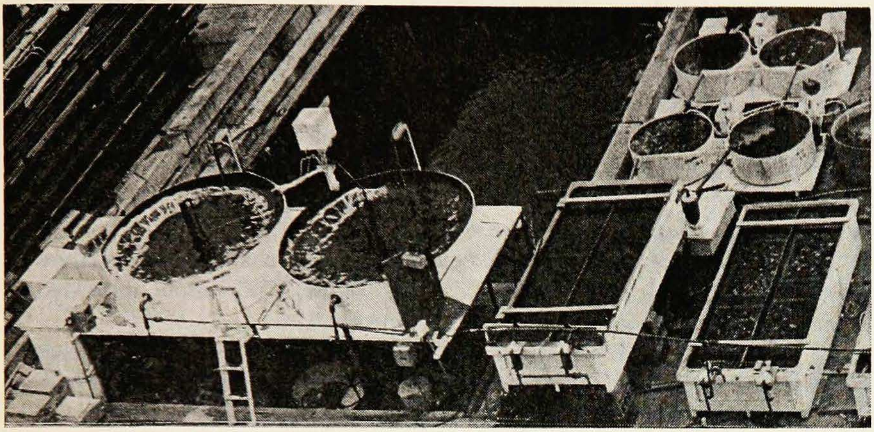

Figure 1. Experimental algae ponds and invertebrate culture tanks.

was partitioned down the middle into two (265 × 62 × 53 cm high) experimental tanks, each containing 760 liters of seawater. These tanks contained two stacks each of three trays made of wood frames with Vexar® mesh and the tanks were covered with plywood sheets to reduce temperature fluctuations and growth of epiphytes. Each tank received a controlled supply of food (an average of 0.345 liters/min from a manifold by pipette cones calibrated to known flow rates. Each tank also received 5 to 8 liters/min of seawater filtered through 100 $\mu$ Fluflo® cartridges that removed small crustaceans and other fouling organisms. This dilution was needed not so much to supply adequate flow for oxygen needs and removal of metabolic wastes, but to dilute the food concentration to optimum levels (about 600 $\mu$g C/liter) for bivalve growth (Tenore and Dunstan, 1973a). The ambient water temperature ranged from about 17°C to 25°C during the course of the experiment.

Small American oysters, *Crassostrea virginica*, were kindly supplied by Flower Brothers Oyster Farm, Bayville, Long Island. The initial average length of the oysters was 2.7 cm and average dry meat weight was 53 mg. Fifteen hundred oysters were placed in each of the two invertebrate tanks. All of the oysters were individually marked and their initial lengths recorded. During the experiment, dead animals were removed, measured, recorded and replaced by new oysters.

The bottom of one oyster experimental tank was covered with crushed rock and 60 small polychaetes, *Nereis virens*, were added. The initial wet weight of these worms was recorded and converted to dry and carbon weights. The other oyster experimental tank was covered with 100 kg dry weight of fine sand and seeded with 200 polychaetes, *Capitella capitata*.

Particulate carbon and nitrogen determinations (Perkin Elmer Model 240 Elemental Analyzer) and chlorophyll measurements (Yentsch and Menzel,

1963) were regularly carried out on the phytoplankton culture and filtered seawater entering the experimental tanks. Samples of the outflowing seawater were similarly analyzed. These data, along with the precise flow rates of food and seawater, enabled us to calculate the percentage of carbon removal by the oyster populations. We initially measured these parameters in one of the tanks without animals present and found no significant differences due to settling algae. Dissolved oxygen was also monitored and aeration was supplied during the period of high temperature to insure favorable conditions.

The present data for the oysters describe the food chain dynamics from 19 July to 28 August, a period of 40 days. In August, a subsample of 50 oysters was measured and growth of the population calculated.

At that time, *Nereis virens* were removed and final wet and dry weights recorded (90°C; 24 hrs). Nine 27 $cm^2$ samples were collected from the bottom of the tank initially stocked with *Capitella capitata*. These samples were screened (0.3 mm) dried (90°; 24 hrs) and biomass of the organisms recorded. Tissue samples were used for particulate carbon determinations.

