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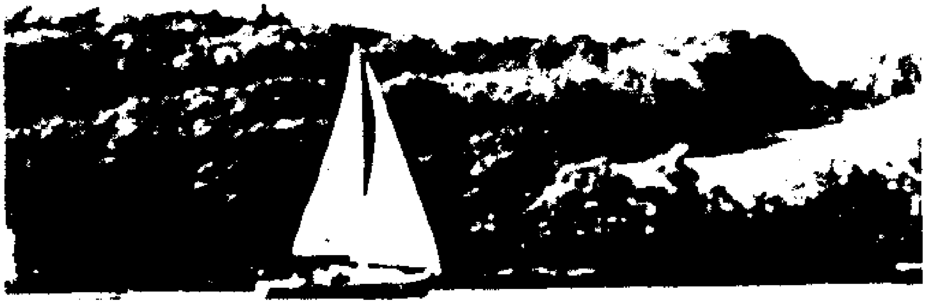

RAFT CULTIVATION OF MUSSELS IN MAINE WATERS - ITS PRACTICABILITY, FEASIBILITY AND POSSIBLE ADVANTAGES

Richard A. Lutz
UNIVERSITY OF MAINE AT ORONO

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Richard A. Lutz
Ira C. Darling Center
Walpole, Maine 04573
207/563-3146

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INTRODUCTION

Meat shortages and food price increases have focused recent attention on the exploitation of various under-utilized marine species. One of these is the blue mussel (Mytilus edulis), found in abundance along the Maine coast. Although it has achieved great popularity throughout Europe, this shellfish is relatively unknown to the American consumer. Now, for the first time since the Second World War, there appears to be a serious interest in the utilization of this natural resource.

Given a marked increase in the exploitation of this species along the coast of Maine, is it reasonable to assume that with adequate conservation measures, we are dealing with a fishery which has an extremely high maximum sustainable yield? To answer this question it is necessary to examine the situation during the 1940's -- the only period of our history that mussels were utilized to any great extent. During 1942-43, a survey conducted by Scattergood and Taylor of the U. S. Fish and Wildlife Service estimated the total usable supply of mussels from Eastport to eastern Penobscot Bay to be approximately 310,000 bushels (Scattergood and Taylor, 1949a). The total production figures of Maine mussels for the next few years compiled by the Maine Department of Sea and Shore Fisheries (Dow and Wallace, 1954), reveal considerable exploitation of natural mussel populations:

Year	Pounds (Wet meat)
1942	114,000
1943	1,983,450
1944	2,633,635

Year	Pounds (Wet meat)
1945	2,574,945
1946	2,314,210
1947	40,260
1948	124,129

While the increased production during the war years should need no explanation, the sudden drop in 1947 does. In a bulletin released by the Department of Sea and Shore Fisheries in 1954, Dow and Wallace attribute this sharp decline to two principal factors: (1) the availability of other protein foods considered to be more desirable and (2) the lack of available good quality mussels. Concerning the second factor, they state that the "canning operations during the preceding war years had cropped almost completely the readily available supply" (Dow and Wallace, 1954).

If mussel harvesting increases to near World War II dimensions due to recent interest, the need for conservation of known banks and for additional sources of supply should be obvious. In light of this, the practicality, feasibility, and possible advantages of the raft culture of mussels in the State of Maine are currently being explored under the 1972-1974 SEA GRANT Program at the University of Maine. A brief review of European cultivation methods and experimental rafting techniques in Maine waters will help clarify the final section, which discusses the advantages of raft culture as a new source of Maine supply.

CULTIVATION TECHNIQUES AND THEIR APPLICABILITY TO MAINE WATERS

According to Mason (1971), the culture of mussels began over 700 years ago, when in 1235 a shipwrecked Irish seaman by the name of Walton planted wooden posts in a beach at Aunis (a former province of France). From these posts he suspended a large net in an effort to catch water fowl abundant in the area. Although this attempt met with limited success, he soon discovered that his supporting posts provided an excellent substrate for the collection and fattening of mussels, which soon became his primary source of food. With only minor modifications, Walton's system has slowly evolved into the so-called "bouchot" system of mussel culture which is still used extensively along the western coast of France.

Since the 13th century, several additional methods of mussel cultivation gradually have evolved. At present, there exist three principal methods, all of which have met with varying degrees of success in different countries: (1) cultivation on posts and stockades - France, (2) bottom culture - Holland, and (3) raft cultivation using hanging ropes - Spain and Scotland (Havinga, 1956; Andreu, 1958, 1968; Mason, 1969). The most successful of these appears to be raft cultivation which is practiced extensively in the Spanish Galician Bays, where production rates as high as 50 tons of meats per acre per year are reported. According to Mason (1971), this is approximately 200 times greater than yields from any other type of husbandry or culture in which animals are grown naturally with no supplement or artificial feeding. The Spanish worker, Andreu (1968), pointed out that this type of cultivation has the advantages of the greatest utilization of available space (3-dimensional), better circulation of the water around the mussels, constant submergence, and the best use of the available nutrients, organic matter and plankton. Raft culture also greatly reduces loss due to predation (snails, crabs, starfish, etc.). The following paragraphs describe this technique as it has been successfully applied (on an experimental scale) to the culture of mussels in Maine waters.