### 3. Results

The food chain dynamics of the experimental system are summarized in Figure 2. The average concentration of phytoplankton in the algae ponds during this period was 21 mg carbon/liter. Thus the standing crop of biomass in each of the algae ponds averaged 48 g C. Although a diurnal change in concentration from 17 to 25 mg/liter was observed, the samples in the invertebrate tanks were taken in the early afternoon at about the time of average algal density. Half of the standing crop was harvested each day and each of the invertebrate tanks received 12 g C/day from this algal culture and another 1.1 g C/day from the 100r$\mu$-filtered seawater. The oysters under this regime thus received a daily food ration of about 20% of their biomass. The oysters removed 83% of this available food, i.e., an ingestion rate of 10.9 g C/day.

The standing crop of the oyster population grew from 29.4 to 72.2 g C during the 40 day period. Thus, the average standing crop of the oysters was 50.8 g C. On the basis of these figures, the total food ingested by the oyster population during this period was 436 g C and the ecological efficiency (net production ÷ food ingested) of the oysters was 9.8%.

The biodeposition rate of feces and pseydofeces by the oyster population was estimated from data collected in laboratory experiments. Tenore and Dunstan (1973a) used trays with flowing seawater and continual addition of different concentrations of phytoplankton cultures of mixed species to measure the feeding and biodeposition rate of bivalves. The same authors (unpublished data) conducted a similar experiment using phytoplankton culture similar in species dominance (*Phaeodactylum* and large pennates) to the present experiment. The biodeposition rate of these oysters was 0.375 g C/g carbon of oyster per day,

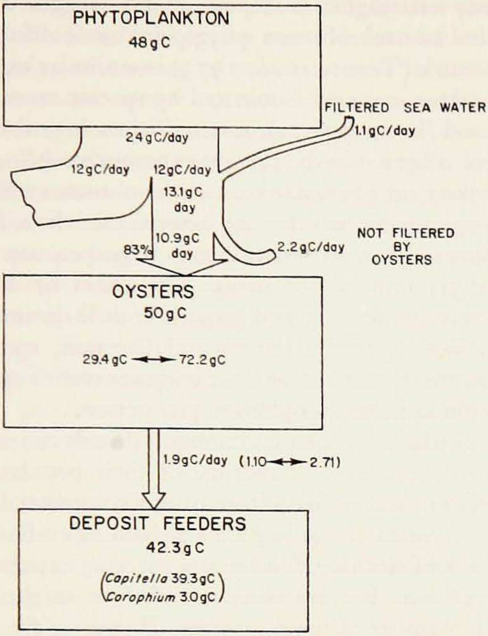


Figure 2. Diagram of carbon flow in a moderate-sized aquaculture system. The values in the blocks are standing biomass of the different trophic levels. For the oysters, the mean, initial, and final biomasses are given. The values given in the arrows represent average daily carbon flow for each trophic level.

therefore, the estimated biodeposition rate of the average standing crop of the oyster population was 1.91 g C/day. The range (1.12 to 2.71 g C) represents the estimated deposition rate of the initial and the final biomass of the oyster population.

The *Nereis virens* population, although showing a decrease in the total number of worms, exhibited almost a threefold increase in average worm weight. The mean weight of the 60 worms initially added to the bottom of the oyster tank was 0.126 g C, a total of 7.56 g C. A total of 38 worms, with a mean weight of 0.355 g C and a total weight of 13.49 g C, were recovered.

The other oyster tank that was initially seeded with the small number of the capitellid polychaetes had a high standing crop (42.3 g C) of macrofauna composed of 93% by carbon weight (110,000 ind/m$^2$) of the capitellids and 7% of the amphipod, *Corophium* sp.