In practice, the method is relatively simple and consists of hanging ropes (varying in length from 10 to 30 feet) from floating platforms of various constructions (Figure 1). Ropes are spaced at approximately two-foot intervals and allowed to hang free in the water. In areas influenced by strong currents, certain precautions may have

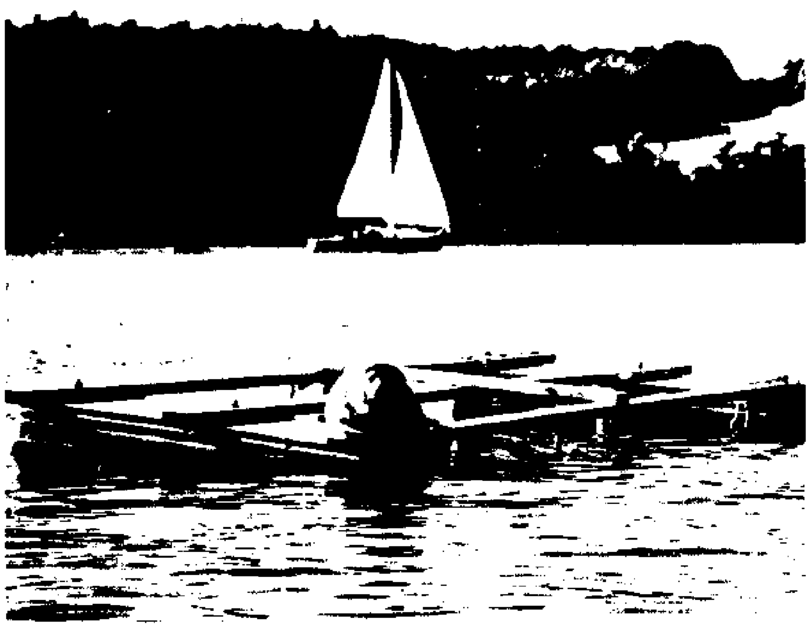

Figure 1. Experimental raft (and visitor) with hanging ropes used for the collection and growth of mussels in waters near the University of Maine's marine laboratory.

to be taken in order to prevent the entanglement of ropes (underwater spacing devices such as long pipes or structural frames attached to and interconnecting the bases of several ropes).

In a series of preliminary experiments undertaken at the University of Maine's marine laboratory, manila rope was found to be superior for the collection of spat (newly settled mussels) to both nylon and dacron although the differences between the three types of rope were small. In general, the more "hairy" the rope the more suitable it will be for use in spat collection. The unavailability of ropes such as coir, sisal, and those made from esparto grass, all of which have proved very successful throughout Europe, necessitated the use of manila and nylon for experimental work in Maine.

According to Field (1922), the spawning season of mussels along the Atlantic coast begins in April and continues on through the summer well into September. In Maine, perhaps due to the comparatively cold waters of the Gulf of Maine, spawning appears to be delayed until relatively late in the spring (late May) and continues throughout the summer, often with two peak spawning periods, one in late May - early June and the other in late August - early September. This spawning pattern, however, may vary greatly among localities. It is also important to bear in mind that a peak in spawning need not be followed by a peak in larval settlement, the latter being largely a function of larval survival and the presence of a suitable substrate as well as successful spawning. Despite these complicating variables, in most environments throughout the state it is advisable to place the ropes in the water during late April or early May. This allows sufficient time for the ropes to "condition", ridding themselves of the excess processing oil that may inhibit larval settlement and can be toxic to larvae in large concentration. In addition, this period of "conditioning" allows time for an accumulation of filamentous algae on the ropes that may stimulate the settlement of mussel larvae according to Scottish (Mason, 1969) and British (Bayne, 1965) workers.

Certain areas along the Maine coast are more favorable than others for the collection and growth of spat. The most favorable areas have yet to be determined and their distribution may limit the practice of rope cultivation methods to only certain regions of the coast. In addition, a particular locality will vary from year to year with regard to the success encountered in the collection of spat.

In years of good settlement the ropes will be covered with spat by the end of July (Figure 2). These remain on the ropes until the

Figure 2. Manila rope with encrusting seed mussels (2 months after settlement).

following spring at which time small wooden dowels (about 4 inches in length) are pushed into the lay of the rope, at right angles and at intervals of about 12 to 18 inches, to prevent the mussels from sliding down the ropes. This technique has been described by Edwards (1968) and is currently employed in the rafting operations of the Spanish Galician Bays. By the following fall (in favorable environments) (Figure 3), a large number of mussels will have reached marketable size (two inches or greater in length) and can be removed from the ropes. The culling of individual marketable mussels from the ropes is not only time-consuming but also results in considerable loss of smaller mussels. For this reason, it is advisable to haul individual

Figure 3. Same rope (see Figure 2) 14 months after settlement. Numerous mussels have attained marketable size (2 inches or greater in length).

ropes to the surface and remove all the mussels from the rope surface. Vigorous shaking of the ropes over large containers should be sufficient to facilitate such removal (Andreu, 1968). Marketable mussels can then be separated and the smaller individuals reattached to the ropes. The standard method of reattachment, recommended for use in Maine waters, consists of surrounding the cultivation ropes with mussels with the help of a very fine mesh net of cotton or synthetic fibers (Ryther and Bardach, 1968). The mussels eventually attach themselves firmly to the rope. The mesh net should be weak enough so that once the mussels have firmly attached themselves onto the ropes they can readily break through. In many areas overcrowding may cause a marked decrease in growth rate. In general, the fewer mussels per rope, the faster the growth rate. We recommend that the growing population be thinned periodically before harvesting. The mussels removed can be replanted on additional ropes.

Preliminary results as reflected in Figures 2 and 3 suggest that the raft culture of mussels in Maine waters is biologically feasible; but are such methods environmentally compatible if practiced on a much larger scale? Certainly no one who appreciates the natural beauty of so much of our Maine coast would relish the addition of a flotilla of floating parks similar to those employed in the Spanish Galician Bays. For this reason, alternate design and constructions of rafts, compatible with both navigation and the aesthetic preservation of the environment should be considered. Cultivation in offshore environments and the application of techniques similar to those currently being explored for the cultivation of oysters using submerged rafts offer several attractive alternatives. The detailed designs of such rafts have yet to be worked out.

ADVANTAGES OF RAFT CULTURE

To assess the practicality of raft culture in Maine waters, a few of the advantages of such culture methods over the exploitation of natural populations should be enumerated.

Increased Supply

First of all, raft culture provides a method of actually increasing the supply of available mussels. For two to four weeks after spawning the mussel larvae remain within the plankton and swim about feeding on minute planktonic algae (see Appendix). Each adult female is capable of giving rise to several million such larvae per season (Field, 1922). Only a small percentage of these survive to become mature adults. Factors affecting survival include the duration of the planktonic existence, the successful settlement of larvae in suitable environments, and post-settlement predation. When these factors are considered separately, and the effect of raft culture upon each is evaluated, it becomes apparent that the cultivation of mussels on hanging ropes could provide a means of greatly increasing the survival rate and hence the available supply. First, preliminary experimental results suggest that manila rope provides an excellent substrate for attachment. Mussel larvae, in the absence of such a suitable substrate, are capable of delaying metamorphosis (and hence remaining in the water column) for a period of several weeks (Bayne, 1965). The length of this planktonic existence is important, as there is generally an inverse relationship between the amount of time that larvae spend in the water and their percentage of survival since such larvae are a primary food source for many larger organisms. Therefore, the mere presence of the ropes serving as extremely good substrates should decrease the amount of time that a large number of larvae remain in the water and thereby increase the supply of available spat. Secondly, once the larvae have settled, the rafted condition provides an excellent environment for survival. The advantages of constant submergence, constant supply of plankton, and better water circulation, as well as isolation from the majority of common predators, provide an environment most favorable to survival.

Increased Growth Rate and Fishery Productivity

In addition to an increasing survival rate, preliminary results from experimental cultures suggest that the growth rate is increased several-fold over that of adjacent shore populations. These results have further shown that through the use of rafting techniques, a marketable mussel (two inches or more in length) can be obtained in Maine waters in a period of 12 to 15 months. Reported estimates of the average growth rate of mussels in natural populations (submerged and intertidal - the North Atlantic region) vary from 0.33 to 0.63 inches per year (Mossop, 1923). Thus, cultivation on hanging ropes may increase the growth rate as much as three to six fold over that of natural benthic populations. The initiation of raft culture ventures with the associated high growth and survival rates should greatly increase the productivity of the existing fishery.

The potential for such increased productivity is dramatically illustrated by comparison of the 1947 production of mussels in the State of Maine with that of an average Spanish raft in the Galician Bays. In 1947 the annual Maine production was 40,000 pounds of meat, a figure which, according to Dow and Wallace (1954), is largely a reflection of the over-utilization of this species during the preceding years. In comparison, an average Galician raft produces some 50,000 pounds of meat per year (Edwards, 1968), or approximately 1.25 times the total 1947 Maine production. When this figure is compared with the annual Maine production for 1971 (approximately 150,000 pounds - Maine Landings, Annual Summary 1971), one finds that it is only necessary to harvest three rafts in order to equal the current Maine production - and there are over 3,000 such rafts in existence in Spain.

Superior Quality

In addition to the above advantages, the quality of the average rafted mussel should be far superior to that of the average mussel harvested from natural populations. In their 1942-43 survey, Scattergood and Taylor's figure of 310,000 available bushels was an estimate of only those mussels which were considered satisfactory for human consumption. This resulted in the exclusion of a large quantity of mussels considered to be of poor quality and generally unsatisfactory for commercial exploitation. The principal objections to certain mussels have been enumerated by Dow and Wallace in their 1954 bulletin. These include: (1) the large number of pearls found within the tissues of the animals, (2) poor meat yields - a condition which appears to be characteristic of the high intertidal mussel beds, (3) the unaesthetic appearance of the meats (off-colored and discolored), which the authors feel is undoubtedly traceable to feeding conditions, and (4) foreign material (silt, sand, and other particles) within the shell cavity. As further pointed out by Dow and Wallace (1954), the sale of these poor quality mussels by less scrupulous dealers during the period since the Second World War has resulted in reports similar to that of the so-called green sheet report of Fulton's Market for January 15, 1954 which stated "Mussels - Maine - poor quality, not sold". To assess the quality of cultured mussels in comparison with that of mussels gathered from natural populations, the above objections should be examined separately.

Pearls

Among the principal objections and limiting factors to the commercial use of a large quantity of Maine mussels is the presence of large and numerous pearls embedded directly in the mantle tissue of the mussel (Figure 4). After their survey, Scattergood and Taylor (1949b) recommended the closing of six areas in Maine with an estimated total supply of 60,000 bushels (about one-fifth the total estimated mussel production) because of pearls within the meats of these mussels. Before examining the effect of rafting upon the presence of pearls, a brief review of the existing knowledge concerning the subject of pearls in mussels might be instructive.

Figure 4. Pearls embedded directly within the mantle tissue of the mussel. Such pearls have been one of the principal limiting factors to the commercial use of large quantities of Maine mussels.

The presence of pearls in mussels has been known for at least 300 years, being first reported by Olaus Worm in 1655 upon examination of mussels taken near Copenhagen (Giard, 1907). In 1872, Garner, working on the English coast, recognized that such pearls were formed as a reaction by the mussel to a small parasite (harmless to man), later found to be a digenetic trematode in the genus Gymnophallus (Figure 5). Dubois (1909) in a review of the subject of pearls in mussels, presents a series of detailed figures illustrating the process of pearl formation resulting from the parasite infection, and speculates upon environmental parameters controlling the presence or absence of the parasite. Since the original description of the trematode by Jameson in 1902, considerable work has been done in France and England to ascertain the life cycle of the beast. Thus far, the suggested life cycle involves a sea duck (either an eider or a scoter) as the adult host, and the blue