## 4. Discussion

The food chain dynamics of the herbivore oyster population were compared to our previous work on feeding and biodeposition of bivalves, and the lower ecological efficiency and higher biodeposition rate suggest the importance of research on species control of mass phytoplankton cultures in aquaculture systems. Previous work (Tenore *et al.*, 1973) in a similar experimental set-up, but with phytoplankton cultures dominated by species more typical of coastal waters (Dunstan and Tenore, 1972), resulted in ecological efficiencies almost double (18%) those observed in the present experiment. Also, the biodeposition rate of oysters feeding on phytoplankton cultures such as *Skeletonema costata* and *Chaetoceros simplex* were half the rate observed for those feeding on culture dominated by *Phaeodactylum tricornutum* and large pennate diatoms (Tenore and Dunstan, 1973a; unpublished data). The effect of difierent species of phytoplankton on bivalve feeding and growth is well documented (Loosanoff and Engle, 1947; Walne, 1970; Tenore and Dunstan, 1973b). Thus future research in aquaculture systems must deal with control of species composition of the phytoplankton cultures to optimize production.

Growth of the nereid polychaetes, although difficult to interpret in this experiment because of absence of knowledge of their population dynamics, do suggest the possibility of successful culture of this commercially-valuable worm as a detritavore component in polyspecies aquaculture. Basic information is needed on the effects of stocking density and carrying capacity on growth and interspecific competition. For instance, cannibalism might have caused the decline in the total number of nereid worms. However, the high growth rate of the surviving worms indicated that the biodeposits (and perhaps associated micro and meiofauna) were a good food source. Bass and Braffield (1972) reported the annual weight increase for newly-set *Nereis virens* in the Thames estuary of 3 to 7 grams wet weight, a yearly rate of about 0.263 g C. In comparison, the growth rate for only 100 days in the aquaculture systems was 0.229 g C, comparable to a yearly rate of 0.836 g C. Although these data are not specifically comparable in terms of environmental conditions nor age class structure of the species, they do suggest that good growth rates can be obtained for *Nereis virens* by culturing on biodeposits. Further work is needed on the exact food chain pathways, i.e., the role of meiofaunal species such as nematodes as preliminary links in a detrital system.

The high standing crop of the *Capitella-Corophium* community suggest that these species would be a successful detritus-feeding component in polyspecies systems. In addition, these species have short generation times and thus, with adequate food supply, could exhibit high productivity rates. For instance, *Capitella capitata* has a generation time of 30 to 40 days in nature (Grassle and Grassle 1974). Similar time periods are characteristic of the deposit-feeding amphipods. The standing crop observed in the oyster tank was equal to 24.4 g C/m$^2$, a value higher than those reported for productive or eutrophied areas in nature. For instance, Smith (1973) reported the standing crop of macrofauna off Sapelo Island as 3.7 to 10.1 g C/m$^2$. Similarly, Rowe (1971), working in the New York Bight, showed the biomass of macrobenthos at most stations to be under

10 g C/m² and O'Connor (1972) found values far less than 0.3 g C/m² in Moriches Bay, N.Y. Our high figures are understandable in view of greatly increased food supply and absence of predation with its concomitant effect on population efficiency. Also longer operation time spans with periodic sampling of the macrobenthos are needed for polyspecies systems containing such opportunistic species as *Capitella capitata* in the detrital trophic level. These species are characteristically successional species and subject to great population fluctuations. The micrbial and meiofaunal components of the community were not measured. Such species must be considered as possible food chain links for macrobenthos species in detrital oysters.

The daily food ratio of the biodeposits to the detrital community was 6.4% of the standing crop. This value might be deceptive if microbioal recycling of carbon and fixing of both inorganic nutrients or heterotrophic activity of the dissolved organics produced by the soluble excretory products of the animals results in a higher amount of organic carbon available as a food source to the benthos.

The successful culture of both the nereid polychaete and the *Capitella-Corophium* benthos on the biodeposits of oysters results in both increased efficiency in utilization of the energy initially introduced into the aquaculture system and also an increase and diversification in the rearing of commercially-important species. The nereid worms are valuable in themselves as bait for sport fisheries. The *Capitella-Corophium* benthos can serve as a food source in the production of species at the carnivore trophic level. Winter flounder, *Pseudopleuronectes americanus*, feed on both of these species and research is currently underway in our laboratory to quantify the food chain dynamics of this species and introduce it into the polyspecies system.

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