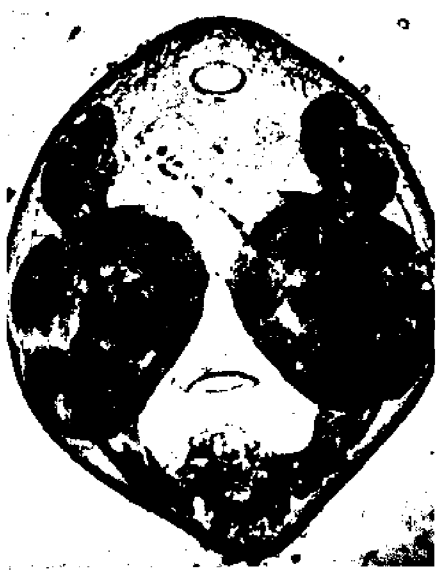

Figure 5. A trematode of the genus Gymnophallus (isolated from the mantle tissue of a mussel from Maine waters) thought to be responsible for the initiation of pearl formation. (x 500)

mussel as the intermediate host. Whether a second intermediate host is required remains uncertain (Stunkard and Uzmann, 1958). In general, therefore, the life cycle of the trematode is not well established and attempts at further unravelling of the cycle have been frustrated largely because of the state of taxonomic chaos emphasized by the statement of Stunkard and Uzmann in 1958 that "specific identification (of Gymnophallids) is so uncertain that we prefer to list the worms by host and location rather than propose names that might further confuse the taxonomic situation."

Research in progress at our laboratory suggests that the presence of pearls in mussels from Maine waters is also the result of infection by the trematode Gymnophallus. In support of this idea are three pieces of evidence: (1) when the pearls are treated with dilute hydrochloric acid, the resulting residue consists of an amorphous mass, which is probably organic in nature. It is reasonable to conclude that this may be the remains of a trematode although, conceivably, it may represent the remnants of the organic matrix within the structure of the pearl itself, (2) the diameters of the smallest pearls found correlate quite nicely with the lower limit of the size range reported for the larval trematode (approximately 120 microns), and (3) larval trematodes which are morphologically very similar to those figured by Jameson in 1902 have been isolated from the mantle tissue of mussels from Maine waters (Figure 5).

Whatever the factors involved in pearl formation (trematode infection or otherwise), preliminary observations suggested that raft-based mussels contained fewer and smaller pearls than mussels of similar size obtained from nearby shore populations. In an attempt to get a quantitative measure of the effect of rafting upon the presence of pe mussels from three separate rafts were examined. Each raft had the water for different lengths of time - one year, three years years. Marketable mussels were sampled from each raft and stat: compared with mussels of similar length obtained from adjacent shore populations with regard to the number and size of pearls within the mussel meats. Individual pearls were obtained using a modification of the potassium hydroxide technique used by Scattergood and Taylor (1949b). A statistical analysis run on the resulting data revealed highly significant differences between the raft and shore populations. Under the criteria established by Scattergood and Taylor during their survey, the large number of pearls found in each of the examined shore populations would render these populations unsuitable for commercial use. By contrast, the mussels obtained from each of the rafts contained no pearls with diameters greater than one millimeter. According to Scattergood and Taylor (1949b), pearls with diameters smaller than this value should have no effect on the commercial acceptability of the meats. This conclusion is supported by the results of an informal taste panel which sampled 500 mussels collected from the raft left in the water for three years. No pearls were detected in any of the mussels by members of the panel although numerous pearls with small diameters were found in the laboratory.

There are two possible explanations for the observed differences between the raft and shore populations, not necessarily exclusive. First, the mussels obtained from the rafts could be considerably younger than those of similar length obtained from the shore populations. The observed population differences may be merely a reflection of such an age differential. As mentioned earlier, a comparison of the growth rates of rafted mussels with those of shore-based individuals reveals considerably faster growth when rafting techniques are employed. In further support of this explanation is the fact that the mussels obtained from the raft left for five years contained slightly larger and more numerous pearls than those mussels gathered from either of the rafts left for shorter periods of time (one and three years).

Regarding age, it is interesting to speculate that perhaps the differences reported by Scattergood and Taylor (1949b) in the size and number of pearls in various populations throughout the state are largely a reflection of differences in the ages of the studied populations, i.e., older populations might naturally be expected to contain larger and more numerous pearls. If so, the locations of pearl-producing areas might be expected to fluctuate with time depending on the age structure of the various mussel populations. The exact relationship between age and the incidence of pearls is currently under investigation; the results should shed considerable light on factors affecting the presence or absence of large quantities of pearls in certain populations.

Apart from possible differences in the rates of growth between the raft and shore environments, there exists the possibility that the constant position in the water column or the lack of contact with the sediment provides an environment unfavorable to the formation of pearls. This may reflect the distribution patterns of the trematode, *Gymnophallus*. Whatever the factors involved, the raft culture of mussels provides a means of producing a commercially superior product even in areas where the presence of large and numerous pearls has proved to be a deterrent to the commercial exploitation of the species.

Increased meat yield, pleasing appearance, cleanliness

Another objection to certain mussels obtained from natural populations is low meat yield - a condition which, as mentioned earlier, appears to be characteristic of the high intertidal mussel beds (Dow and Wallace, 1954). With rafting this problem is virtually eliminated, largely as a result of constant submergence. Spanish workers report meat yields of 40-50% of the total wet shell weight (Mason, 1971), while workers in Scotland using rafting techniques similar to those employed in Spain, report extremely good meat yields among cultured mussels as compared to mussels from natural populations (Mason, 1969). It is reasonable to assume that similar high yields can be expected from essentially the same techniques in Maine waters. In addition, meats obtained from rafts are much more aesthetically pleasing than meats obtained from certain natural populations which are sometimes off-colored or discolored. Even the shells of the rope-cultivated mussels with their clean brown surfaces and sharp edges present a much more attractive appearance to the consumer than the majority of those mussels gathered from natural populations (particularly those found intertidally), the frequently eroded shells of which are often bluish-black with rounded edges (Mason, 1971). In addition, foreign matter such as silt, sand, particles, et cetera,is virtually absent due to the off-bottom position of the hanging ropes. Another problem often encountered when obtaining mussels from natural populations is the presence of mud-filled shells, often difficult to detect if they remain tightly closed. If not removed, these will break apart during steaming or at the shucking table, with a resultant mixture of meats and muds. During canning operations, when smeared with mud, the meats must be washed more vigorously and consequently will often break apart and produce an inferior pack (Herrington and Scattergood, 1942). This problem is not encountered with cultured mussels as mud-filled shells are nonexistent in rafted environments.

Thus, in the face of an increased demand for the underutilized blue mussel in the State of Maine, the raft culture of this species offers many attractive potentials. Given the biological and economic feasibility on a scale larger than that of the experimental culture described above, such cultivation methods should not only increase the supply of available mussels but also furnish the fishery with a product superior to that obtained by local gatherers.

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APPENDIX

Figures 6 - 12 illustrate the early life history stages (fertilized egg- settlement) of the blue mussel, *Mytilus edulis*, (as reared under laboratory conditions) and should facilitate identification of these larvae in the plankton.

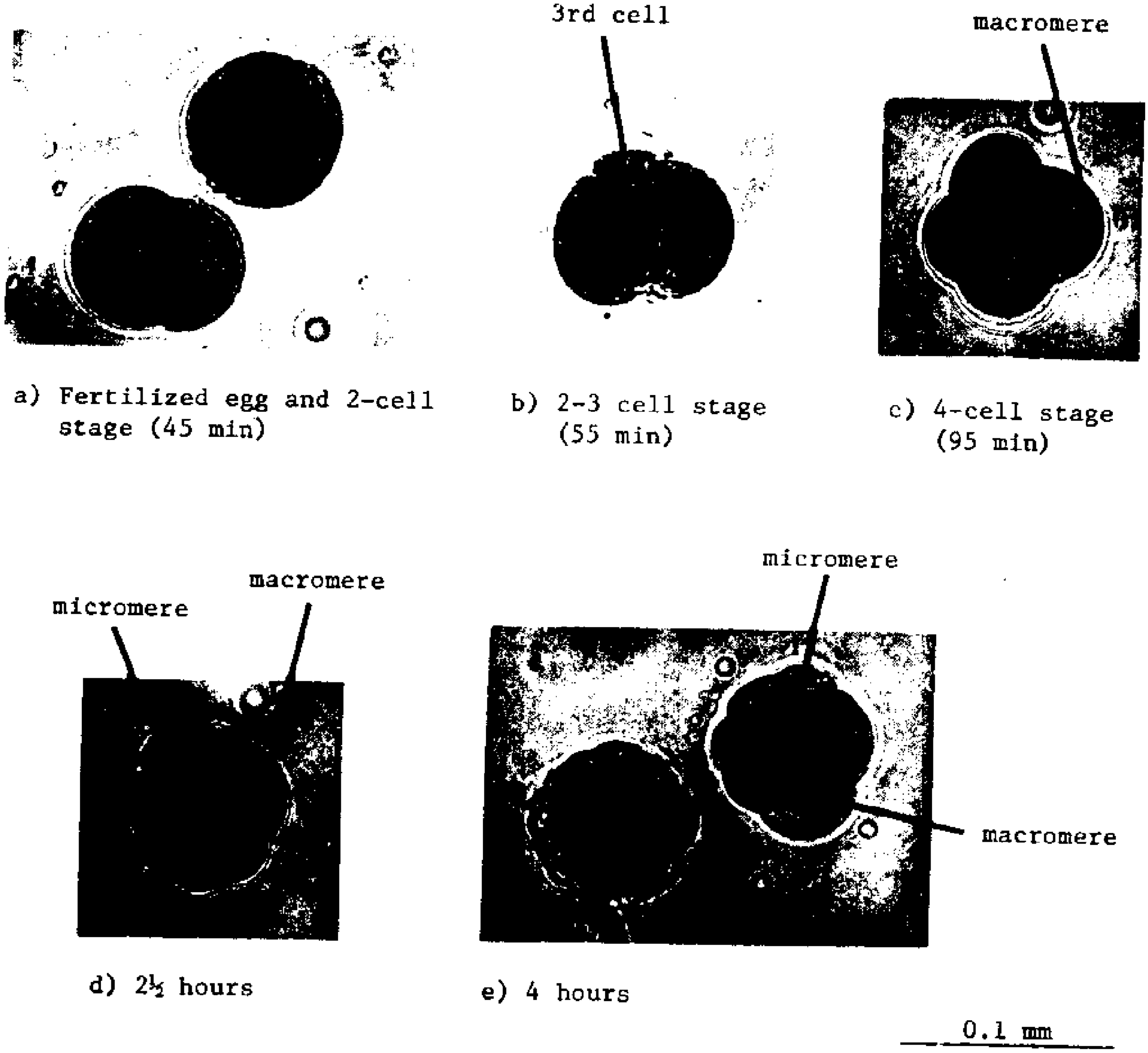
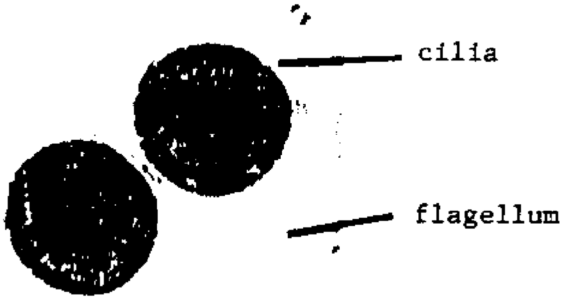
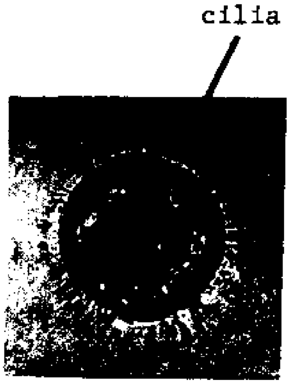


Figure 6. Sequence showing various developmental stages from 45 minutes to 4 hours after fertilization.

a) 6 hours

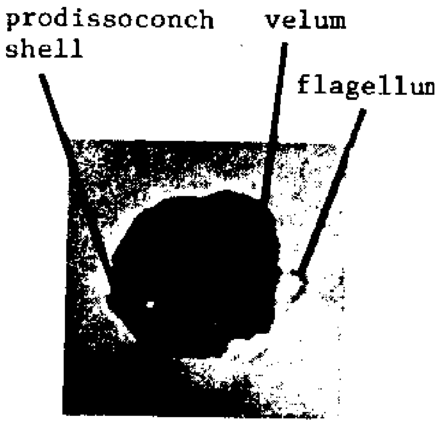


b) Ciliated trochophore
(20 hours)

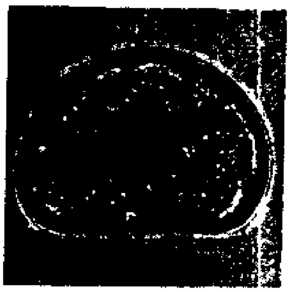


e) Ciliated trochophore
(24 hours)

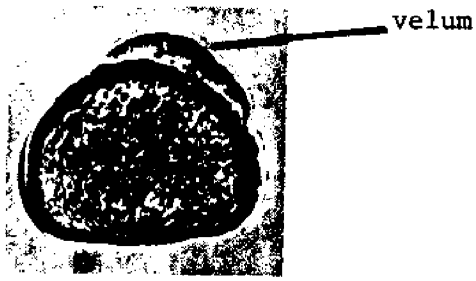
d) Ciliated trochophore
(36 hours)



e) Initiation of
shell formation
(44 hours)



f) Straight-hinge
stage (2 days)



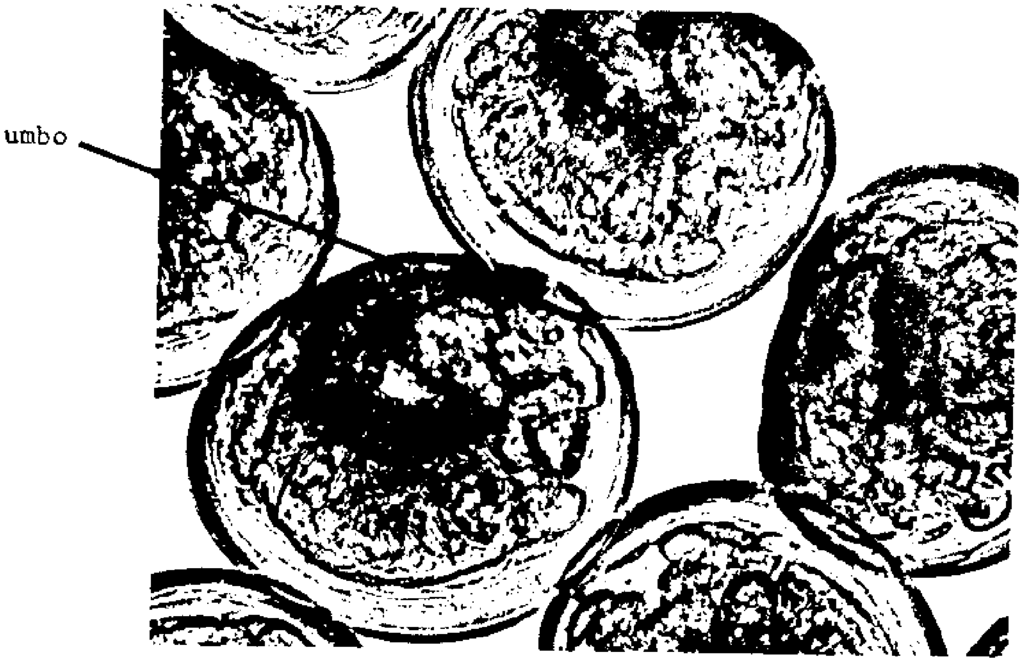
g) Straight-hinge
stage (2 days)

0.1 mm

Figure 7. Sequence showing developmental stages from 6 hours to 2 days after fertilization.

a) 5 days

Figure 8. Late straight-hinge stage larvae.



a) 12 days

0.1 mm

Figure 9. Early-umbo stage larvae

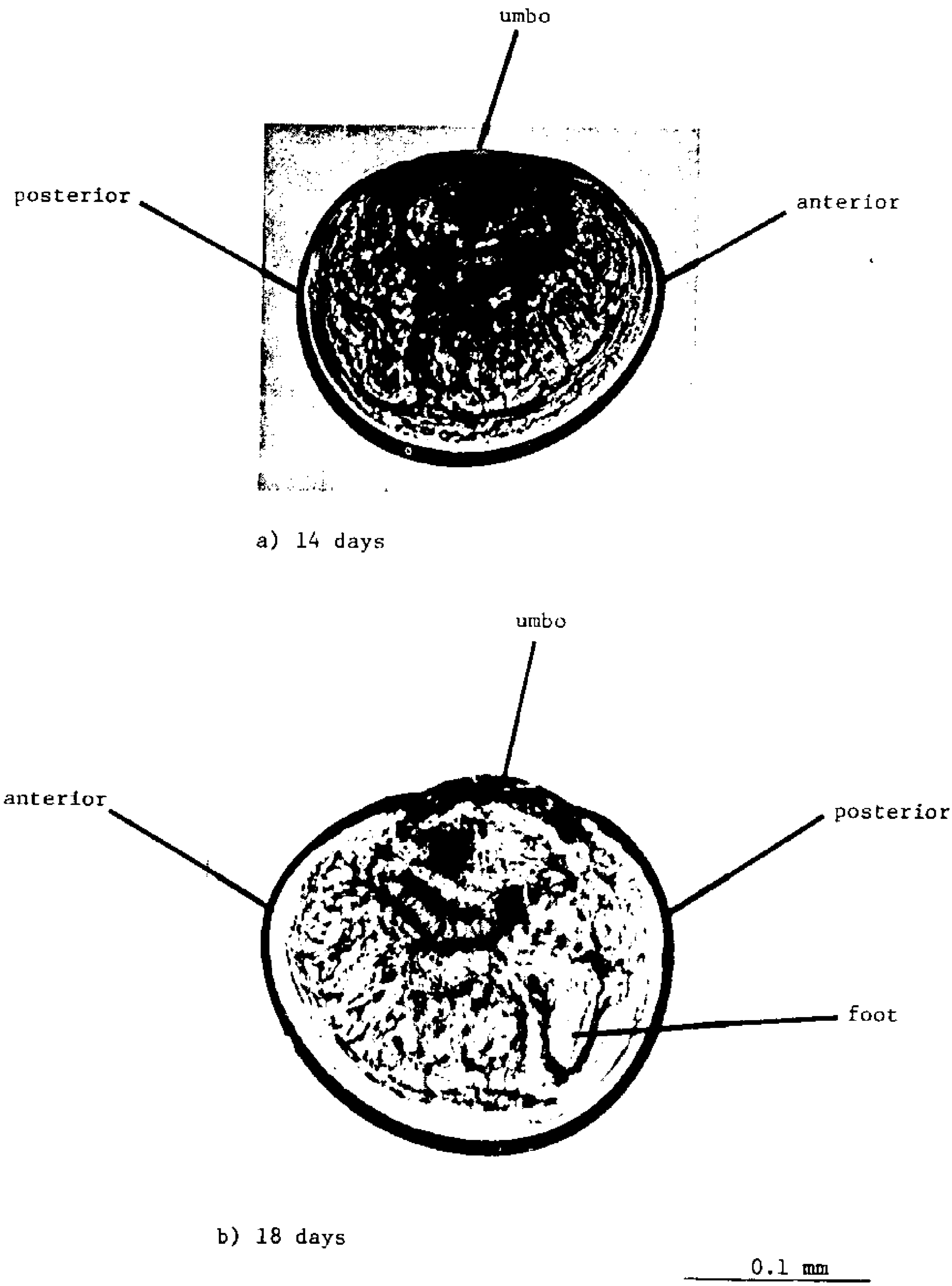
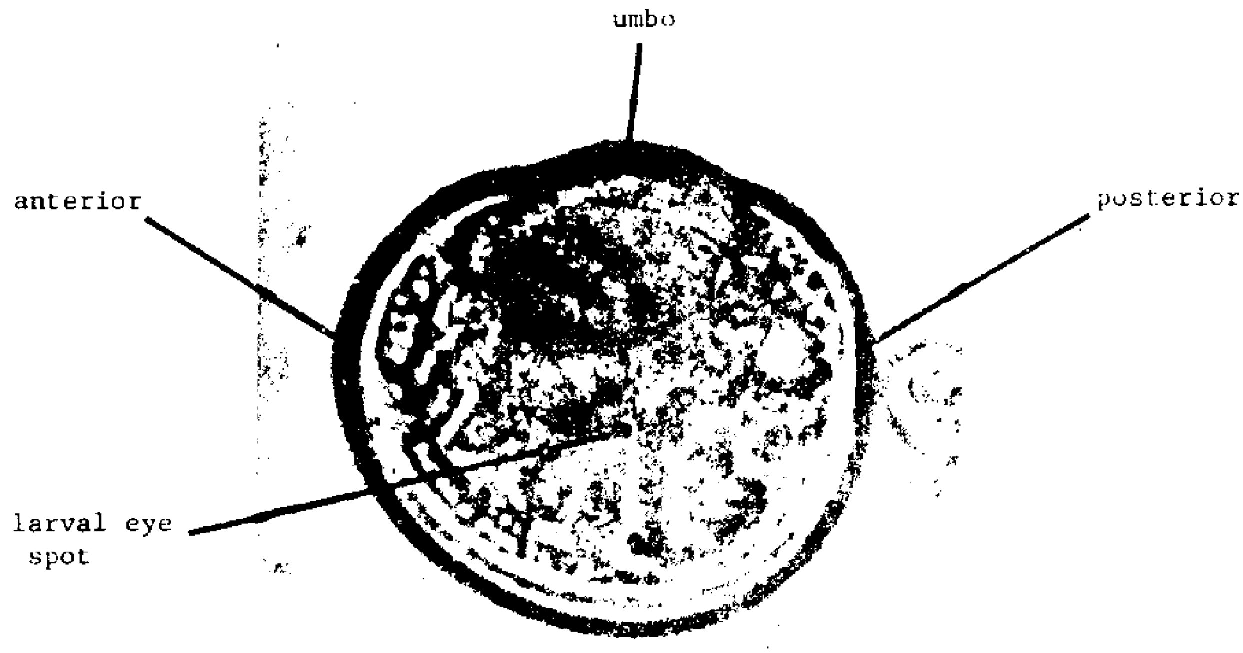
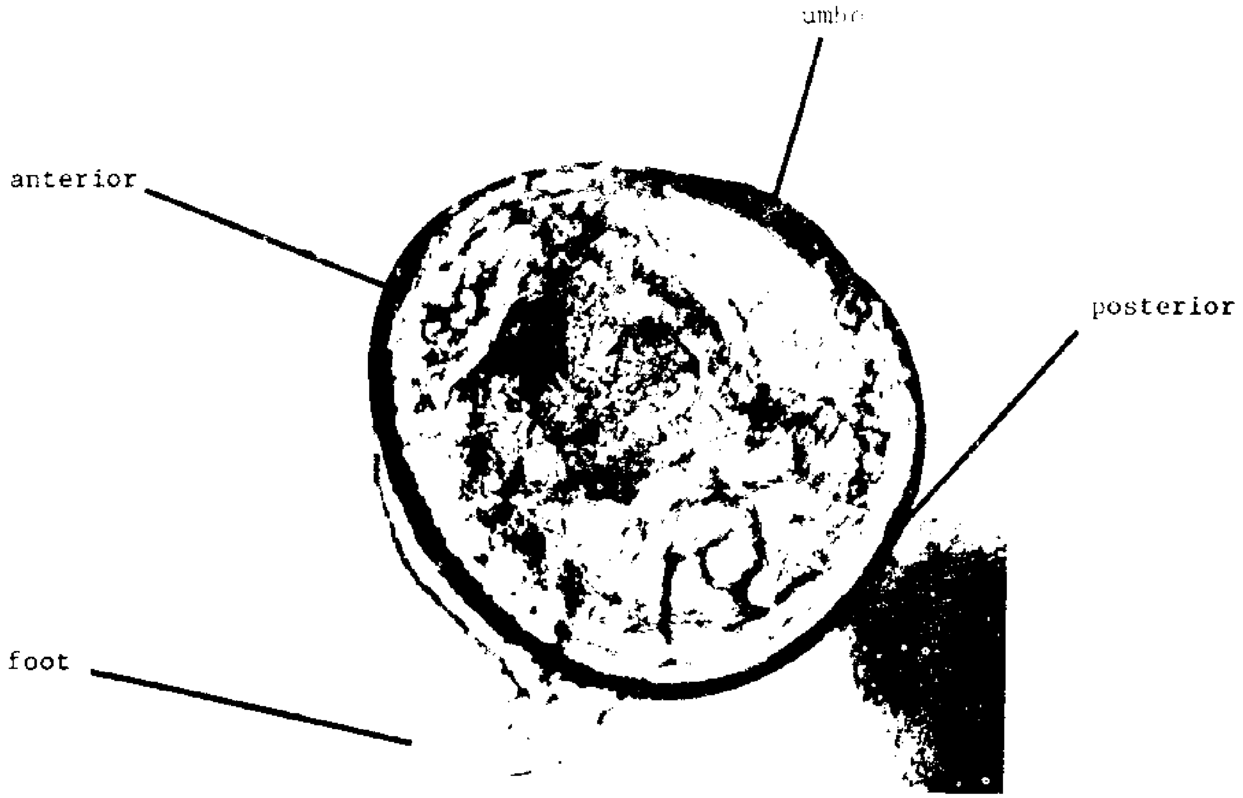


Figure 10. Late-umbo stage larvae showing pronounced shell asymmetry.



a) 18 days

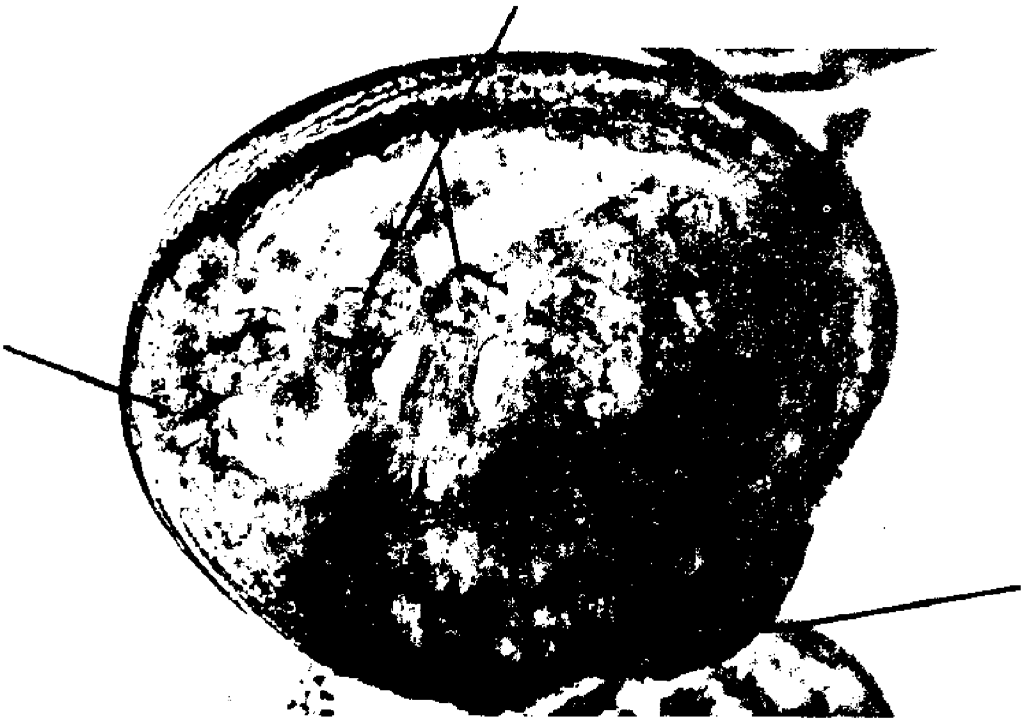


b) 20 days (Stage III pediveliger)

0.1 mm

Figure 11. Mature larvae

a) Swim-crawl stage (21 days) 0.1 mm



b) 21 days (Metamorphosing juvenile) 0.1 mm

Figure 12. Mature larvae (Stage III pediveligers) and juvenile

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